Photos courtesy of Environment Canada, National Research Council Canada, and Paul Nicklen

Community Workshop on Science from Suborbital Vehicles (Balloons, Aircraft, Sounding Rockets)

Toronto, Ontario, Canada

McTaggart-Cowan Auditorium at Environment Canada
4905 Dufferin Street, Downsview, Ontario

February 1 and 2, 2007

Workshop Proceedings

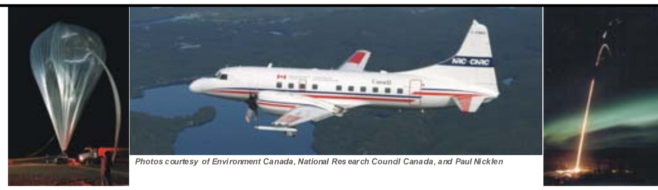
This Workshop is supported by the Canadian Space Agency and hosted by Environment Canada.

CSA ASC

Environment Canada   Environnement Canada

Talks – Day 1

Thursday, February 1						
Chair	**Start**	**End**	**Duration**	**Session**	**Name**	**Theme**
	8:30	9:00	30	Coffee & Refreshments		
Strong	9:00	9:15	15	Opening Plenary	Strong	Opening
Strong	9:15	9:30	15	Invited Talk	Kendall	Opening
Strong	9:30	9:45	15	Invited Talk	McArthur	Opening
Strapp	9:45	10:15	30	Invited Talk	Jones	Aircraft
Strapp	10:15	10:45	30	Invited Talk	Tuck	Aircraft
	10:45	11:15	30	Posters / Refreshments	**See list below**	
Hudak	11:15	11:30	15	Past / Case Studies	Strapp	Aircraft
Hudak	11:30	11:45	15	Past / Case Studies	Wolde	Aircraft
Hudak	11:45	12:00	15	Past / Case Studies	Whiteway	Aircraft
Hudak	12:00	12:15	15	Past / Case Studies	Parrington	Aircraft
	12:15	1:15	60	Lunch		
Degenstein	1:15	1:45	30	Invited Talk	Pierce	Balloons
Degenstein	1:45	2:15	30	Invited Talk	Hertzog	Balloons
Degenstein	2:15	2:30	15	Past / Case Studies	Strong	Balloons
Degenstein	2:30	2:45	15	Past / Case Studies	Netterfield	Balloons
Degenstein	2:45	3:00	15	Industrial capabilities/interests	Sommerfeldt	Balloons
Degenstein	3:00	3:15	15	Past / Case Studies	Fogal	Balloons
Degenstein	3:15	3:30	15	Past / Case Studies	Wolff	Balloons
	3:30	4:00	30	Posters / Refreshments	**See list below**	
James	4:00	4:30	30	Invited Talk	Pfaff	Rockets
James	4:30	5:00	30	Invited Talk	Lübken	Rockets
James	5:00	5:15	15	Past / Case Studies	Knudsen	Rockets
James	5:15	5:30	15	Industrial capabilities/interests	Legary	Rockets
James	5:30	5:45	15	Past / Case Studies	Aase	Rockets
James	5:45	6:00	15	Past / Case Studies	Yau	Rockets
	6:00			End		



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COMMUNITY WORKSHOP ON SCIENCE FROM SUBORBITAL VEHICLES (BALLOONS, AIRCRAFT, ROCKETS)

Workshop Introduction and Overview

Kimberly Strong

Department of Physics, University of Toronto

Toronto, 1-2 February 2007

Genesis of the Workshop

- Concept emerged from discussions about the future of scientific ballooning in Canada
- Proposed a two-day workshop to CSA
- CSA welcomed this proposal and agreed to provide support
- Scope: science from suborbital vehicles, particularly balloons, aircraft, and rockets
  - Decided to extend it beyond atmospheric science, given common interests in using these platforms
  - Relevant to all communities included within the anticipated Small Payloads Program

Aim of the Workshop

To bring together those in the Canadian science community who have an interest in using suborbital vehicles as platforms for scientific exploration, and to get people dreaming about new ideas.

Objectives

- To raise the profile of balloons, aircraft, and rockets as platforms for scientific investigations
- To stimulate discussion of new approaches and new science questions that can be addressed with such platforms
- To determine the level of interest in these flight opportunities in Canada
- To identify the infrastructure needed to enable new missions
- To provide a vision for a “program” with regular flight opportunities
- To enhance and create new collaborations between Canadian universities, government agencies, and industry

Relevance to CSA

Suborbital platforms offer a number of advantages that are closely allied to the mission of the CSA:

- Scientific exploration, including atmospheric science, space science, astronomy, and astrophysics
- Technology development, including testing prototypes of satellite instruments
- Validation of satellite missions, such as those making height-resolved atmospheric measurements
- Training of scientific and technical personnel, who will become the next generation of scientists, including our next generation of Principal Investigators

Expected Outcomes

- A ten-year vision
- A game plan for the next year
- A list of potential new missions
- A description of the infrastructure that will be needed for each platform, to allow such missions to be accomplished
- Recommendations for what is needed to maintain continuity

Ideally, we would like to see these outcomes providing input to the anticipated new Small Payloads Program.

Program Structure - Day 1

- Invited talks on science from balloons, aircraft, and sounding rockets
- Contributed talks on past projects and case studies
- Contributed talks on industrial capabilities and interests
- Poster session on both past projects and industrial capabilities and interests - during the coffee breaks

Logistics:

- Invited talks are 25 + 5 = 30 minutes
- Other talks are 12 + 3 = 15 minutes total
- Please upload your talk before the start of your session
- Let us know if you do NOT want your talk to be made publicly available

Please keep to time!

Program Structure - Day 2

- Talks on proposals for future projects
- Talks by graduate students and postdoctoral fellows: "If I Had a Million Dollars…".
- Break-out groups on balloons, aircraft, rockets
  - To review current capabilities in Canada and abroad, novel technologies and opportunities, the scope for new and exciting projects, logistical issues, etc.
  - **See page 17 in the Program Book for a list of topics to start thinking about**
- Final plenary session to bring together reports and recommendations from the break-out groups

www.ec.gc.ca

Welcome: Community Workshop on Science from Suborbital Vehicles

Science and Technology Branch

L.J. Bruce McArthur
February 1, 2007

Environment Canada Environnement Canada

Canada

A significant history using suborbital vehicles

Environment Canada launches over 70 radiosondes every day. Once a week extra balloons are launched in order to obtain profiles of ozone through the atmosphere.

Environment Canada Environnement Canada

Canada

A significant history using suborbital vehicles

Tetherered balloons are used to better understand surface characteristics and radiative and chemical properties of the lower troposphere.

A significant history using suborbital vehicles

Since the mid-1970’s Environment Canada has been involved in over 20 major stratospheric balloon campaigns to better understand ozone chemistry.

Environment Canada Environnement Canada

Environment Canada commitments

- To continue to support the development of new technologies, the deployment of these technologies and the use of data generated from these technologies in order to improve environmental forecasts.
- To support programmes, such as the suborbital programme, as a means of supporting the mandates of Environment Canada.
- To ensure that those programs to which we commit, we bring the funding necessary to be full partners throughout the life of the project.

Aircraft Experiments?

- Aircraft are becoming an essential tool in the domains of research and routine observation.
- We will continue to partner with other government departments and agencies, universities, and international collaborators in the development of research programmes using aircraft platforms.

Environment Canada Environnement Canada

Canada

The Balloon Launch Facility?

- The present facility is inadequate to meet any long-term high-altitude balloon programs.
- Environment Canada does not have the resources necessary to re-develop the facility without partners.
- Scientists within EC recognize that research opportunities exist under the EC mandate to fully utilize such a facility should the appropriate partnerships develop.

Environment Canada Environnement Canada

Canada

Workshop Outcomes:

- ASTD encourages the development of a concise, yet far-reaching vision for the use of suborbital platforms for atmospheric science.
- ASTD will work with our partners (CSA, universities, OGDs, industry) in whatever ways possible to support atmospheric research using these platforms.

Environment Canada Environnement Canada

Canada

Atmospheric research using the new UK research aircraft

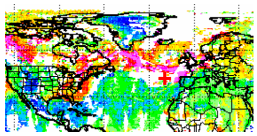
Roderic Jones
Department of Chemistry, University of Cambridge

Abstract:

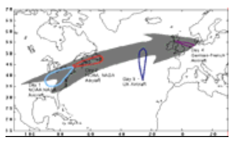
The Facility for Airborne Atmospheric Measurements (FAAM) BAES 146 aircraft is the principal airborne platform used in the UK for atmospheric research. In this presentation the main features of the platform will be presented, together with some results from recent field campaigns. Finally, some upcoming instrument developments for the aircraft will be discussed.

Presenting Author Name:	Roderic Jones
Organization:	Department of Chemistry, University of Cambridge
Presenting Author Email:	rlj1001@cam.ac.uk
Presenting Author Telephone:	44-1223-336466
Session:	Invited Speaker
Presentation Method:	Talk
Presenting Author Title:	Professor

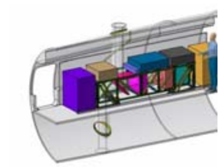
Atmospheric Research using the new UK research aircraft



Rod Jones
University of Cambridge
Department of Chemistry



- FAAM BAES 146 research aircraft
- Pollution transport: ICARRT/ITOP
- Future developments: LIDAR



BAES 146 aircraft

- Successor to UK MRF C130
- (Some) new instrumentation (composition, aerosol, structure)
- Modular (interchangeable) layout (chemical, radiation,cloud physics)

•Operated jointly by NERC (for universities) and Met Office

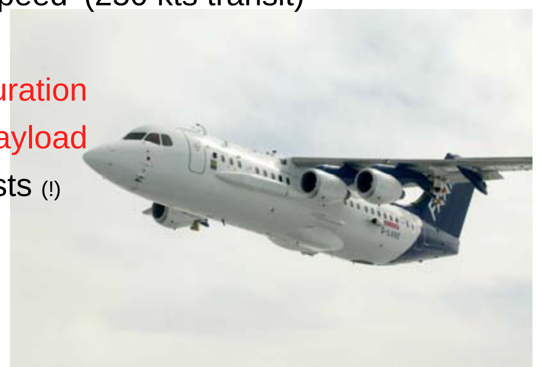
2001

➡

2004-present

FAAM BAES 146 characteristics

- Altitude 50 ft - 35,000 ft
- 200 kts 'science speed' (250 kts transit)
- 3700 km range
- Up to 5.5 hours duration
- 4000kg science payload
- 3 crew, 18 scientists (!)



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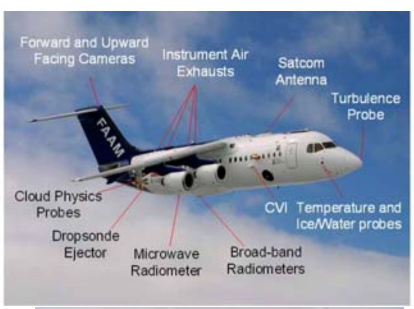
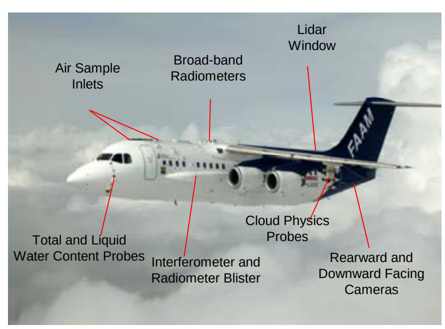
FAAM BAES 146 instruments



•'Core' instrument suite
•Specialised instruments
•Standardised instrument racks



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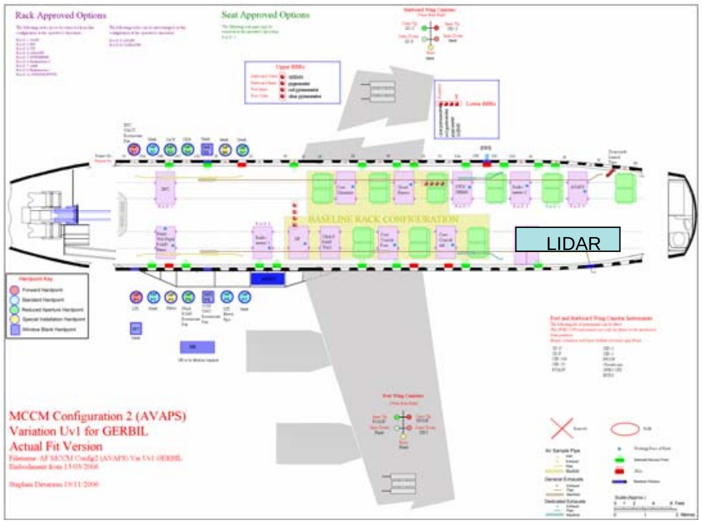
BAES 146 cloud physics/radiation fit



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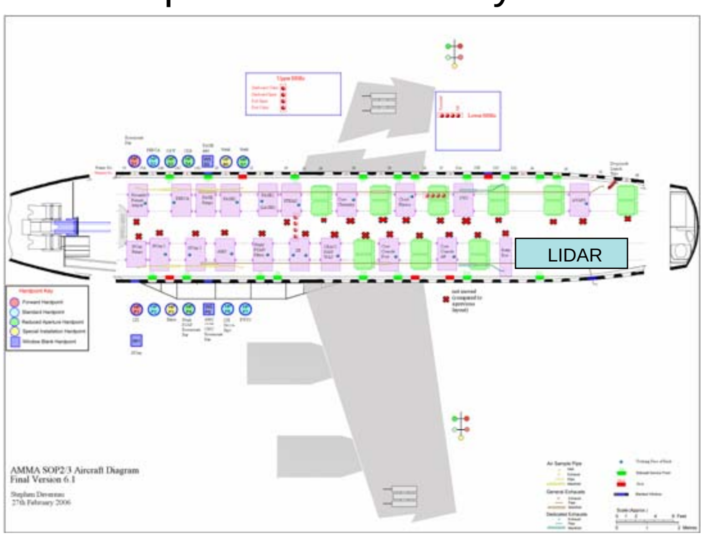
Composition 'chemistry' fit



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FAAM BAES 146

Funding model (NERC):

•'free at point of use'*

•Use of 'core' data

•Individual 'blue skies' funding applications (~£300-500k)

•Consortium proposals (inter-university) (~£3-4M)

* + detachment costs

Since July 2004: *259 Science flights, 27 campaigns, 9 detachments*

www.faam.ac.uk

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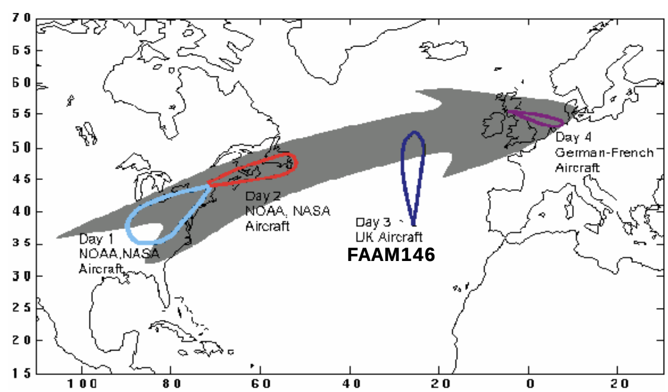
Intercontinental Transport and Transformation
– Experimental Concept
UK PI: Alistair Lewis (YORK (UK))



- NCAS Atmospheric Composition, NCAS FAAM
- Universities of York, Leeds, UEA, Reading, Leicester, Manchester, Cambridge
- International Partners, NASA, NOAA, USEPA, DLR, CNRS, 60 others

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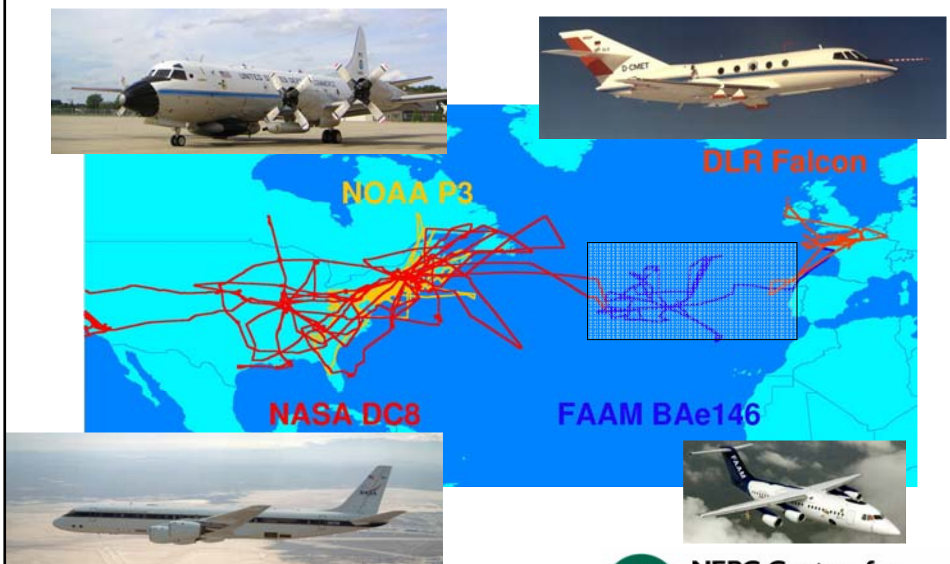
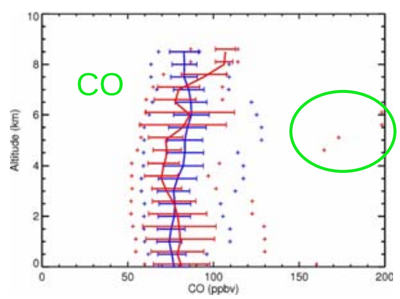
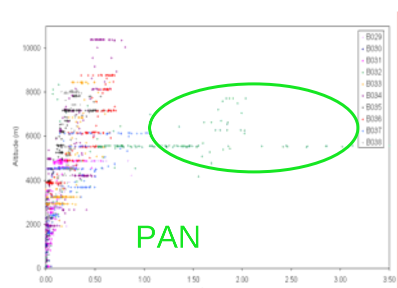
Participating aircraft



Selected BAe 146 measurements

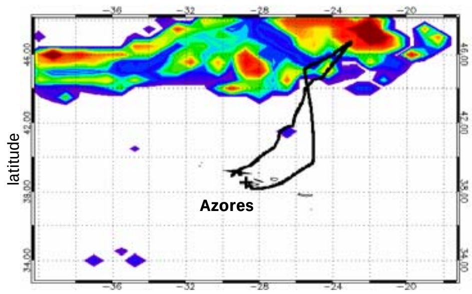


Mid Atlantic CO profiles
Red 2004, Blue 1997 crosses at 1 and 2 sigma
Note outliers in middle Troposphere in 2004 due to biomass burning

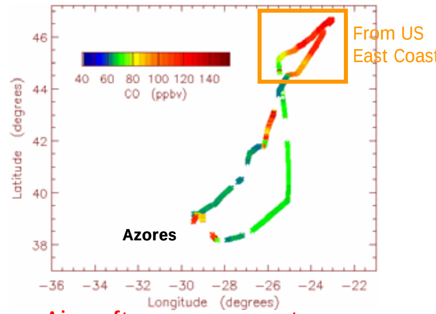


Mid Atlantic PAN – Summary
Very obvious where biomass plumes have been intercepted.
Eg B032

Interception of pollution plume from US East coast (CO)

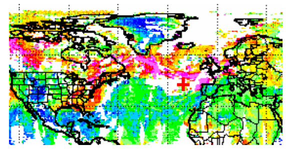


Model prediction of CO (Methven)



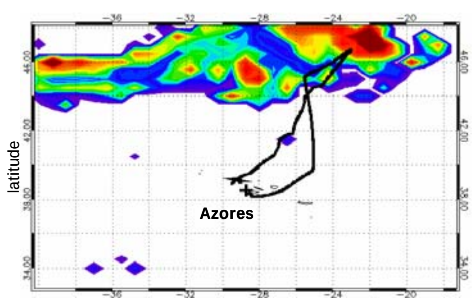
Aircraft measurements

- Successful test of model prediction of long range plume transport

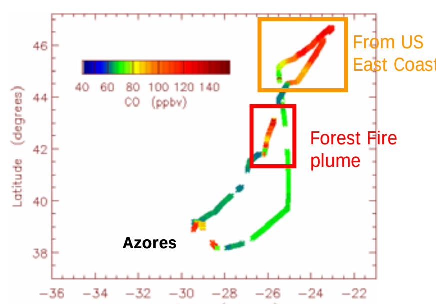


MOPITT observations

Signature of biomass burning (Alaska)



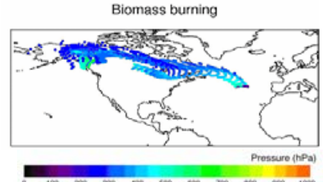
Model prediction of CO (Methven)



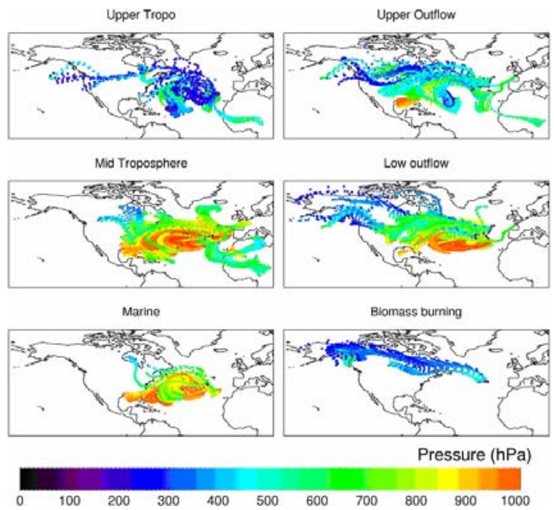
Aircraft measurements

- Successful test of model prediction of long range plume transport
- Long range transport of forest fire emissions.

Biomass burning



Trajectories classified by origin for ITOP



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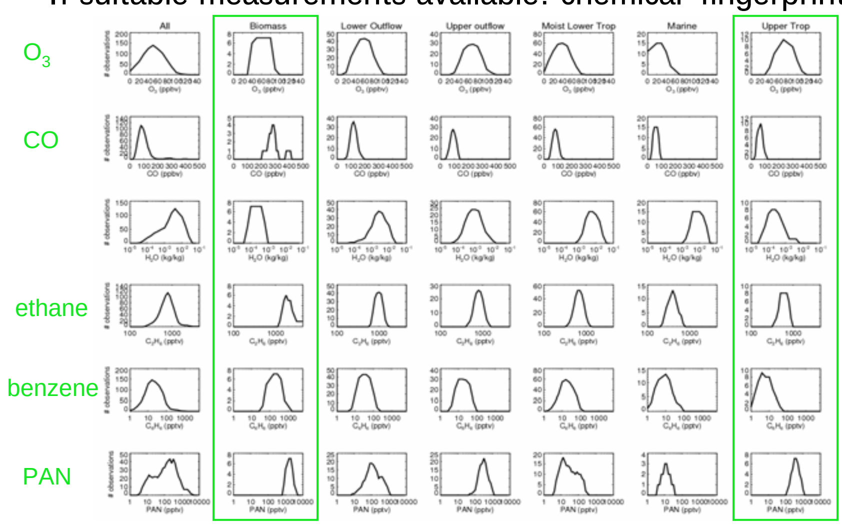
If suitable measurements available: chemical 'fingerprints'



- Fingerprints are conserved over large distances – 1000s km
- As good an indication of air origin as meteorological analyses

(Most common fingerprint was 'polluted')

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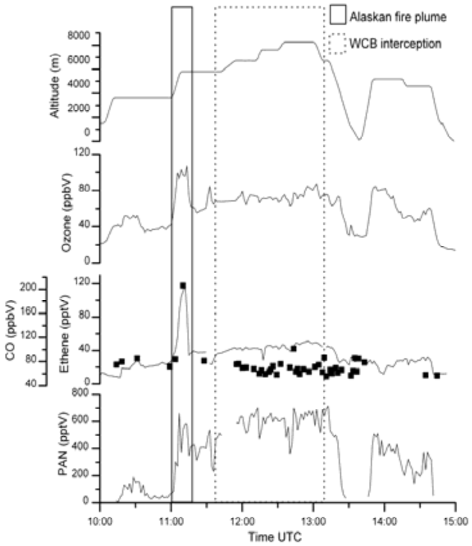
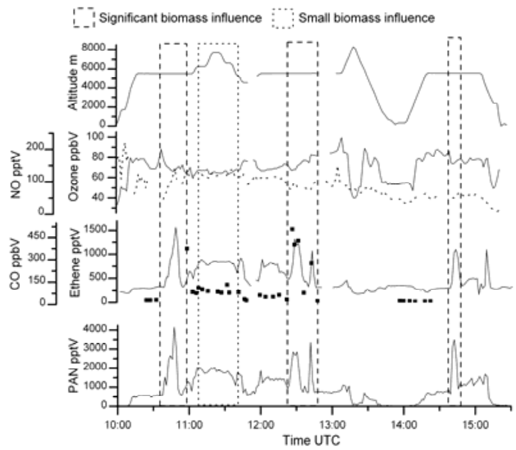
Interception in mid Atlantic of biomass burning plume - 1



'warm' plume 268K at 5.6K
– enhanced ozone in plume

PAN comparable with
WCB anthropogenic plume

Interception in mid Atlantic of biomass burning plume - 2



'cold' plume 263K at 5.4km
No ozone enhancement

PAN remains very high

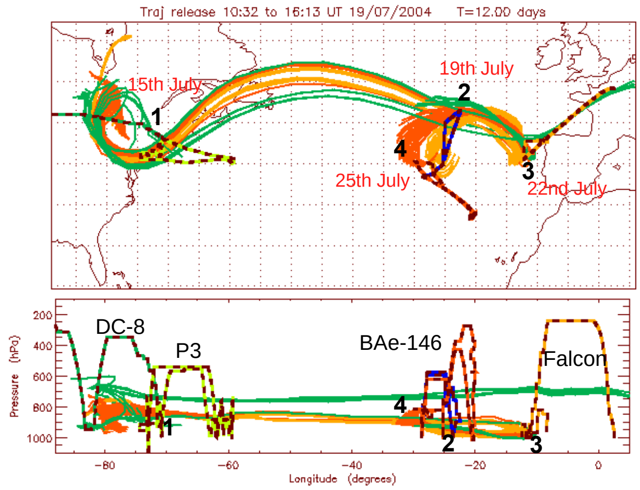
High ethene, - low OH

Injection height of burning emissions is very influential

Poses stringent tests for models:

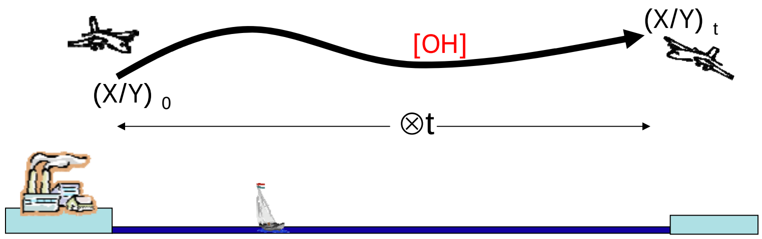
not resolvable from space….
ensembles of measurements…

Detecting Chemical **Transformation**



Trajectories from BAe146 flight track (blue) back and forwards from 19th July flight

Estimating pollution destruction over the Atlantic



Within an air mass:

$$\ln(X/Y)_t = \ln(X/Y)_0 - [(k_x-k_y)\ [OH]\ \otimes t]$$

Measurements of multiple voc species essential to account for plume dispersion….

Time-averaged [OH] in the air mass based on chemical changes observed in multiple species.

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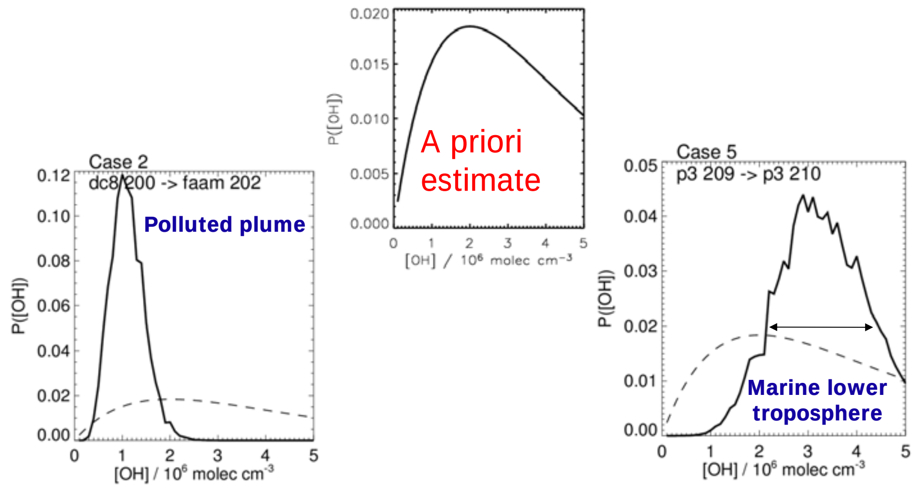
Oxidising capacity in different airmass types



Well-constrained and rigorous estimates of averaged [OH] in single air masses over intercontinental scales (Alistair Lewis et al.)

stringent tests of models.....

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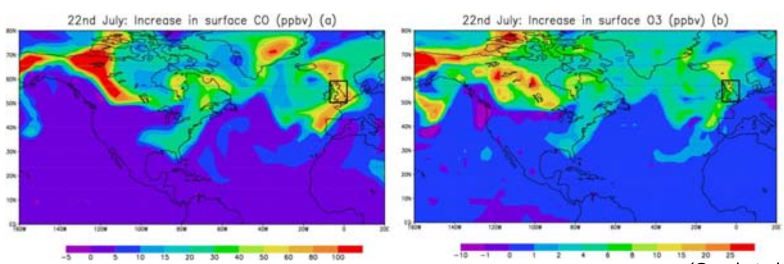
ICARRT/ITOP

- Validation of (Lagrangian) model calculations
- Chemical fingerprinting
- Proxy [OH] determination

⇒Tests of fundamental chemical and dynamical processes to constrain models



(Good et al.)

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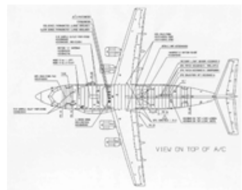
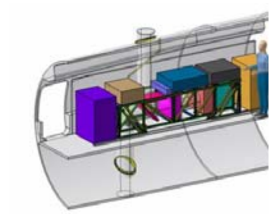
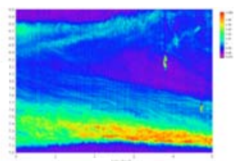
Combined airborne O_3, H_2O and aerosol lidar



University of Cambridge
UMIST/University of Manchester
National Physical Laboratory
(Q-Peak)

FAAM/NERC

Cranfield Aerospace
BAE Systems
Direct Flight/Avalon

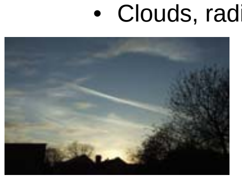
Scientific Rationale:

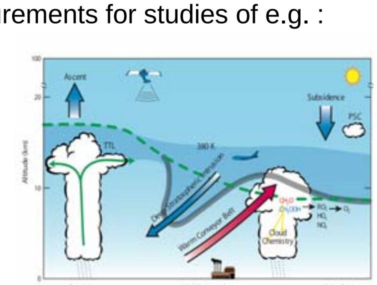
H_2O, O_3 and aerosol fundamental to chemical processes, radiative properties, physical structure of the atmosphere. High spatial resolution measurements also provide context for *in situ* physical or chemical measurements

Airborne lidar systems exist for H_2O and O_3 individually.

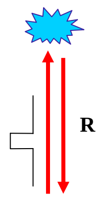
⇒ Combine to provide synergistic measurements for studies of e.g. :

- Atmospheric structure
- Chemical composition
- Transport processes (tracers)
- Clouds, radiation





LIDAR: Light **D**etection and **R**anging



$$R = c \times \frac{elapsed\_time}{2}$$

Instrumental and backscatter parameter

$$S = S_0 \times A \times \frac{1}{R^2} \times e^{-2\int_0^R \alpha \times c \times dR}$$

DIAL: Differential **A**bsorption **L**idar

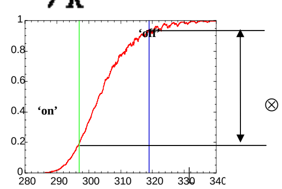
$$S1 = S_0 \times A \times \frac{1}{R^2} \times e^{-2\int_0^R \sigma 1 \times c \times dR}$$

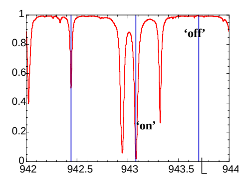
$$S2 = S_0 \times A \times \frac{1}{R^2} \times e^{-2\int_0^R \sigma 2 \times c \times dR}$$

$$\frac{S1}{S2} = e^{-2\int_0^R \Delta\sigma \times c \times dR}$$

⊗ ∫

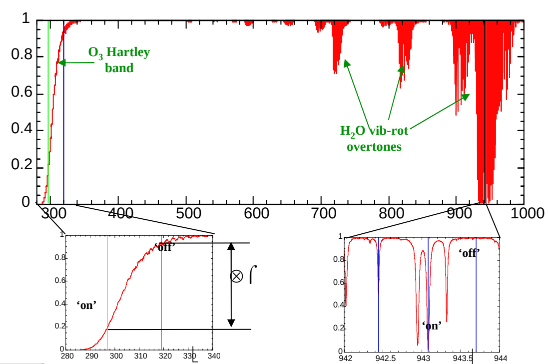
Concentration =F(R)





Implications….

Technical issues:



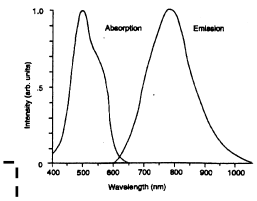
	H_2O	O_3
wavelengths	700-950 nm	266-320 nm
features	Highly structured narrow vibration rotation features -high λ stability required	Lower resolution absorption - less stringent

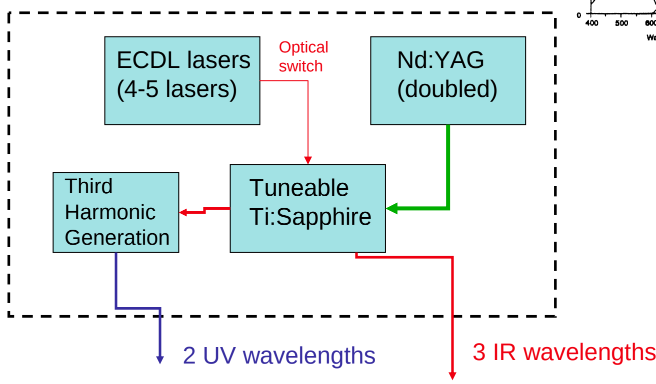
® IR *and* UV wavelengths needed

Seeded Ti:Sapphire Laser

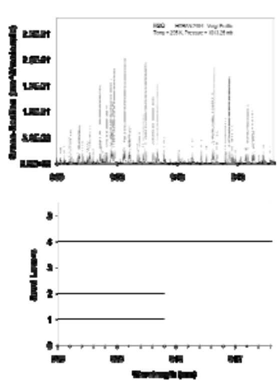
•Solid state tuneable laser, 600-1000nm

•Seeded with wavelength controlled ECDL

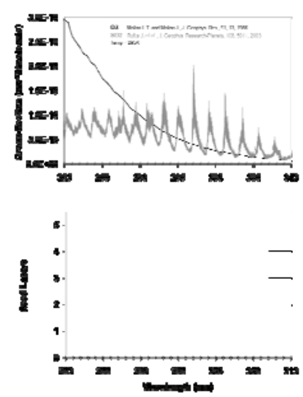




+ diagnostics



IR Spectral Region Seed Lasers



UV Spectral Region Seed Lasers

λ tuning for different atmospheric conditions..

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Sub-orbital workshop
Toronto, 1-2 February 2007
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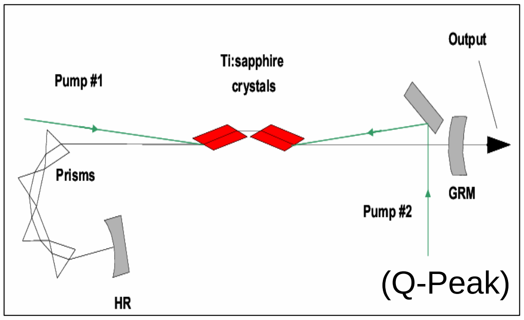
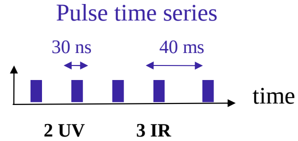


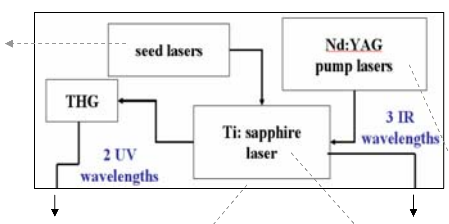


PREDICTED CHARACTERISTICS

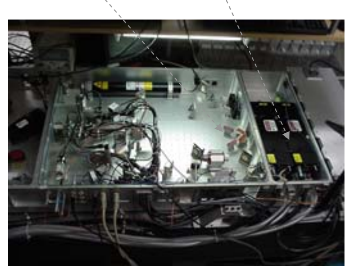
	UV	IR
Emitted Energy:	30 mJ /pulse	100 mJ /pulse
Optical Efficiency (filter incl):	6 %	18 %
Quantum efficiency of PM:	20 %	50 %
Spectral linewidth	< 50 pm	< 1 pm

Telescope Diameter: 40 cm
Gain of PM: 10^6

Ti:Sapphire Laser



- 30 ns pulse
- 5 wavelength
- 25 Hz rate
- Online pulse wavemeter
- Water vapour and SO_2 Cells
- Developed specifically for this application

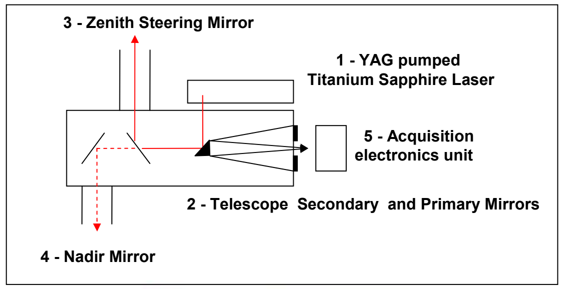


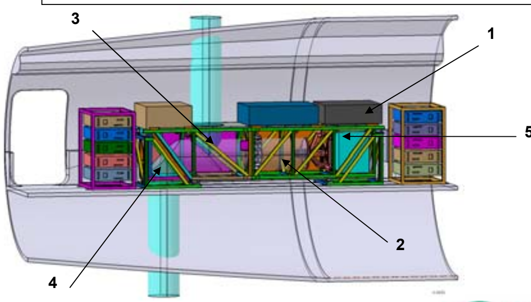
NPL diagnostics

Key Components

Length: ~ 460 cm
Depth: ~ 80 cm
Height: ~ <150cm

Estimated
Total Weight:
~810 kg





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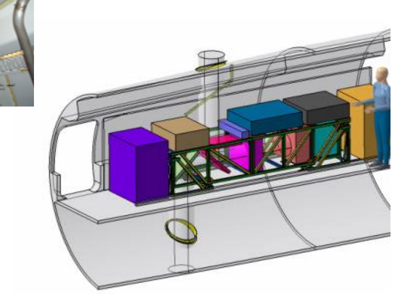
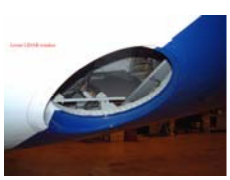
Trial Fit Oct 2006





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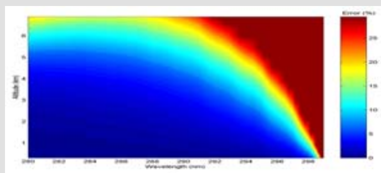
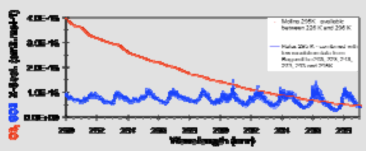
Performance: Ground-based ZENITH viewing

283-313nm **930-948 nm**

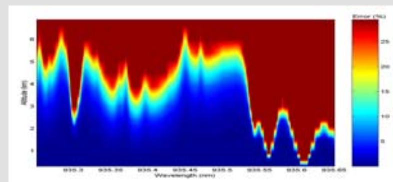
OZONE **WATER VAPOUR**

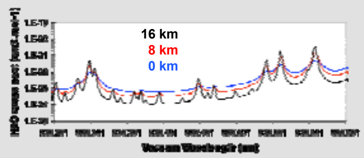
OFF = 299 nm





OFF = 935.227 nm





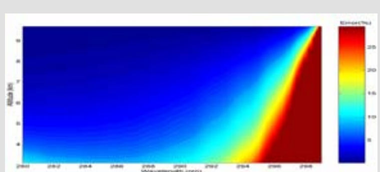
(Stephane Garcelon)

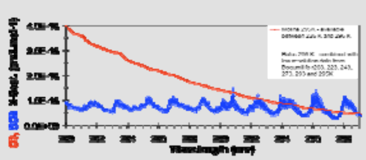
Performance: 10 km NADIR viewing

283-313nm **930-948 nm**

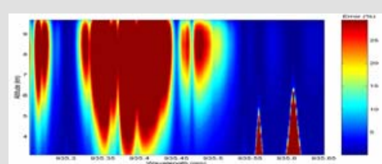
OZONE **WATER VAPOUR**

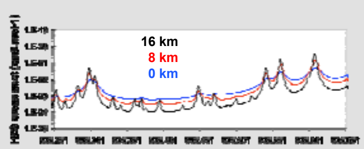
OFF = 299 nm





OFF = 935.227 nm





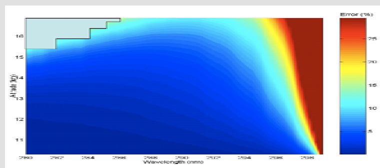
(Stephane Garcelon)

Performance: 10 km altitude ZENITH viewing

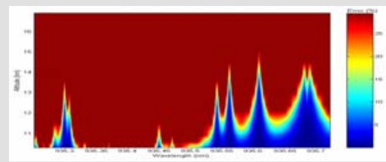
283-313nm | **930-948 nm**

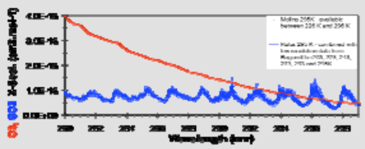
OZONE | **WATER VAPOUR**

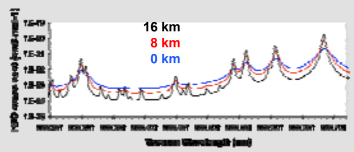
OFF = 299 nm



OFF = 935.227 nm







(Stephane Garcelon)

Lidar projected performance

Parameter	Ozone concentration profile	Water vapour mixing ratio profile	Aerosol backscatter profile
Vertical resolution	≤ 300 m	≤ 300 m	~ 30 m
Time resolution	≤ 1 minute	≤ 1 minute	≤ 1 minute
Maximum range	≥ 5 km	≥ 5 km	10 km
Accuracy	10% or 5 ppb	10%	10%
		Strong and weak absorption lines	Sizing based on measured depolarisation ratio
Installation May 2007			

Choice of suitable ⌊ pairs: H_2O: tropics *vs* polar, UTLS *vs* nadir etc.
O_3: stratospheric *vs* tropospheric, pollution (SO_2, aerosol)

Conclusions/Discussion

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Acknowledgements

FAAM aircraft

UMIST, University of Cambridge, UK Met Office, NERC, BAE Systems, CAe

ICARRT/ITOP

ITOP members (many UK Universities), international partners, NERC….

LIDAR

University of Cambridge, National Physical Laboratory, Q-Peak, FAAM, BAE Systems, CAe

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Science Mission on Global Hawk

Alexander E. MacDonald, NOAA Forecast Systems Lab
***Adrian F. Tuck**, Meteorological Chemistry Program, NOAA Aeronomy Lab
David W. Fahey, NOAA Aeronomy Lab

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Organization:	NOAA-ESRL/CSD6, Meteorological Chemistry Program
Presenting Author Email:	adrian.f.tuck@noaa.gov
Presenting Author Telephone:	303 497 5485
Session:	Invited Speaker
Presentation Method:	Talk
Presenting Author Title:	Government

Note: The proposal for the Global Hawk Tropical Tropopause Experiment (GHATTEX) has been added as an appendix at the end of these proceedings for the benefit of this community.

Science Mission on Global Hawk

Alexander E. MacDonald, Director, NOAA Earth Systems

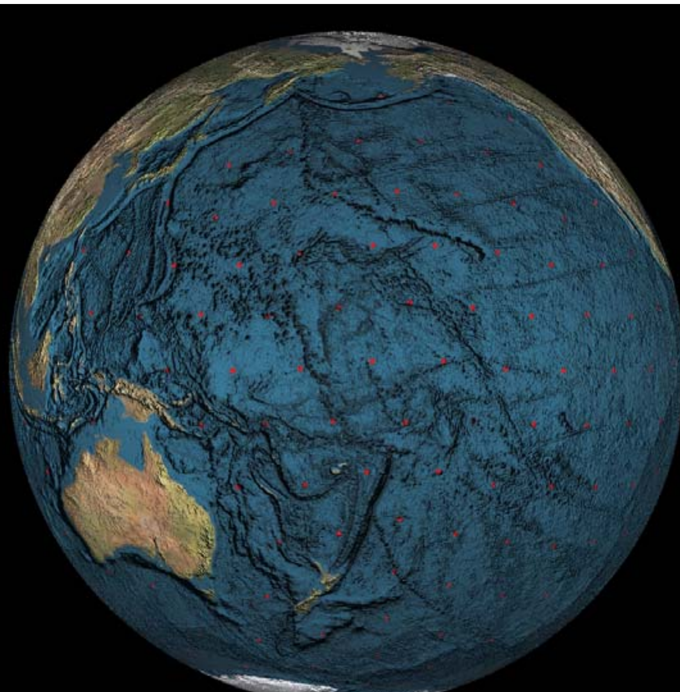
Research Laboratory

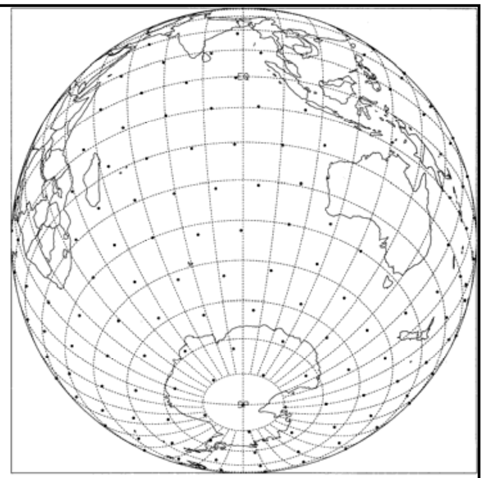
Adrian F. Tuck, Chief, Meteorological Chemistry Program, NOAA ESRL-CSD6

David W. Fahey, Physicist, NOAA- ESRL-CSD6

Global Unified Profiling System

Complete the global observing system with an essential component needed for long term climate projections.





The main idea of the **Global Unified Profiling System** is to take the most accurate possible profiles from the stratosphere to deep in the ocean over as much of the earth as possible. (Land too!)

The profiles should include state (T,p,u,v,q in atmosphere, temperature, current and salinity in the ocean), forcing, and chemistry.

Talk Summary

1. **Requirement**

Sound scientific answers on climate change.

2. **Deficiencies**

The current global observing system is inadequate to DETECT climate change.

The current global observing system is inadequate to PROJECT climate change.

3. **Remedy: Global Unified Profiling System Description**

4. **GUPS Development Concept**

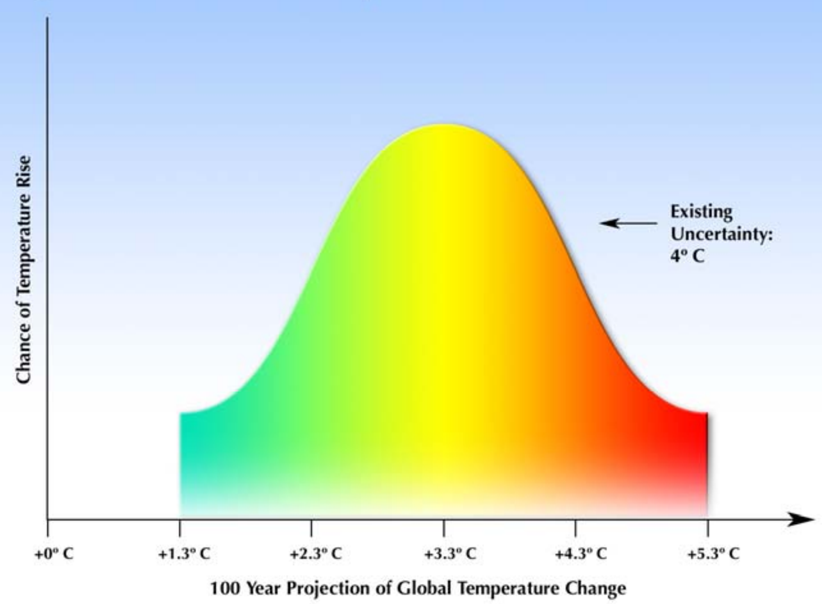
What is the requirement for long term (e.g. 100 year) climate projection?

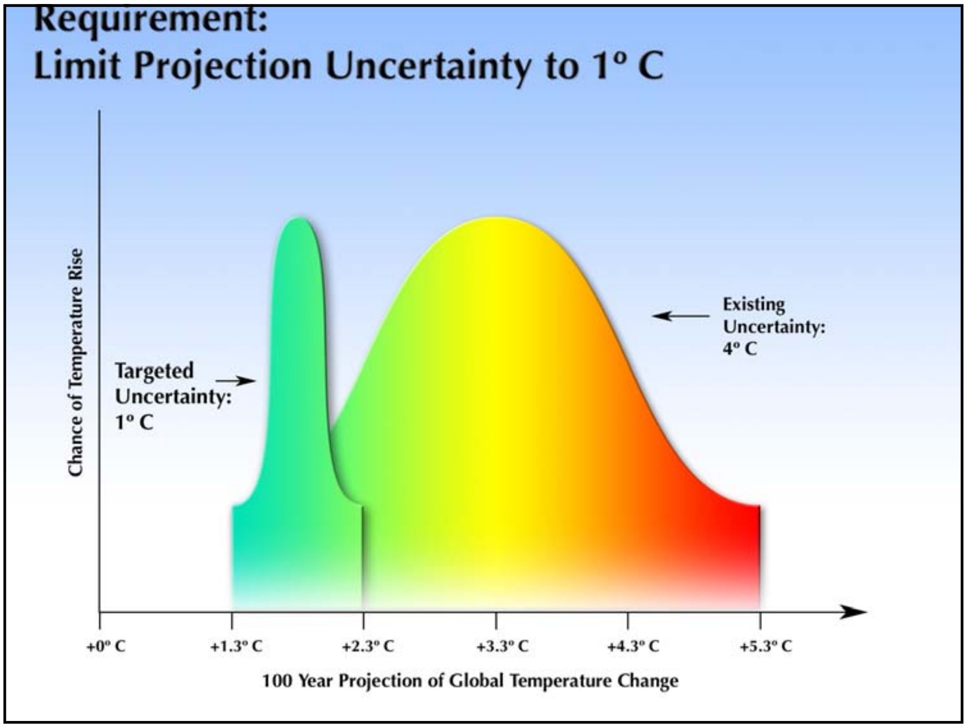
“If, however, by 2012, our progress is not sufficient and sound science justifies further action, the United States will respond with further measures . . .”

George W. Bush, Silver Spring MD, February 14, 2002

Requirement: Sound science to support an action decision regarding energy policy in 2012.

Current:
Projection Uncertainty of 4° C





Although the upper air polar regions are warming, the tropics seem to be cooling as seen by the Microwave Sounding Unit (MSU) satellite, according to Christy and Spencer. NO NET WARMING.

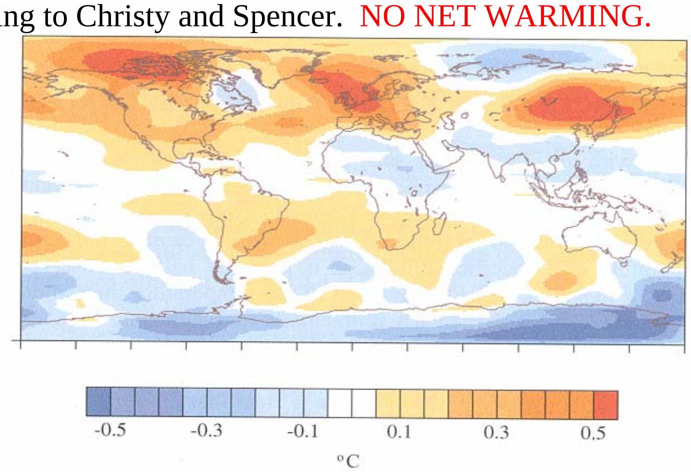
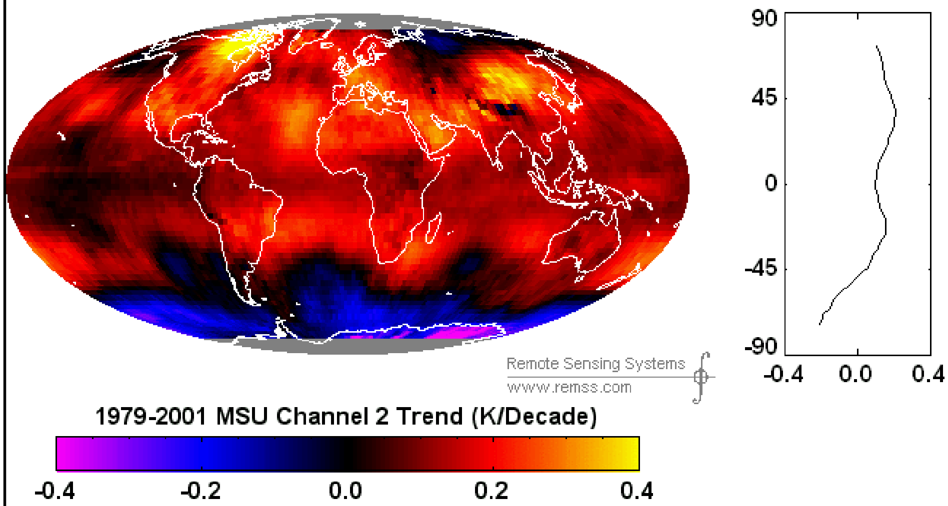
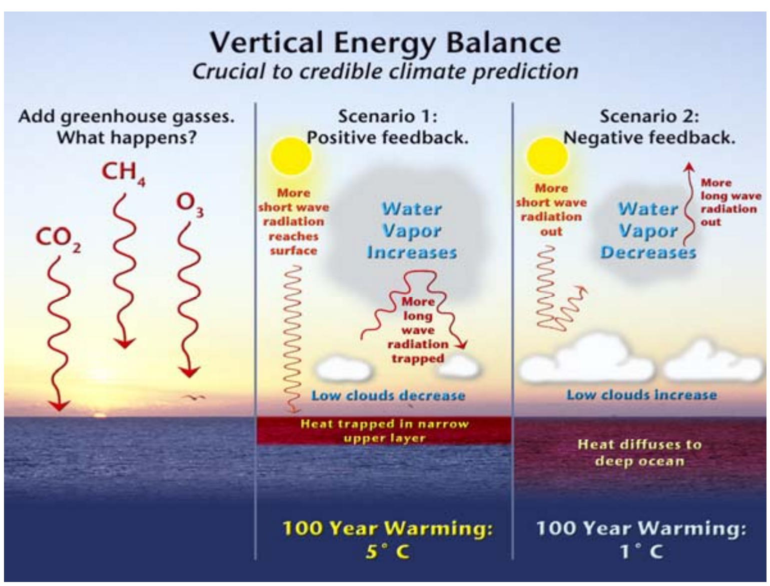


FIGURE 7.1 Global lower to mid-tropospheric temperature trends (°C/decade) from the MSU version D over the 20-year period 1979-98. These ordinary least square trends are computed from data from Christy et al. (2000).

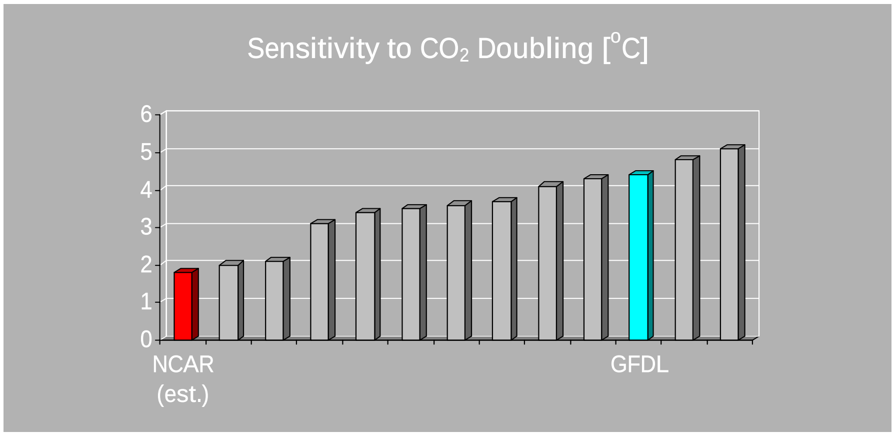


F. Wentz, using the same data finds the globe warming significantly in the troposphere (Approx. .2/decade)

1. CCSP: How much of the expected climate change is the consequence of feedback processes?

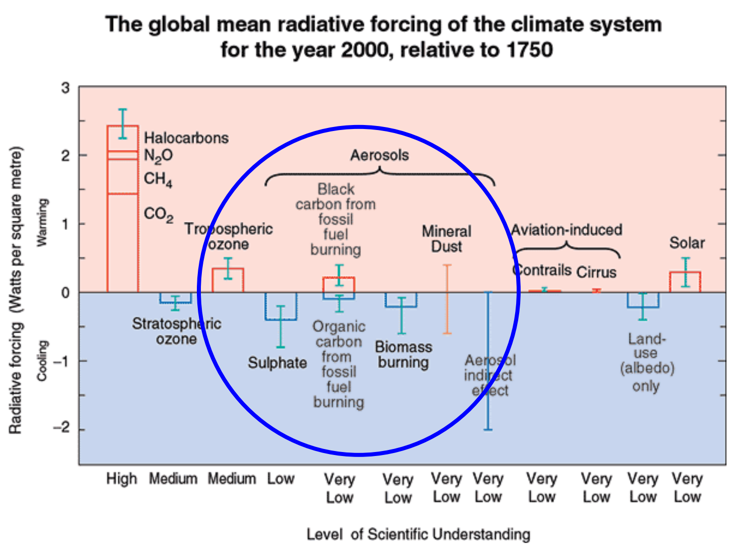


Uncertainties in Climate Sensitivity



Slide from Ants Leetma

3. CCSP: What aerosols are contributing factors to climate change and what is their relative contribution?



System Description:

Global Hawk could be the Unmanned Aerial Vehicle platform:

* Range: 14,000 miles
* Speed: 350 knots
* Altitude: 60,000 feet
* Payload: 1960 lbs
* Lease Cost: $ 4 M /plane
* Year ops: $ 3 M per plane
* ConOP: 2 aircraft, 25% duty cycle
* Prime: Northrop-Grumman

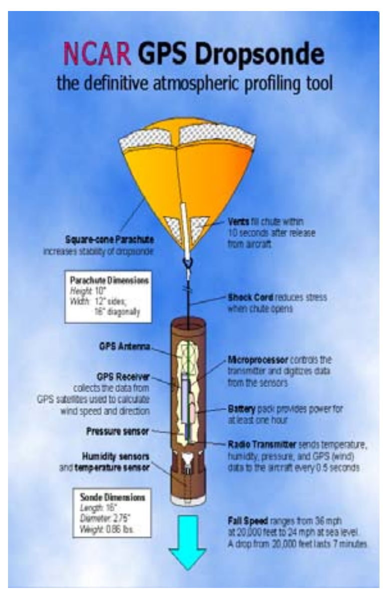
AEM in situ

Dropsonde

GPS Dropwindsonde Specifications

	Operate	Accur-acy	Resolu-tion	Time Const.	Typ. Error
Pressure	1060-20mb	0.5mb	0.1mb	<0.01 sec	1.0mb
Temperature	-90 to 45ºC	0.2ºC	0.1ºC	2.5 to 3.7 s	0.2ºC
Humidity	0 to 100%	2.0%	0.1%	0.1 to 10 sec	<5%
Winds	0 to 150 m/s	0.5 m/s	0.1 m/s		0.5 to 2.0ms

Starting from the existing dropwindsondes, a sonde can be developed that has the extremely high accuracy and time continuity needed for climate trends.



Clouds, Radiation, Aerosols and Chemistry

Another feature of the operations concept is the ability of the aircraft to descend from 60,000 feet to near the surface to take detailed observations of chemistry, radiation, aerosols and clouds. The aircraft could be equipped similar to NASA's ER2 for in situ measurements. Some examples of potential on-board instruments:

On-board Instruments

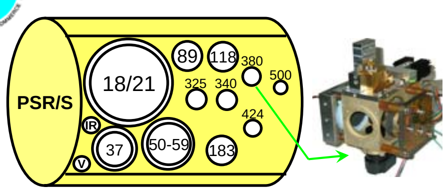
Cloud Microphysics and aerosol:

Cloud total water content	Lyman-Alpha absorption hygrometer (20 Hz)
Cloud liquid water content	Johnson-Williams hot-wire probe
Cloud (liquid + total water content)	Nevzorov probe
Cloud droplet size spectrum	Optical probe (PMS FFSSP)
Cloud particle size spectrum	Optical imaging probe (PMS 2D-C)
Precipitation size spectrum	Optical imaging probe (PMS 2D-P)
Aerosol size spectrum	Optical probe (PMS PCASP)
Cloud condensation nuclei	Saturation gradient chamber
Condensation nuclei	CN counter
Aerosol light scattering	Nephelometer
Aerosol absorption of black carbon particles	Particle Soot Absorption Photometer (PSAP)
Aerosol capture	Counter-flow Virtual Impactor (CVI)
Video impactor	Cloud Scope
Filter sampling	Millipore 47 mm/90 mm
Ice particles	Small Ice Detector (SID) axial scattering probe
• Ice nuclei	Ice nucleus counter
• Aerosol size and composition	Volatility chambers + optical probe
• Cloud droplets	ADA-100 Phase Doppler Particle Analyser - cloud droplets in the range 0.7–128 µm
• Cloud particle analysis/images	Cloud Particle Imager - images/analyses particles up to 2 mm diameter

Atmospheric Chemistry:

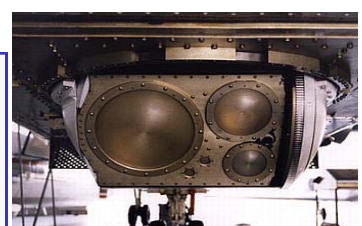
Water vapour	Lyman-Alpha fluorescence water vapour sensor (FWVS)
Ozone	UV absorption (TECO 49)
NO, NO_x, NO_2	TECO 42 chemiluminescence
CO	Fluorescence
SO_2	TECO 43C Trace gas analyser
• Peroxy acetyl nitrate (PAN)	EC gas chromatograph
• NO, NO_2, NO_y	4-channel chemiluminescence
• Hydrogen peroxide & organic peroxides	Fluorescence
• NO_2 (can be set up for other species)	Tuned diode laser
• Formaldehyde	Fluorescence
• Peroxy radicals	Chemical amplifier
• SO_2/DMS/H_2SO_4	APCI mass spectrometer
• $J(O^1D)$ photolysis rate	Photometer
• $J(NO_2)$ photolysis rate	Photometer

NOAA/ETL Passive Microwave Sounder



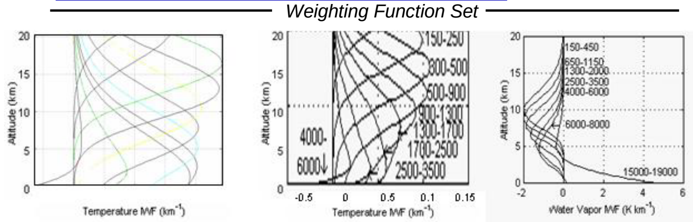
An evolved airborne sounder for use in providing temperature and moisture sounding curtains from UAVs.

PSR/S	18.6-18.8	(v,h,U,V)	8º	
Sounding	21.4-21.7	(v,h)	7º	H_2O
Bands:	36-38	(v,h,U,V)	7º	
Frequencies	50-56 7x	(v)	3.5º	O_2
Polarizations	86-92	(v,h,U)	3.5º	
Beamwidths	118.750 7x	(v)	3.5º	O_2
	183.310 7x	(v)	1.8º	H_2O
	9.6-11.5 um IR	(v+h)	1.8º	



PSR/A Scanner on P-3 Aircraft

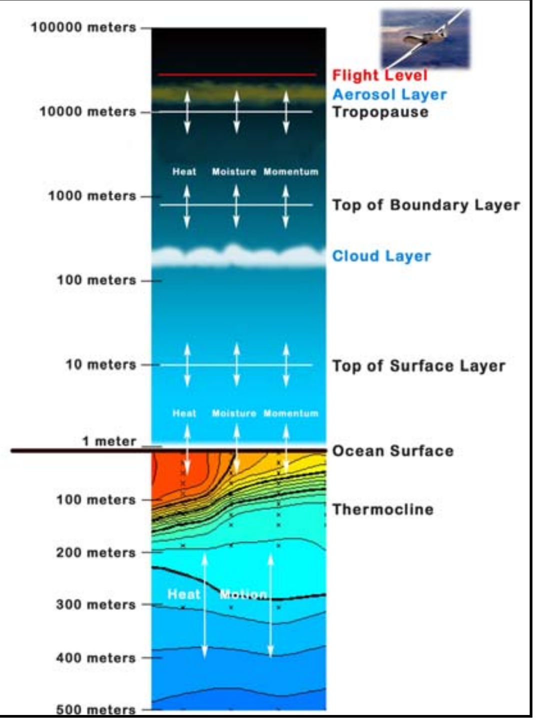
Weighting Function Set



NOAA Applications to:
- ***PacJet***
- ***THORPex***
- ***PacPlus***
- ***GUPS***

Vertical Profiles

Detailed and accurate profiles of temperature, moisture, momentum, cloud and aerosol properties will be crucial for climate models of the future.



Integrated

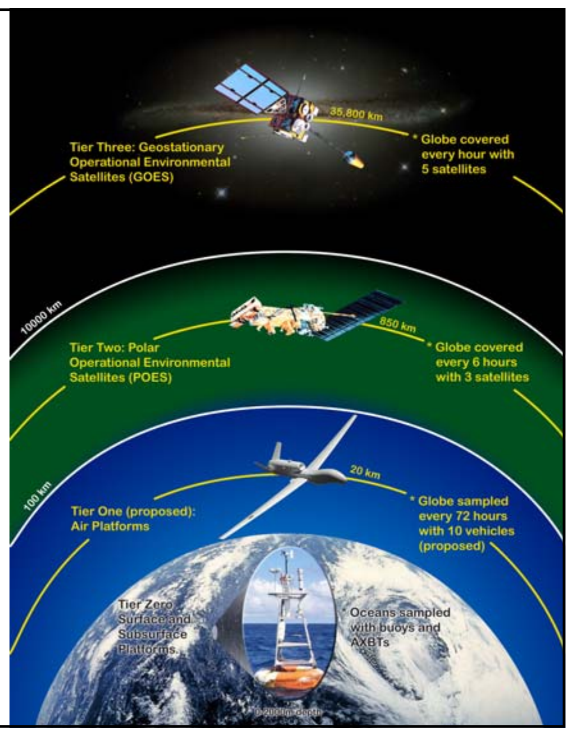
Global

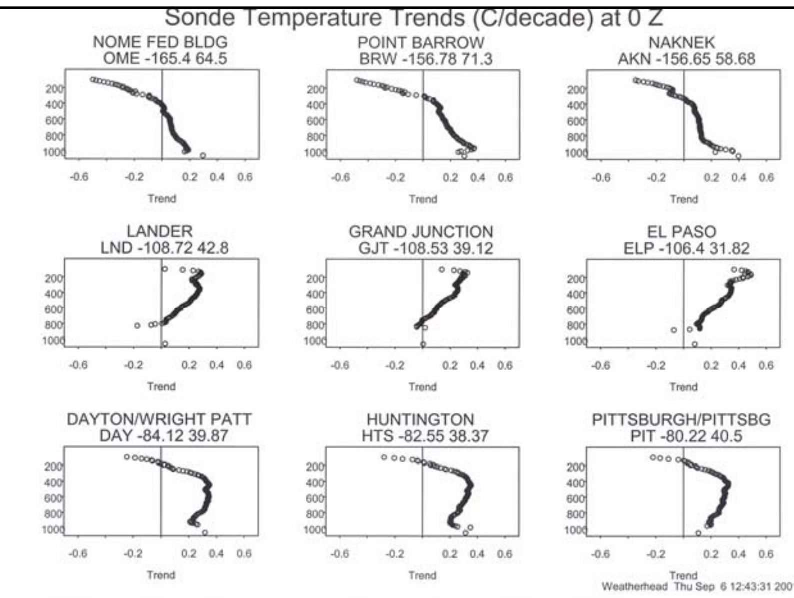
Observing

The global observing system must be designed to support the scientific questions inherent in long term climate diagnosis and prediction.

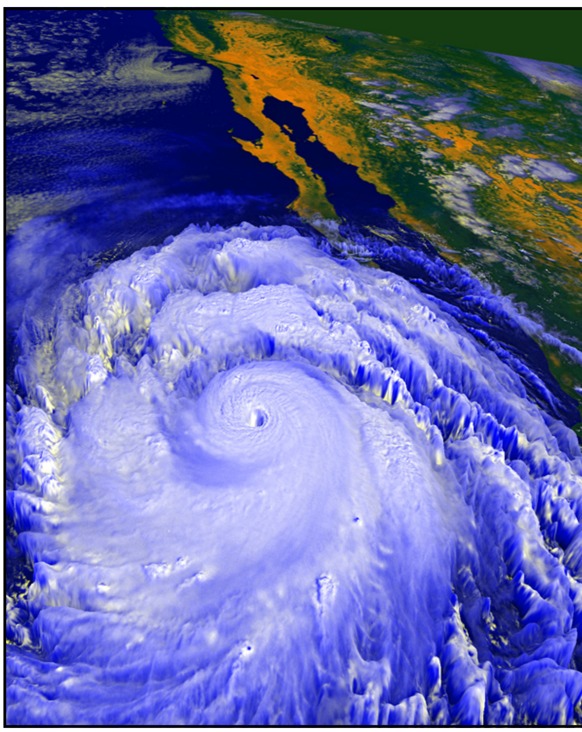
The strategic triad of global observing:

Satellites – UAVs - Buoys



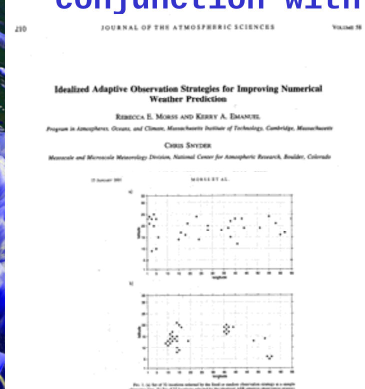


Preliminary studies indicate a spatial scale of a few thousand kilometers.



Adaptive Observations:

Pacific Plus would test adaptive observations in conjunction with



JOURNAL OF THE ATMOSPHERIC SCIENCES

Idealized Adaptive Observation Strategies for Improving Numerical Weather Prediction

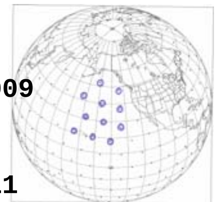
Rebecca E. Morss and Kerry A. Emanuel

Program in Atmospheres, Oceans, and Climate, Massachusetts Institute of Technology, Cambridge, Massachusetts

Chris Snyder

Mesoscale and Microscale Meteorology Division, National Center for Atmospheric Research, Boulder, Colorado

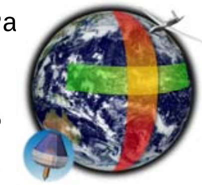
A Grand Challenge for NOAA



Phase 0. Payload Test 2008-2009

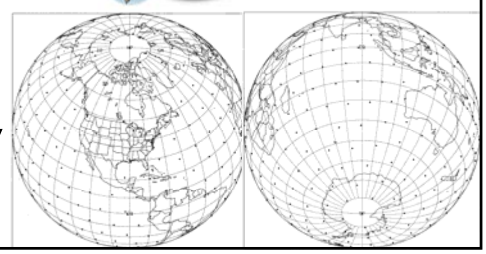
Phase 1. Pacific Pilot 2010-2011

Profiles 11 points in northeast Pa



Phase 2. Pacific Plus 2014-2016

Profiles 60 points across Pacific



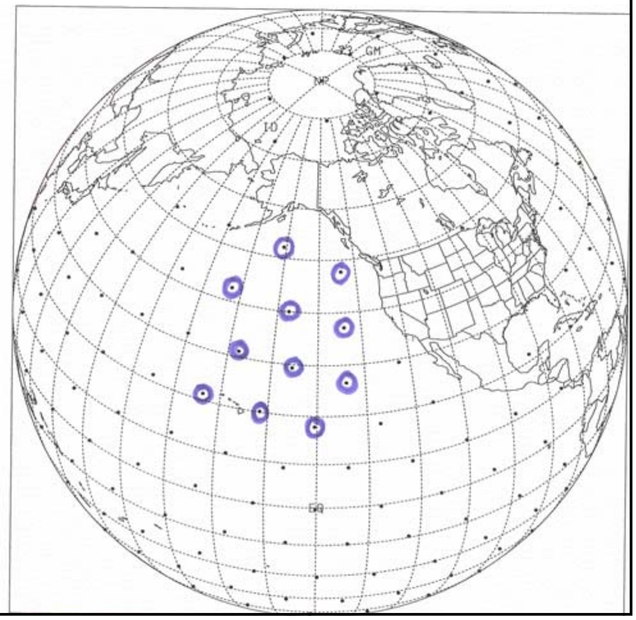
Phase 3. GUPS 2017-2100

Profiles 240 points globally

Actions in Progress

- Interagency MOA (NOAA OAR and NASA Dryden) to pursue role of Unmanned Aerial Vehicles in the global observing system.
- Meeting at Scripps in mid November 2003, included members of climate community to discuss organizational and conceptual approach needed for UAV and buoy component of global observing. (Meeting sponsored by Scripps, NOAA, NASA, DOE and National Space Grant Universities).
- Discussions with Northrop Grumman and General Atomics concerning payload tests in 2008 and 2009.
- Discussions with government, university and laboratories (NCAR, Scripps, etc.) concerning development plans.

Global Unified Profiling System Phase 1: Pacific Pilot



Profile approximately 10 points in the eastern Pacific, with oceanic, atmospheric, chemical, ecological and ocean geochemical measurements.

Budget

FY 09 $ 10 M

FY 10 $ 15 M

FY 11 $ 25 M

FY 12 $ 25 M

Global profiles are essential both to detect and to project climate change.

Initial demonstration late FY 09.

Pacific Pilot could be done FY 10-14.

Three decades of airborne collaborative research by Environment Canada and the National Research Council of Canada.

J. Walter Strapp*, D. Marcotte, S. Cober, G. Isaac, A. Korolev, M. Wolde, and R. Srinivasan

Abstract:

Environment Canada and the National Research Council of Canada have collaborated on airborne atmospheric research since the 1960s. The series of over 100 projects that has been accomplished reflects the topical areas of government atmospheric research over this time. Through the 1970s an 1980s, projects were performed mainly with the NRC Twin Otter research aircraft in the areas of weather modification, cloud physics, and air quality. In 1993, the two agencies formalized the relationship, committing up to 6 months of Twin Otter and 6 months of Convair-580 aircraft time to environmental research. Since then, 40 environmental research projects have been performed in the fields of meteorological, air quality, and climate research. An overview of the program will be provided, along with a brief description of the research aircraft and the instrumentation development.

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Preferred Session:	Past projects and case studies
Presentation Method:	Talk
Presenting Author Title:	Government

Three decades of Airborne Environmental Research

J. Walter Strapp, Stewart Cober, George Isaac, Alexei Korolev
Environment Canada, Cloud Physics and Severe Weather Research Division

Dave Marcotte, M. Wolde, and R. Srinivasan
Flight Research Laboratory, National Research Council of Canada

Canada

Background

Relationship between Environment Canada and National Research Council of Canada for airborne research

- informal 1975-2002 (Twin Otter, Beech 18, T-33)
- since 1993, formal Memorandum of Agreement provides 6 months Twin Otter and 6 months Convair-580 time per year for environmental research
  - Purpose within EC is to provide airborne platforms for research projects of the Climate, Air Quality , and Meterological Research Divisions of EC

Canada

Science Project Selection

• Yearly ‘Call for Projects’ distributed every December soliciting proposals from AQRD, CRD, and MRD.

•Open to all EC-ASTB researchers. Others (e.g universities, OGDs) are welcome to apply with legitimate EC-ASTB collaboration

•Projects are evaluated by an EC-NRC committee, and formally adopted and scheduled if they fall within the EC-NRC science mandates.

•Aircraft hourly rates and other costs are subsidized by a yearly stipend from EC. NRC recovers only a fraction of their declared full costs.

Canada

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Funding

• Aircraft infrastructure and instrumentation costs normally from NRC and EC internal regular funding

• Airborne research projects sometimes from internal budgets, but more often recently from outside agencies:

• Examples :
- Canadian Forestry Service
- Search and Rescue Secretariat,
- PERD,
- MOE,
- Transport Canada,
- Federal Aviation Administration,
- Canadian Space Agency
- The Boeing Co.
- Airbus Ind.
- NASA

Canada

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Projects to Date

• 66 EC-NRC airborne collaborative research projects since 1975 (plus independents) – 2.1 projects / year

• Since MOA discussions (1992), 41 airborne research programs -2.6 projects/year

•Typical project 1 month installation time and 1 month in the field – typically ~ 50-100 aircraft hours

• All projects have been in North America (most in Canada) : from California to Inuvik to St. John's

Canada

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Project Evolution

Project Type	1975-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2007
Weather Modification	4						
Severe Weather	1	2	1	2		4	
Acid Rain		6	2	1			
Clean Air			2	3	2	4	
Remote Sensing Validation				2	4	5	3
Aircraft Icing					3	2	
Other				3	4	2	

Canada

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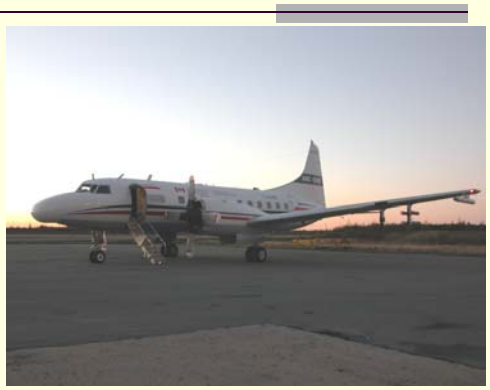
Project Lead

Project Type	1992-2007
AQRD	10
CRD	15
MRD	15

Canada

NRC Convair-580 Aircraft

- large twin-engine turboprop, IFR and VFR
- ceiling 7000 m, duration ~5 hours
- ~1000 kg scientific payload
- ~ ten 19" racks for scientific equipment
- typically 7-9 seats on board for MSC scientists



NRC Convair-580 in SOLAS project, Oct. 2003

- specializes in cloud and storm measurements, and air quality measurements

Canada

Convair-580 Major Instrument Installations

Cloud Microphysics:

- full array of bulk and particle spectra and imaging probes for cloud and aerosol measurement (next slide)

Remote Sensing:

- Ka band (up/down) cloud radar
- dropsonde system
- 532/1064 (up/down) lidar
- new NAWX radar (polarized/dopplerized X and W band)
- multi-channel 180 GHz microware radiometer

Chemistry:

- a wide variety of trace gas measurements
- Aerosol Mass Spectrometer
- PILS system
- plans next year for PTRMS system

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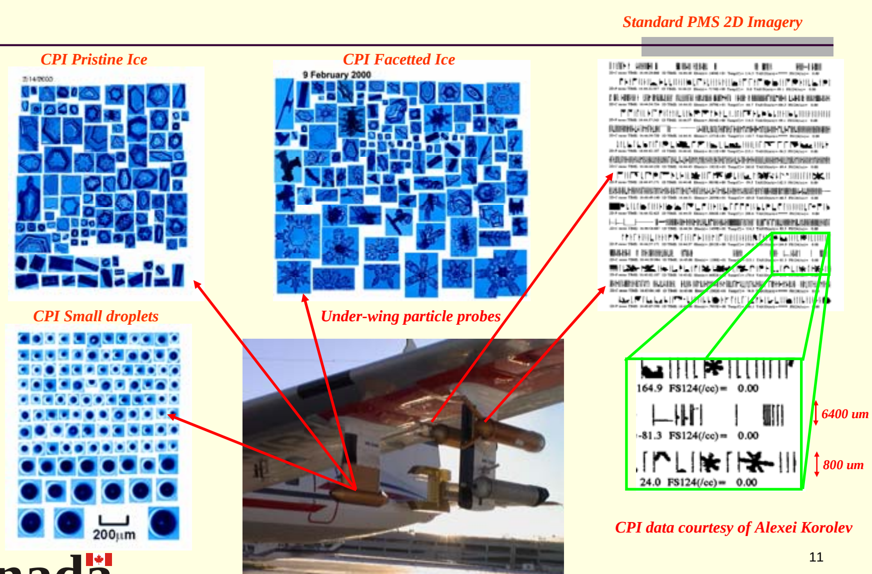
Convair-580 Cloud Particle Probes



CPI data courtesy of Alexei Korolev

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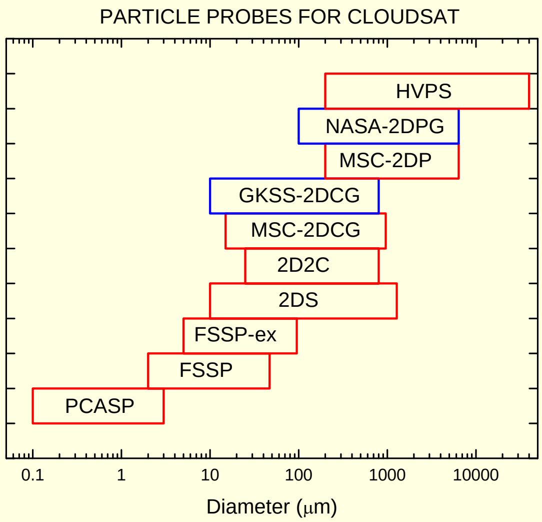
Particle Probe Ranges



Canada

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NRC Twin Otter Aircraft

- small twin-engine turboprop, IFR and VFR
- ceiling 5500 m (with O_2), duration ~2.5-3.0 hours
- ~250 kg scientific payload
- ~ 3-4 19” racks for scientific equipment
- typically 2 seats on board for mission scientists

NRC Twin Otter in Prince Albert, SK, Feb. 2003

- specializes in microwave radiometer measurements, and wind and flux measurements, has been used for plume studies (e.g. MITE)

Canada

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Twin Otter Major Instrument Installations

- 4 exterior under-wing particle measuring probes from 0.1 µm to 6.4 mm, imaging > 50 µm
- Microwave radiometers for remote sensing of surface conditions and satellite validation (19 GHz, 37 GHz, 89 GHz, 1.4 GHz, and 6.9 GHz)
- World leading wind and flux measurements system (heat, momentum, $H_2$0, and CO_2 fluxes)
- Relaxed eddy accumulation system for flux measurements of trace gases ($N_2$0, CH_4, O_3, have been done to date)
- Recent NRC use for Hyperspectral Imager

Canada

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Twin Otter Microwave Radiometer Installations

- New microwave radiometers for remote sensing of surface conditions and satellite validation (~$1 M invested since 1995)
- 19 GHz, 37 GHz, 89 GHz for snow water equivalent
- 1.4 GHz for soil moisture (in development stage)
- 6.9 for lake ice and soil moisture

Canada

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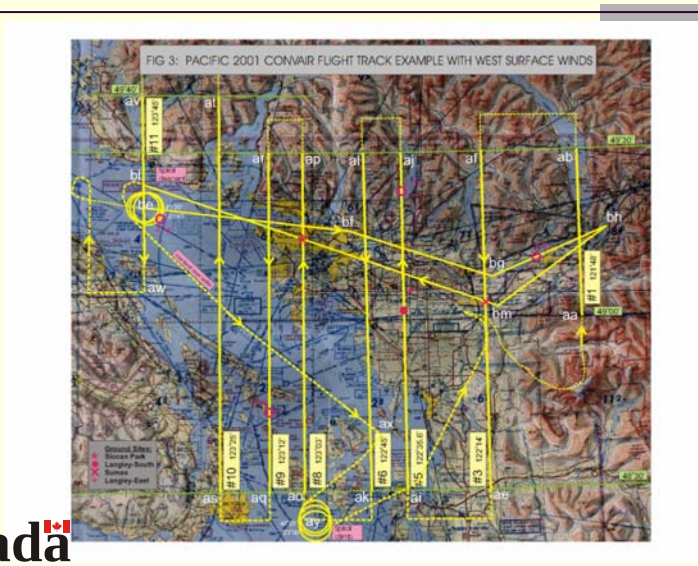
Example: Pacific 2001 - Convair Flight track over Lower Fraser Valley



Canada

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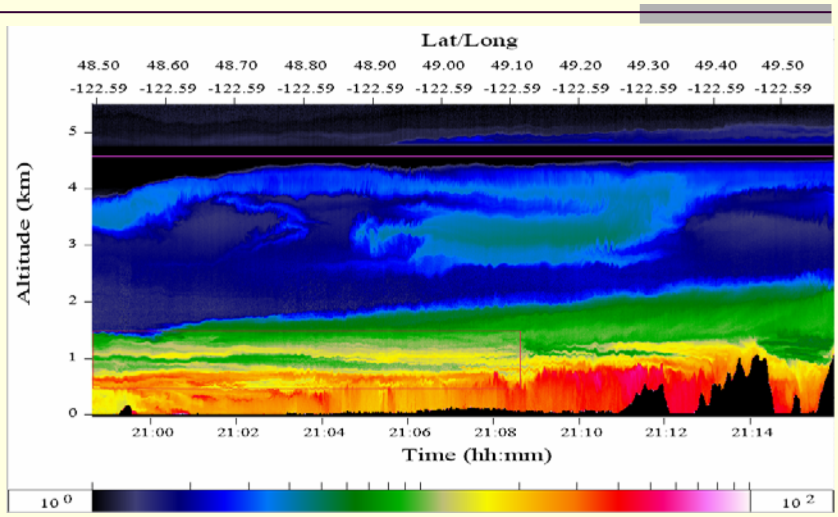
Example: Pacific 2001 LIDAR Data

Aug. 14 (Line 5, N-S)



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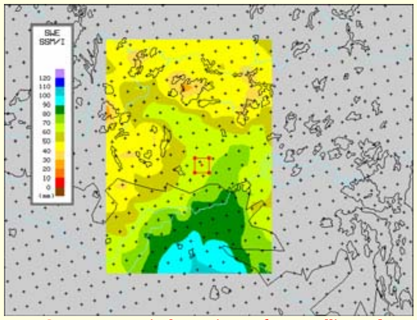
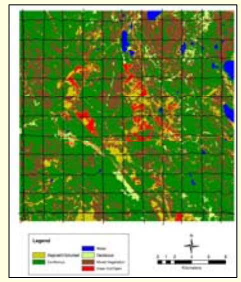
Example: CRD Twin Otter Microwave Program - Prince Albert 2003

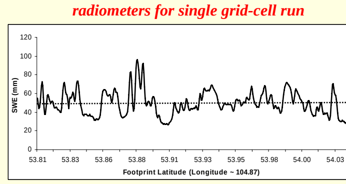


Snow water equivalent estimates from satellite, and satellite grid cell for intensive measurements for Prince Albert study



Land type and flight grid

Snow water equivalent estimates from airborne radiometers for single grid-cell run



Courtesy of Anne Walker and Chris Derksen, CCRP

Canada

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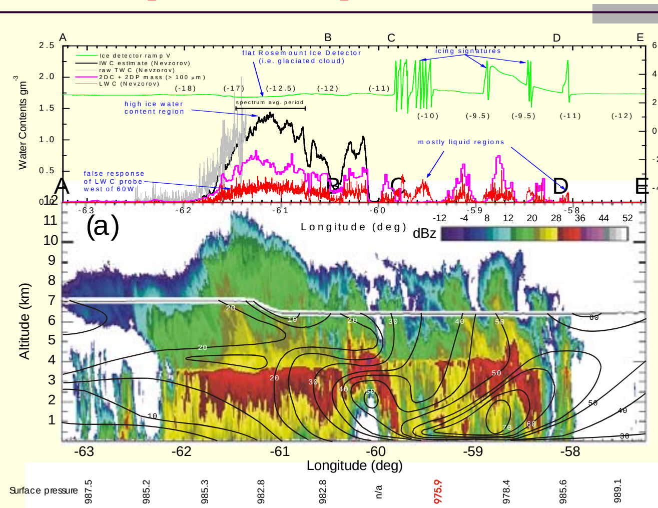
Example: Hurricane Michael (Oct. 19, 2000 (Convair-580) ;

radar and dropsonde wind speed cross-section



Canada

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End of Presentation

Thank You.

Canada

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NRC Airborne Cloud Radar Capability and Recent Research Activities

Mengistu Wolde
NRC

Abstract:

The Flight Research Laboratory of the National Research Council (NRC) operates a Convair 580 aircraft that is being used for various airborne research studies including aeromagenetics, target detection using Synthetic Aperture Radar (SAR) and studies of atmospheric systems and processes. These research activities have been typically collaborative in nature involving government agencies, universities and international partners. The Convair-580 atmospheric research capability has been developed jointly by NRC and Environment Canada. This presentation focuses the Convair-580 atmospheric cloud remote sensing capabilities and provides examples of use of airborne polarimetric measurements in supporting studies of cloud microphysical structure and processes. Specifically the presentation provides:

- Polarimetric W-band Doppler radar use and result from the second Alliance Icing Research conducted in 2003
- Development of the NRC Airborne Dual-frequency W and X-band (NAWX) fully polarimetric and Doppler radar system on the Convair
- NAWX use during the Canadian CloudSat and CALIPSO validation project (C3VP).

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Presentation Method:	Talk
Presenting Author Title:	Government

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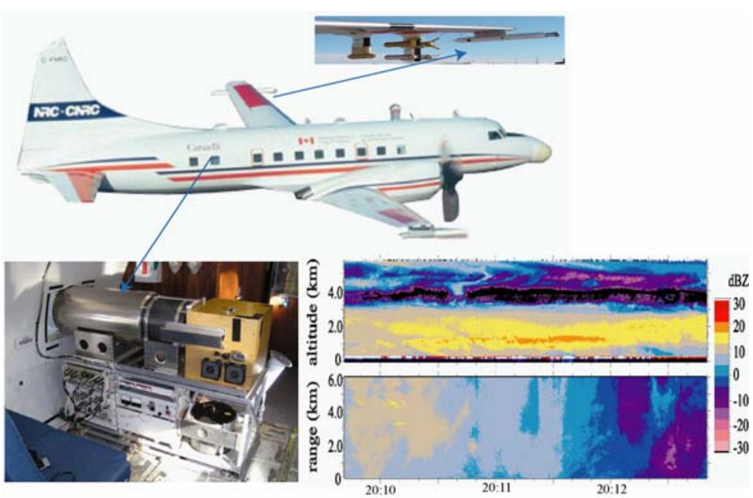
NRC Airborne Cloud Radar Capability and Recent Research Activities



Mengistu Wolde
Flight Research Lab, Ottawa, Canada

Collaborators: EC Cloud Physics and Severe Weather Research Section
NRC Airborne Research group
Canadian Space Agency

Workshop on Science from Suborbital Vehicles
Toronto, Feb 1-2, 2007

National Research Council Canada
Conseil national de recherches Canada

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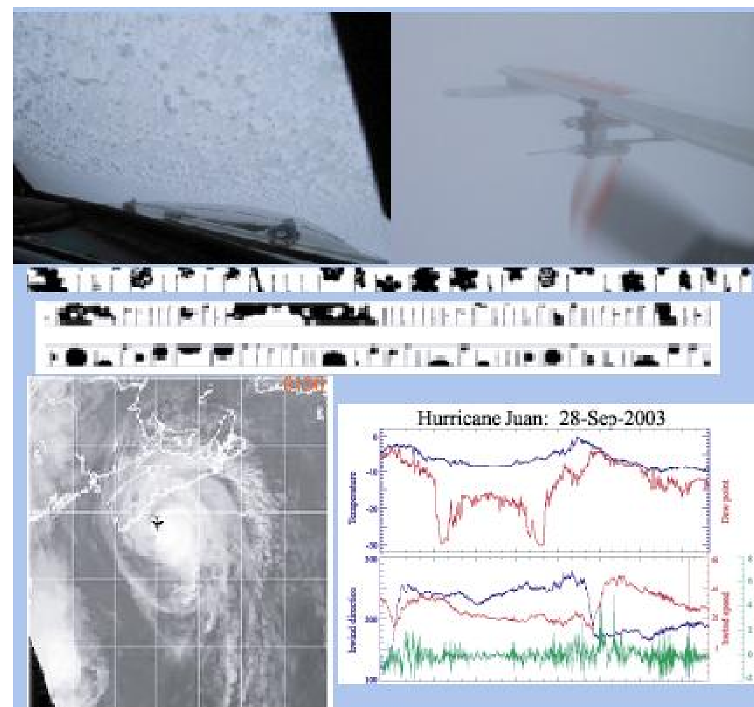
http://www.nawx.nrc.gc.ca

Canada

NRC Convair Research Aircraft

- ***Principal Canadian airborne atmospheric and geophysical research platform***
  - ***Instrumented by NRC, EC and DND***

- ***Used for various research applications***
  - ***Icing***
  - ***Hurricane***
  - ***Air quality***
  - ***Remote sensing system development***



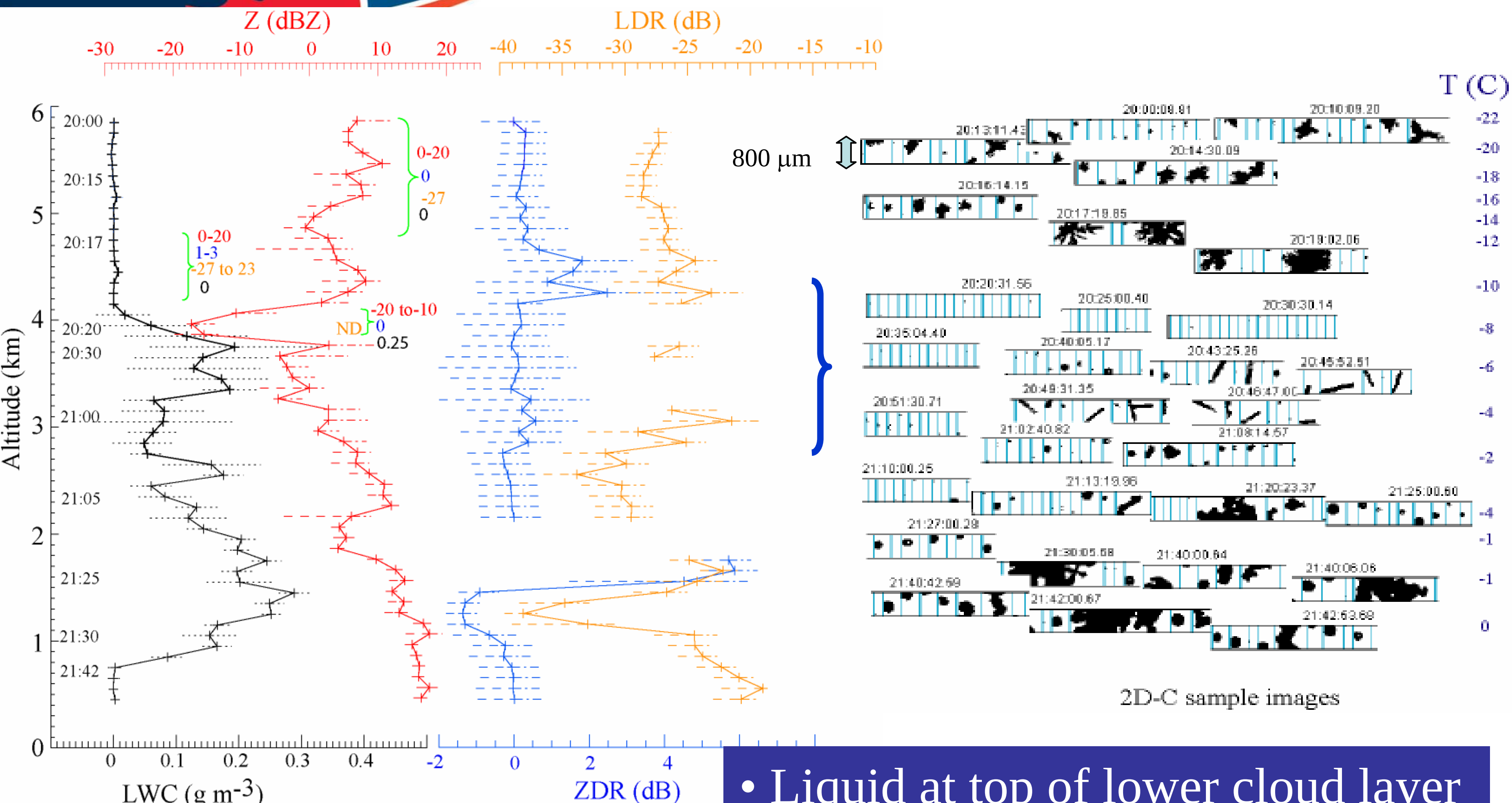
Cloud Radar on NRC Convair 580

- *1999 – EC Ka-band radar (EC: W. Stapp et al.)*
  - *Nadir and zenith view*
- *2003 – Porlarimetric W-band (95 GHz) – AIRS II*
  - *Nadir and Side-view (dual-pol)*
  - *One time installation of University of Wyoming Cloud Radar*
- *2006 – NRC Airborne W and X-band (NAWX) Polarimetric radar system*
  - *Currently used in the Canadian CloudSat and CALIPSO satellite validation project*

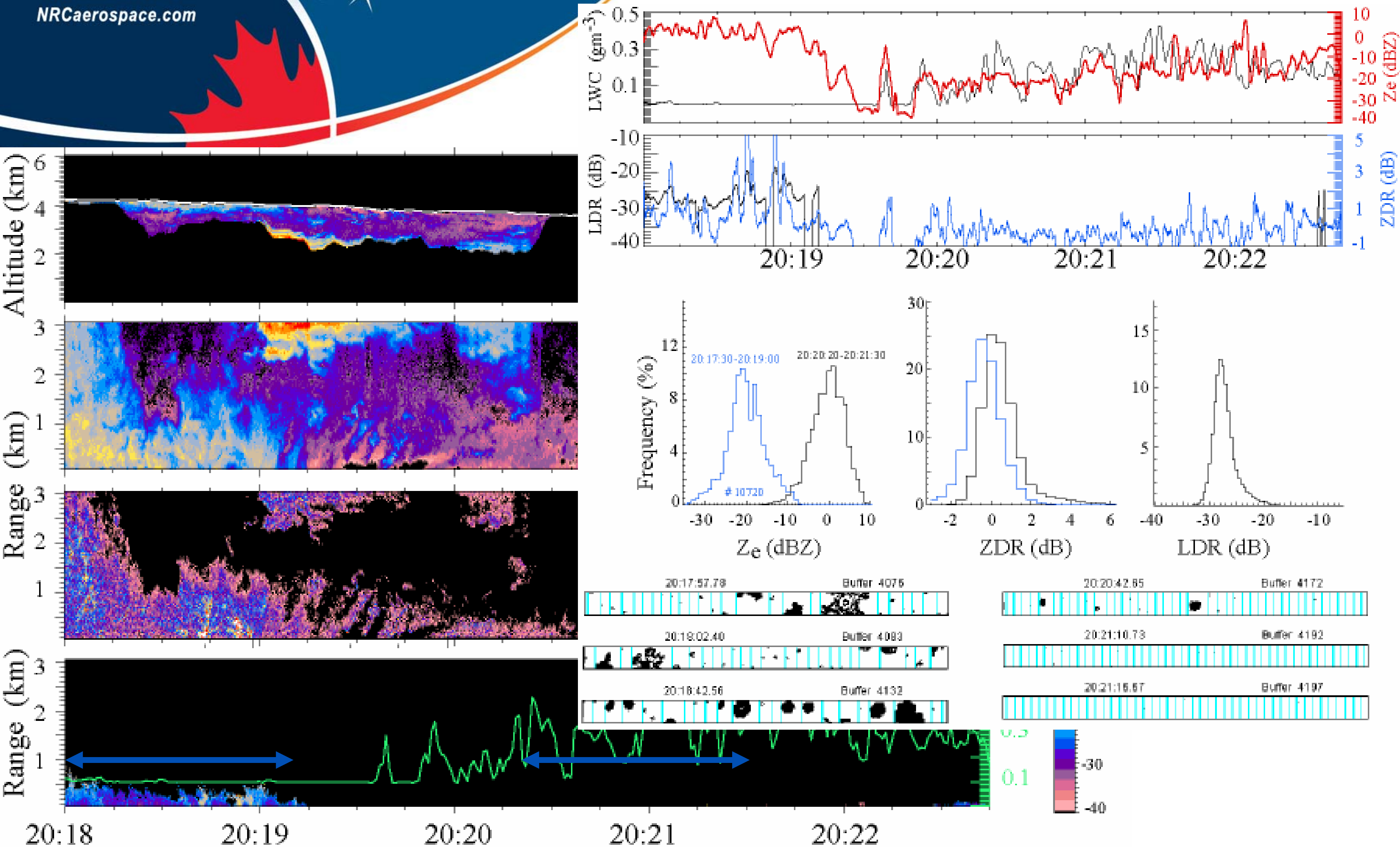
W-band radar – AIRS II

- ***AIRSII (EC: Isaac et al)***
  - ***Second Alliance Icing Research Study conducted in Ontario and Quebec (http://www.airs-icing.org)***
  - ***Multiple science and operational objectives***
    - ***Develop cloud particle classification and SLD detection algorithms using radar data***
    - ***Studies of icing variability and cloud processes – using in-situ and W-band***

Layer average (100 m) radar range: 60-105m



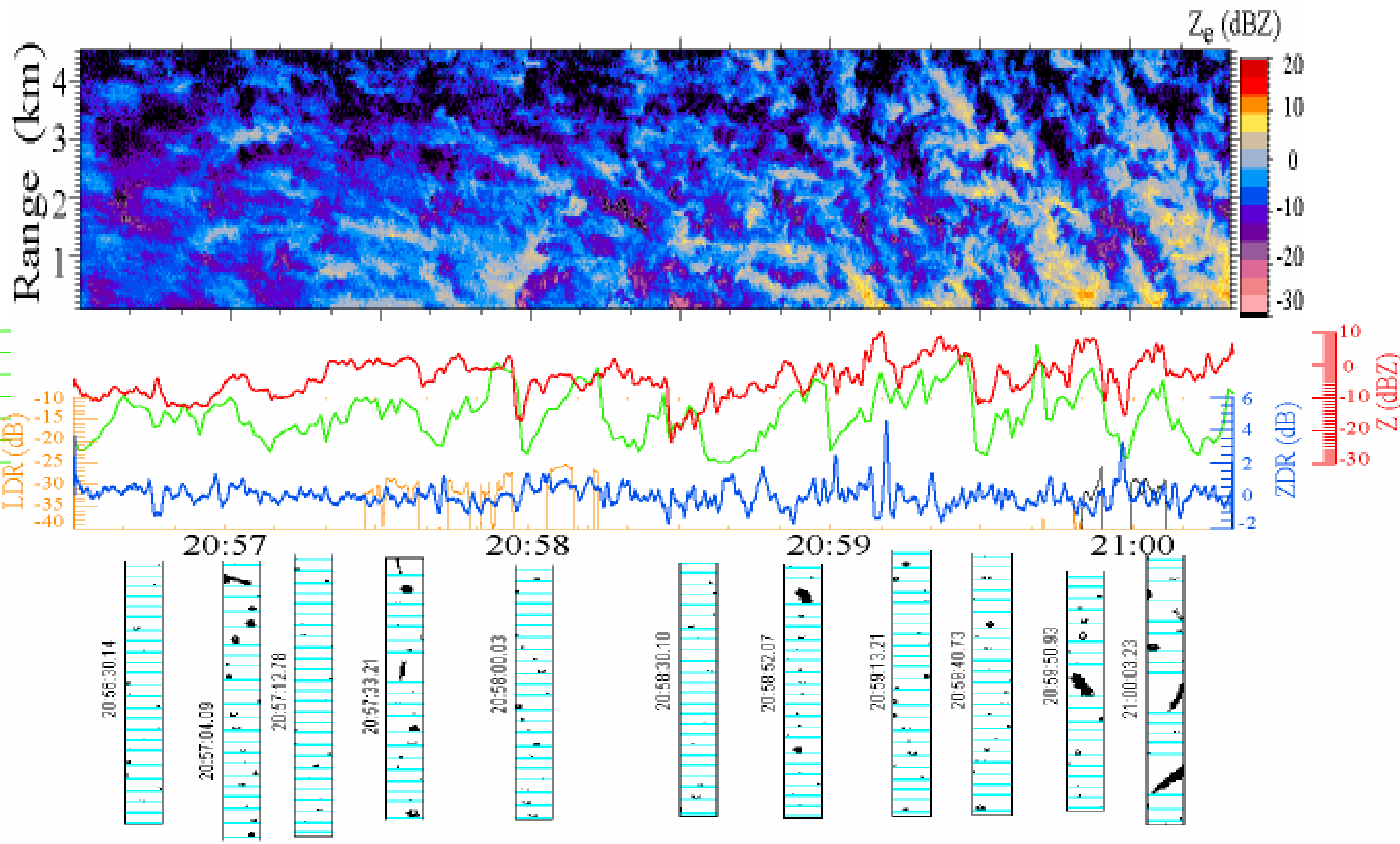
- Liquid at top of lower cloud layer
- LWC max – LDR < -35 dB



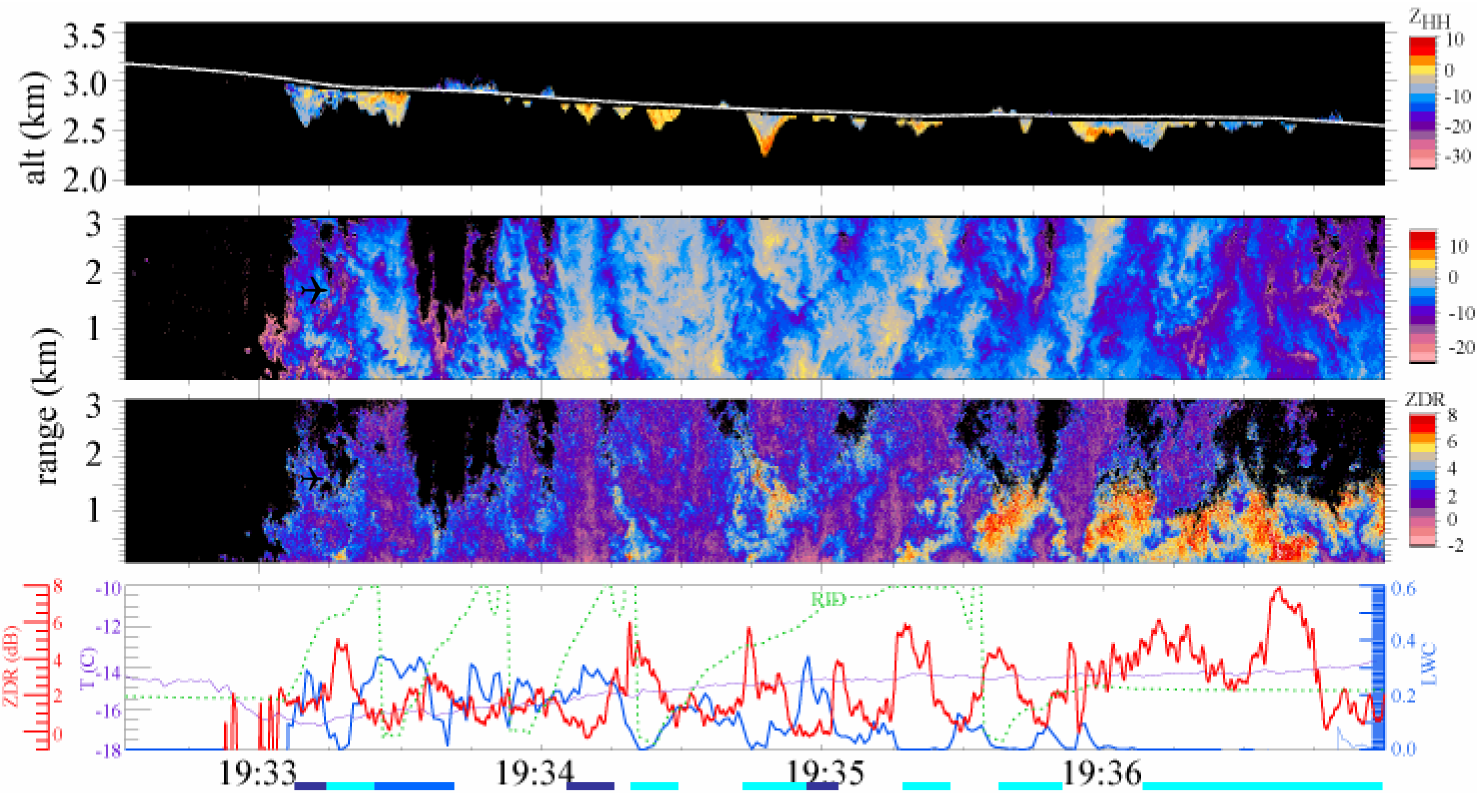
Planar Ice -Z > -10 dBZ, ZDR > 2 dB - LDR ~ -25 dB

Fine-scale Z/LWC fluctuations

Drizzle / Mixed phase
-4ºC @ 3 km



Nov 24 –Plates and liquid



T ~ -15°C

Z_{HH} -20 – 0 dBZ

ZDR 0 – 6 dB

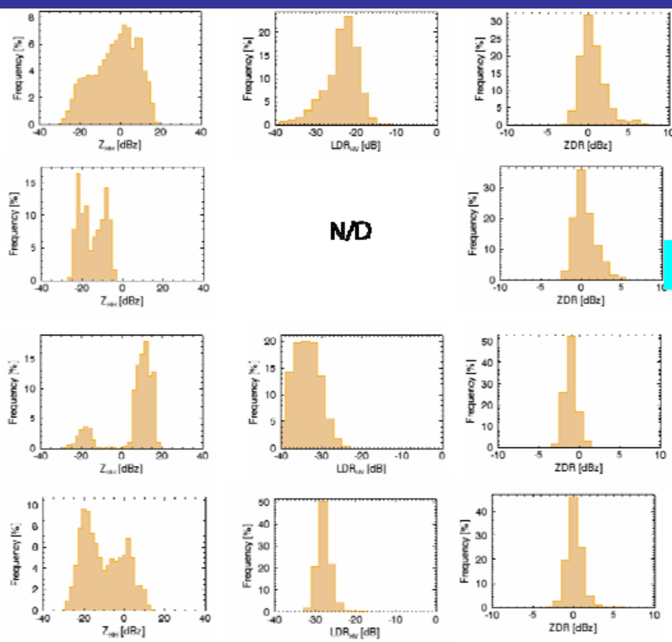
Mixed phase/ice

Ice - ZDR > 2 dB - P1e/P1d – 0 LWC

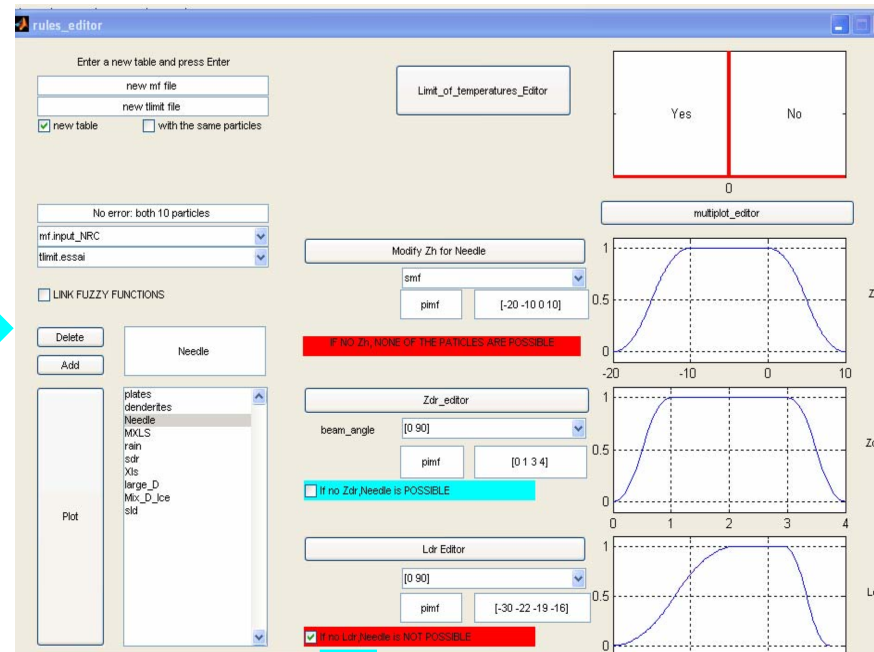
LWC > 0.1 g m^{-3} – ZDR ~ 0 dB

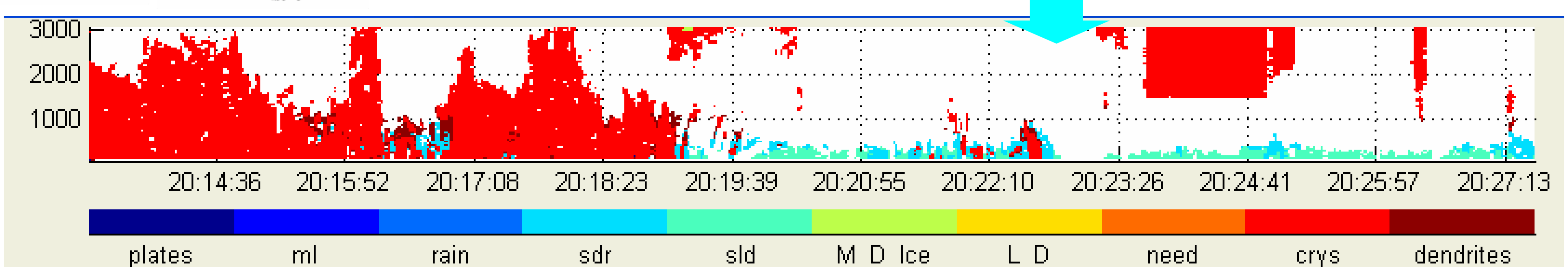
Fuzzy-logic based classification of particles types

Radar signatures of particles – coincident radar and in-situ measurements



Determine particle membership functions





AIRS II - Summary

- ***Good correlations between in-situ and radar data at close range (60-105 m)***
- ***Fine-scale cloud organization in icing and mixed phase segments***
- ***Measurable LDR and high ZDR in Pristine crystals***
- ***Icing layers (all liquid) weak Z (<-10 dBZ) and zero ZDR and no measurable LDR***

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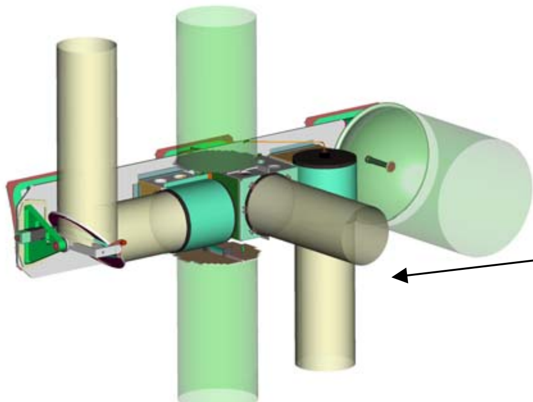
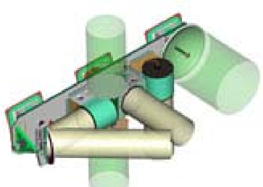
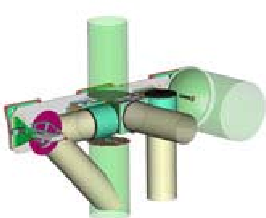
NRC Airborne W and X-bands radar (NAWX)



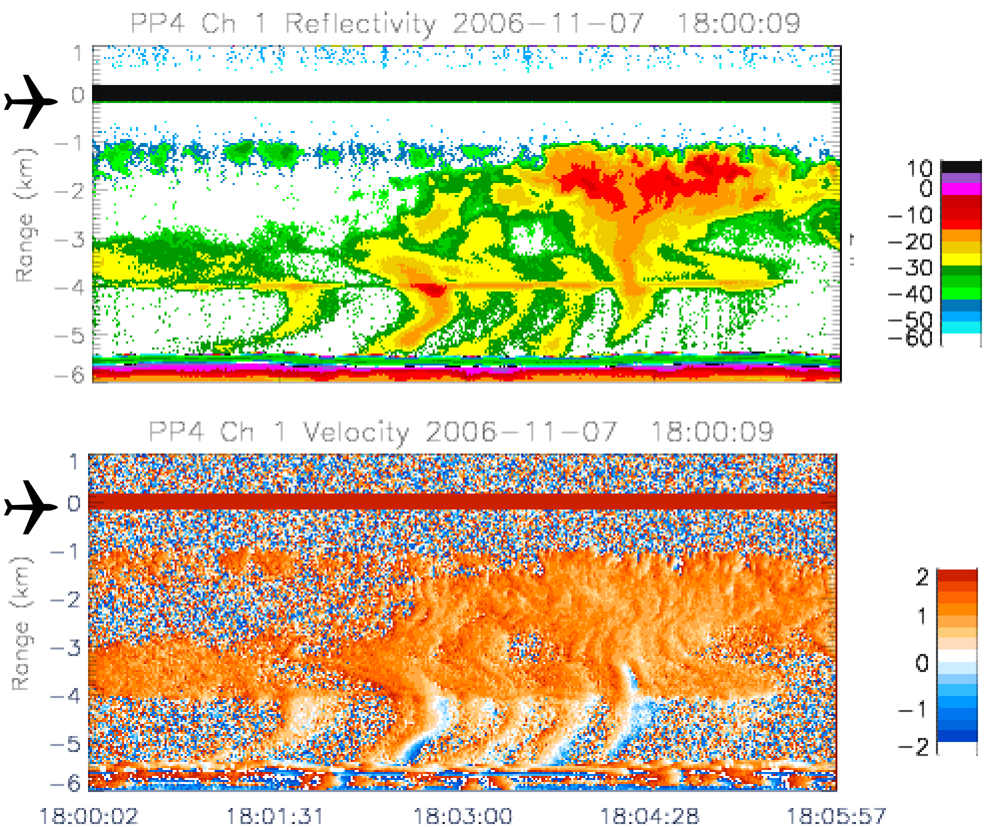




NAWX	W-band	X-band
Transmitted Frequency (GHz)	94.05	9.41
Peak Tx Power (KW)	1.7 - typical	25 (split b/n two ports)
Polarization	Co and Cross	Simultaneous H and V
Doppler	Pulse Pair and FFT	Pulse Pair and FFT
Pulse Duration (μs)	0.1 - 10	0.11-1
Max PRF (KHz)	20	5
Ant. 3 dB BW (°)	0.75	3.5
Antenna ports	5	4
View direction	Up, down and side	Up, down and side

More details/updates: **http://www.nawx.nrc.gc.ca**

NAWX - CloudSat



- ***Fully operational***
- ***First project use: C3VP***
- ***Figure: Example of vertical cross-sections of radar reflectivity and Doppler velocity images obtained at altitude of 6 km in one of the C3VP flights***

NAWX-X

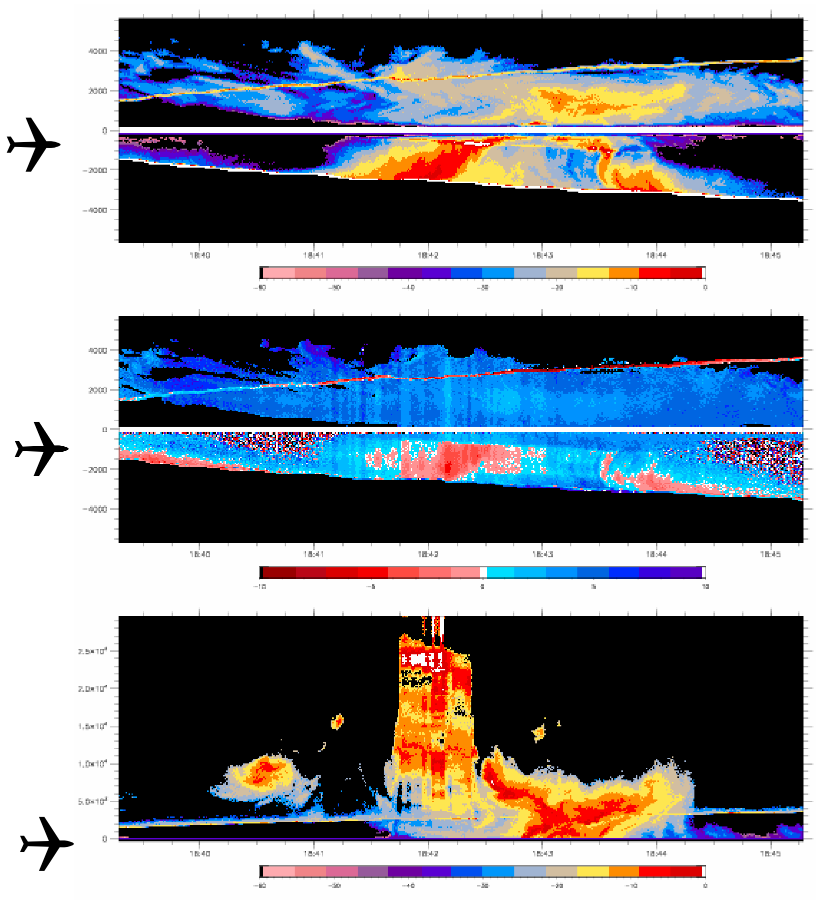


Figure: Example of vertical and horizontal cross-sections of radar reflectivity and Doppler velocity from C3VP flight Nov 9, 2006: Ascending through a BB

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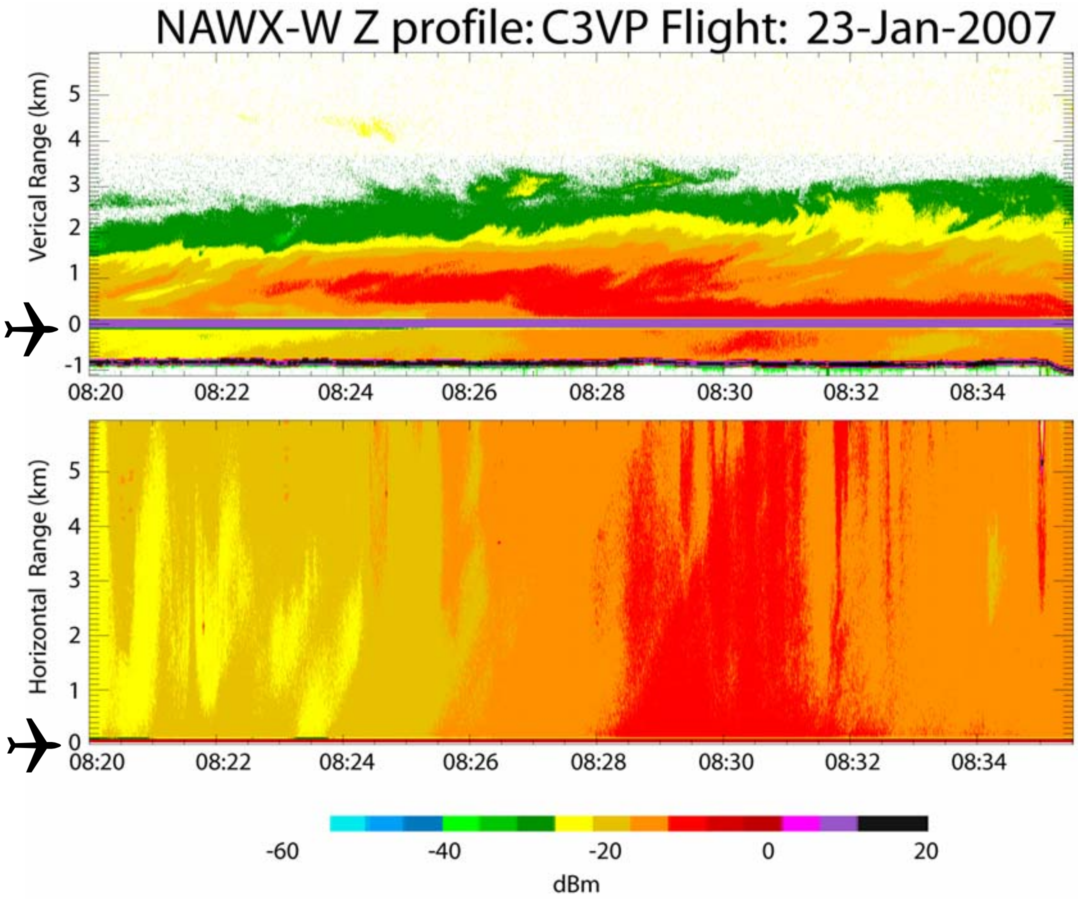
NAWX-W



❖ ***Figure: Example of vertical and horizontal cross-sections of radar reflectivity from C3VP flight 23-Jan-07 near Toronto***

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NAWX

- *In the last five years NRC partnered with government agencies and Universities in the development of airborne cloud radar systems and methodologies*
- *NAWX is now fully integrated on the NRC Convair and currently used in the Canadian CloudSat and CALIPSO satellite validation project (C3VP)*

Airborne atmospheric research at York University

Jim Whiteway
Department of Earth and Space Science & Engineering
York University

Abstract:

Recent airborne measurement campaigns have focused on the tropical tropopause region. This has included studies of gravity wave breaking, cirrus clouds, and the anvil outflow from tropical convection. These experiments have involved two aircraft. The Egrett was flown at heights of up to 15 km for in situ sampling, while a second aircraft (King Air or Twin Otter) was flown directly below the Egrett for laser remote sensing (lidar) measurements. Scientists on board the low flying aircraft were able to view the lidar measurements in real time and decide on flight patterns for the Egrett.

In the summer of 2007 there will be two airborne measurement campaigns. These will involve lidar measurements from a Twin Otter aircraft. For the first campaign in Southern Ontario the Twin Otter will carry a downward viewing ozone lidar for pollution transport studies. For the second campaign the Twin Otter will carry two upward looking lidars; one for measuring clouds and aerosol, the other for ozone. The focus will be on the upper level outflow from pyro-convection around boreal forest fires. The goal is to determine if forest fire smoke is injected directly into the stratosphere.

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Presentation Method:	Talk
Presenting Author Title:	Professor

Atmospheric Research with Aircraft

At York University

(and University of Wales)

Jim Whiteway

Humidity, turbulence, and microphysics in mid-latitude and tropical cirrus

EMERALD: funded by UK NERC CWVC programme

J. Whiteway (1), M. Gallagher (2), T. Choularton (2), J. Harries (3), R. Busen (4), J. Hacker (5), P. May (6), K. Bower (2), R. Aspey (1), P. Connolly (2), C. Cook (1), M. Flynn (2), P. Green (3), J. Murray (3), and G. Straine (3)

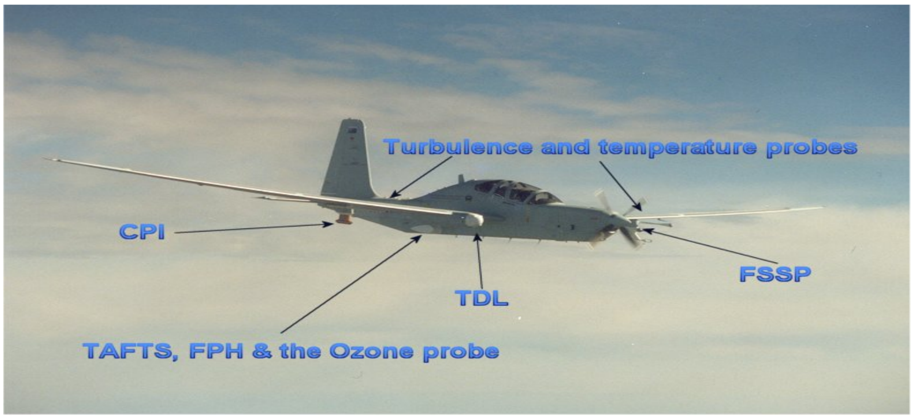
(1) University of Wales, Aberystwyth (Now at York University, Toronto)
(2) UMIST, Manchester, UK
(3) Imperial College, London
(4) DLR, Germany
(5) Airborne Research Australia, Adelaide

The Egrett

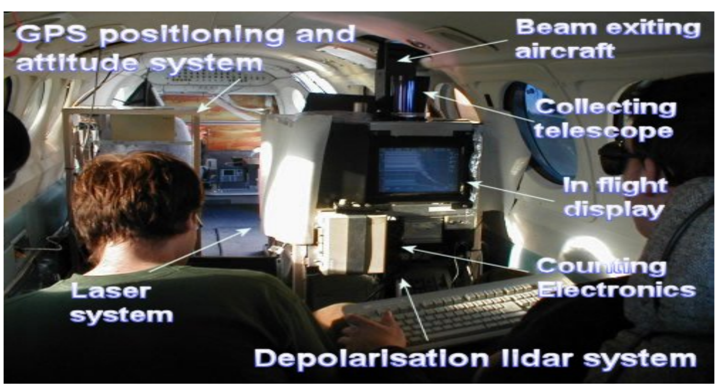
15 km

70-100 m/sec

750 Kg

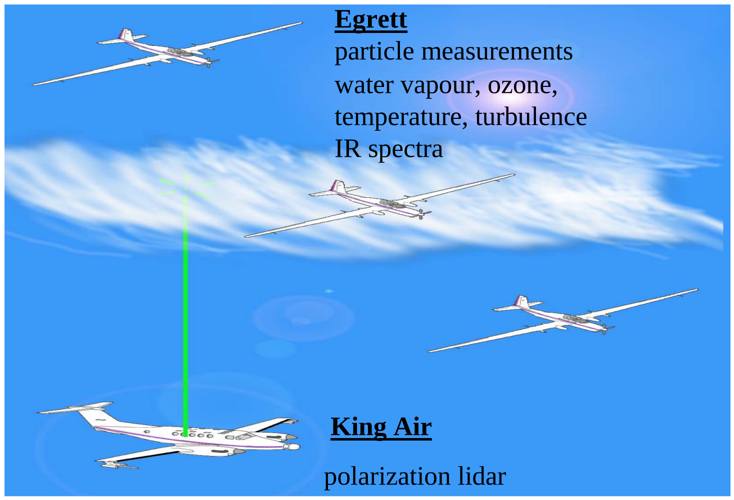


The King Air



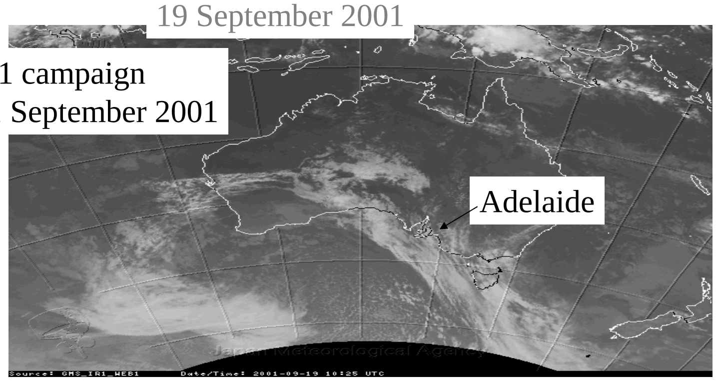
EMERALD

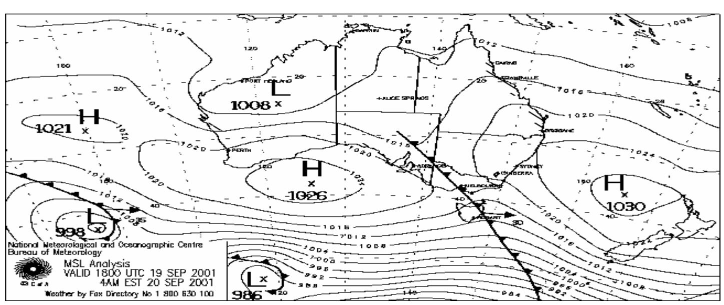
Egrett Microphysics Experiment with Radiation, Lidar, and Dynamics



19 September 2001

Emerald-1 campaign
Adelaide, September 2001





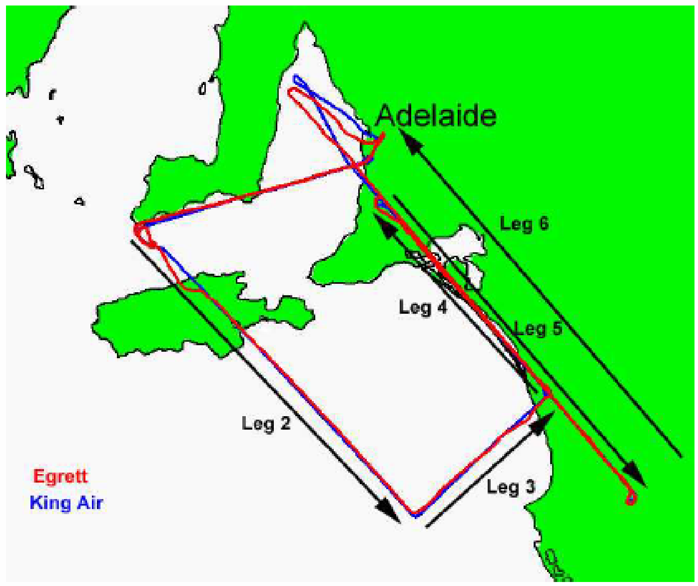
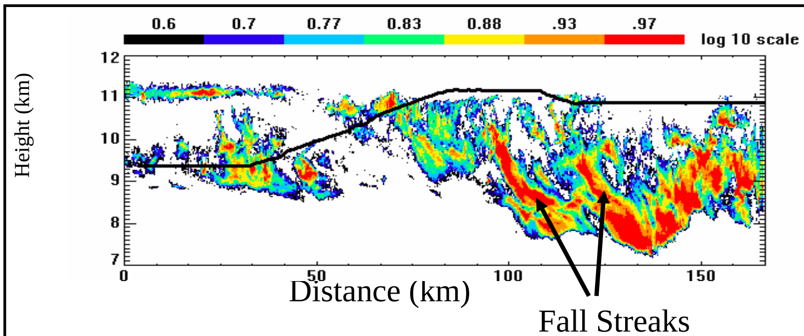
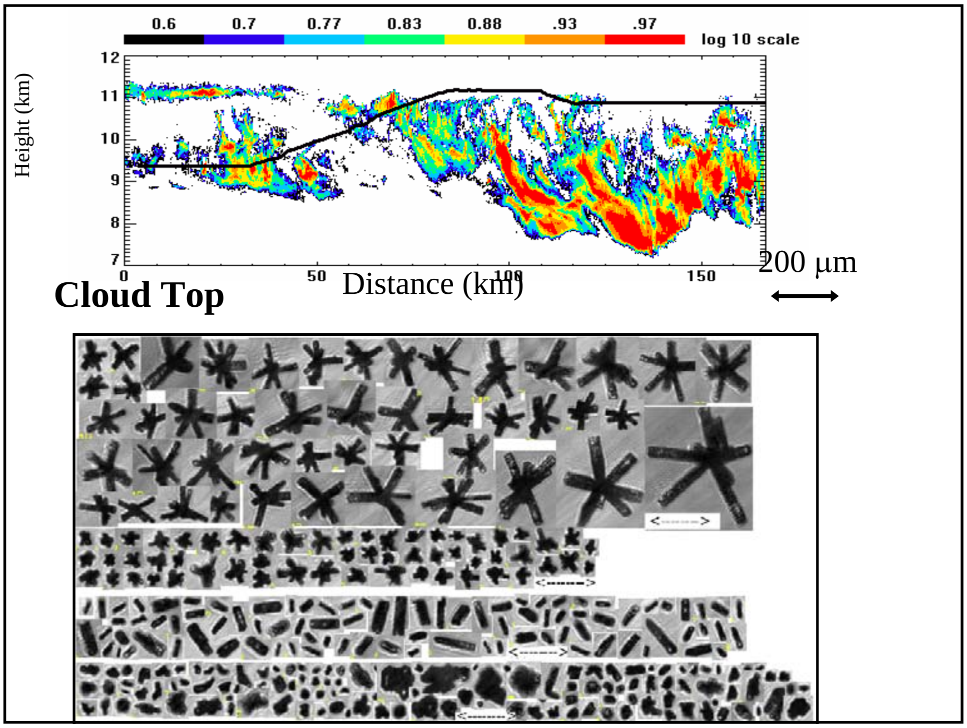
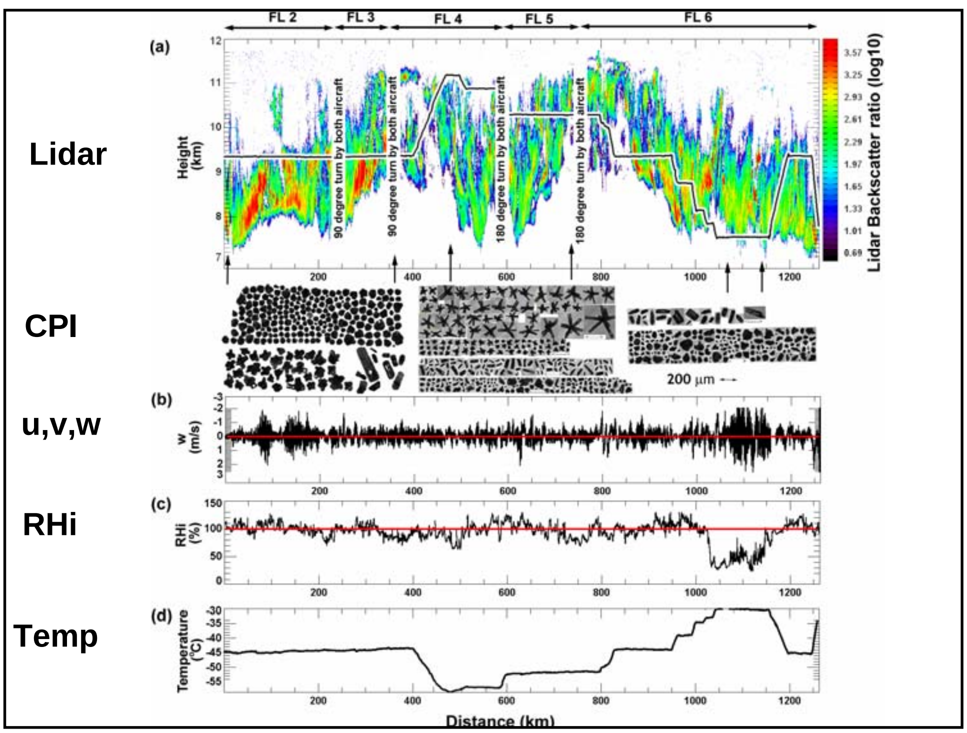


Figure 4.2: Flight paths of the two EMERALD aircraft. The blue line is the Egrett and the red line is the King Air.



Lidar backscatter signal

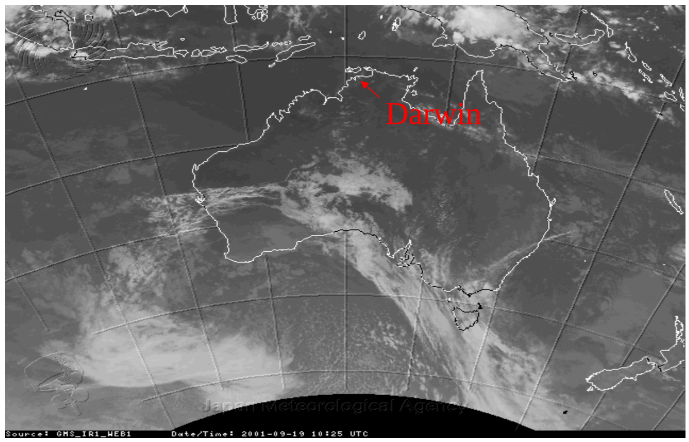

0.6
0.7
0.77
0.83
0.88
.93
.97
log 10 scale
Height (km)
Distance (km)
200 μm
Cloud Top

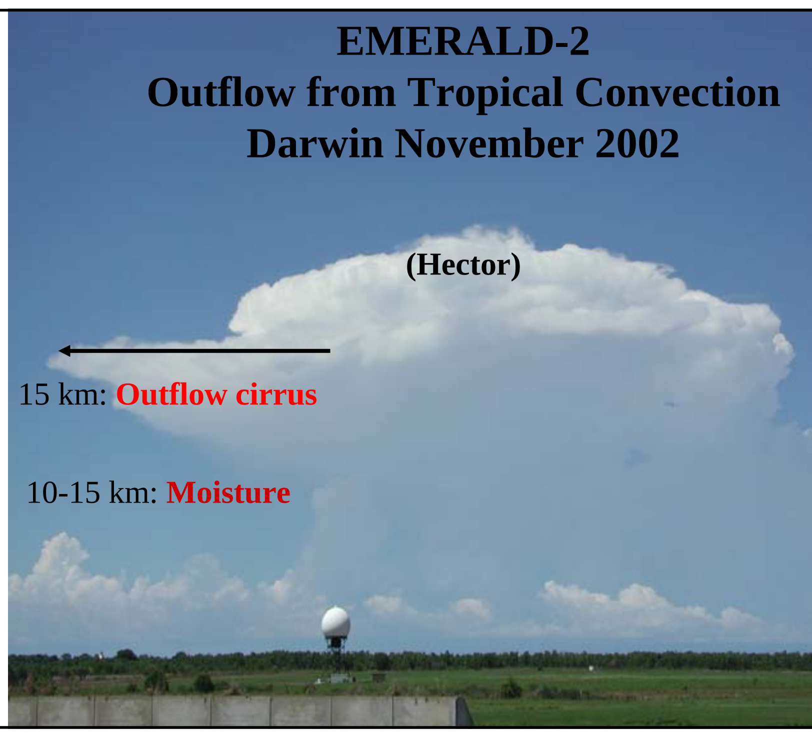

FL 2
FL 3
FL 4
FL 5
FL 6
(a)
Lidar
Height (km)
90 degree turn by both aircraft
180 degree turn by both aircraft
Lidar Backscatter ratio (log10)
CPI
200 μm
(b)
u,v,w
w (m/s)
(c)
RHi
RHi (%)
(d)
Temp
Temperature (°C)
Distance (km)

EMERALD-2

At Darwin Australia

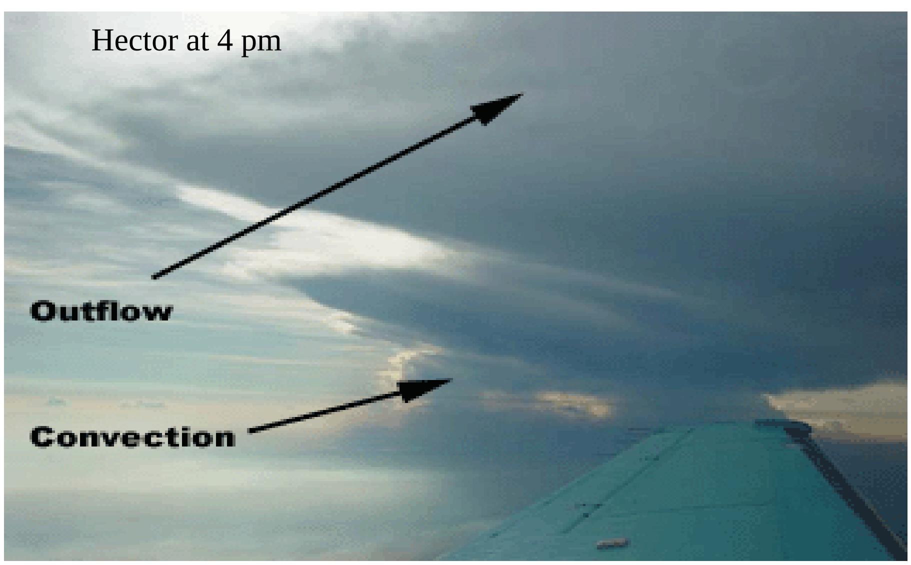
Measurements in the outflow from tropical Convection



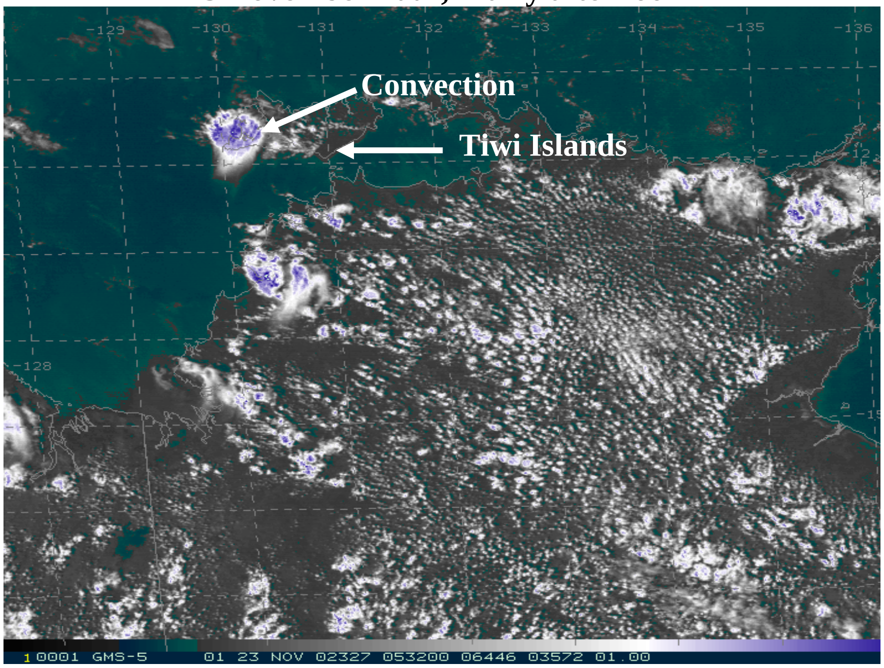


View from the Egrett at height 15 km

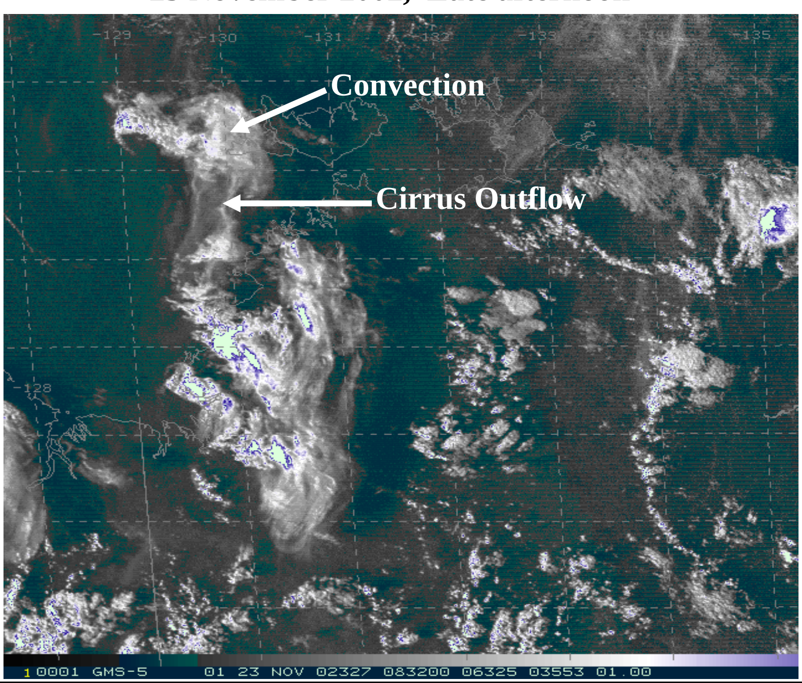
View from the King Air at height of 5 km



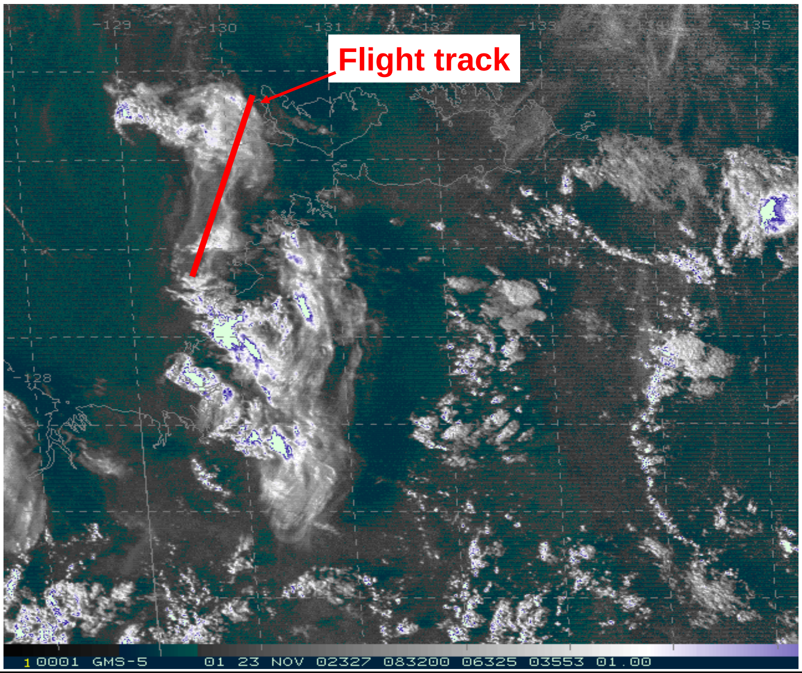
23 November 2002, Early afternoon

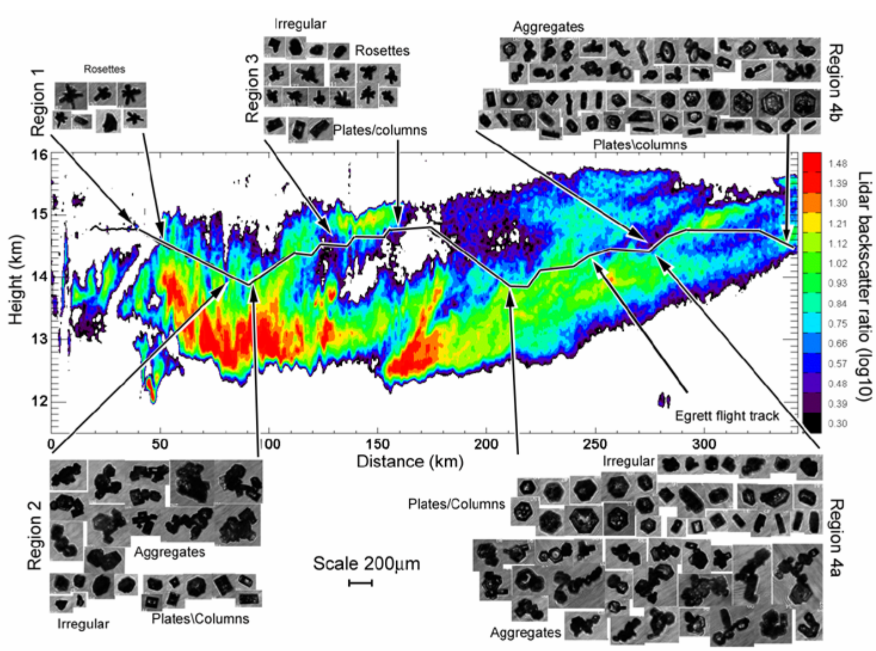


23 November 2002, Late afternoon



Flight leg along the outflow





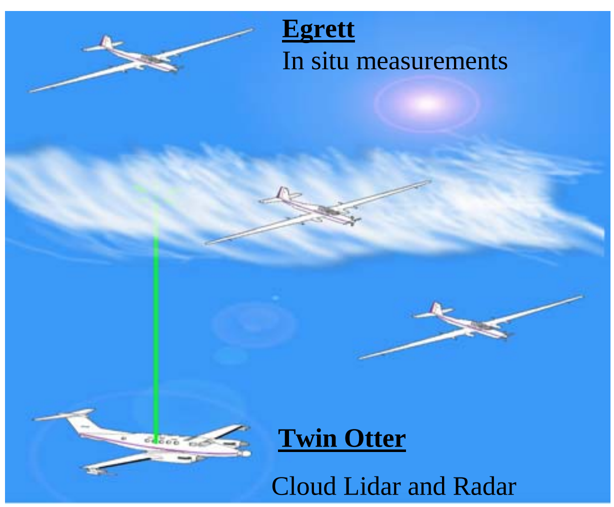
2006 Darwin Campaign

UK: ACTIVE (NERC)
Microphysics and chemical measurements

York U: **ECHO (CFCAS and CFI)**
Water vapour measurements with open path TDL on Egrett
Ozone lidar on Egrett
Cloud Lidar on Twin Otter

Darwin Field Campaign

January/February 2006

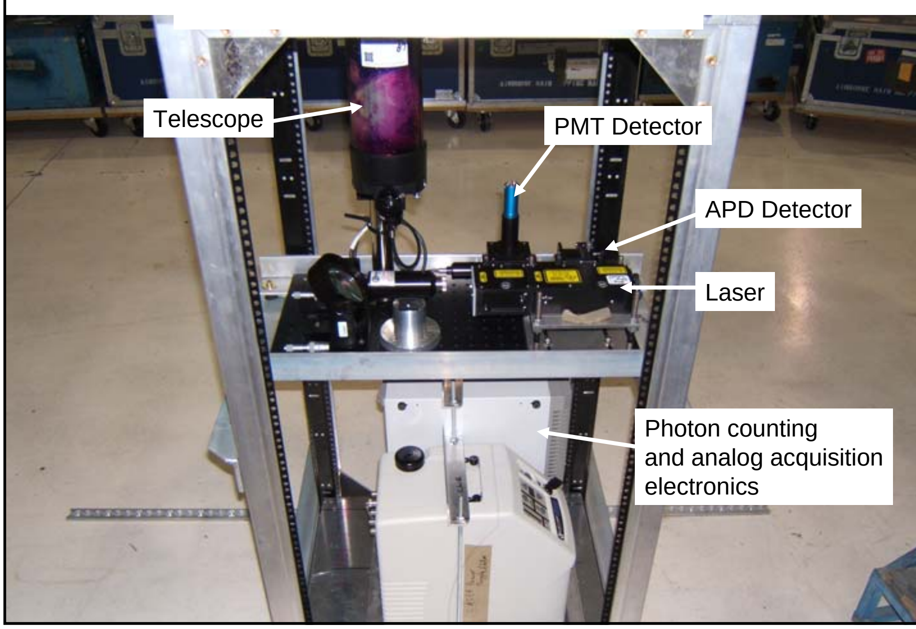


York Lidar on Twin Otter

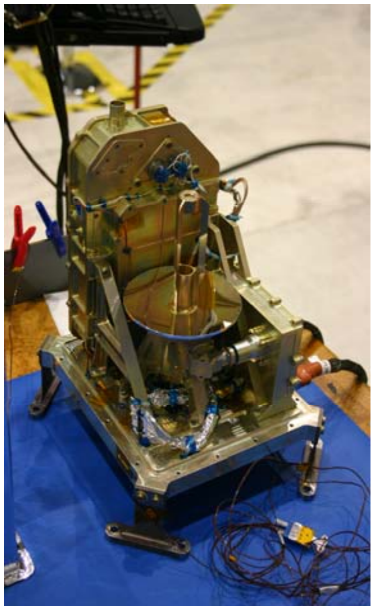
Figure 3. Photograph of the Twin Otter aircraft (left) and the new Phoenix Field Lidar (right) during installation on the Twin Otter at Grand Junction Colorado (base of Twin Otter Airborne Research).

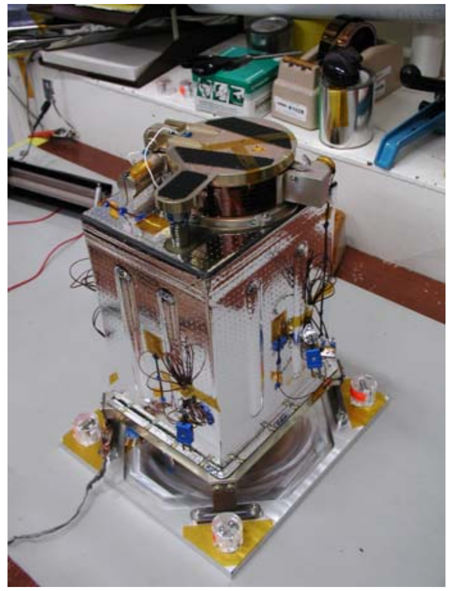
<u>Phoenix Field Lidar</u>

Equivalent to lidar for Mars mission



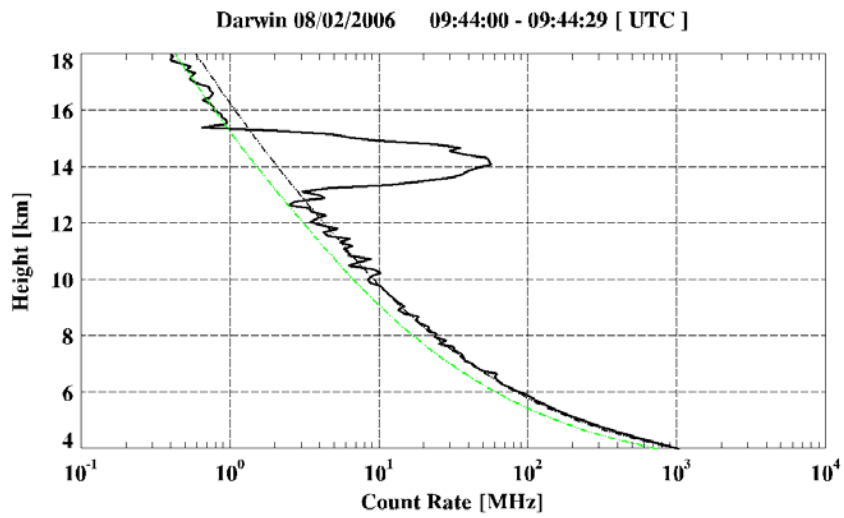
Phoenix Lidar



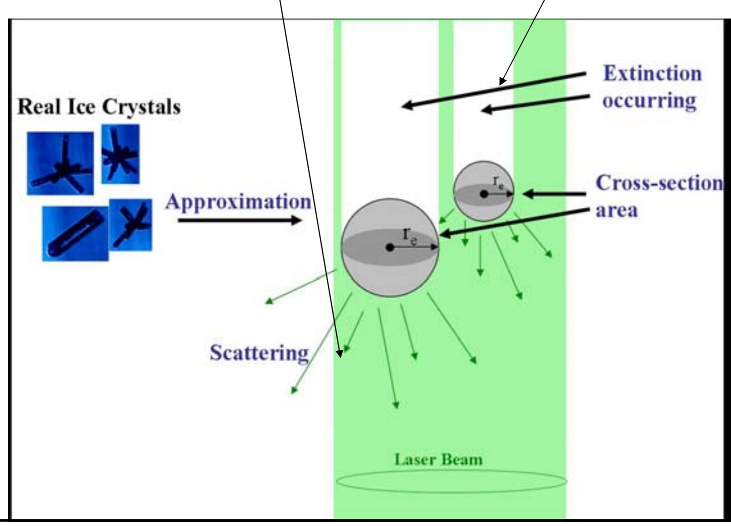


Cloud Ice Water Content from Lidar measurements

Raw Signal

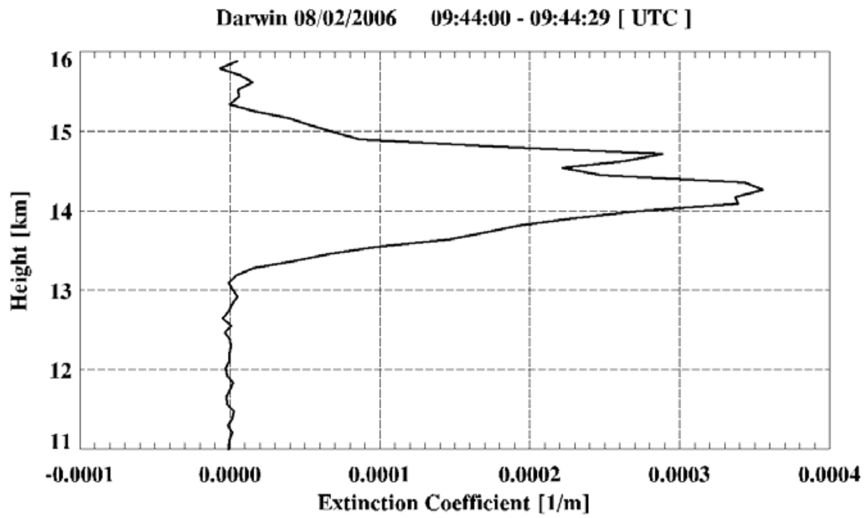


$$S(z) = \frac{C}{z^2}\,\beta(z)\exp\left[-2\int_0^z \alpha(z)dz\right]$$



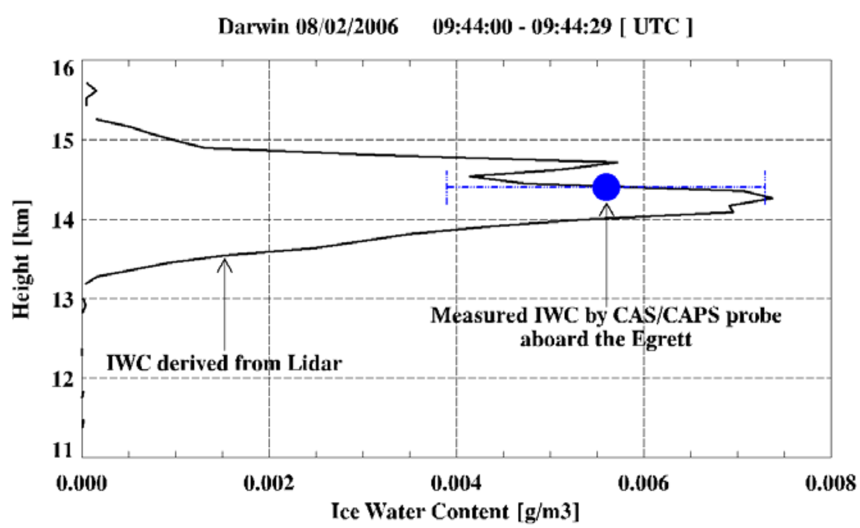
Cloud Ice Water Content from Lidar measurements

Extinction coefficient

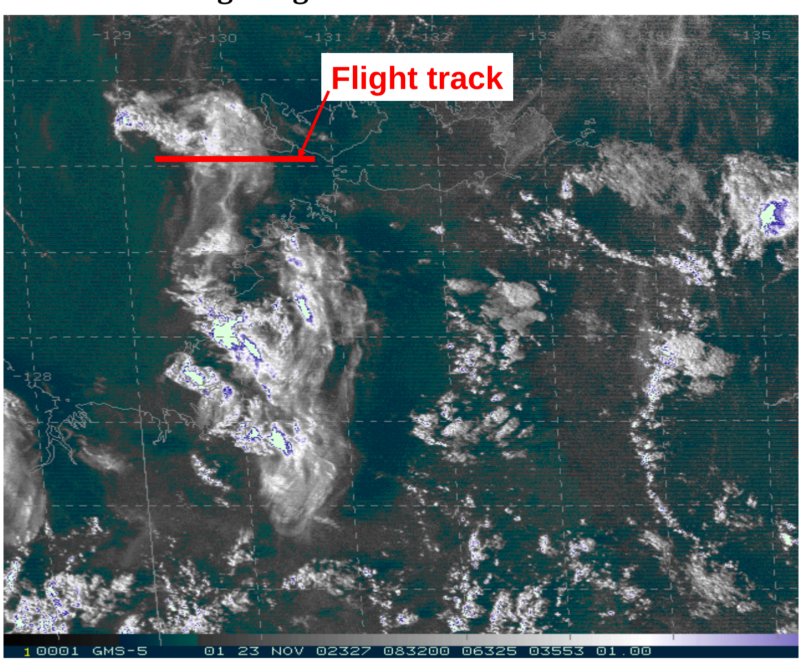


Cloud Ice Water Content from Lidar measurements

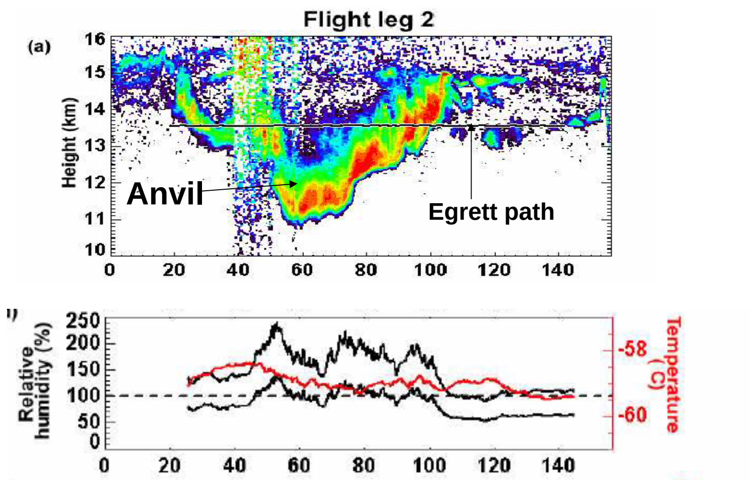
Vital for Mars mission



Flight leg across the outflow



Relative Humidity in the Anvil



Emerald-2 Water Vapour Measurements

Frost Point Hygrometer
R. Busen, DLR

Tunable Diode Laser
J. Whiteway, UWA

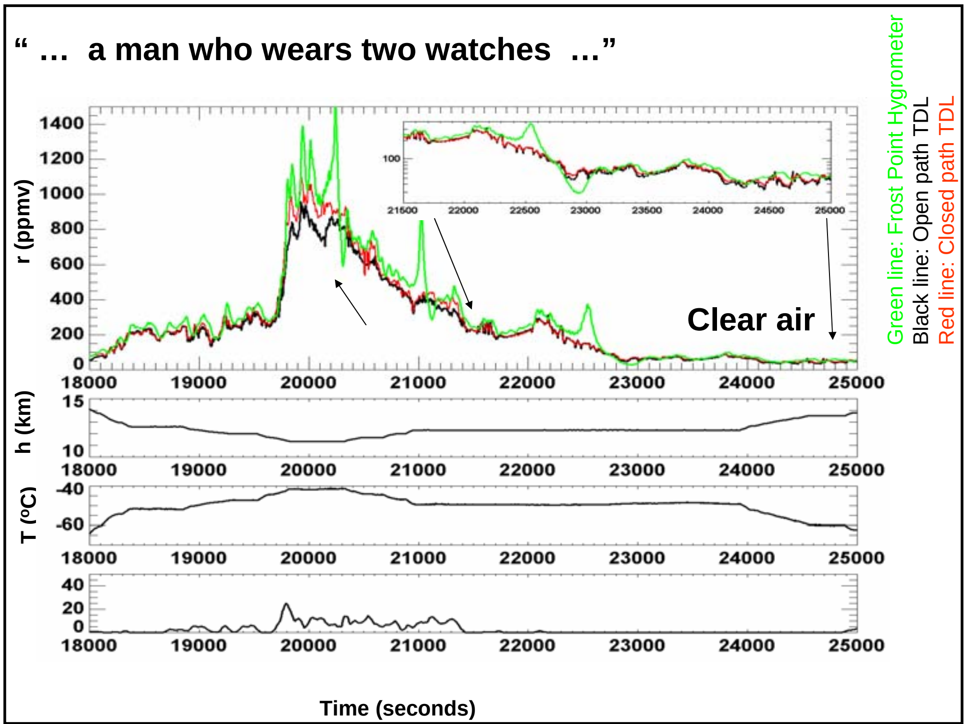
Both employ standard air inlets (Rosemount)

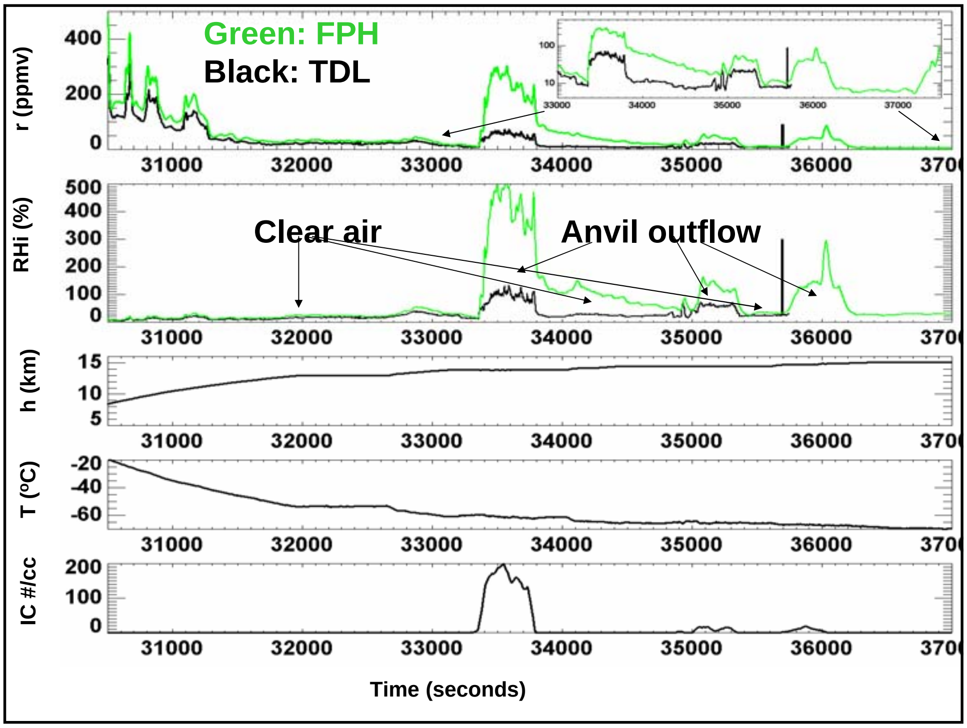
Addition of a third instrument for Water Vapour on the Egrett

Tunable Diode Laser with Open Path Herriott Cell

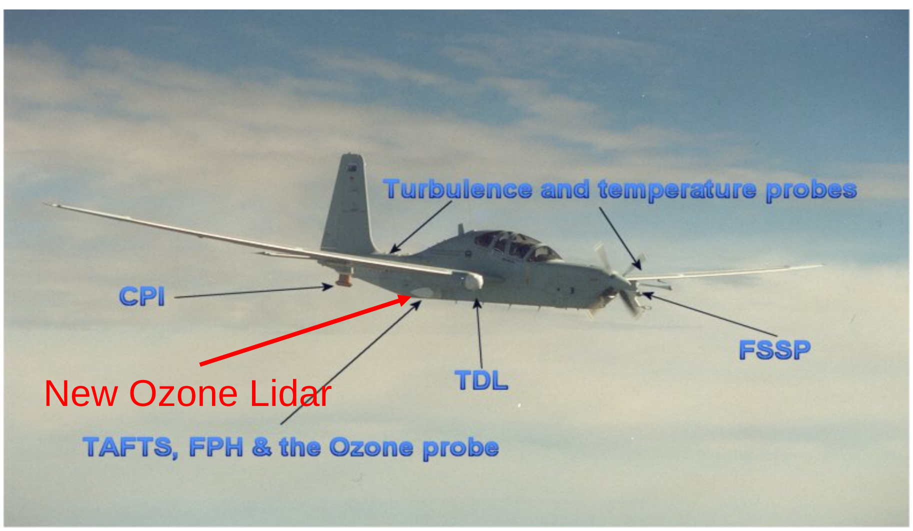
From York University (Built by R. May, MayComm)

" … a man who wears two watches …"

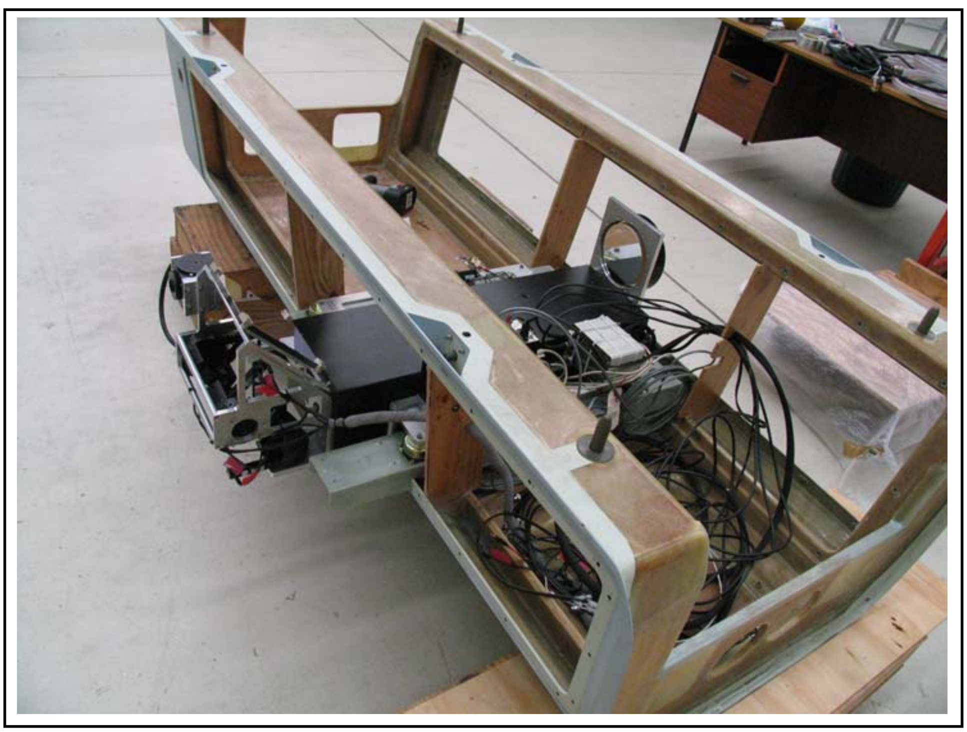




Airborne Ozone Lidar




Ozone Lidar in Egrett U-Bay



Next: Ozone Lidar on Twin Otter

Next Aircraft Campaign:

ECHO: Effects of Convection on Humidity and Ozone (CFCAS)

Does pyro-Cb transport smoke to the stratosphere?

Lidar observations of pyro-Convection in Northern Canada

Cloud Lidar and Ozone Lidar on Twin Otter

Observe height distribution of smoke from forest fires

Associated with POLARCAT IPY project

Utilization of suborbital measurements of tropospheric composition in the validation of chemical data assimilation studies

Mark Parrington* and Dylan Jones
University of Toronto

Abstract:

We are studying the chemical and physical processes governing the distribution of tropospheric ozone and carbon monoxide through the assimilation of ozone and CO observations, from the Tropospheric Emission Spectrometer (TES) on the NASA EOS Aura satellite, into two global models of tropospheric chemistry and transport. Observations of tropospheric composition from suborbital vehicles (including instrumentation on both balloons and aircraft) are crucial to understanding the output from a chemical data assimilation system as they provide independent, high precision data on both assimilated and non-assimilated tracers in the system. Presented here are results for March 2006 over North America, during which time the INTEX-B field campaign provides a large number of aircraft and ozonesonde data.

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Presenting Author Email:	mark.parrington@utoronto.ca
Presenting Author Telephone:	416-978-7796
Preferred Session:	Past projects and case studies
Presentation Method:	Talk
Presenting Author Title:	Postdoc

Utilization of suborbital measurements of tropospheric composition in the validation of chemical data assimilation studies

Mark Parrington, Dylan Jones, Dave MacKenzie
University of Toronto

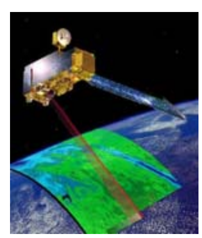
Kevin Bowman
Jet Propulsion Laboratory
California Institute of Technology

Larry Horowitz
Geophysical Fluid Dynamics Laboratory

Objective: Integrate satellite data to better quantify the budget of tropospheric O_3

TES (Profiles of CO and O_3)
- Infrared Fourier transform spectrometer
- Nadir footprint = 8 km x 5 km
- Orbit repeats every 16 days
- Observations spaced about 5º along orbit track

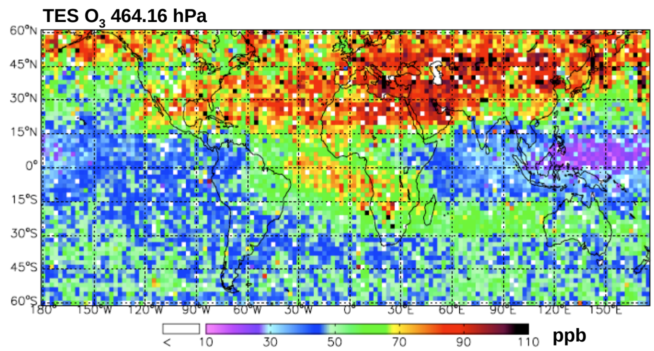
MOPITT (Profiles of CO)
- Gas correlation radiometer
- Nadir footprint = 22 km x 22 km
- Orbit repeats every 3 days
- 612 km cross-track scanning swath



QuickTime™ and a TIFF (LZW) decompressor are needed to see this picture.

SCIAMACHY (NO_2 columns)
- solar backscatter spectrometer
- Nadir footprint = 30 km x 120 km
- Orbit repeats every 6 days

TES Global Survey Observations, July 4-31, 2005



- Enhanced O_3 abundances from central Asia, across the Middle East, and over the subtropical Atlantic
- High O_3 over the southeastern USA

Tropospheric Models

AM2-Chem

- GCM developed at NOAA GFDL
- 2.0° latitude x 2.5° longitude, 24 vertical levels (top level approx. 10 hPa)
- Chemistry scheme based on MOZART-2 [Horowitz et al., 2003; Tie et al., 2004]
- Model dynamics constrained by Newtonian nudging to NCEP reanalyses

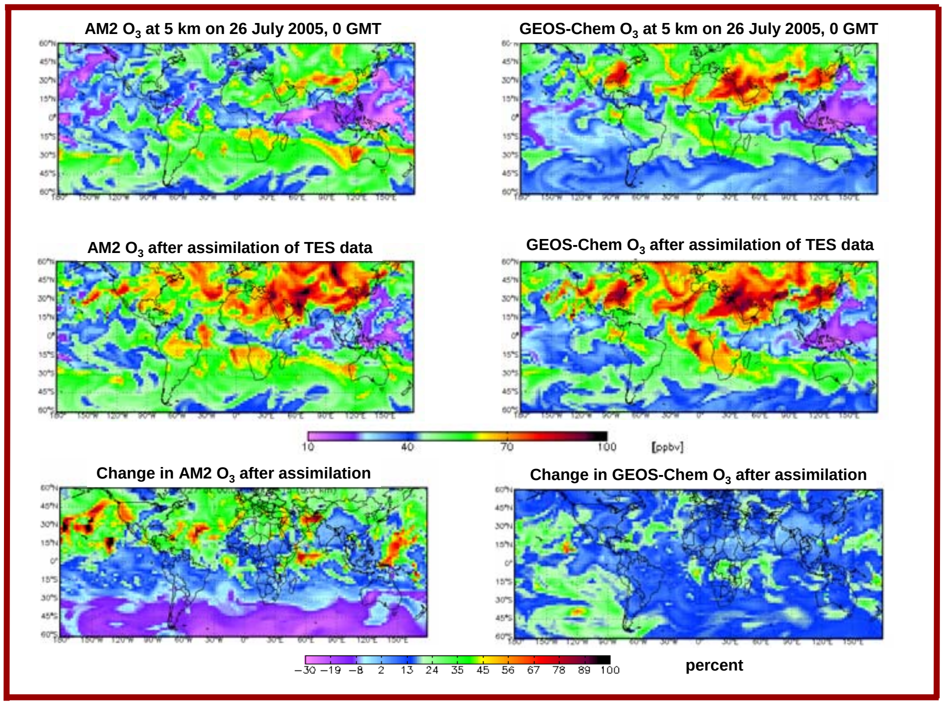
GEOS-Chem

- Chemical transport model
- 2.0° latitude x 2.5° longitude, 55 vertical levels (top level approx. 0.01 hPa)
- Model transport driven by GEOS-4 GMAO analyses

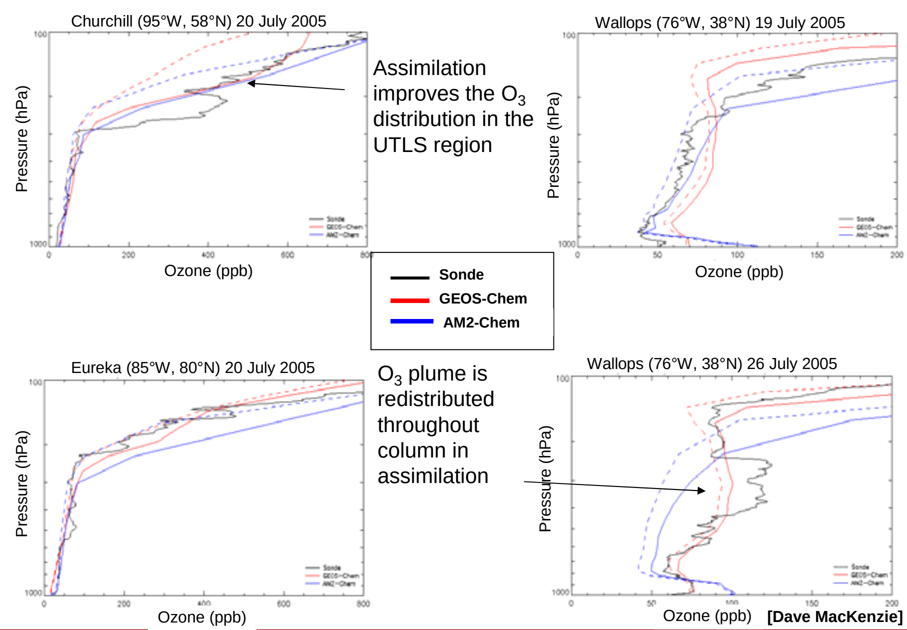
Sequential Kalman filter approach to the assimilation of TES ozone and carbon monoxide profiles.

Results for two different periods are presented here:

- July 2005 - comparison to ozonesondes (GEOS-Chem + AM2)
- March 2006 - comparison to DC-8 measurements during INTEX-B (AM2)

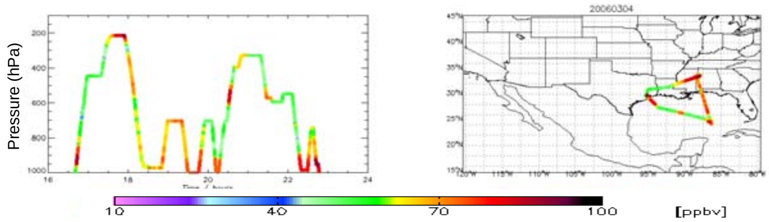


Comparison with Ozonesonde Data



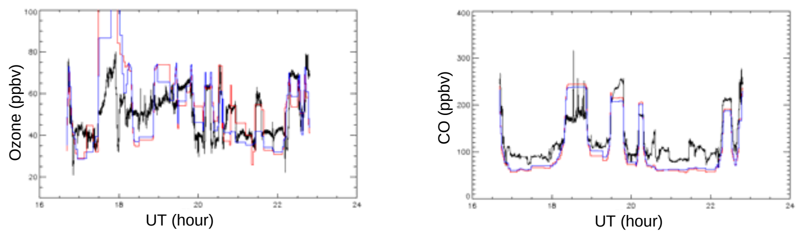
Comparison with aircraft data: 4 March 2006

FASTOZ ozone

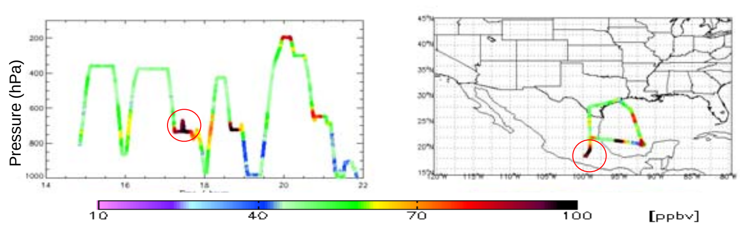


Model and assimilation follows the aircraft data although with some discrepancies which assimilation of TES data goes some way to accounting for

- Aircraft
- No assim
- Assim

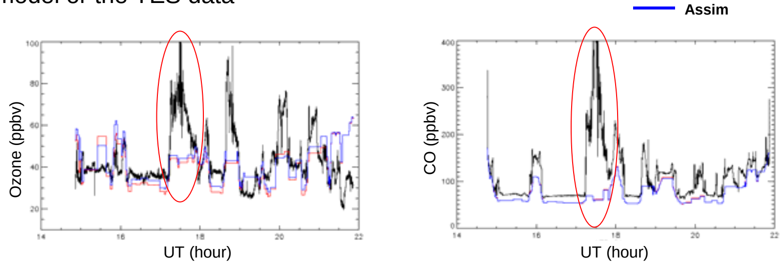


Comparison with aircraft data: 16 March 2006

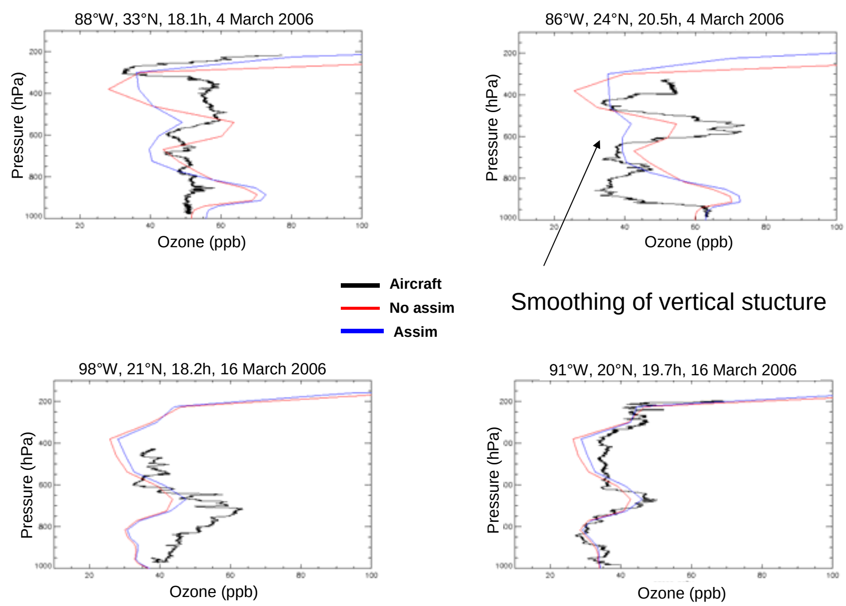


Mexico City pollution is not captured in the model or the TES data

- Aircraft
- No assim
- Assim



Profile comparison with aircraft spirals



Conclusions

- **TES data have sufficient information to dramatically improve the model simulations of O_3, which will enable us to better constrain the different chemical and dynamical processes controlling O_3**
- **Comparisons of model ozone and CO with independent data (i.e. ozonesondes and aircraft measurements) are a vital component of these studies as they can verify the impact of assimilation in a chemistry model**
  - **In general, the assimilation adds value to a model simulation, bringing the model state to a truer state**
  - **There are discrepancies which may be attributable to limited vertical resolution in the TES data, and limits in the spatial and temporal resolution of the model**
- **Could further value be added to chemical data assimilation studies through assimilating aircraft data to further constrain models where the spatial resolution is insufficient to capture localized pollution events?**
  - **Synergistic application of orbital and sub-orbital datasets to better understand processes controlling tropospheric composition**

Future of NASA Scientific Ballooning in Space and Earth Science Research

***David Pierce**
NASA Balloon Program Office, NASA Goddard Space Flight Center
Wallops Flight Facility, Wallops Island, Virginia
Danny RJ Ball
NASA Columbia Scientific Balloon Facility

Abstract

The U.S. National Aeronautics and Space Administration (NASA) Balloon Program continues to support the scientific community providing enhanced capabilities across a spectrum of balloon related space and Earth science disciplines. Long Duration Ballooning (LDB) continues to be a prominent element of the program with a mission model of a three-flight campaign from Antarctica and the Arctic per year.

Long Duration Ballooning has set new expectations in the science community toward longer duration flights. NASA also completed development and flights of advancedellooncraft systems including the Command Data Module (CDM) as part of LDB missions launched from Antarctica.

The Swedish Space Corporation/Esrange and the National Aeronautics and Space Administration (NASA) inaugurated a joint European / U.S. capability for LDB balloon flights from Sweden to Canada in June 2005 and will continue annually. This will complement the NASA / U.S. National Science Foundation Office of Polar Programs achievement of more than a decade of successful long-duration flights around Antarctica.

The Ultra-Long Duration Balloon (ULDB) project continues the development of a superpressure balloon capability for 60-100 day flights. An overview of the various aspects of the NASA Balloon Program will be presented as well as the outlook for the future.

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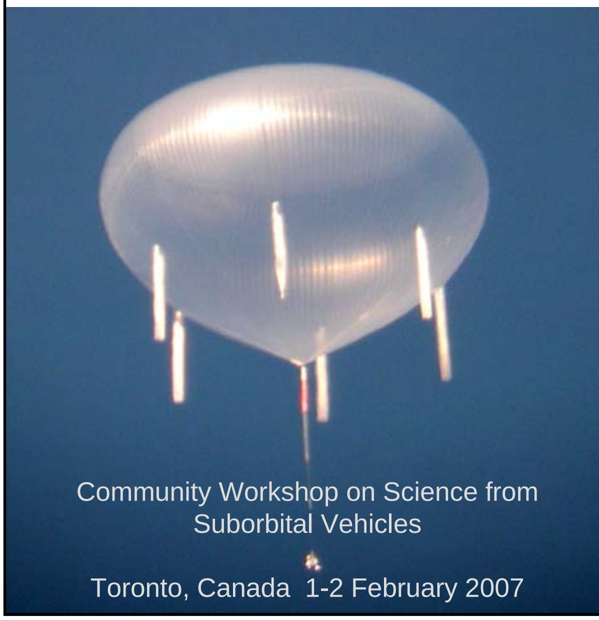
Session:	Invited Speaker
Presentation Method:	Talk
Presenting Author Title:	Government

Future of NASA Scientific Ballooning in Space and Earth Science Research



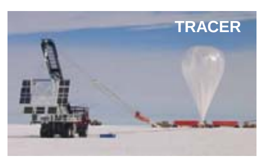
Community Workshop on Science from Suborbital Vehicles

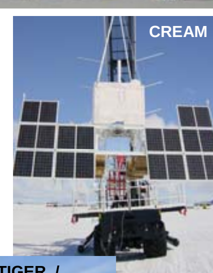
Toronto, Canada 1-2 February 2007

Mr. David Pierce
NASA Balloon Program Office
Goddard Space Flight Center
Wallops Flight Facility

Mission of the NASA Balloon Program

- The NASA Balloon Program provides low-cost, quick response, near space access to NASA's science Community for Heavy payloads conducting Cutting Edge Science Investigations
  - Observatory-class Payloads With Advanced Technologies and Large Aperture/Mass
- Serve as a technology development platform
  - Instrument/Subsystem development for NASA Spacecraft Missions
- Provide hands-on training of Students and Young Scientists





3

CSBF Implements NASA's Program

- *Launch, track, and recover large scientific balloon payloads from launch sites all over the world.*
- *Provide sophisticated telemetry, command, and specialized flight control systems for science users*
- *Provide logistics and field support for operations and science personnel at remote launch sites*
- *Develop new balloons and launch methods to enhance the capability of NASA's Balloon Program*

Balloon Sizes / Suspended Capability

Conventional Ballooning

2 hours to 3 days duration

Long Duration Ballooning

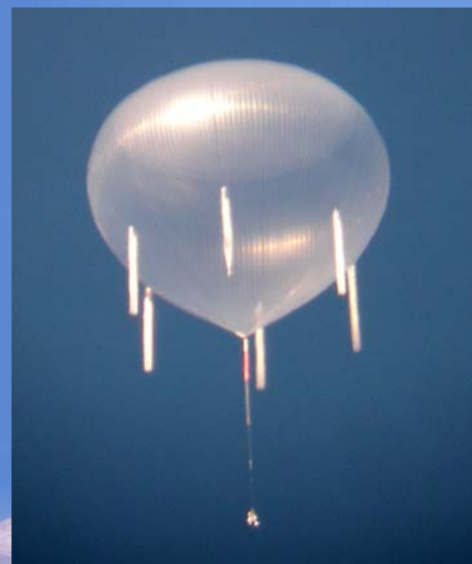
Up to 41+ days duration

Balloon Size	Maximum Suspended Weight (lbs)	Float Altitude (ft)
59.84 MCF	*1650*	*160,000*
36.73 MCF	*8000*	*120,000*
39.97 MCF	*6000*	*127,000*
28.47 MCF	*6500*	*119,000*
11.82 MCF	*7450*	*98,000*
11.82 MCF	*2875*	*116,000*
4.0 MCF	*3500*	*96,000*

5

…How Big?

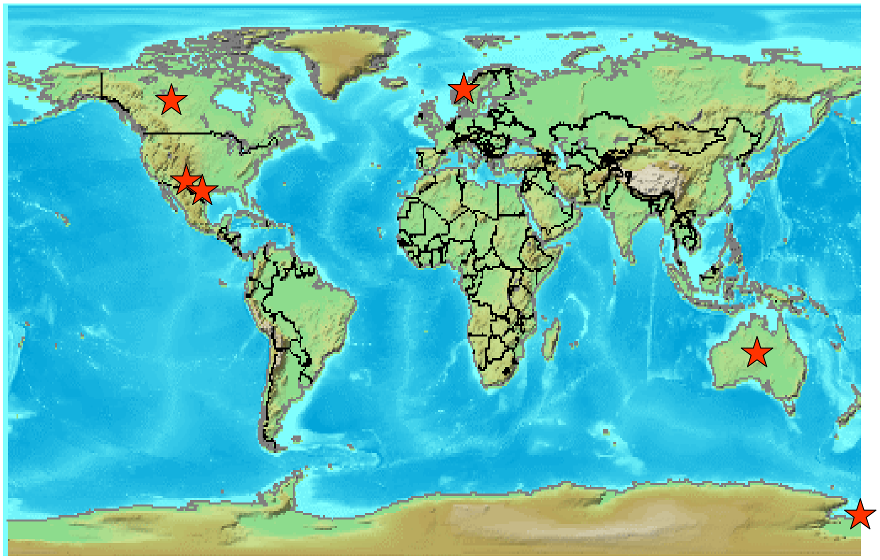
- *60 MCF Balloon*
  - *2 ½ football fields long at launch*
  - *534 feet in diameter at float*
  - *28 acres of material*
  - *29 miles of seams*
  - *Visible for 200 miles*
  - *Roughly the size of the Houston Astrodome*



Recent Capability of Balloon Program

Baseline Mission Model	Current Capability	2004	2005	2006	2007	2008	2009
Conventional	Ft. Sumner, NM Palestine, TX Lynn Lake, CA	~16 Flights / Year					
Long Duration Balloon (LDB) Antarctica		2 Flights / Campaign New Antarctic Facilities					
LDB or ULDB Northern Hemisphere		2 Flights / Campaign Alternating every other year with Southern Hemisphere Campaign					
LDB or ULDB Southern Hemisphere		2 Flights / Campaign Alternating every other year with Northern Hemisphere Campaign					

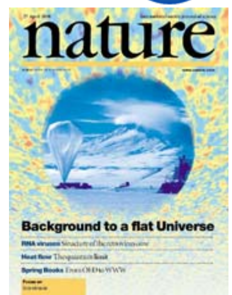
Launch Sites

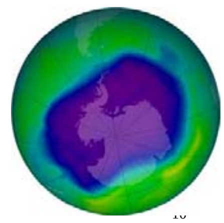


8

Ballooning has produced important new science

- Boomerang and MAXIMA flights mapped the anisotropies of the Cosmic Microwave Background.
  - Result confirmed the inflation model of the early universe.
- Cosmic-ray antiprotons were identified.
  - They were shown to be the result of well known cosmic rays colliding with interstellar gas and dust, placing constraints on the kind of supersymmetric particle that makes up the dark matter.
- Early detections of
  - Gamma-ray lines from SN1987A
  - Positron emission from the Galaxy
  - Black-hole X-ray transients in the galactic center region
- Balloons observed chlorofluorocarbons (CFCs) and chlorine monoxide (ClO) radicals in the stratosphere
  - Confirmed the CFC ozone-depletion theory.

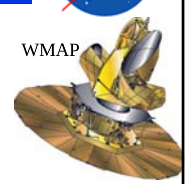




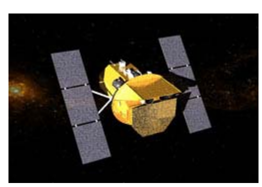
Balloon missions have contributed in essential ways to scientific spacecraft missions.

- CMB balloon flights in the late 80's and 90's laid the critical ground work for the design of **WMAP**.
- Detectors on the **RHESSI** mission were first developed and demonstrated on balloon-borne instruments.
- The scintillating fiber trajectory detector on the **ACE** Cosmic Ray Isotope Spectrometer was demonstrated first in a balloon flight.
- On the **EOS-Aura satellite**, the MLS, TES, and HIRDLS instruments all trace their heritage to instruments that first flew on balloons.
- Three Balloon flights of the cadmium-zinc-telluride CZT array produced data needed to design the **Swift** Burst Alert Telescope (BAT) instrument.
- Balloons supported full engineering prototype flights of the Gamma-ray Large Area Space Telescope **GLAST**

WMAP



RHESSI



Swift

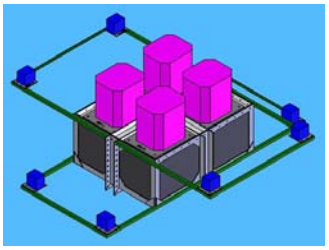
11

2006 Nobel Prize for Physics
Congratulations to the COBE Team

COBE Science Team with balloon scientists identified.

Educational Flight Projects

- Provides student teams the opportunity to develop and operate inexpensive small payloads on a dedicated balloon platform.
  - Flight test up to 12 student built payloads.
- First HASP Flight contained 7 student payloads from 5 institutions as follows:
  - **University of Alabama – Huntsville:** Infrared telescopes to remotely study the thermal characteristics of the balloon envelope (3 small)
  - **Texas A & M University:** Video camera system to study remote sensing from high altitude (1 small)
  - **University of Louisiana – Lafayette:** Nuclear emulsion stack to investigate high energy cosmic rays (1 large)
  - **Louisiana State University (Mechanical Eng.):** Study the flow characteristics of various rocket nozzles as a function of altitude (1 large)
  - **Louisiana State University (Physics):** Prototype of an accelerometer based inertial navigation system (1 small)
- The selection of 2007 student payloads was announced in January.

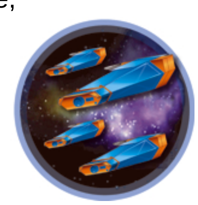


Ballooning Contributions to NASA Strategic Objectives
***The Physics of the Universe* – February 2004**

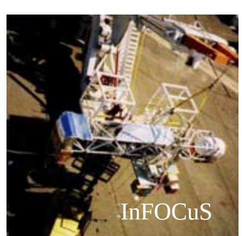
- Theme 5: "Birth of the Universe Using Cosmic Microwave Background"
  - "Measurement of the portion of the polarization of the CMB that was caused by primordial gravitational waves offers great promise for understanding the inflationary period of the universe."
  - "Ground-based and **balloon-borne experiments** provide initial data to advance and constrain cosmological models, and play a key role in developing detectors and techniques for space-based CMB polarization measurements."
- Planned balloon instruments PAPPA, EBEX,BLAST
  - Will themselves make important measurements of CMB or foreground.
  - Are vital for developing and proving techniques for future satellite-borne investigations of CMB polarization.

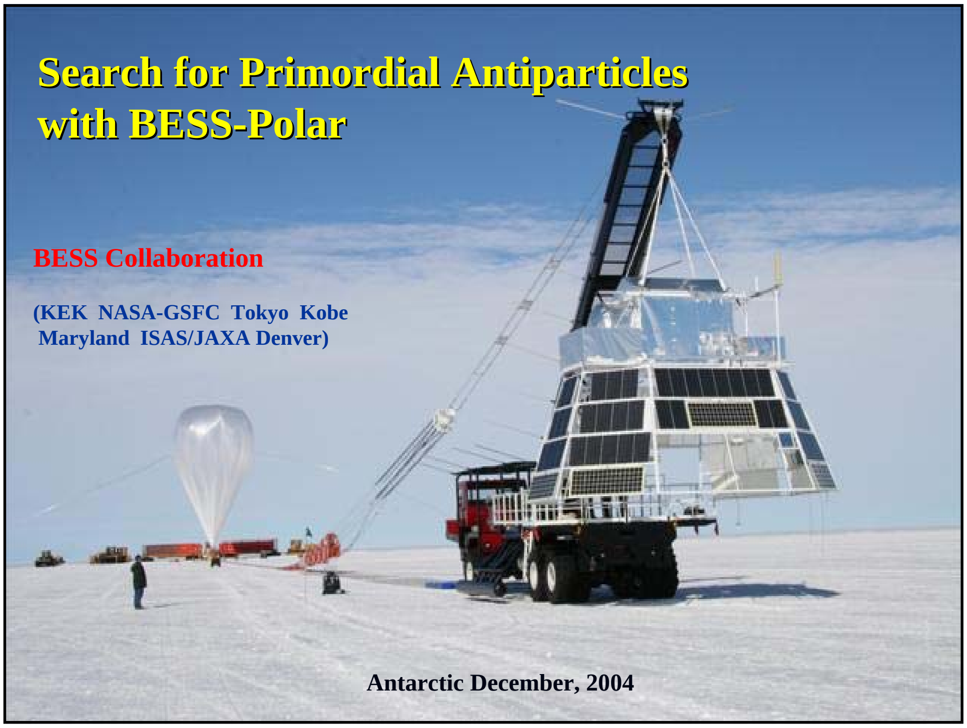
Ballooning Contributions to NASA Strategic Objectives
***Space Science Enterprise Strategy* – October 2003**

- Strategic objective 5.11 – "Learn what happens to space, time, and matter at the edge of a black hole"
  - "Constellation-X will greatly extend our capability for high-resolution X-ray spectroscopy"
  - *SEU Roadmap* ***"Beyond Einstein"*** January 2003 re Constellation-X: "… key areas of technology, including … CdZnTe detectors for hard X-rays"
- Balloon investigations supporting developments for Constellation-X: HERO, InFOCuS, HEFT

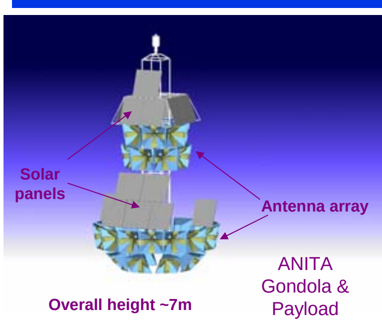


Constellation-X





Astrophysical Neutrinos



- ANITA (Antarctic Impulsive Transient Antenna) opens a new observational window into astrophysical sources that would complement photon-based measurements.
- A Null result would indicate a breakdown in understanding of particle physics or a significantly smaller ultra high energy (UHE) proton flux.
- Identifies UHE neutrinos by detecting RF signals emitted when neutrinos interact in Antarctic ice shelf
- Achieves enormous effective areas (10^6 km^2) by flying a multi-element pulse-phased radio frequency antenna on balloon around Antarctica.

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Ballooning Contributions to the *Earth Science Strategy* – October 2003

- Strategic question #2: "How will future changes in atmospheric composition affect ozone and climate?"
  - *Atmospheric Composition Roadmap*: "Systematic measurement of ozone, aerosols, and trace gases … Assessment of potential for future major Arctic ozone depletion … Evaluation of feedbacks among stratospheric and tropospheric ozone, water vapor, aerosols, and climate."
- Balloons complement Earth observing satellites by providing *in situ* validation.
- Balloons provide observations of detailed processes on much finer spatial and temporal scales than satellites.
  - Arctic winter flights could probe detailed microphysical processes leading to polar stratospheric clouds, which cannot be resolved from space.
  - Trajectory-controlled, long-duration tropical flights could resolve spatial and temporal processes controlling cross-tropopause transport, which cannot be resolved by space-based remote sensing instruments.

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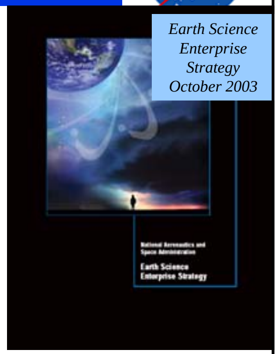
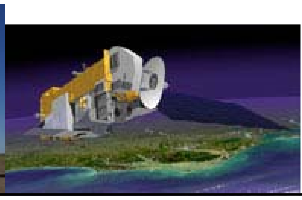
Balloons in Support of Earth Science

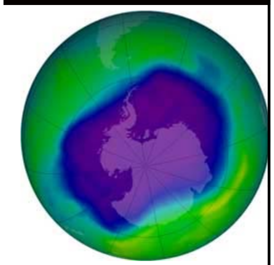


Providing access to near-space conditions for Earth Science
- Observed chlorofluorocarbons (CFCs) and chlorine monoxide (ClO) radicals in the stratosphere

Calibration/Validation Satellite under-flights, e.g.,

- The FIRST instrument is a NASA-unique instrument capable of observing infrared emission from the earth at wavelengths between 15 and 100-um, measuring approximately 50% of the energy leaving the planet
  - FIRST provided under flight of Aura, CALIPSO, and CloudSat during its September 2006 flight.
  - SLS (Submillimeterwave Limb Sounder) / FIRS2 (far-IR limb sounder) and Mark IV Interferometer will under fly AURA to take measurements of the composition of the stratosphere.





Balloons in Support of Earth Science

Simultaneous with 2006 Antarctic operations, Balloons prepared for winter flights in Arctic/Sweden in early February.
• 2 Balloon flights are being conducted from Esrange, Sweden, in February 2007 to provide validation data for instruments aboard NASA's EOS Aura satellite.
• These payloads will make measurements of the composition of the stratosphere by using a suite of 4 instruments.

SLS (Submillimeterwave Limb Sounder) **/ FIRS2 (**far-IR limb sounder**) (J. Margitan/ R.Stachnik JPL)**
A successful flight of the JPL SLS/FIRS2 payload was conducted on January 23, from Sweden.
The FIRS2 / SLS payload was successfully flown deep inside the polar vortex in the near perfect conditions.

Mark IV Interferometer (J. Margitan/ G. Toon JPL)
Will measure the absorption of sunlight by atmospheric molecules using the MkIV instrument designed to remotely sense the composition of the Earth's atmosphere by the technique of solar absorption spectrometry.

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Flight Program Summary

- 2006 Flight Program completed with a total of 13 flights
  - 9 Science, 1 EPO, and 3 flight tests

✓ 2	*Ft. Sumner, New Mexico*	*(Fall 05)*	*Conventional*
✓ 2	*Antarctica*	*(Winter 06)*	*LDB*
✓ 3	*Kiruna, Sweden*	*(Summer 06)*	*LDB/ULDB*
✓ 1	*Palestine, Texas*	*(Summer 06)*	*Conventional*
✓ 5	*Ft. Sumner, New Mexico*	*(Fall 06)*	*Conventional*

- 2007 Flight Program 19 Flights: 3 Domestic and 2 Foreign Campaigns

✓ 3	*Antarctica*	*(Winter 06)*	*LDB*
- 2	*Kiruna, Sweden*	*(Winter 07)*	*Conventional*
- 3	*Ft. Sumner, NM*	*(Spring 07)*	*Conventional*
- 4	*Palestine, Texas*	*(Summer 07)*	*Conventional*
- 7	*Ft. Sumner, NM*	*(Fall 07)*	*Conventional*

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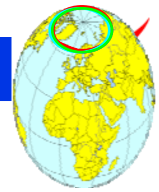
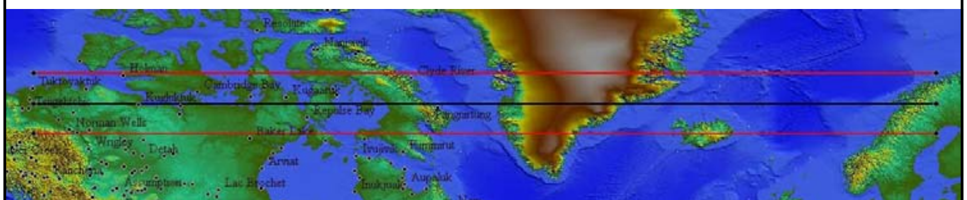
SWEDEN CAMPAIGN OVERVIEW



- Established Northern Hemisphere 2005 (Sweden to Canada)
- Payload Weights up to 3600 kgs
- Float Altitudes of +36 km
- Minimal Altitude Excursions



- Flight durations on the order of 4 to 7 days
- Hopeful of future circumnavigation over Russia in 2008 with flight durations on the order of 3 weeks
- Accessible for International Scientists
- World Class Facilities & Support

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TRACER Trajectory – Sweden 2006

ANTARCTIC CAMPAIGN OVERVIEW

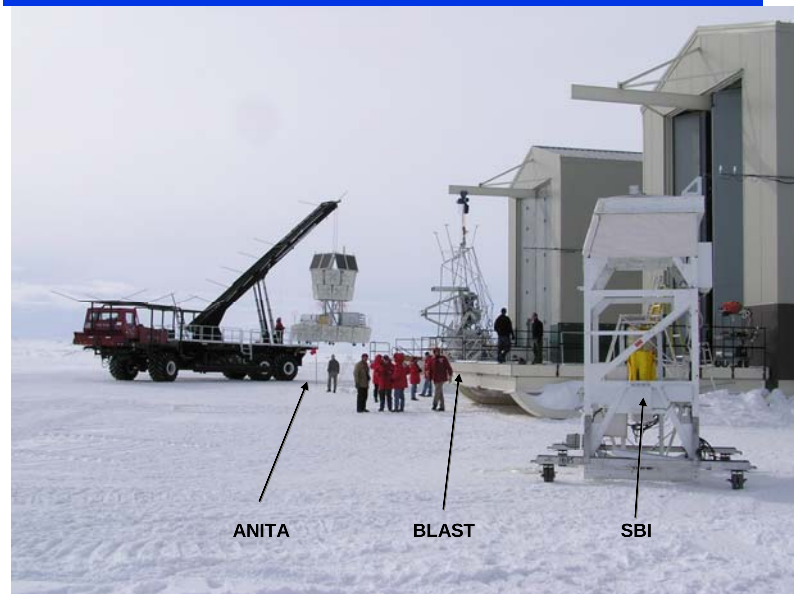
- Annual Campaign since 1989
- A third flight was added to annual Antarctic LDB program to meet science demand for LDB flights in polar region
- Payload Weights up to 3600 kgs
- Float Altitudes of +36 km
- Minimal Altitude Excursions
- Flight durations on the order of 20-40 days
- World Class Facilities & Support

Antarctic LDB Facilities

New LDB/ULDB Operational Control Center

- Located at CSBF in Palestine, Texas
- Can support 3 LDB payloads in flight simultaneously
- Receipt and processing of telemetry
- Flight management
- Transferring experiment data to users
- Communications
- FAA Airspace coordination

Antarctic Campaign 2006



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2006 Antarctic Campaign
Balloon-borne Large Aperture Sub-millimeter Telescope (BLAST)

BLAST - Mark Devlin, U Penn, PI
- Barth Netterfield, U Toronto,Co-I

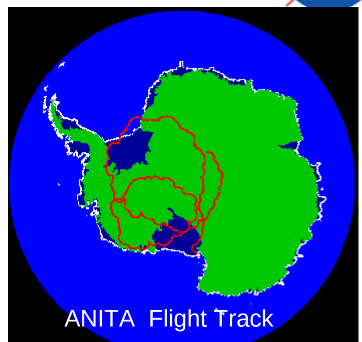
BLAST incorporates a 2 m primary mirror and large-format arrays operating at 250, 350 and 500 um.

It will provide the first sensitive, large-area (>>10 deg2), sub-mm survey at these wavelengths.

- The 2006 BLAST LDB flight in Antarctica was successfully completed
  - 11 days and 23 hours
  - Science objectives of the flight were met, and science data were of excellent quality throughout the flight.
  - NASA's parachute release system failed to operate after flight termination, and the payload was dragged across ice and severely damaged.
  - Currently investigating the termination system failure to reduce reoccurrence.

2006 Antarctic Campaign
Antarctic Impulsive Transient Antenna (ANITA)

- **<u>ANITA- Peter Gorham, U Hawaii, PI</u>**
- Launched December 15, 2006
- The ANITA payload completed 3 ½ circumnavigations of the Antarctic continent, and was at float for 35 days.
- ANITA was recovered in single aircraft flight

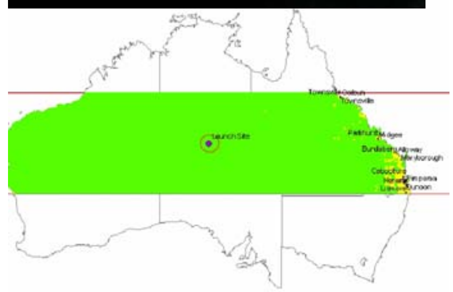


- The Antarctica Impulsive Transient Antenna (ANITA) mission is designed to be the first instrument to detect the ultra-high energy (UHE) cosmogenic neutrino flux
- ANITA uses an array of ultra-broadband quad-ridged horns to synthesize an antenna array that can view the Antarctic ice sheet from horizon to horizon.

Recovery Loading

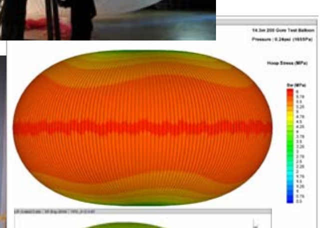
Australia 2008

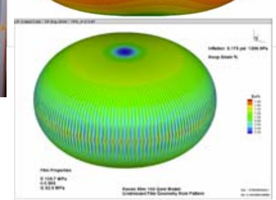
- NASA is planning for an Australia Campaign September- December 2008.
- Science Teams have expressed interest in conducting mid-latitude flights
  - UC Berkeley/Boggs (LDB)
  - GSFC/Barbier (conventional)
  - GSFC/Tueller (conventional)
  - Cal Tech/Harrison (conventional)
  - UC Riverside/ Zych (conventional)
  - MSFC/ Ramsey (conventional)
- Wallops Safety Office completed Safety Analyses for both Conventional and LDB flights from Australia
  - Nominal flights meet the safety criteria for over flight of Australia, Africa, and South America



Ultra Long Duration Balloons

- The Balloon Program continues development of a Super Pressure Pumpkin Balloon for Ultra Long Duration (ULDB) Flight.
- <u>ULDB Demonstration Requirements</u>
  - 1-ton instrument to 110 kft
  - Little or no day/night altitude variation
  - 60 - 100 day flights: Demonstration scheduled for launch in 2010
  - Super-pressure, pumpkin-shape (no diurnal ballast required)
  - First new balloon design in more than 50 years
  - ULDB exposure is competitive with satellites for investigations that can be done in near-space: 1000 kg x 100 days = 200 kg x 500 days

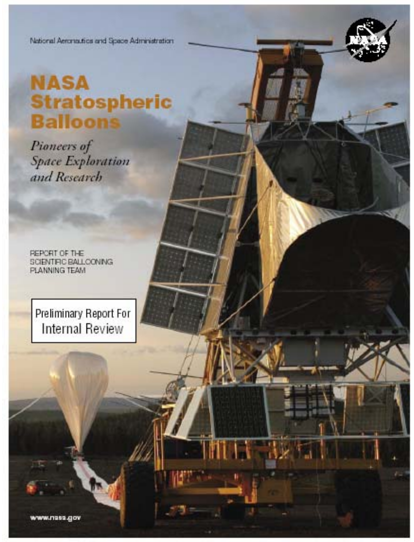




Balloon Roadmap Report

- The Balloon Program developed a Roadmap for Balloons in 2005
- **The Roadmap team, chaired by Martin Israel, Wash U., will update the roadmap and formally publish by mid-2007**
  - Identify the scientific objectives for which ballooning has the greatest potential to contribute significantly, and show their connection to NAS reports, NASA strategic objectives, or other planning documents
  - Identify the ballooning requirements for optimal and minimal programs, both in the near term and over the next 10 -15 years
  - Identify the highest priority augmentations and their science impacts

Down load prelim report at: www.wff.nasa.gov/balloons



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Balloon Program in implementing Recommendations

- The Roadmap Team has placed high priority on increasing the number and capability of LDB flights
  - ✓ Thanks to NSF for supporting this year's campaign with 3 payloads.
  - Another Payload Building is needed to sustain 3 flights in Antarctica
  - ✓ Have conducted Sweden campaigns(2005 &2006) & next in June 2008
  - ✓ Australian campaign is planned for early Fall 2008
- The BPO will work with NSF Office of Polar Programs to secure a larger airplane for same-season recovery of nearly-intact payloads
  - This would significantly reduce the cost of payload refurbishment
- Increase the (ULDB) super-pressure balloon altitude to 125,000 ft
  - This is critical for gamma-ray and hard X-ray LDB missions at mid-latitudes
- Develop a trajectory control capability with 1 m/sec control authority
  - Simulations show that 0.5 meter/sec control authority would have kept the CREAM II trajectory over the continent for at least 3 very tight orbits

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Capability Increase for Long-Duration (LDB) Flights

Add third flight to annual Antarctic LDB program to meet science demand for LDB flights in polar region

- Program has backlog of funded payloads (FY07-11) requesting to fly from Antarctica
- To accommodate 3rd flight, need 3rd payload building at McMurdo.
- Adding dedicated aircraft support for recovery will permit full recovery of payloads each year with minimal disassembly.

Capability to SMD:	
3rd Payload Support	FY07
Dedicated Aircraft Support	FY08
3rd Payload Building Operational	FY10

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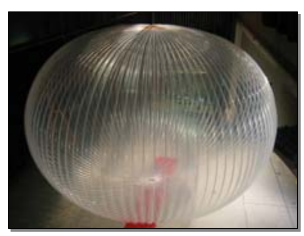
Capability Increase for Super Pressure (LDB & ULDB) Flights

Super Pressure Balloon Vehicle

A series of small scaled model tests will be completed during 2007.

Plans call for a small 6MCF pumpkin-shaped super-pressure balloon to be tested between Sweden and Canada in summer 2008. The flight test will validate design to higher level of confidence.

Completion of the super pressure balloon will enable the Gamma Ray/Hard X-Ray community long duration mid-latitude flights at a constant altitude.



Capability to SMD:
22 MCF (1000 Kg to 110K FT) FY10
30 MCF (1000 Kg to 125K FT) FY12

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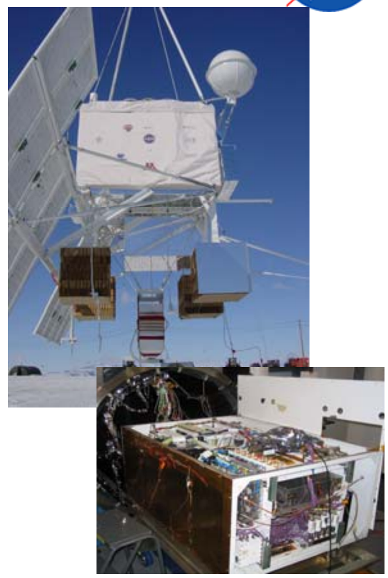
Balloon Program Continues Development of Advance Technologies

- NASA's Balloon Program developed, tested and integrated a NEW Balloon Support Systems, including the Command Data Module (CDM) for ULDB Missions.
  - It was used in support of the CREAM/LDB Missions (Dec. 2004 & Dec. 2005) in Antarctica.
- An advanced ballooncraft support system is needed to provide redundant, reliable power, high rate data communication systems for long duration flights.



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Trajectory Control System Development

Trajectory Control System

Trajectory control is needed for LDB/ULDB to meet flight safety and environmental restrictions

- Keep Antarctic trajectory over the continent even after two circuits
- Ensure that mid-latitude flights do not fly over densely populated areas
  - Will aid in seeking international flight clearances
- TCS is an essential technology for ULDB flights of 100 days or more

Capability to NASA:

Prototype Flights	FY09-10
Operational System	FY11

Propeller Concept

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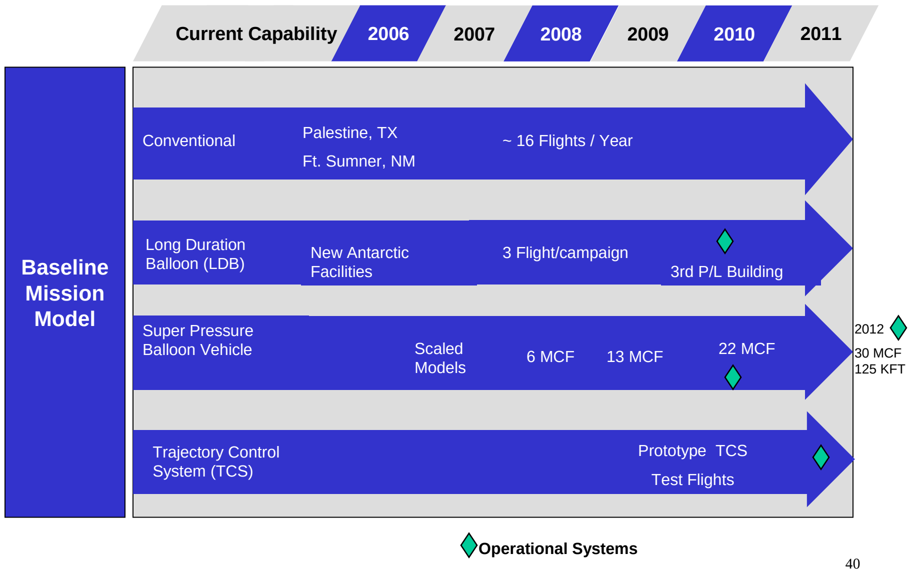
Future Balloon Program Capabilities



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Ballooning Will help achieve NASA Strategic Objectives

- Strategic objective 5.1 – "Learn how the solar system originated and evolved into its current diverse state."
- Balloons capable of deployment elsewhere in the Solar System – Venus, Mars, Titan
  - Atmospheric studies and Close monitoring of ground
- Collection of *in-situ* atmospheric data and high-resolution geological, geochemical and geophysical data is best done by an aerial platform.
  - The Russian-French-US VEGA mission to Venus in 1985 successfully deployed two balloons in the dense Venus atmosphere for about two Earth days and collected in-situ data there.

Artist's concept of super-pressure balloon on Mars

Artist's concept of a Venus deep atmosphere balloon

Artist's concept of an aerobot at Titan

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Conclusion

- Scientific ballooning has made important contributions to NASA Science
- Scientific ballooning directly linked to NASA's objectives
  - *Physics of the Universe, Space Science Strategy, Earth Science Strategy*

- The current balloon program has substantial capability, but
  - Funding is inadequate for payloads and advanced technologies

- The Roadmap team has identified high-priority needs for operations & science
  - Increased capability for long-duration balloon (LDB) flights
  - High-altitude (125 kft) super pressure balloon

- There are exciting new possibilities for the next 10 to 30 years
  - Flights at 160 kft (less than 1 mb residual atmosphere)
  - Advanced trajectory control and large aerostats
  - Balloons capable of deployment on Venus, Mars, Titan

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Balloon Program Office Acknowledgements

- **NASA/Headquarters**
  - Dr. Vernon Jones, Program Scientist
  - Dr. Mark Sistilli, Program Executive

- **New Mexico State University/Physical Sciences Lab (PSL)**
  - Mr. Steve Hottman, Contract Program Manager
- **Columbia Scientific Balloon Facility (CSBF)**
  - Mr. Danny Ball, Site Manager & Staff

- **Aerostar International, Inc.**
  - Mr. Mark West, Mr. Loren Seely & Staff

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The contribution of long-duration balloon flights in the study of stratospheric dynamics: the example of Strateole/Vorcore

A. Hertzog(*)(1), F. Vial(1), Ph. Cocquerez(2)
(1) Laboratoire de meteorologie dynamique, Palaiseau, France
(2) Centre National d'Etudes Spatiales, Toulouse, France

Abstract:

In 2005, 27 superpressure balloons were launched from McMurdo (Antarctica) in the framework of the Strateole/Vorcore campaign. These balloons can fly for several months in the lower stratosphere (17-20 km) where they behave as quasi-Lagrangian tracers of air motions. During Vorcore, the scientific payload performed continuous observations of pressure, temperature and wind and the collected dataset is used to document the dynamics of the polar lower stratosphere. In particular, it will be shown that these data can provide unique information on the gravity-wave activity in the lower stratosphere. Future superpressure balloon campaigns and new instrumental developments will also be presented, as well as the expected outcome of those new projects.

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Session:	Invited Speaker
Presentation Method:	Talk
Presenting Author Title:	Research Associate

The contribution of long-duration balloon flights in the study of stratospheric dynamics: The example of Stratéole/Vorcore

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Ph. Cocquerez

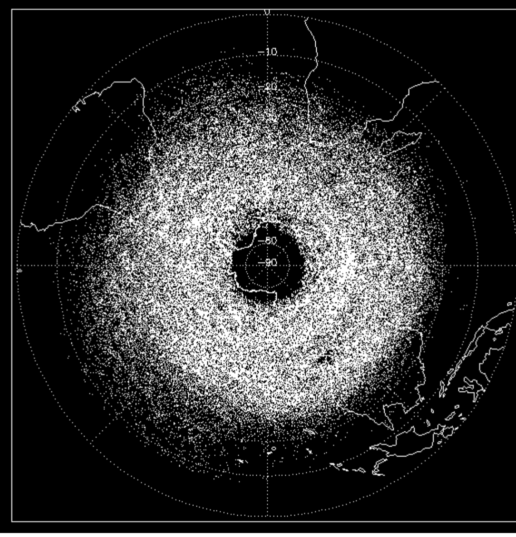
LMD/CNRS cnes

Outline

- Historical perspective
- Scientific motivations for long-duration flights
- Long-duration ballooning
- Vorcore
- Future campaigns and developments

Recent history

- Development of long-duration ballooning after World War II
  - Provide upper-air observations over empty places
- Big projects in the 60's (Ghost) and 70's (Eole, Twerle)



Recent history

- Development of long-duration ballooning after World War II
  - Provide upper-air observations over empty places
- Big projects in the 60's (Ghost) and 70's (Eole, Twerle)
  - With already some mid-stratospheric flights (up to 18 hPa)
- Few flights in the 80's and 90's (except some IR Montgolfières and EMA/ELBBO)
- Vorcore in 2005

Motivations for long-duration flights for atmospheric studies

- Ability to fly almost everywhere from the upper troposphere to the mid stratosphere
- Provide high-resolution data over wide areas (ocean/land, clear/cloudy sky, etc.)
  - Long duration => large datasets
- Provide accurate observations
  - Assimilation, satellite validation
- Superpressure balloons are quasi-Lagrangian tracers
  - Follow modifications of air-parcel physics and chemical composition
- Direct access to wave intrinsic frequency

Suborbital Vehicle Workshop, Toronto, Feb. 1-2, 2007

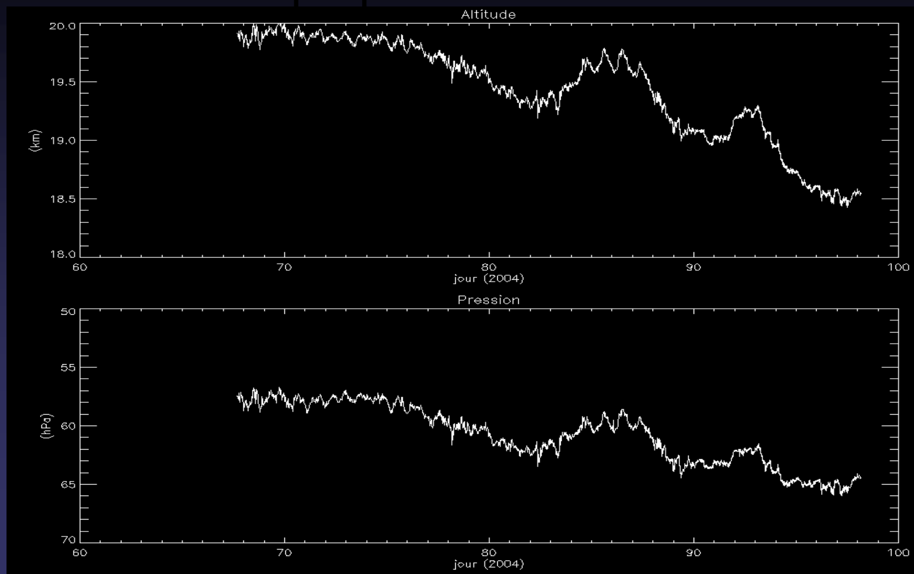
Vorcore superpressure balloons

- Closed, stiff, 55µm-thick envelop, helium filled balloon
- 10 m, 33 ft (60 hPa), 8.5 m, 28 ft (80 hPa)
- Life time > 3 months
- Science payload: 15 kg, 30 lbs
- Constant-density (isopycnic surface)

$$\rho_b \, dw_b/dt = - \rho_b \, g - dp/dz$$
$$= - (\rho_b - \rho_a) \, g$$

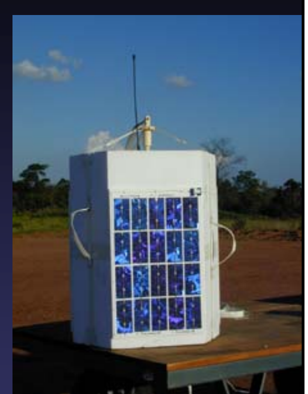
Suborbital Vehicle Workshop, Toronto, Feb. 1-2, 2007

Vorcore superpressure balloons



Vorcore observations

- Scientific gondola:
- 1 observation/15 minutes
  - Position: GPS (10/20 m)
    - Horizontal velocities (0.02 m/s)
  - Temperature: 2 thermistors
    5 m below the gondola (0.25 K)
    (when not broken)
- 1 observation/1 minute
  - Pressure: Paroscientific (1 Pa)
    - Vertical velocity
- Data sent through ARGOS system



Vorcore

McMurdo, Antarctica

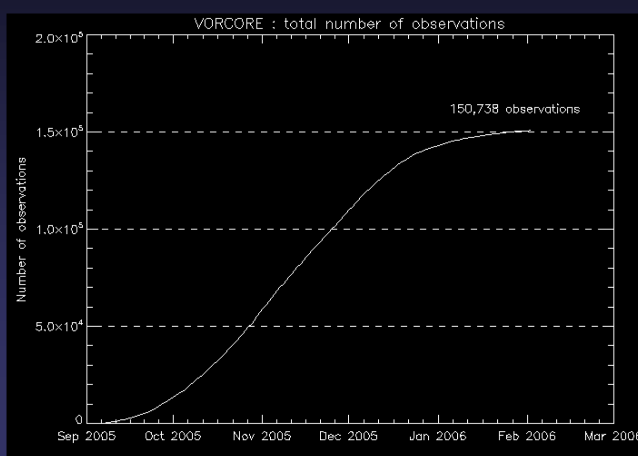
27 flights: September 5 - October 28

Mean duration: 58.5 days

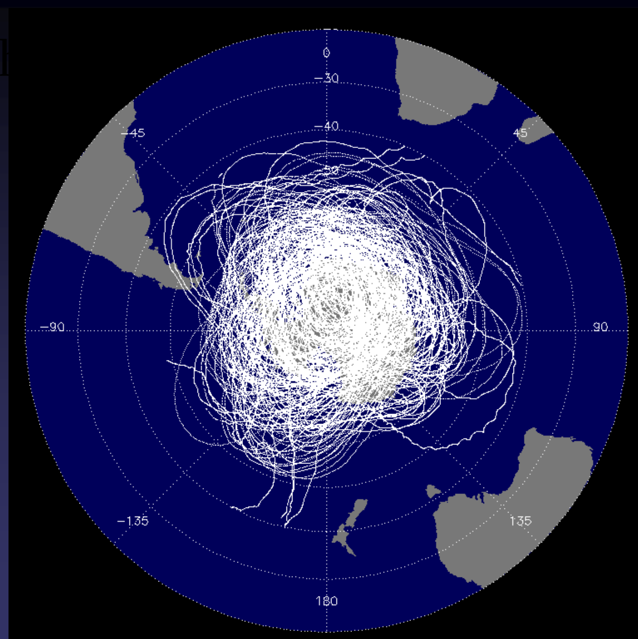
Longest flights: 109 days

Flights

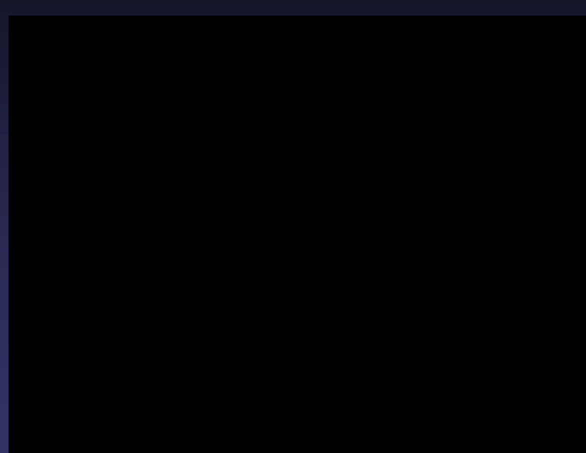
- Vorcore has been an operational and technical success

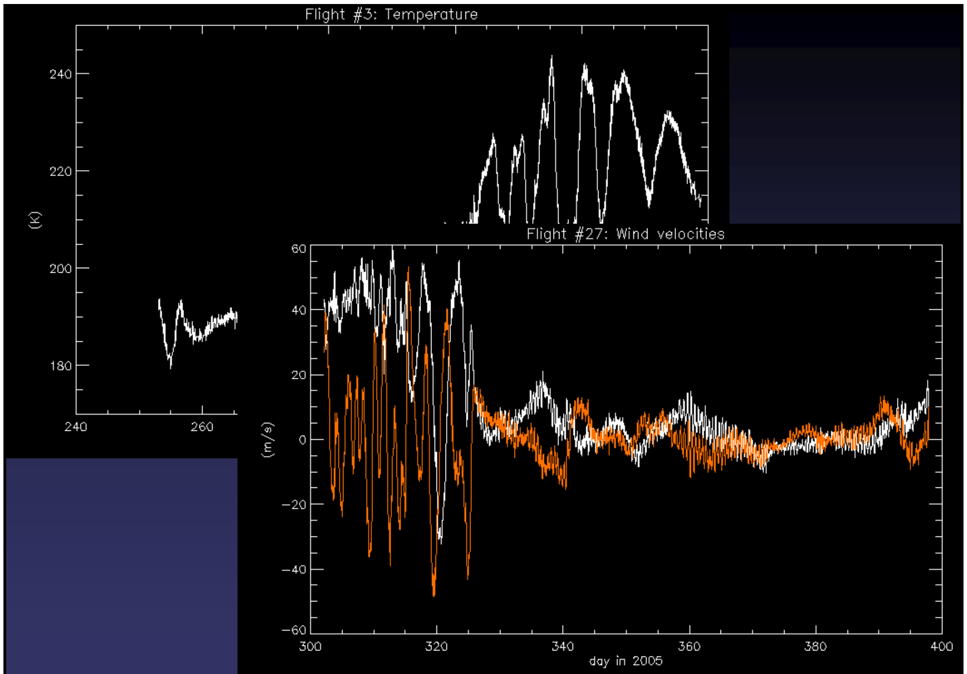


Fligh



movie





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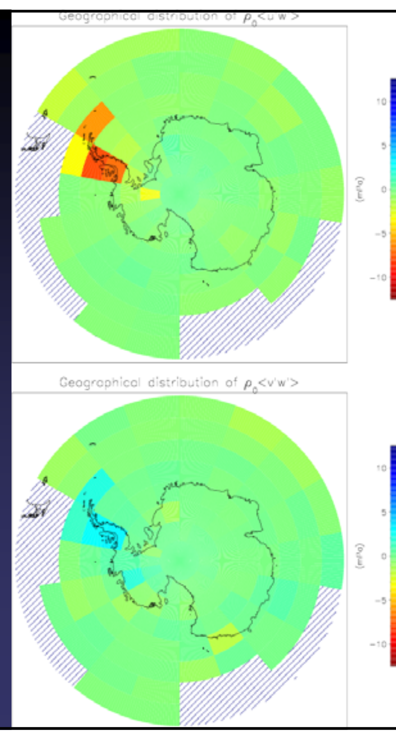
Gravity-wave momentum flux

Zonal component

Meridional component



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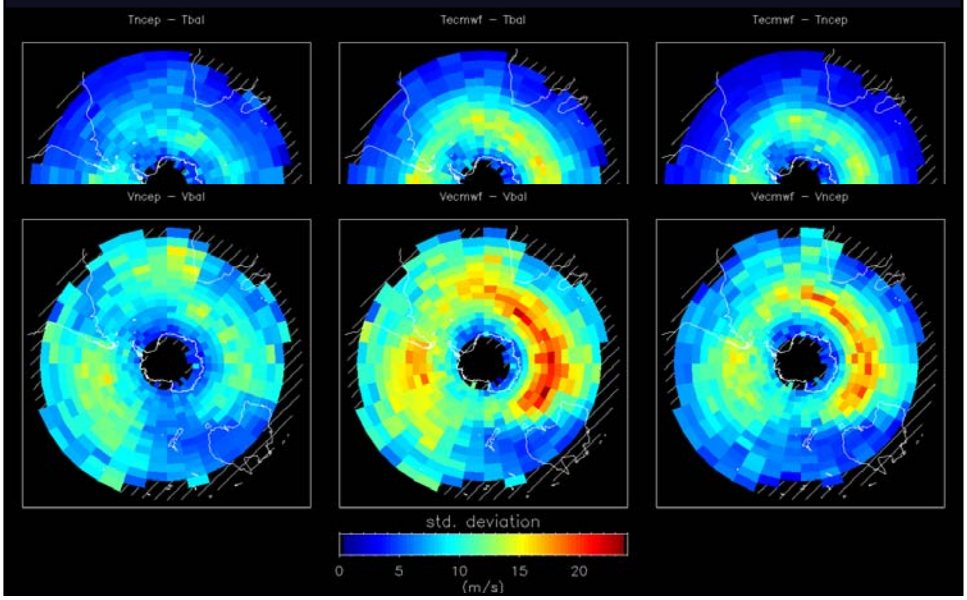
Late Eole Results (1971-72)



Current developments

- Balloon
  - Larger (12-m diam.), able to carry heavier payloads
  - Already tested in 2006
- Gondola
  - New telecommunication (Irridium)
    - 2-way link
    - Larger data rate => higher sampling rate

Current developments

- Instruments
  - Driftsonde (NCAR/EOL)
  - Particle counter (U. Wyoming), lidar (CNR)
  - Ozone, Water vapour (GSMA)
  - GPS Radio-occultation (Purdue U.)
- Future campaigns
  - Concordiasi, McMurdo 2008
  - Equatorial campaign 2009/2010
  - ...

Probing the Atmosphere from Balloon Platforms

Kimberly Strong
Department of Physics
University of Toronto

Abstract:

High-altitude balloon-borne platforms offer a number of advantages for atmospheric measurements. They can be used to carry payloads ranging from a few kg to several tons, consisting of extractive, in situ, and remote sounding instruments. These typically reach float altitudes of 35 to 40 km, allowing the atmosphere to be probed from above rather than looking up through the dense lower atmosphere, as must be done with ground-based measurements. Height-resolved measurements of atmospheric properties can be made on ascent, or from float using spectroscopic remote sounding techniques that scan through a range of elevations in solar occultation or limb-viewing mode. Customized balloon flights, such as valve-controlled slow descent, double ascent, or long duration "boomerang" flights, can be designed to match the scientific requirements. These enable instruments to make measurements over periods ranging from several hours to several weeks.

This presentation will summarize some of the capabilities, advantages, and disadvantages of using balloon-borne platforms to probe the atmosphere. Their usefulness for technology development and training of personnel will also be highlighted. The MANTRA (Middle Atmosphere Nitrogen TRend Assessment) series of high-altitude balloon flights that have been undertaken since 1998 will be used to illustrate some of these points. Future directions for ballooning, and some thoughts on moving towards a new Small Payloads Program in Canada will also be discussed.

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Preferred Session: Past projects and case studies
Presentation Method: Talk
Presenting Author Title: Professor

Probing the Atmosphere from Balloon Platforms

Kimberly Strong
Department of Physics, University of Toronto

Community Workshop on Science from Suborbital Vehicles

Toronto
1-2 February 2007

Why Use Balloon Platforms?

Balloon platforms offer excellent opportunities for

- Scientific exploration
  - → Atmospheric observations looking through the atmosphere
  - → Astrophysical observations from above the atmosphere
- Technology development
- Testing prototypes of satellite instruments
- Satellite validation
- Training of scientific, engineering, and technical personnel

Some Canadian History

- First balloon-based atmospheric measurements used infrared spectrometers to study the Earth's airglow (U. Sask.)
- **1960** - Noxon and Vallance Jones, working with the Canadian Armament Research and Development Establishment (CARDE), measured OH emission
  - → Further balloon-borne measurements of OH followed (e.g., UWO)
- **1962** - Gush and Buijs were the first to detect the 1.27 μm band of O_2 in the nightglow using a Michelson interferometer
  - → Followed by filter photometer observations of O_2 by Evans et al.
- **1970s & 1980s** - Atmospheric Environment Service in Canada led the Stratoprobe series of balloon flights
  - → Included measurements of NO_2 & HNO_3, predating ozone depletion
  - → Provided early estimates of northern hemisphere mid-latitude odd-nitrogen budget, and a useful benchmark for current measurements

Probing the Atmosphere from Balloon Platforms - K. Strong *CWSSV 2007 - Slide 4*

MANTRA

- Balloon mission to study the changing chemical balance of the mid-latitude stratosphere
- Supported by the Canadian Space Agency and the Meteorological Service of Canada (all flights), CRESTech (1998), NSERC (2002, 2004)
- Four late summer campaigns from Vanscoy, SK (52°N, 107°W)

Probing the Atmosphere from Balloon Platforms - K. Strong *CWSSV 2007 - Slide 5*

MANTRA Campaigns

MANTRA 1998

- First Canadian launch of large high-altitude balloon in ~15 yrs
- Ambitious payload that combined older and newer instruments
- 8 flight instruments, 3 ground-based instruments, sondes

MANTRA 2000

- Engineering test flight of a new pointing control system
- 4 flight instruments, 3 ground-based instruments, sondes

MANTRA 2002

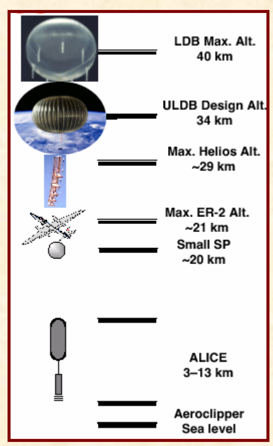
- Large payload - added second FTS and French SAOZ
- 9 flight instruments, 4 ground-based instruments, sondes

MANTRA 2004

- 7-week campaign, two launch attempts, SAOZ-BrO flight
- 11 flight instruments, 6 ground-based, 21 sondes
- 43 days of ground-based measurements

Advantages of Balloons - 1

- Can carry payloads ranging from a few kg to several tons
- Can carry a variety of payloads - sampling, in situ, and remote sounding instruments
- Can fly at altitudes from near the surface to the upper stratosphere
- Reach float altitudes of 40 km
  - → Near-space conditions, 99% of the atmosphere is below
  - → Allow the atmosphere to be probed from above
- Provide height-resolved measurements of the atmosphere
  - → Can be made on ascent or from float by scanning in elevation



GAC Report 140-76811-01
April 2002

Advantages of Balloons - 2

- Can be designed for special flights to match requirements
  - → e.g., valve-controlled slow descent, long duration flights, tethered
  - → Can make measurements from several hours to several weeks
- Short timescales - typically 2-5 years from concept to flight
- Allow testing of new instruments with little or no flight heritage
- Balloon payloads are recoverable
- Much less expensive than satellite programs
- Many applications
  - → Atmospheric chemistry and dynamics
  - → Radiation
  - → Weather and climate
  - → Astronomy and astrophysics

Atmospheric Applications

"It can effectively be asserted that balloons have no substitute for :

- *observations and measurements both in situ and by remote sensing, of ozone and atmospheric minor constituents, water vapour, ...in the range of 20 to 40 km, at all latitudes and all seasons,*
- *studying the atmospheric dynamics as balloons can perform Lagrangian measurements within air tresses and their trajectories provide information at all scales and in wide range of altitudes on circulation, winds, turbulence and waves."*

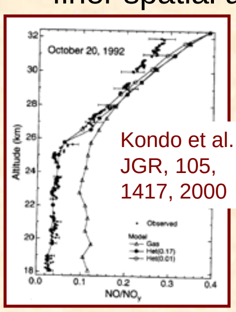
Sadourny, *Adv. Space Res.*, 30 (5), 1105, 2002

Disadvantages of Balloons

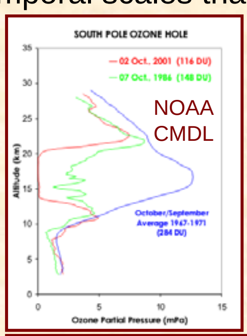
- Depend on meteorological conditions at launch
- Logistical factors
- Their trajectories depend on the winds at float, making them less predictable than satellite
  - → Future: trajectory control systems are being developed
- Limited duration (~100 days max, most less than 3 weeks)
  - → Zero-pressure balloons limited by ballast/vent diurnal cycle
  - → Superpressure balloons limited by leaks and UV damage
  - → Future: long duration superpressure balloons that use high-quality engineered seams and UV-resistant materials
- Don't provide global view
  - → Future: global constellations of long duration balloons
- Political issues associated with overflight of countries

Scientific Exploration

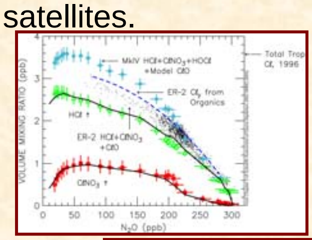
- Balloons provide observations of detailed processes on much finer spatial and temporal scales than satellites.

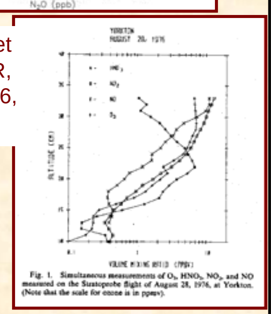


Kondo et al., JGR, 105, 1417, 2000

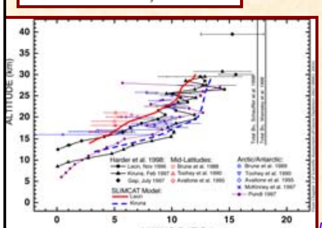


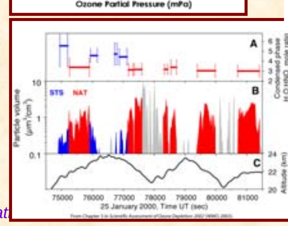
NOAA CMDL





Evans et al., JGR, 86, 2066, 1981

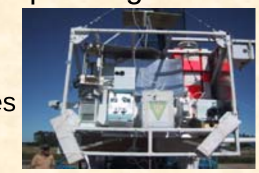




Example: MANTRA

Scientific Objectives

(1) To measure vertical profiles of the key stratospheric gases that control the mid-latitude ozone budget.



→ O_3, NO_2, HNO_3, O_2, O_4, CFC-11, CFC-12, OH, H_2O, N_2O, CH_4, SO_2, BrO, aerosol, J-values

(2) To combine these measurements with historical data to quantify changes in the chemical balance of the stratosphere, with a focus on nitrogen compounds.

→ Includes comparisons with atmospheric models such as CMAM

(3) To compare multiple measurements of the same trace gases made by different instruments.

(4) To use the measurements for validation and ground-truthing of Odin, ENVISAT, and SCISAT-1.

Technology Development

- Balloons provide an excellent platform for testing new instruments in the near-space environment
  - → Enables the assessment of their suitability for satellite missions
- A few examples:
  - → MAESTRO on SCISAT evolved from MSC's SunPhotoSpectrometer; also flew MAESTRO-B on MANTRA 2002
  - → MLS, TES, and HIRDLS on EOS-Aura all have balloon heritage
- These prototypes can later be used for validation and trouble-shooting of the satellite instruments and for complementary measurements

  "*You would have to be foolish to fly a new detector on a satellite without first testing it under the conditions of a balloon experiment.*" Jerry Fishman, GSFC, Compton Gamma Ray Observatory (*Science,* 289, 534-536, 2000)

Example: MANTRA

New Instruments - first flights during MANTRA

- AOTF (1998; ground-based for 2000, 2002, 2004) - York U
- MAESTRO-B (2002, 2004) - MSC, U of T
- PARIS-IR (2004) - U of Waterloo
- AIR (2004) - MSC, York U
- Pointing control system - U of T, York U, SIL
- Ground-based UV-visible grating spectrometer - U of T

Refurbished Instruments

- Emission radiometers - new algorithms - U of T, MSC, York U
- MSC/UofT FTS (2002, 2004) - significant mods - U of T, MSC
- SunPhotoSpectrometers - MSC, U of T
- Denver FTS (1998, 2002, 2004) - DU
- OH spectrometer (1998, 2002, 2004) - MSC

Probing the Atmosphere from Balloon Platforms - K. Strong *CWSSV 2007 - Slide 14*

Training of Personnel - 1

- Ballooning offers students the opportunity to participate in all stages of the experiment from concept to hardware, measurements, and data analysis
- Provides exposure to
  - → Achievement of a scientific goal (the science requirements) through the planning and execution of an experiment
  - → Schedule, weight, and power constraints
  - → Quality control and risk management
  - → Deployment of instrumentation in harsh near-space environment
  - → Field operations, team project
  - → Technical skills associated with launching stratospheric balloons
  - → Handling of large collaborative data sets from a field experiment

Probing the Atmosphere from Balloon Platforms - K. Strong *CWSSV 2007 - Slide 15*

Training of Personnel - 2

"The impact of the NASA Balloon Program goes far beyond the demonstration of technology and the direct science data that are produced - the scientists who 'cut their teeth' in the NASA Balloon Program are very often the leaders of today's NASA space science missions and programs."

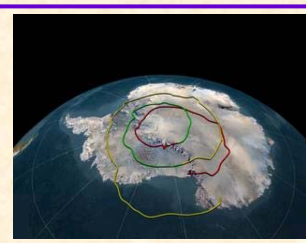
Thomas A. Prince, Caltech Prof. of Physics, JPL Chief Scientist, LISA Mission Scientist

Example: MANTRA

- Theses completed and in progress: 5 BSc, 9 MSc, 8 PhD
- Undergraduate research students: >25
- Post-doctoral fellows and research associates: 8
- Technical personnel: 10 + industrial partner
- 58 people were involved in MANTRA 2004

Future Directions - 1

- Technical advances in
  - → Trajectory control
  - → High quality superpressure balloons
  - → UV-resistant balloon materials
  - → Power systems
  - → Onboard storage
  - → Telemetry (e.g., satellite links)
- Ultra-long duration balloon flights
  - → NASA/NSBF - large (600,000 m^3) superpressure balloons to carry heavy payloads to high altitudes
  - → CNES - smaller pressurised balloons to carry small payloads (10 kg) to 20 km
  - → CNES - Montgolfiere Infra-Rouge (MIR) balloons have two hemispheres for day- and night-time heating to carry 60 kg to 18-22 km (night) to 28 km (day)

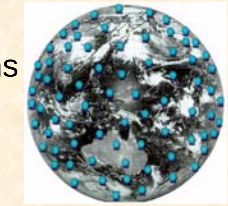


Cosmic Ray Energetics And Mass (CREAM) - 42 days

ULDB at float - www.wff.nasa.gov

Future Directions - 2

- Global networks of hundreds of balloons for long duration (>3 yrs) atmospheric observations
  - → e.g. Global Air-ocean IN-situ System, StratoSat™
- Aerobots - steerable helium-filled blimps with possible landing and floating capabilities
  - → e.g. for planetary exploration, Mars



GAINS network

ALTAIR-2, U of Wales, Aberystwyth

AEROCLIPPER
CNES & www.lmd.ens.fr

- AEROCLIPPER - balloon at 50 m with cable in contact with the surface of the ocean
  - → could cover thousands of km for simultaneous sea surface and boundary layer measurements

Beyond MANTRA - 1

Towards a New Small Payloads Program ...

- Balloons provide an excellent return for level of investment
- Trade-off between flight risk and resources
- Currently not supported & managed as a "space program"
- Moving to a risk avoidance model where all systems are fully flight-tested requires a different approach
  - → Will require an increase in resources, i.e., people, schedule, money
  - → May move some development out of universities and reduce student involvement
- Difficult to manage launch subcontracts from universities
- Equipment at Vanscoy needs significant investment if we are to maintain Canadian launch capability

Beyond MANTRA - 2

- Issue of maintaining momentum for an experimental program
- Students and PDFs get hands-on instrument experience
- Need to continue building expertise
  - → People, instruments, launch support capabilities
- Broaden involvement of Canadian universities in ballooning
- Issue of future roles of CSA & EC in supporting ballooning
- Vital to have science funding (like NSERC CRO)
- Would like to get to a "program status" where we see a 5-10 year horizon for ballooning in Canada
  - → No guarantees but a reasonable expectation of continuity
  - → Need willingness and flexibility to support riskier new instruments as well as proven ones
  - → e.g., AOs for new instruments for program of regular balloon flights?
- New science

Long Duration Ballooning

Barth Netterfield
University of Toronto

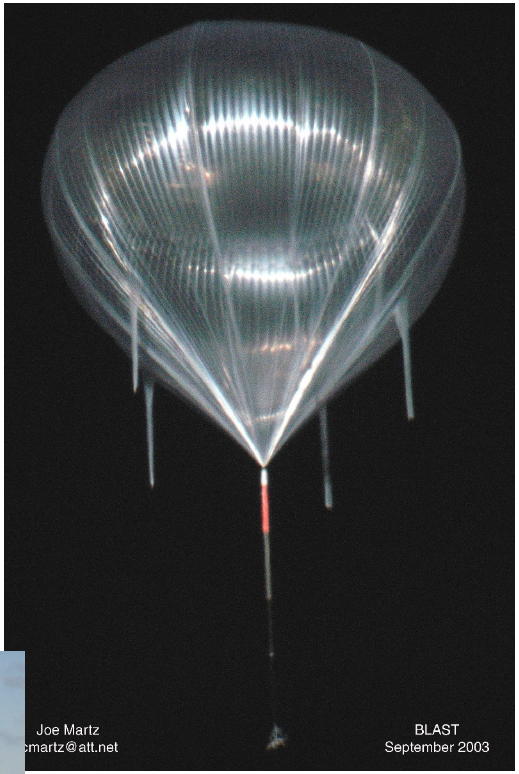
Abstract:

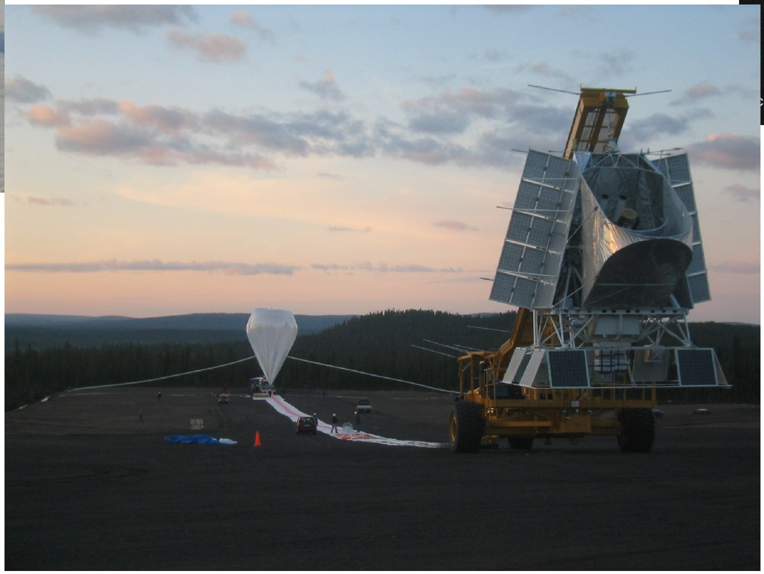
Long Duration Ballooning provides a unique opportunity to place large (2 ton) instruments in a near-space environment for extended periods of time (up to 42 days). I will discuss the logistics, the capabilities, and rewards, and dangers of long duration ballooning, based on our experience with the BOOMERANG and BLAST instruments.

Presenting Author Name:	Barth Netterfield
Organization:	University of Toronto
Presenting Author Email:	netterfield@astro.utoronto.ca
Presenting Author Telephone:	416-978-0307
Preferred Session:	Past projects and case studies
Presentation Method:	Talk
Presenting Author Title:	Professor

Long Duration Ballooning: Case studies...

BOOMERANG
&
BLAST





Stratospheric Balloons for LDB

38km altitude

1800kg payloads

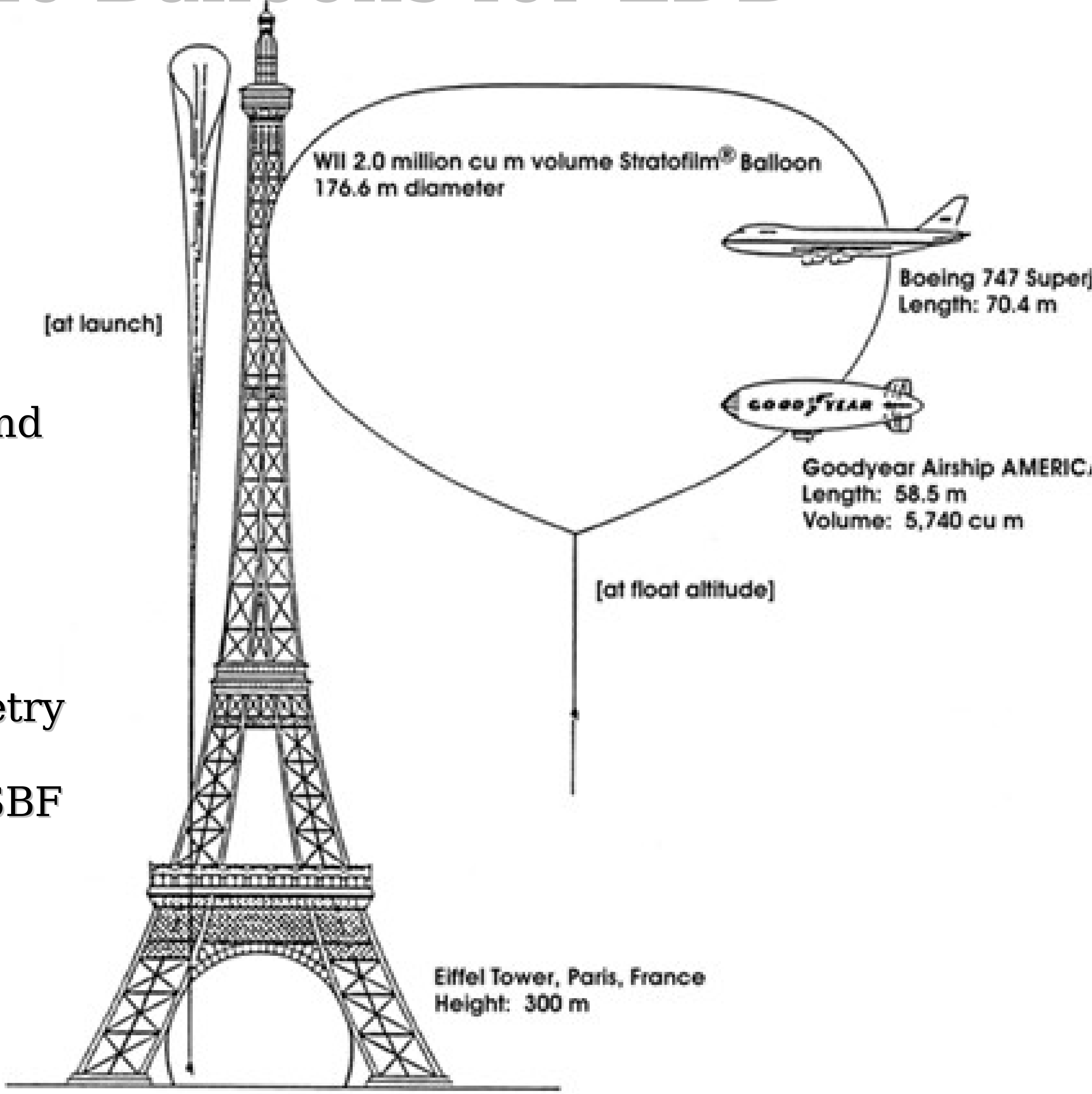
Flights up to 42 days

Launches from McMurdo, Antarctica and Kiruna, Sweden.

All daylight for altitude stability

Near continuous telemetry

Flights are by NASA/CSBF



The Opportunity:

Launch *Explorer* class instruments into a near space environment

Good chance of recovery allows multiple flights (and fixes…)

Budgets and risks consistent with significant (often dominant) Student/ PDF involvement.

Schedules allow flights with new technologies years before satellites

BOOMERANG

- Balloon borne mm telescope:
  (Demonstrated technology now used for the Planck Sattelite)
- 1500 kg payload
- approx $5M (plus launches)
- Proposals written 1992, final flight 2003
- Measure anisotropies in the Cosmic Microwave Background
- Answer many fundamental questions in cosmology

University of Rome I
University of Toronto
Cardiff University
IROE
CalTech
JPL
CWRU

BLAST

•Balloon borne sub-mm telescope:
(Uses the receiver from the SPIRE instrument on Hershel)

•1800 kg payload

•approx $5M (plus launches)

•Proposals written 1999, final flight 2006

•Detect 1000 sub-mm galaxies to z = 5

•Derive photometric redshifts

•Determine star formation rate evolution

•Find cold pre-stellar sources

•Make high-resolution maps of the ISM

University of Pennsylvania
Brown University
University of Miami
JPL
University of Toronto
UBC
Cardiff University
INOE (Mexico)

The Test flight:

If it hasn't been tested... It doesn't work

Required* to qualify for an LDB flight

BUT: Any flight is a risk to the instrument (recovery...) and a short flight may be unlikely to generate much science

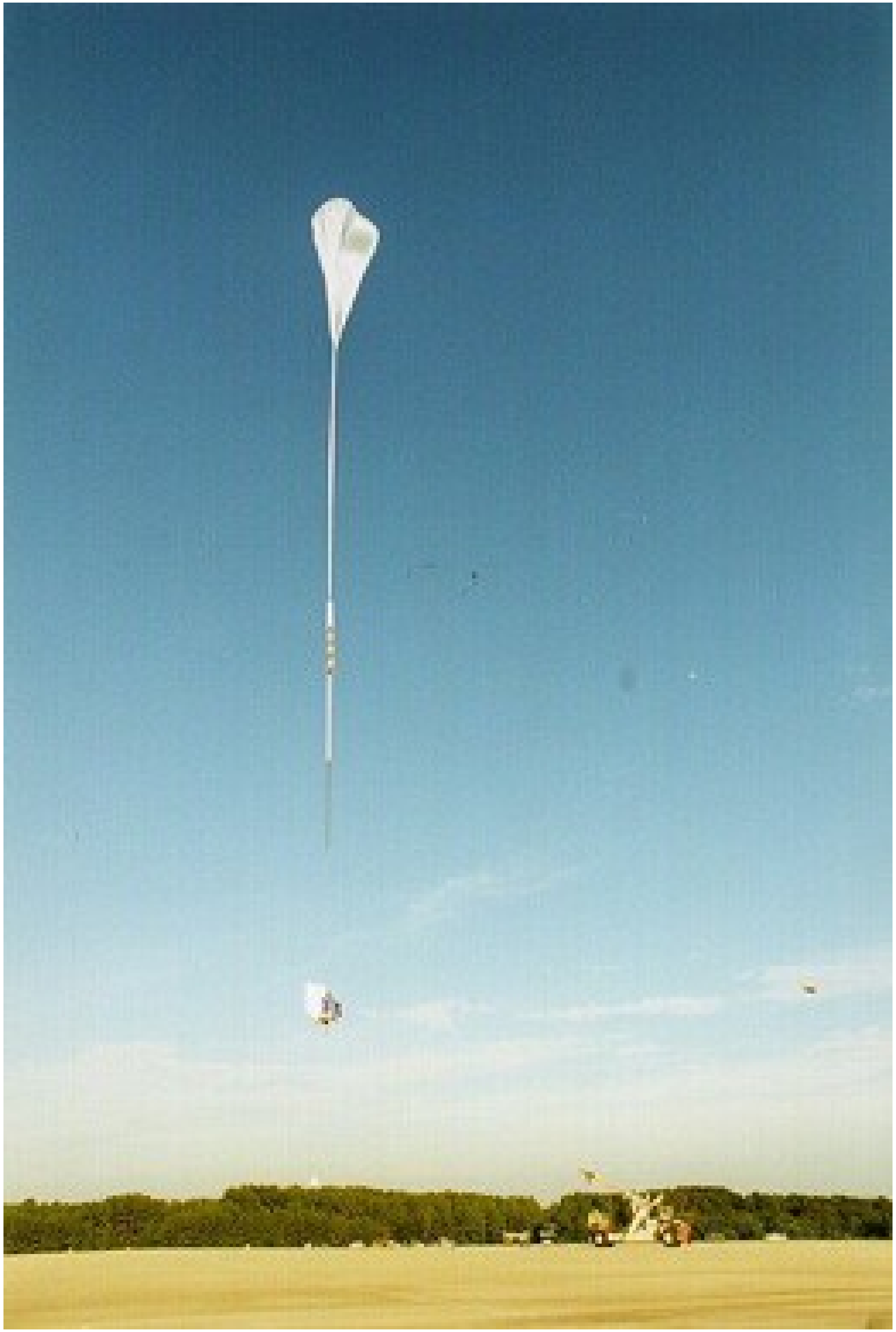
So: The test flight often involves a subset of the final instrument.

* Unless you are "special"

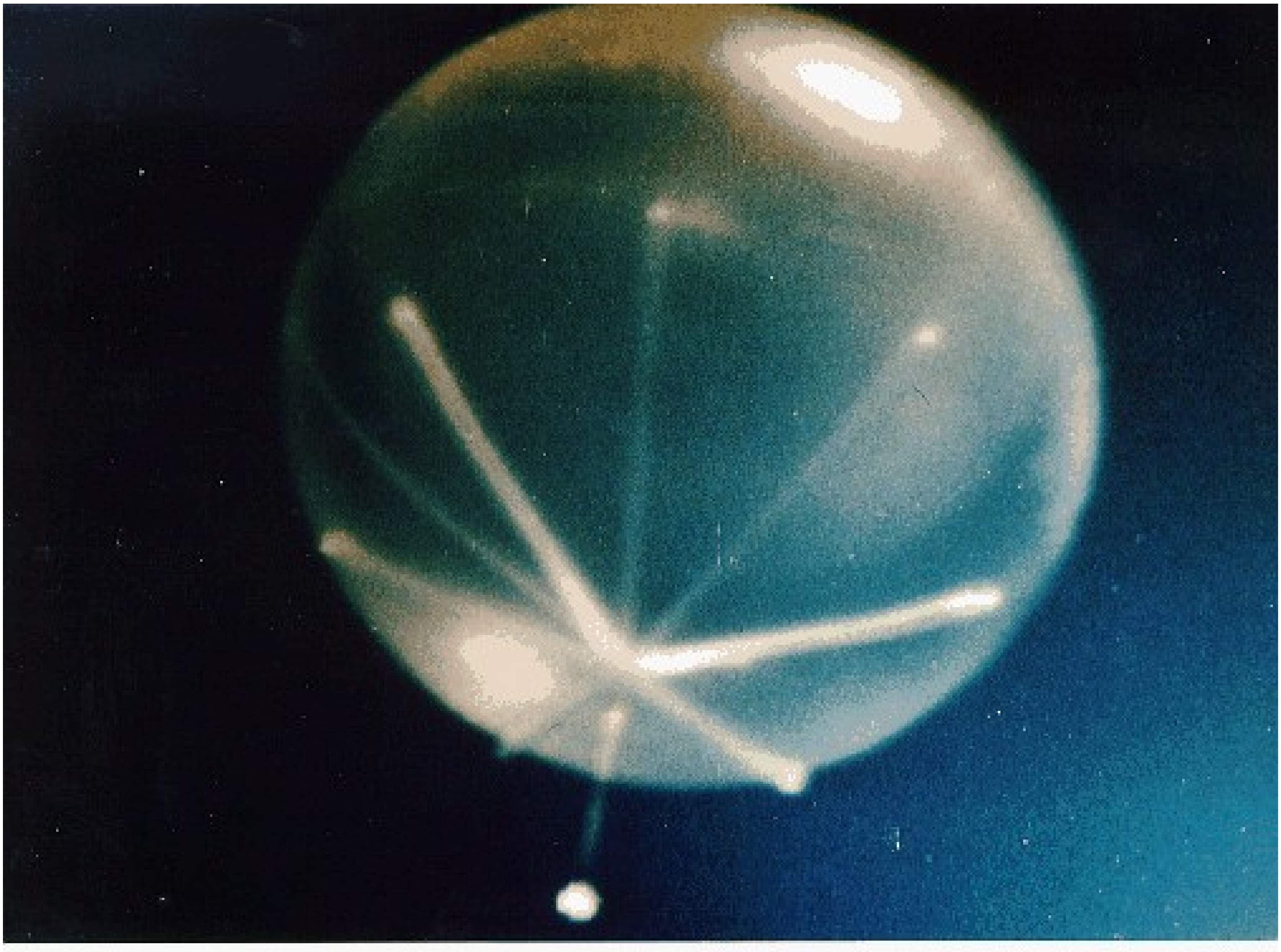
BOOMERANG Test Flight: August, 1997

Prototype detectors

Tested everything except solar power system



BALLOON at Float



BOOMERANG at Float

BOOMERANG Test Flight: August, 1997
Outcome...

Re-flew 13 days later

Perfect flight, good recovery.

All systems worked
(except for a temporary thermal failure during ascent)

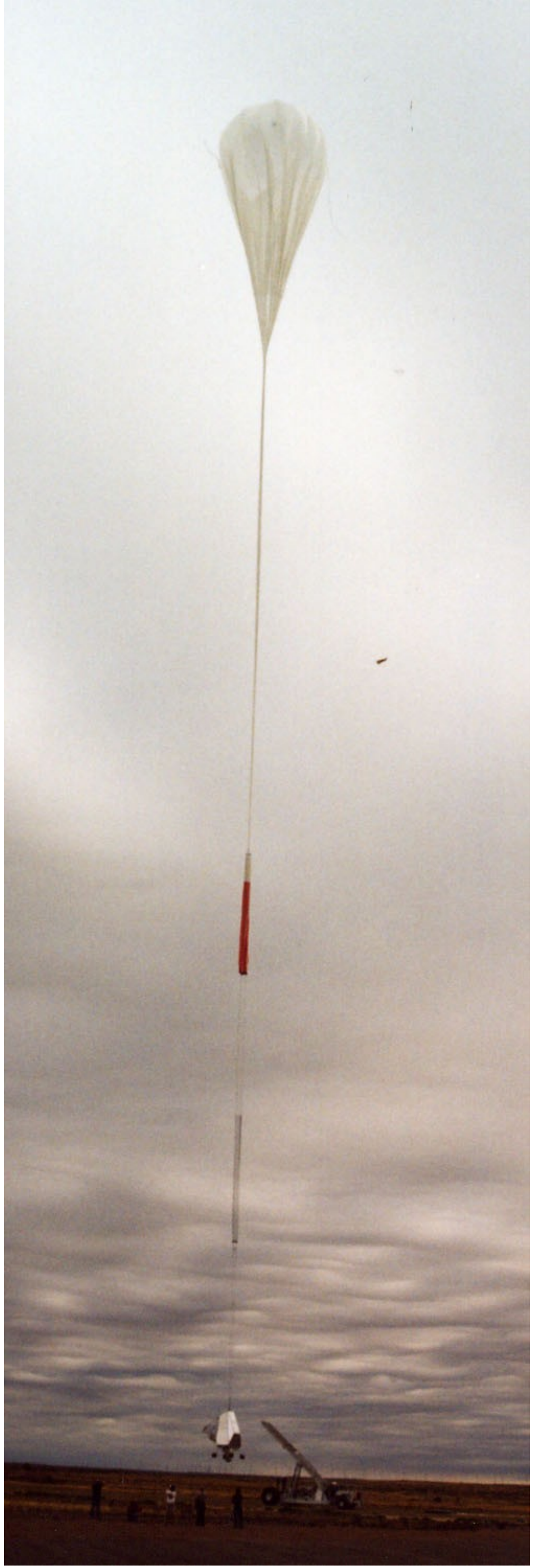
Produced an influential paper!

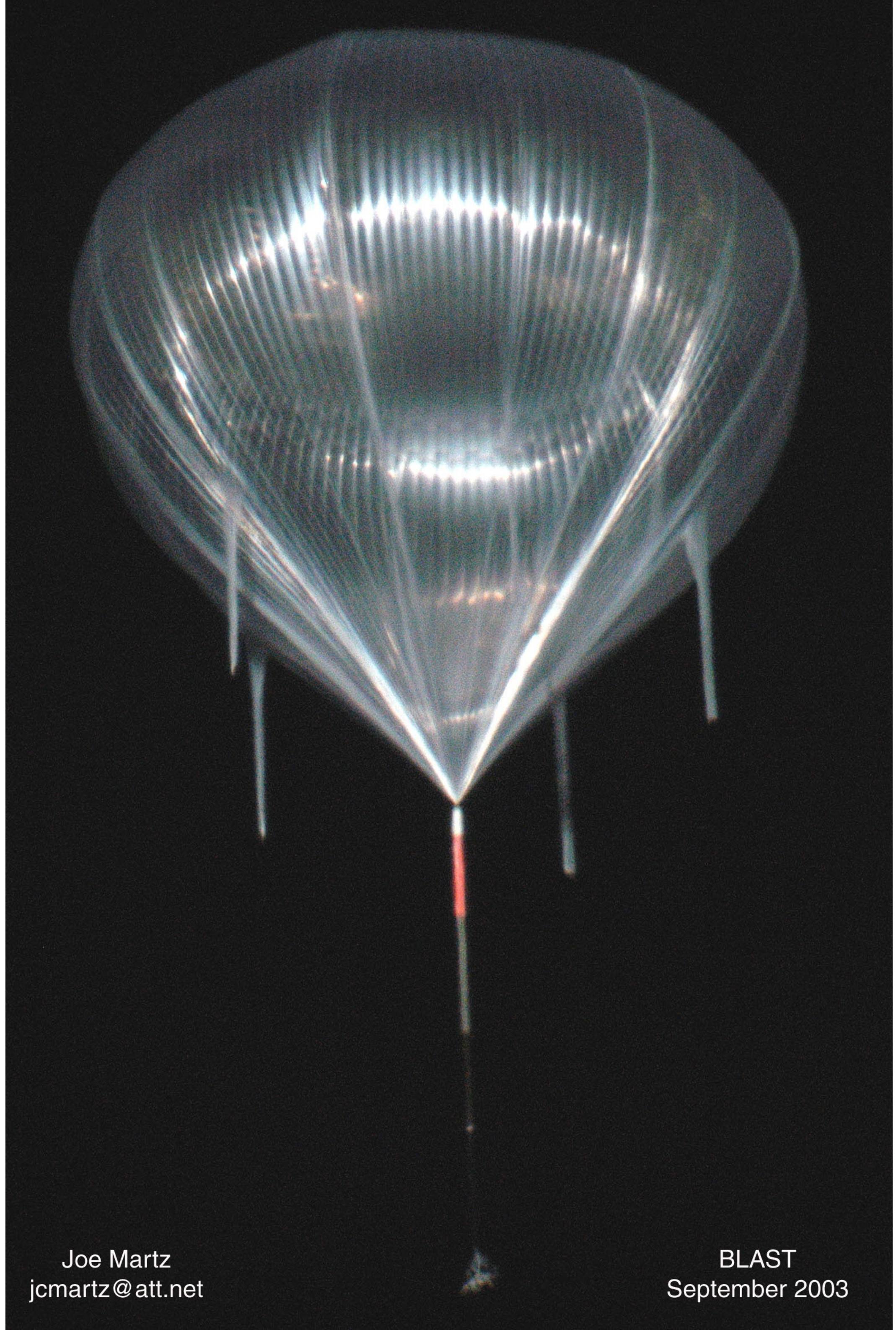
BLAST Test Flight (Ft. Sumner, September, 2003)

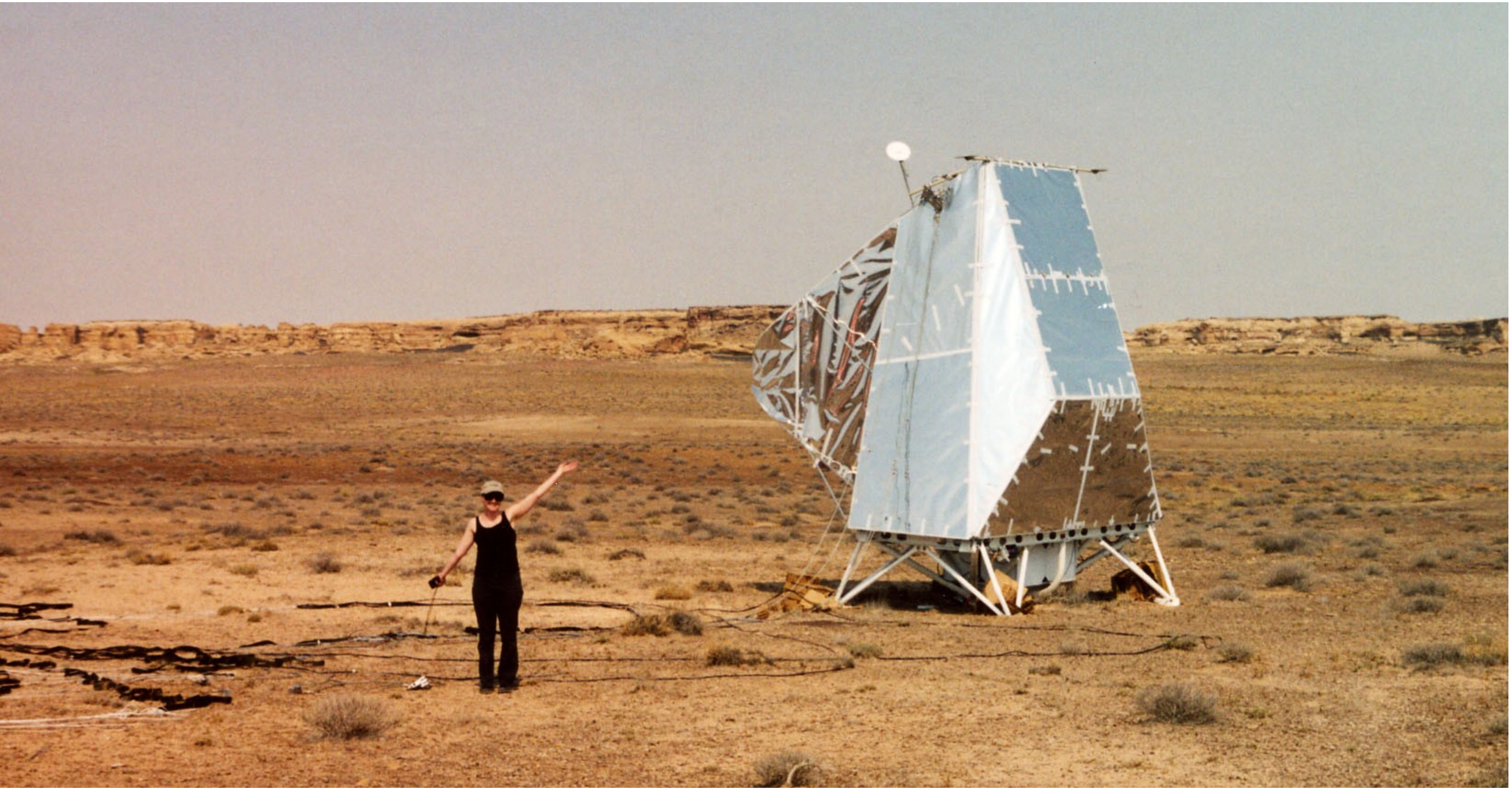
For fear of destroying the mirror, a test mirror was used

A prototype of a subset of the detector array was flown

Solar power not tested




Joe Martz
jcmartz@att.net
BLAST
September 2003



BLAST Test Flight (Ft. Sumner, September, 2003) Outcome…

Perfect recovery! Mirror would have survived

A “successful test” - we found problems.

Integration in Palestine, TX

Fully assemble the instrument before shipment

Integrate with CSBF electronics

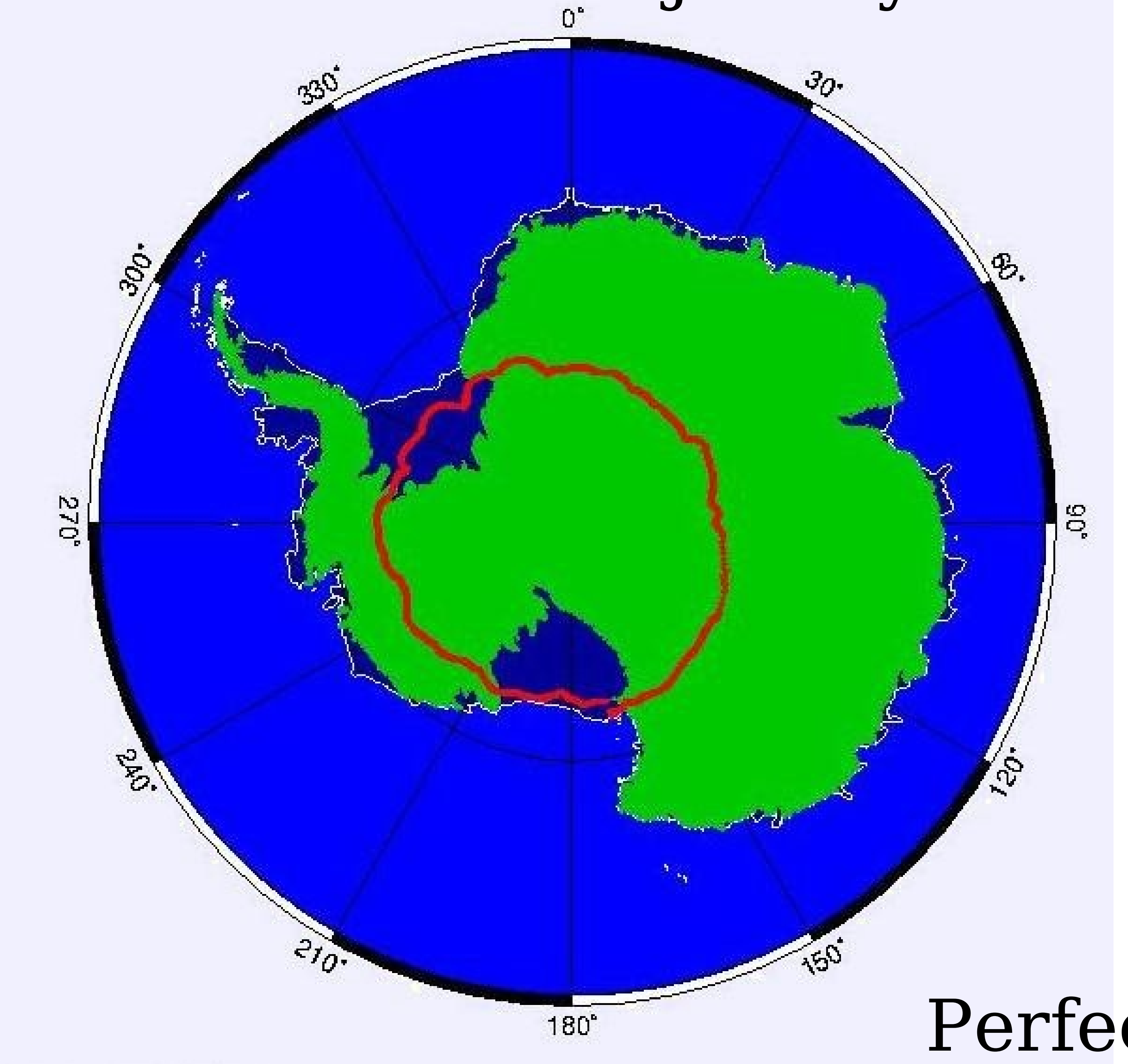
Takes about 1 month

Required*

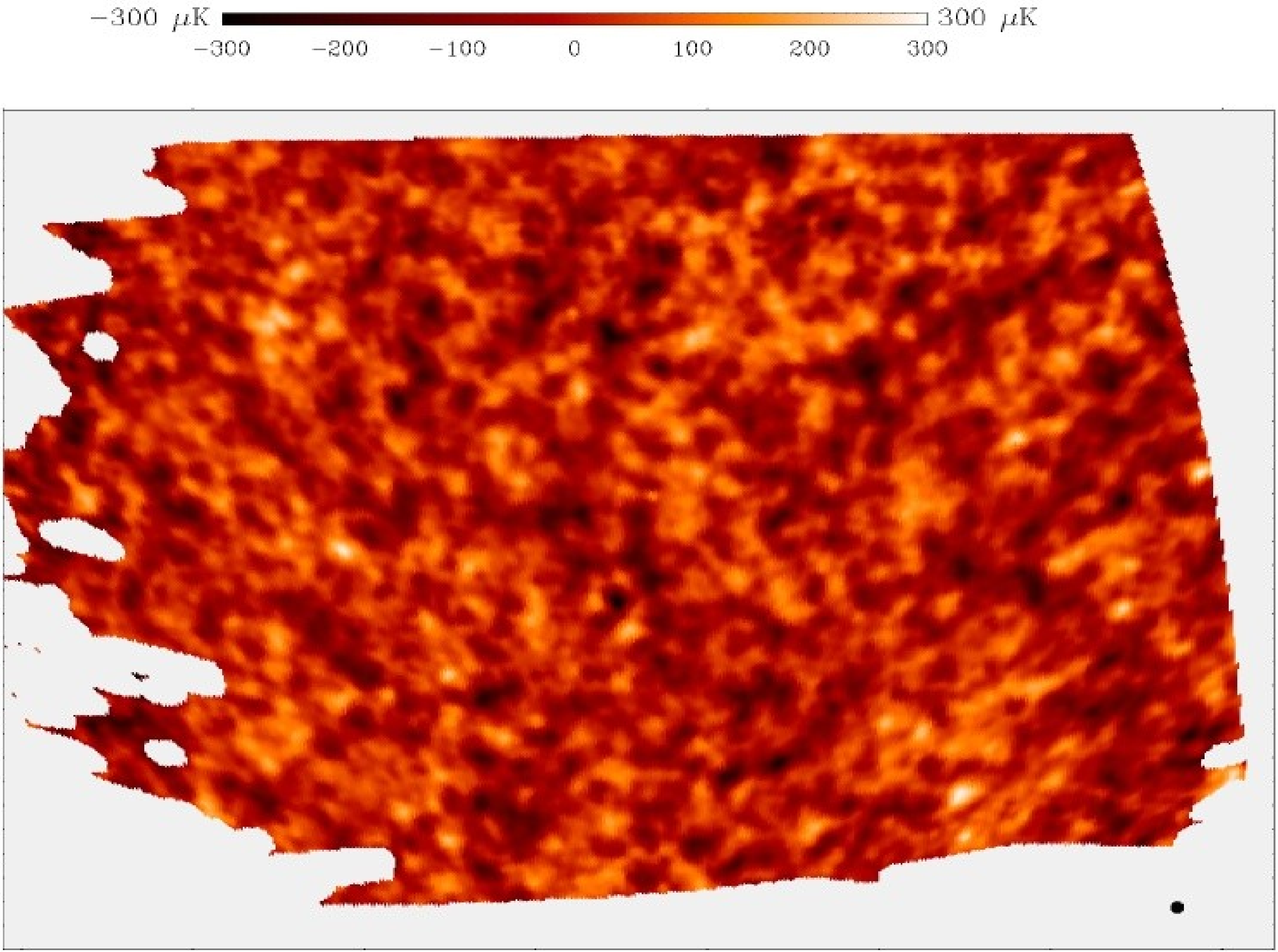
McMurdo Station, Antarctica

Former facilities in McMurdo

BOOMERANG 1998 trajectory



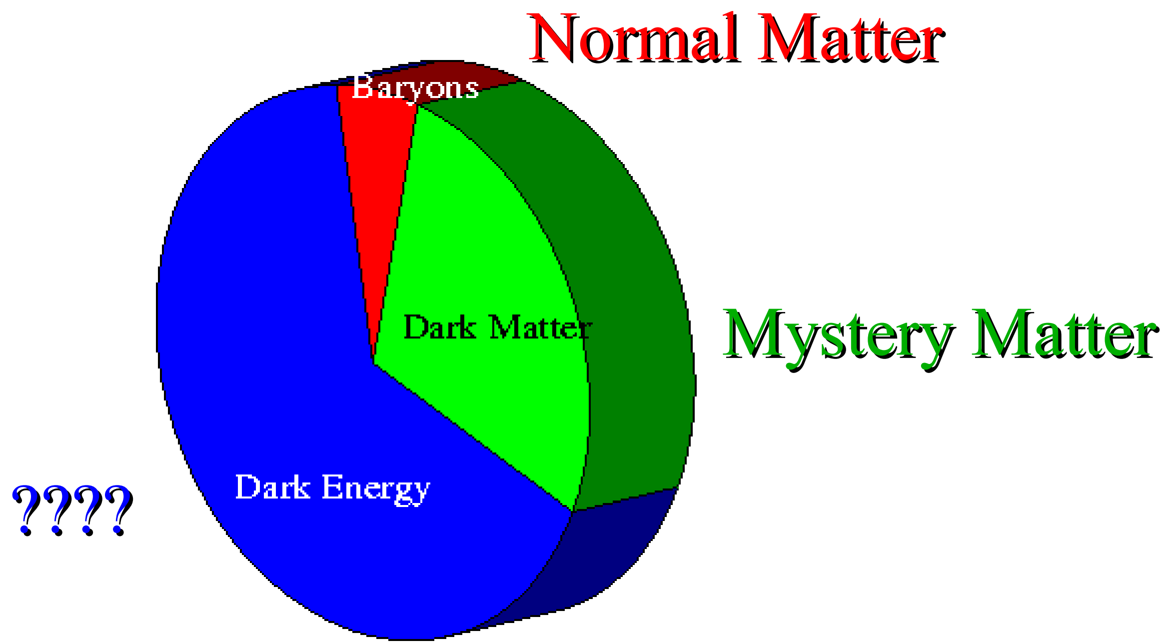
Perfect!



−300 μK
300 μK
−300
−200
−100
0
100
200
300

Some Conclusions:

What is the Universe made of?



What is the Geometry of the Universe?

Euclidian (Flat)

Some Conclusions:

How old is the Universe (as we know it)?

About 14 Billion Years old.

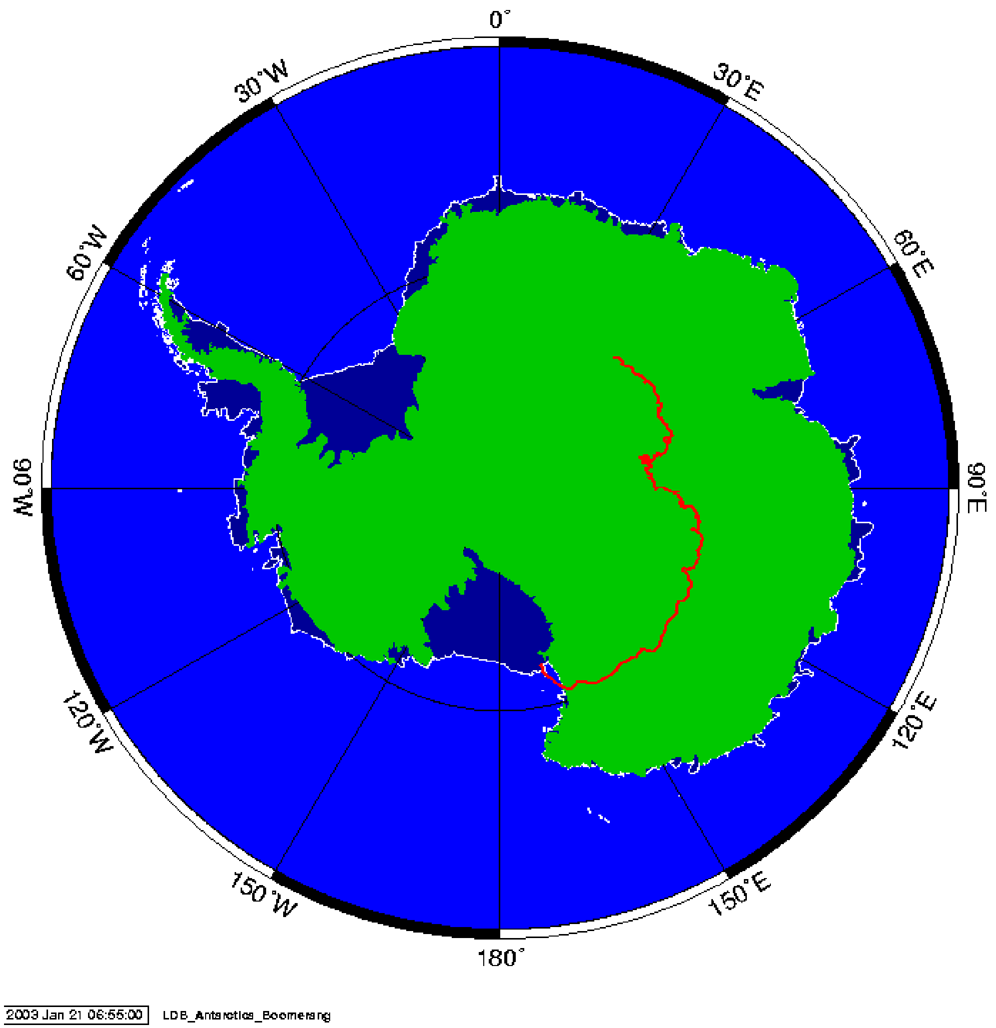
What will the Universe do in the future?

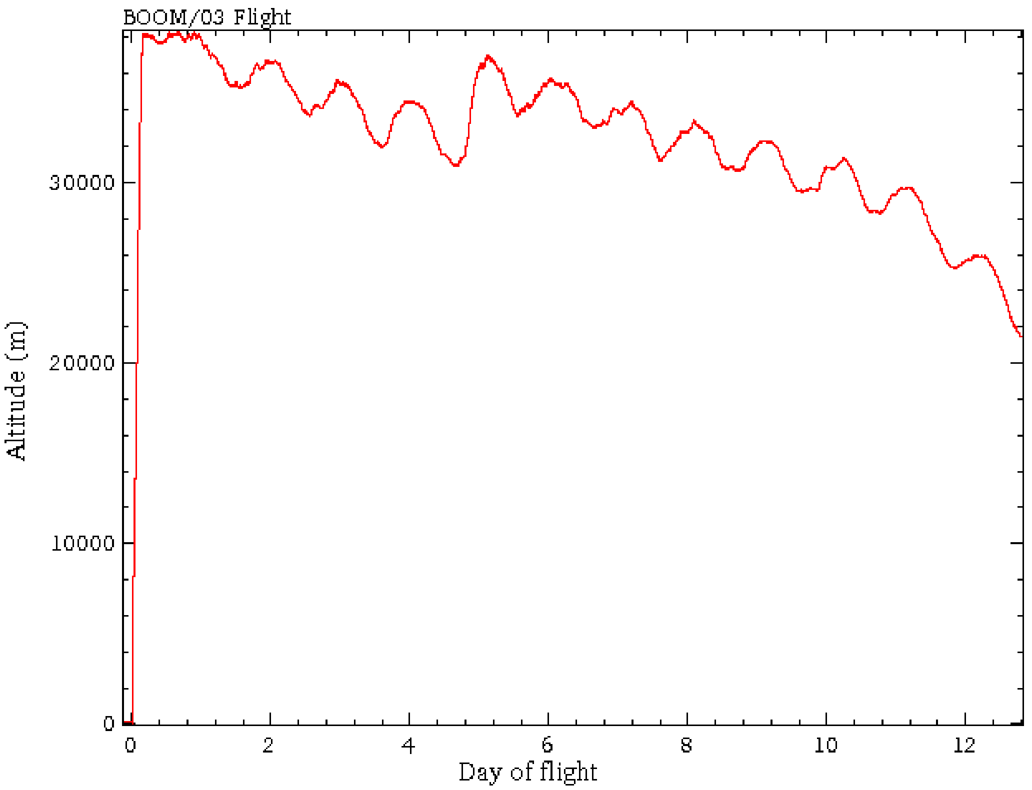
Keep Expanding and Cooling.

Perfect Flight (10.5 days)
Good Recovery
Huge impact

BOOM03 Flight

Launched January 6, 2003 From
McMurdo Station, Antarctica





11.7 days of good data

BOOMERANG
in Cold Storage...

Was recovered
the following
year... cut up.

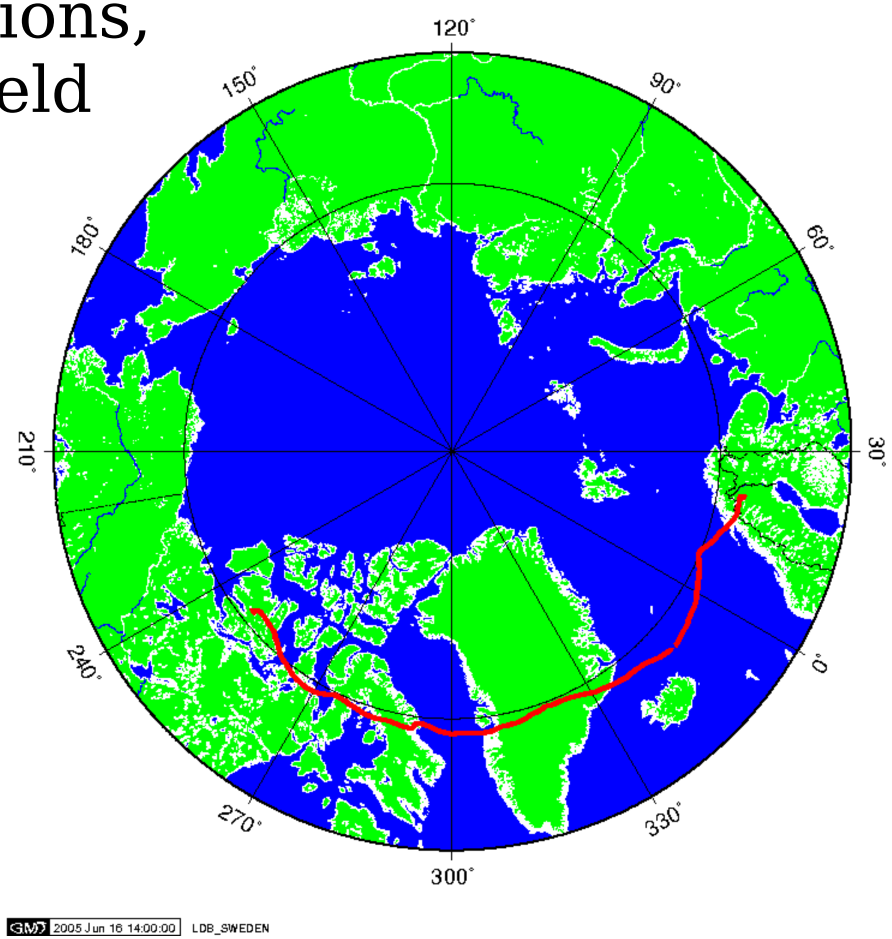
Multiple papers/
good impact.

Kiruna, Sweden (SRANGE)

Integration in
Kiruna,
May, 2005

BLAST LDB flight: June 2005

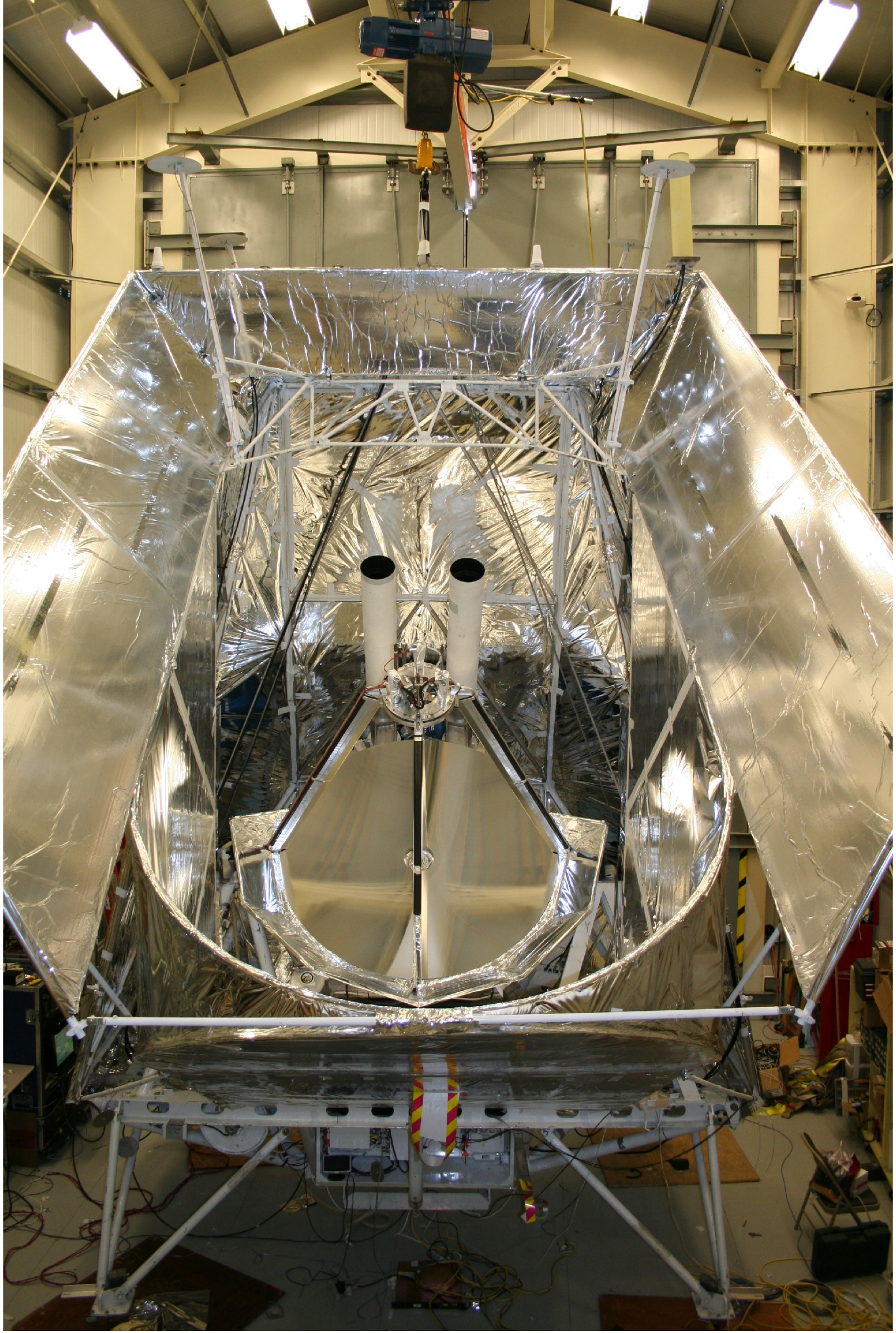
- 4.5 days of data
- Flight from Kiruna, Sweden to Victoria Island, Canada
- Mapped several star forming regions, HVCs and a deep extragalactic field
- Several papers in draft stage.

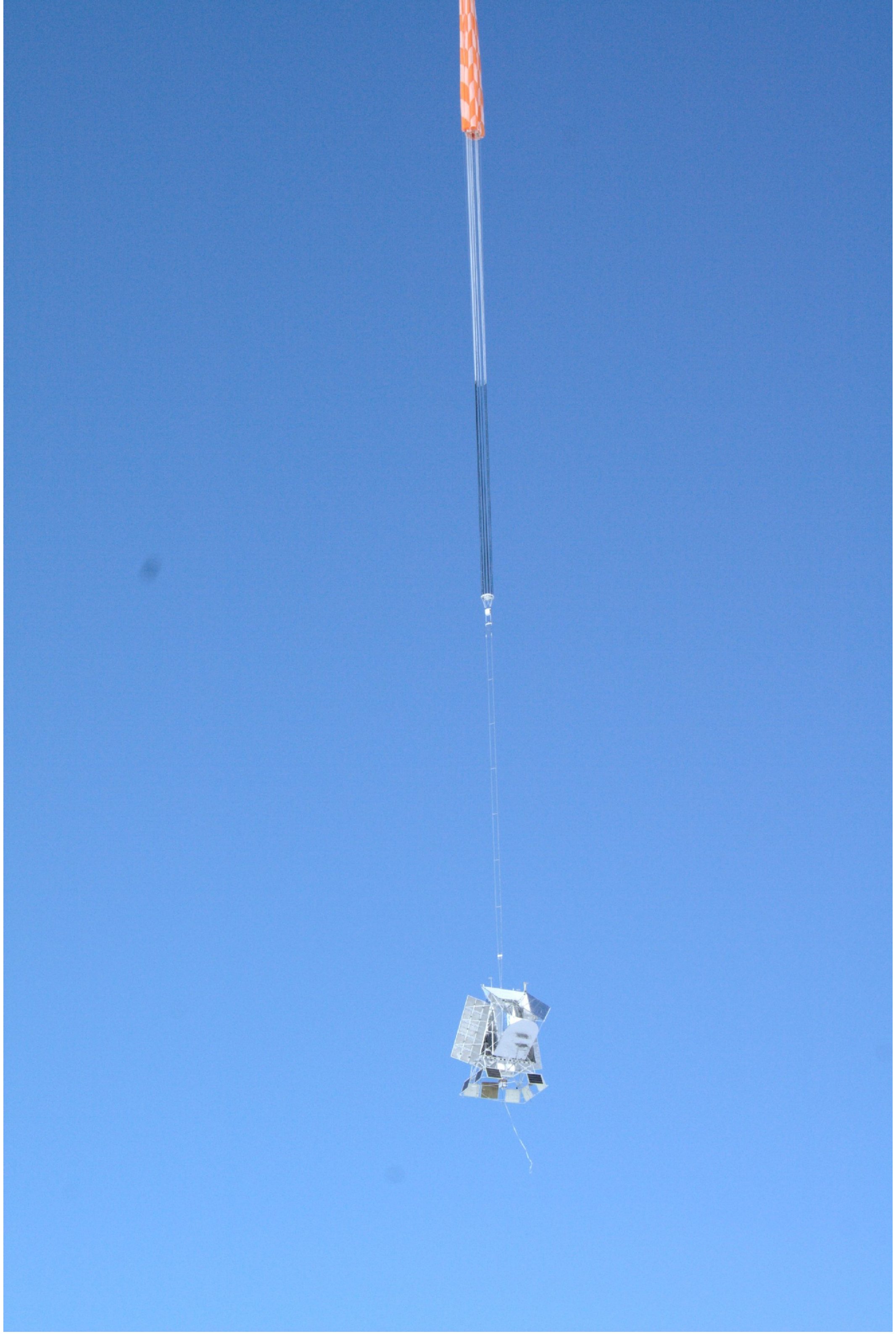


Good recovery, but primary mirror destroyed...(but it was out of focus anyway)

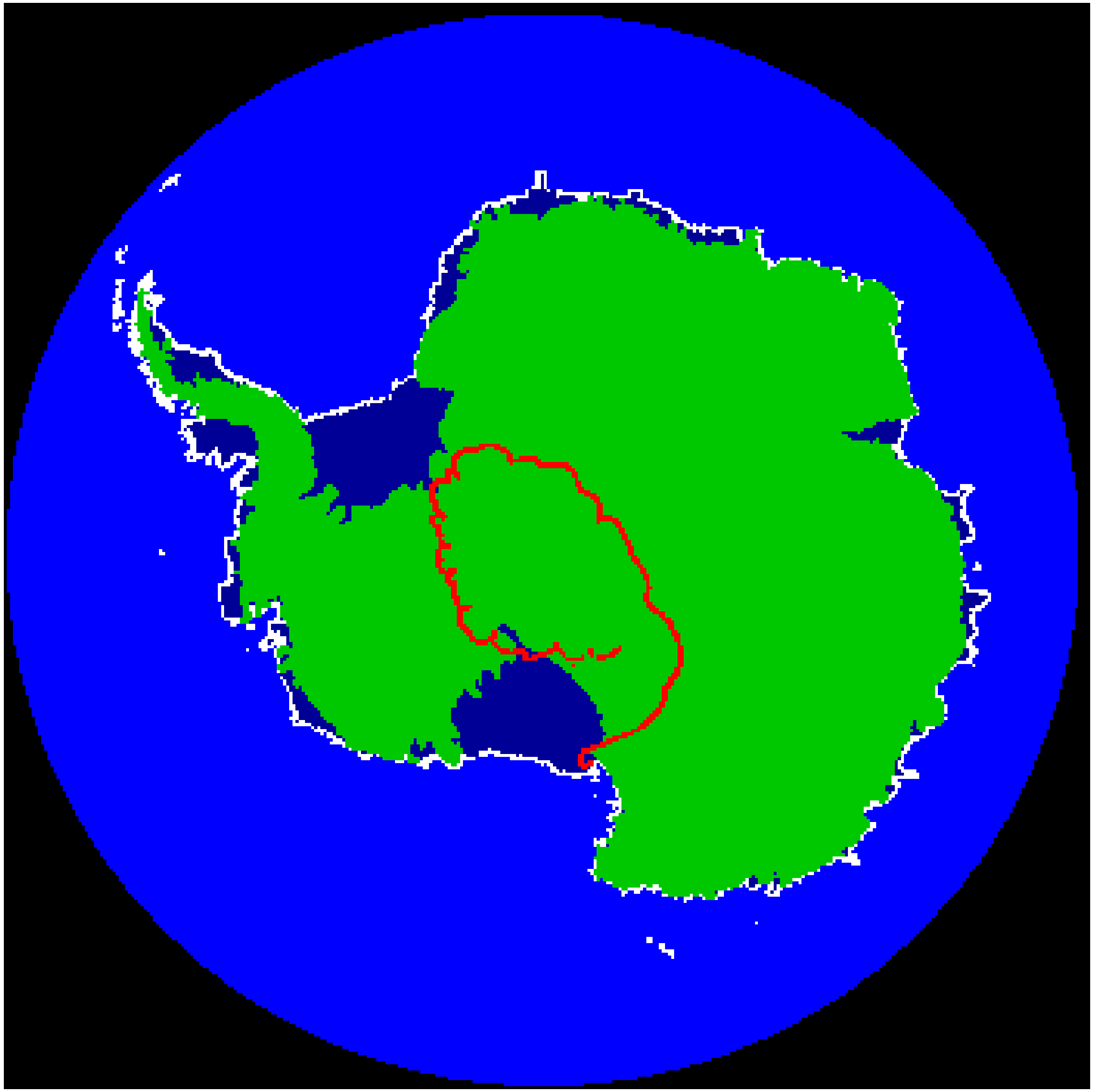
BLAST 2nd LDB flight, December, 2006

Fantastic new facilities in McMurdo!





BLAST Dec 2006 flight trajectory...

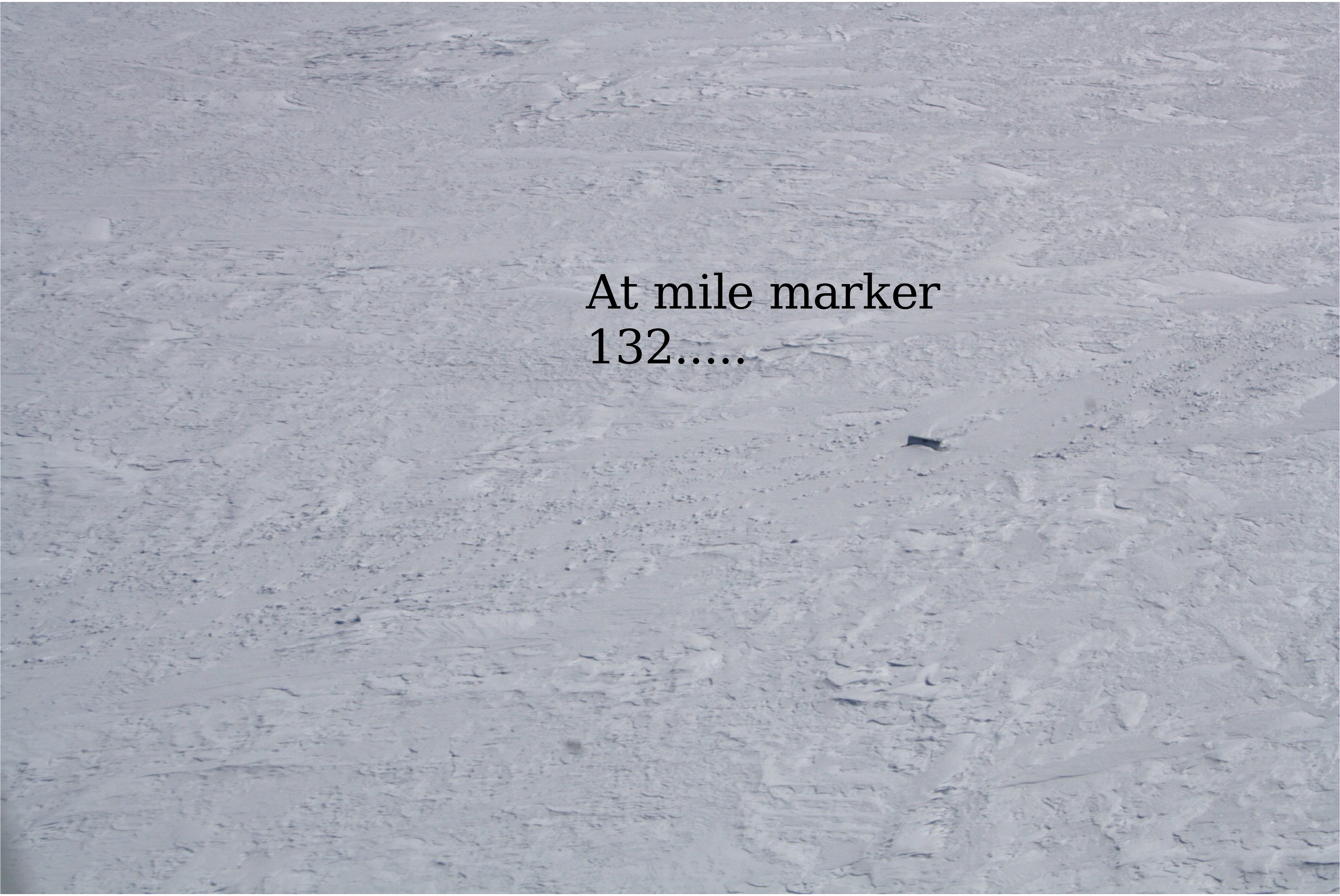


12.1 day flight (cryogens ran out in day 11)

Excellent payload performance

Terminated at aircraft accessible location.


Chute release anomaly
At mile marker 135.....


At mile marker
132.....


Data recovered:
Expect to meet all science goals.
Analysis is beginning...

Telemetry experiences

Downlink:

Line of Sight (~18 hours): 1 Mbps, >99%
TDRSS: 6kbps when satellites in view
(typ 90%)

Commanding:

16 bit command packets, a few per second.
Line of Site for ~18 hours
TDRSS: 20 min / hour when satellites in view
IRIDIUM: up to 6 min delay
nominally continuous, but sometimes flaky

Generally, data vault recovery is required.
Autonomous operation capability critical.

Cutting edge science meets training!

Between BLAST and BOOMERANG:

- 5 Ph.Ds (+9 “in the pipleline”)
- ~10 undergrads
- ~6 PDFs

Students get *whole system* experience.

Conclusions:

LDB ballooning is a risky, but very high potential payoff platform.

LDB ballooning provides exceptional opportunities for training of HQP.

Balloon payload and flight support

Dale Sommerfeldt*
Jeremy Gates
Kevin Nordstom
Werner Ostwald
Chinqiao Tong
Yan Feng
Scientific Instrumentation Ltd

Abstract:

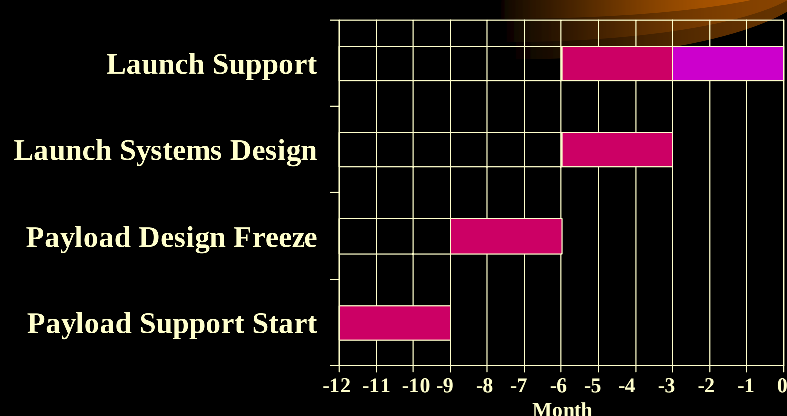
Science studies using balloons have many advantages over other types of vehicles. This talk will highlight these advantages including cost, scheduling and measurement time. It will also provide the launch experience Scientific Instrumentation Ltd (SIL) has had over the past 25 years. SIL has provided engineering design, manufacture and flight support of many space science projects. These include space, near space and ground-based instrumentation. The talk will present some of the projects and outline SIL's support expertise and products available to the science community.

Presenting Author Name: Dale Sommerfeldt
Organization: Scientific Instrumentation Ltd
Presenting Author Email: dale.sil@shaw.ca
Presenting Author Telephone: 306-244-0881
Preferred Session: Industrial capabilities and interests
Presentation Method: Talk
Presenting Author Title: Industry

Science using Balloons

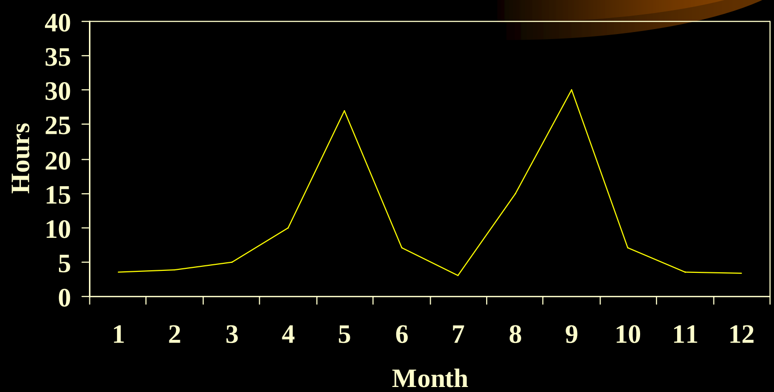
- *Atmospheric <40Km*
- *Low cost*
- *Long measurement time*
- *Instrument quality requirements minimal*
- *Reflight short turnaround*
- *Training base for science students*

Balloon Payload Launch Schedule



Float Time

ALT: 35-37Km   LAT: 53N   Range: 300Km



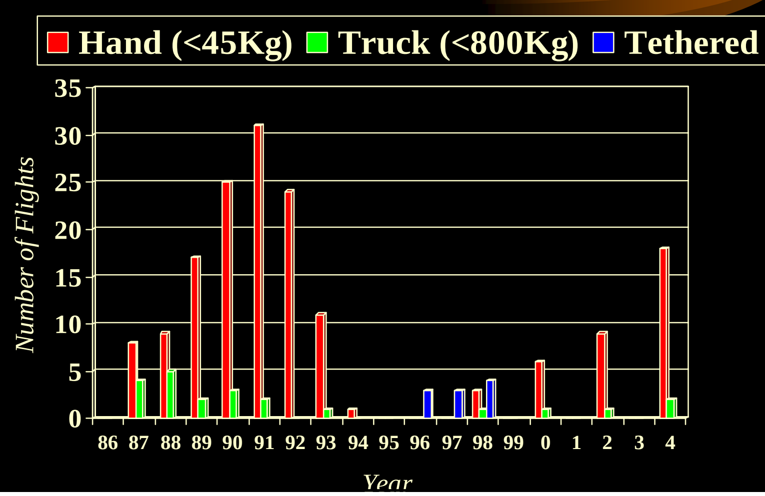
Launch Cost Comparisons

	SMALL		MEDIUM	
	1	2	3	4
Altitude (Km)	37	37	37	38
Balloon (tcm)	8.5	20	120	335
Science (Kg)	10	35	200	400
COST ($1000's)				
Balloon and Gas	4	6	60	115
Launch and Recovery	18	36	67	67
Insurance	?	?	?	?
Total Cost	22	42	127	182
2nd Flight	13	17	88	143

Scientific Instrumentation Ltd

- Incorporated 1980
- Payload engineering
- Payload flight support
- Instrument design and manufacture
- Space, Near Space, Terrestrial applications
- Balloon launch capability since 1987
- ISO 9001-2000 Registered

SIL Balloon Launch Activity



Vanscoy, Sk. Launch Site

Remote launches

- Alert, NWT- 76
- Churchill, Mb- 2
- North Bay,On-1
- Eureka, NWT- 1
- Roleau, SK- 4

Tethered balloons

MANTRA payload

- 12 scientific instruments
- Weight: 650Kg
- Flown four times
- 14Kw power system
- 16ch - 90Kb data down link
- Video link
- 300Kb downlink
- 1 uplink(300 baud)

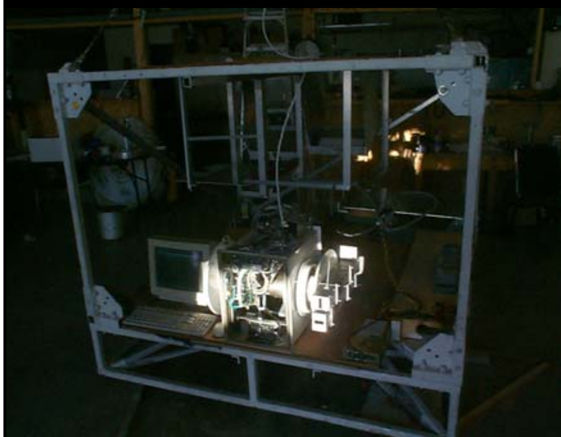
WMO payload

- Ozonesonde intercomparison
- 6 country participation
- 8-10 sondes/flight
- 10 flights-8 days

Mini-Radiometer

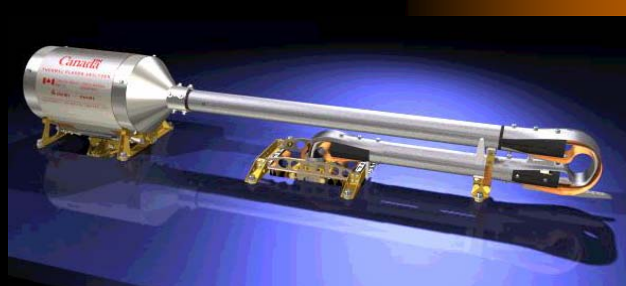
- Developed by MSC
- Scans 4-14 microns
- Measures Nitric Acid
- Manufactured 30+
- Flown in the Arctic
- 2 instruments have been flown several times

Pointing System



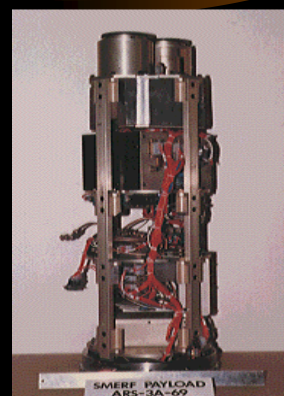
- Solar- Balloon borne
- 2 axis-accuracy 0.1deg
- Azimuth cap. 1300Kg
- Elevation cap. 50Kg
- Under development for limb scanning

Thermal Plasma Analyzer



- Japanese Planet-B Mars probe boom assembly
- Mechanical and Electrical Design and Fabrication

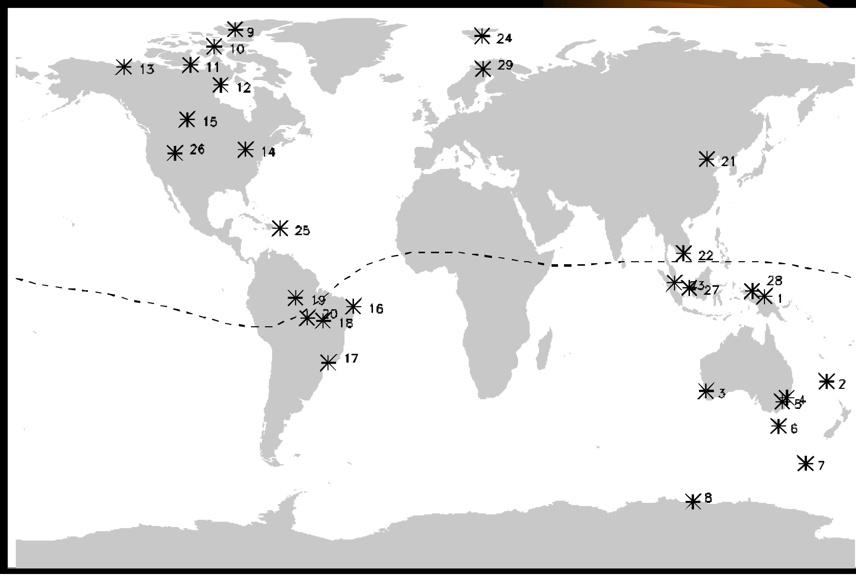
SMERF- BBIII payload



CADI- Digital Ionosonde

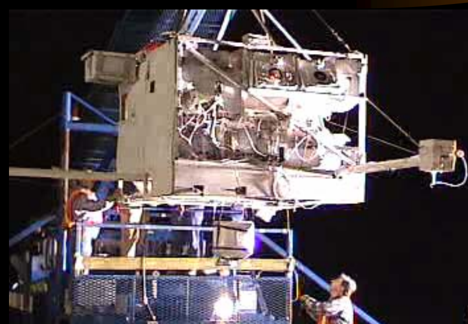
- Type of RADAR
- Operates 1-20MHz
- Height to 1000Km
- Ionization density
- Gravity waves

CADI -sites



Super Dual Auroral Radar Network
SuperDARN

MANTRA Launch



Balloon-borne Infrared Spectrometer Systems Operated by the University of Denver

***Pierre Fogal**, Department of Physics**,** University of Toronto
Ronald Blatherwick, **Frank Murcray**, Department of Physics, University of Denver

Abstract:

This presentation provides a brief recap of some of the technology and results of the ballooning program carried out by the Murcray Group at the University of Denver over the past three decades. During that time, primarily infrared measurements of the atmosphere were undertaken using two types of spectrometer, namely the now ubiquitous Fourier Transform Spectrometer (FTS) and cooled grating spectrometers. These instruments were deployed in various mission scenarios, ranging from a single instrument high resolution FTS, to multiple instrument gondolas such as the Middle Atmosphere Nitrogen Trend Assessment (MANTRA) and the Improved Limb Atmospheric Spectrometer (ILAS) flights, to small sonde-like balloons. Two FTS, both constructed by Bomem of Canada, one having an apodized resolution of approximately 0.002 cm-1 and the other of approximately 0.02 cm-1 were operated in solar transmission mode to record solar occultations at sunrise and sunset. The cooled grating instrument was designed in house, and is known as the Cryogenic Atmospheric Emission Spectral (CAESR) radiometer. CAESR was usually configured to record atmospheric emission data on ascent.

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Presentation Method:	Talk
Presenting Author Title:	Research Associate

Balloon-borne Infrared Spectrometer Systems Operated at the University of Denver

Pierre Fogal, University of Toronto
Ron Blatherwick, University of Denver
Frank Murcray, University of Denver
John Williams

6 Decades of Balloon Flights

- Balloon flight program started in late 1950's
- Included early water vapour measurements, solar constant measurements, and evolved into an infrared spectroscopy based program
- Spanned a range of spectrometer developments and techniques
  - prisms
  - filters
  - gratings
  - interferometers

Notable Spectrometers

- cooled grating spectrometers (BRL, CAESR)
- cooled Fourier Transform Spectrometer (SCRIBE)
  - Idealab instrument
- solar transmission FTS (Bomem designs)
  - 0.01 cm^{-1} BBDA2
  - 0.002 cm^{-1} DA3

Flight Configurations

- Spectrometers flown both as single instrument payloads, or as part of multi-instrument gondolas
- MANTRA (0.01 cm^{-1} Bomem)
  - 1998, 2002, 2004
  - ILAS (CAESR)
    - CLD, LPMA gondolas (1992-2003)
- 0.002 cm^{-1} always flew on its own gondola, sometimes with secondary instrumentation

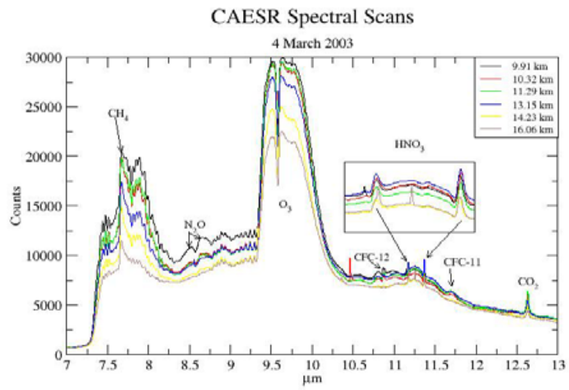
CAESR – The Cooled Atmospheric Emission Spectral Radiometer

- Czerny-Turner design grating spectrometer
  - LHe cooled
  - operated from 8-15 μm
  - single Hg:Ge detector element
  - 20 second scan time
- Spectral resolution: 2-4 cm^{-1}
- about 15kg and 40x60x20 cm flight ready

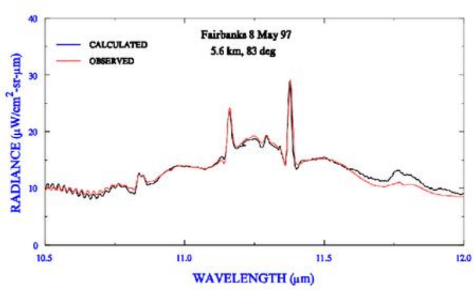
CAESR flights

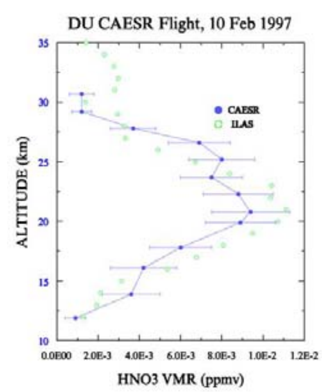
- Usually set up at a fixed observing angle of 6 degrees elevation
- Combination of LHe and LN2 would keep instrument cold and operational for 24>36 hours.
- Could operate either with onboard recorder or ground-station (or both) required no active flight control
- Originally designed as a disposable HNO_3 radiometer to fly on small balloons in Antarctica

CAESR Spectral Measurements



CAESR HNO_3

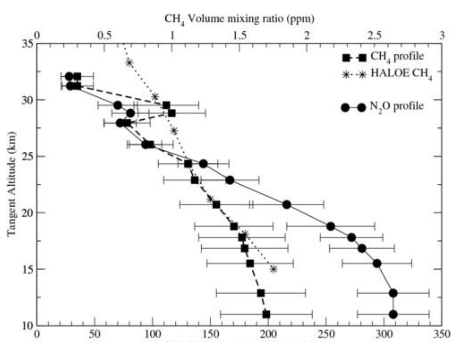


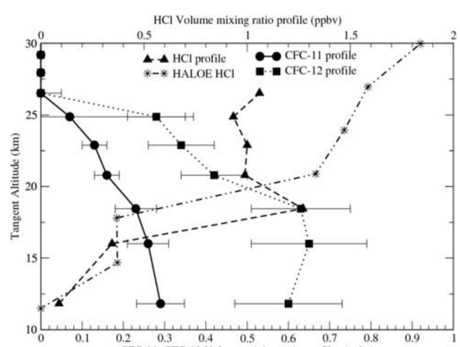


0.01 cm^{-1} Bomem Flights

- Flew as part of the Balloon Intercomparison Campaign (BIC)
- Also flew by itself many times
- Converted to a dual channel configuration in the eighties
- Used in solar occultation mode

Some MANTRA Results...





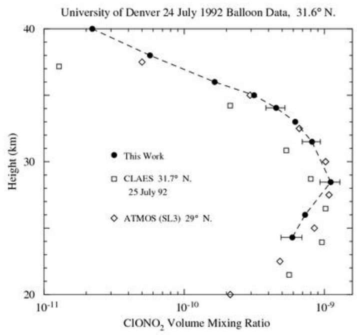
0.002 cm^{-1} Bomem DA3 flights

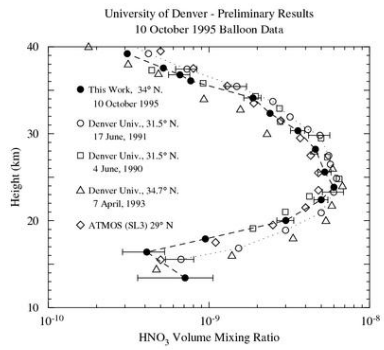
- likely the higest resolution infrared spectrometer flown on a balloon
- first flown in 1985, last flight of record in 1995
  - 13 launches
- flown in solar occultation mode
- single detector, configured with with Kbr or CaFl beamsplitters

Bomem DA3

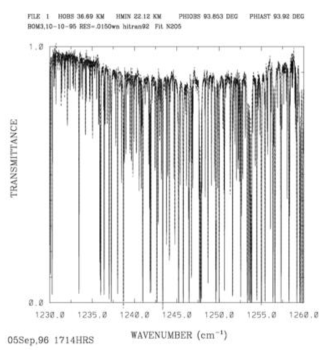
Profiles

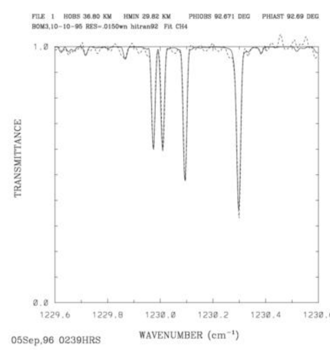
N_2O_5 (Blatherwick), $ClONO_3$ (Goldman)





Stratospheric N_2O_5 and CH_4





Closing Comments ...

- Balloons offer a stratospheric measurement capability
- They offer opportunities to experiment with both equipment and technique
- Relatively short lead times for new measurements
- In the infrared ... still a lot that can be accomplished!
  - develop instrumentation for measuring on ascent
  - longer duration balloon flights
  - measurement of isotopologues

PIOS: a miniature optical sensor for measuring atmospheric trace gases

Mareile Wolff*, University of Toronto
Andreas Herber, Alfred Wegener Institute for Polar and Marine Research, Germany
Wilfried Ruhe, impres GmbH
Otto Schrems, Alfred Wegener Institute for Polar and Marine Research, Germany

Abstract:

The Platform Independent Optical Sensor (PIOS) was developed for simultaneous measurements of trace gas profiles in the atmosphere. Its measuring principle is based on the detection of solar irradiance with a miniature spectrometer (Ocean Optics, Inc., FWHM = 1.3 nm). The wide spectral coverage of the miniature spectrometer (200-850 nm) offers the possibility for measurements of trace gases which absorb within this wavelength range, e.g. O3, NO2 and BrO.

In the first application, PIOS was combined with a commercial radiosonde to produce a balloon-borne version. The sensor can be operated anywhere in the world due to its low weight (1.7 kg) and the autonomous portable telemetry system. Nine balloon-borne PIOS sondes has been launched during two field campaigns: 2004 in Ny-Ålesund, Spitsbergen and 2005 in Hohenpeißenberg, Germany.

The irradiance measurements depend strongly on the instrument's temperature. The temperature-induced wavelength shift, the absolute irradiance, and the dark signal behaviour were characterized depending on the change of the spectrometer's temperature. Based on the pre-flight laboratory characterization, an inflight correction for changes in the dark signal and for the wavelength drift was applied.

In a first demonstration of the new sonde's performance, ozone profiles were retrieved from the flight measurements with an adapted Dobson spectrometer algorithm. The ozone profiles obtained were compared with ozone profiles measured simultaneously by Electrochemical Concentration Cell (ECC) ozone-sondes and a lidar system. The PIOS results agree with the comparison profiles within 20% for altitudes between 15 km and the burst point of the balloon. In the lower stratosphere and upper troposphere the discrepancies increase.

PIOS was planned and constructed for operation on board other suborbital platforms. A rocket-borne version exists and successfully passed all pre-launch tests for launch on board a research rocket. An implementation on board a remote controlled UAV (unmanned air vehicle) is possible and would allow several missions with the same PIOS instrument along controlled flight paths.

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Presentation Method:	Talk
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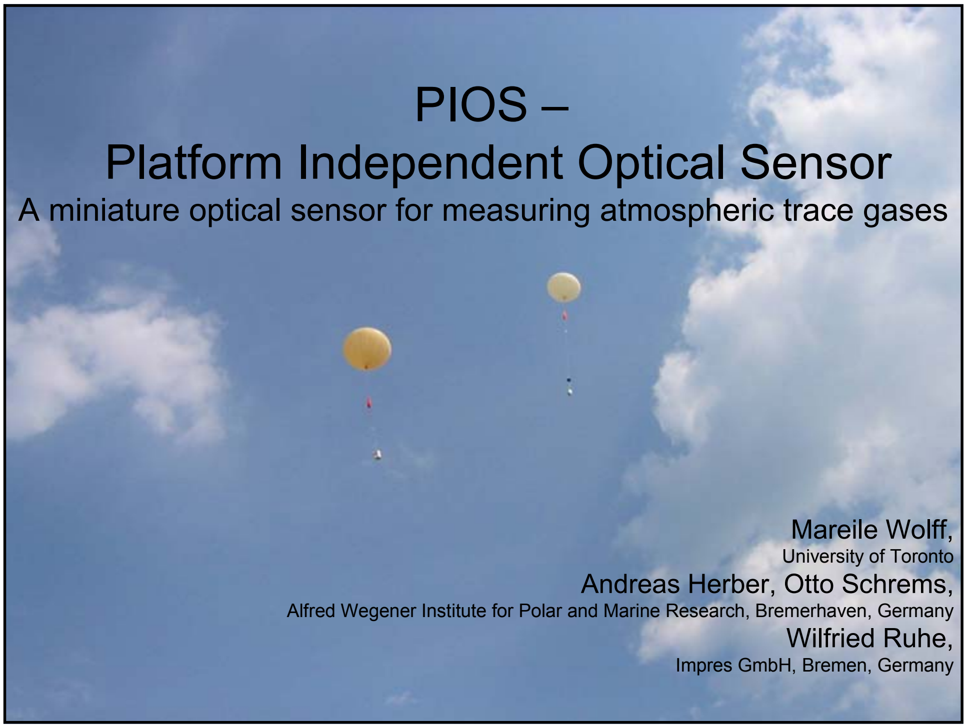
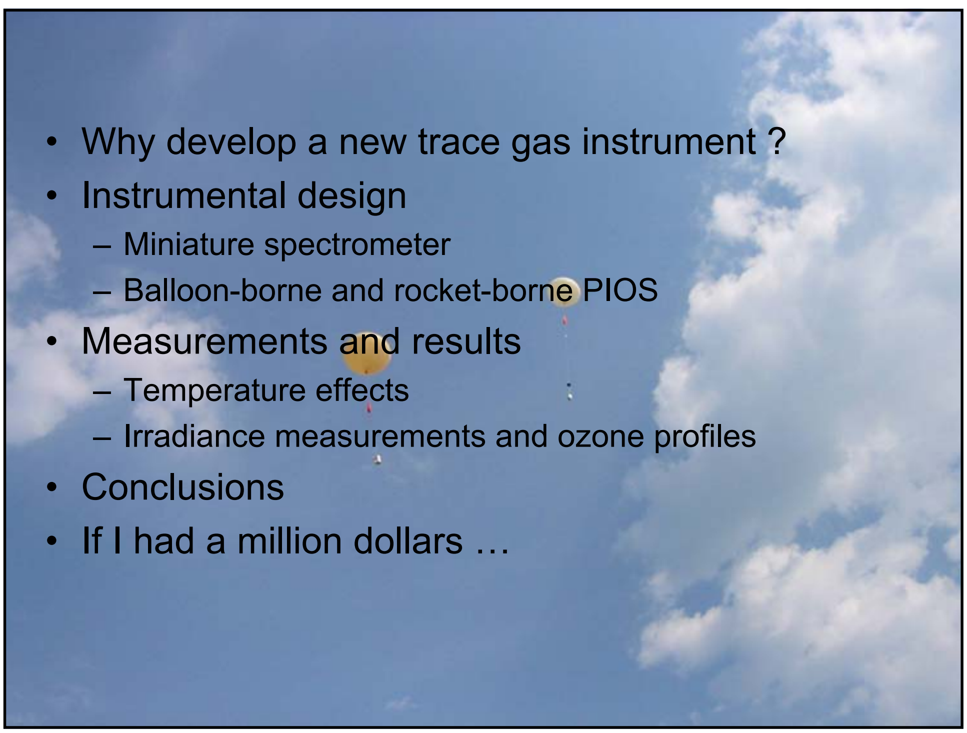

PIOS –
Platform Independent Optical Sensor
A miniature optical sensor for measuring atmospheric trace gases
Mareile Wolff,
University of Toronto
Andreas Herber, Otto Schrems,
Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany
Wilfried Ruhe,
Impres GmbH, Bremen, Germany


• Why develop a new trace gas instrument ?
• Instrumental design
– Miniature spectrometer
– Balloon-borne and rocket-borne PIOS
• Measurements and results
– Temperature effects
– Irradiance measurements and ozone profiles
• Conclusions
• If I had a million dollars …

Observables vs instrument complexity

small optical sonde:
various trace gases
extended altitude range

for: satellite validation and case studies

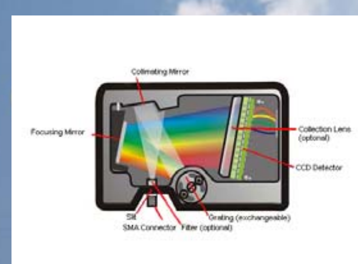
balloon-borne gondolas with optical equipment
various trace gases
very accurate

ECC Sonde:
routinely used for O_3
altitudes < 30km

scientific output

logistics

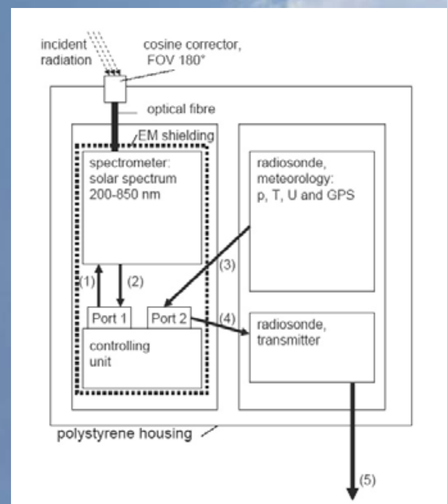
Miniature spectrometer



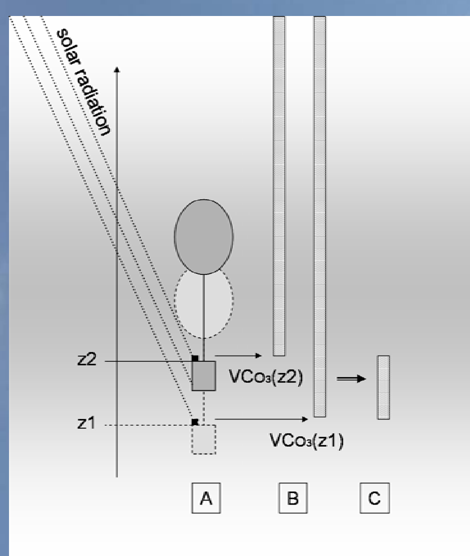
- Wavelength range: 200 – 850 nm
- Number of channels: 2048 ($\Delta\lambda \approx 0.3$ nm)
  PIOS: 1000
- Optical resolution: 1.33 nm (FWHM)
- Detector: CCD-Array

Balloon-borne PIOS

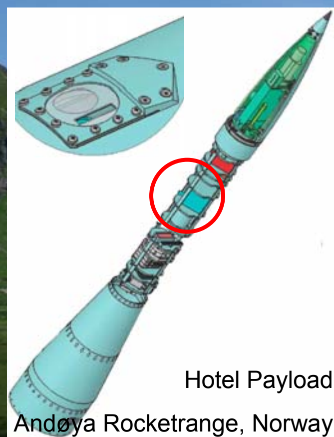
Dimensions: 345 x 210 x 180 mm³
Payload weight: 1.7 kg
Data rate: 0.1 Hz



Measurement principle



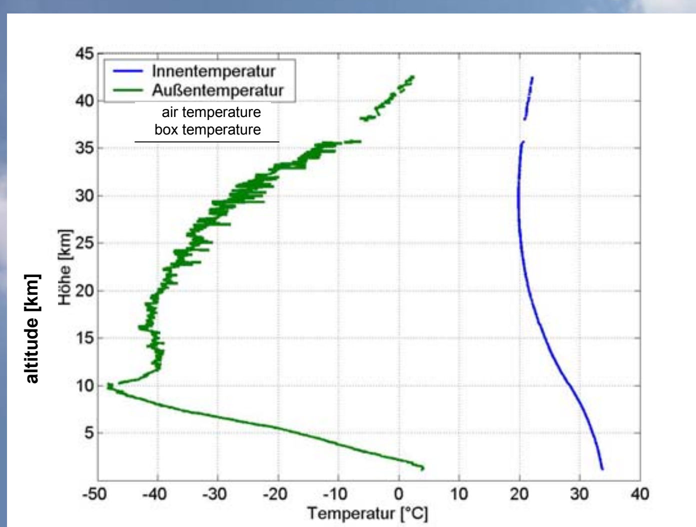
Rocket-borne PIOS



Challenges:

- **Rocket speed**
  - Higher data transfer rate (spectrometer upgrade)
  - Transfer selected channels (750 channels: 200 nm - 450 nm)
  - Measurement rate: ~10 Hz (depending on spin)
- **Sun in field of view**
  - Sun sensor, looking 30° ahead
  - Target spin: 4-5 rounds per second
- **Amount of data – data format**
  - Package sorting by encoder

Correction of temperature effects

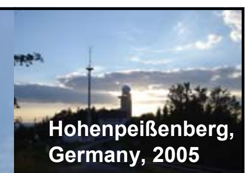


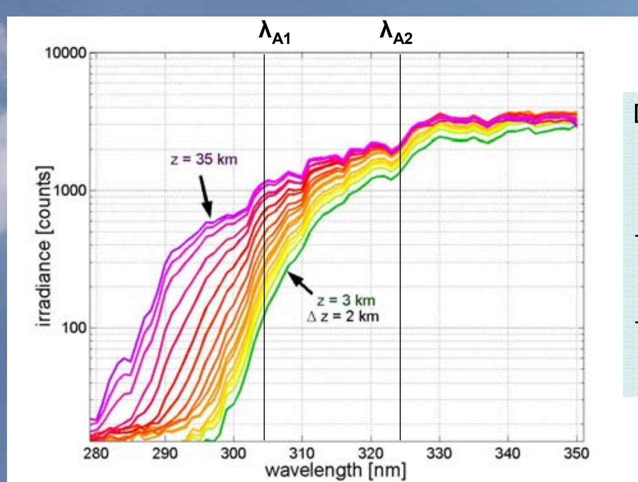
temperature

Correction of temperature effects

- **Dark signal**: linear relationship between the mean dark signal and the temperature of -5 counts K^{-1}.
  - ✓ **Inflight correction: Channel #1 as representative dark channel**
- **Wavelength drift**: non linear relationship.
  - ✓ **Inflight correction: Comparison with Fraunhofer structures**
- **Signal strength**: increasing signal with increasing temperature; dependent on signal strength.
  - ✓ **Negliable: Temperature influence on irradiance ratios is smaller than the measurement error.**

Irradiance data

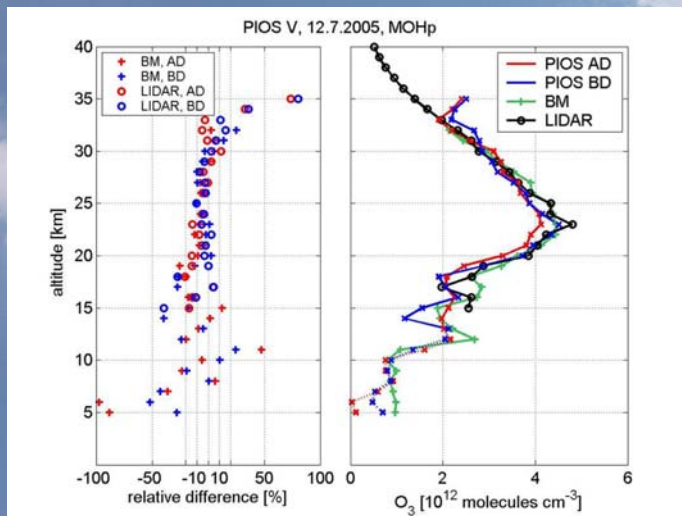




Dobson Wavelengths:

λ_{A1}	**305.5**
λ_{A2}	**325.4**
λ_{B1}	308.8
λ_{B2}	329.1
λ_{D1}	317.6
λ_{D2}	339.8

SZA = 32°, integration time = 250 ms



Conclusions

- Successful development of an autonomous sounding system to probe the vertical distribution of atmospheric trace gases
- Can quantify and compensate for the effects of temperature changes on observed signals
- Ozone profiles can be determined with the adapted Dobson-algorithm
  - Agreement to comparison measurements above 15 km between 10% and 20%
- Potential for further improvements

If I had a million $ …

- Augmented laboratory measurements (pressure-chamber, light sources, …)
- Instrument optimization (other gratings, filters, diffusing material collimating lens)
- Optimize analysis-algorithm with DOAS, RTMs
- Extend retrieval to include other trace gases (BrO, NO_2)
- More balloon flights

PIOS on a UAV

•Controlled flight paths (and landings)

•Several missions with one instrument

•Long duration missions

•Possibility of sun tracking

Overview of the NASA Sounding Rocket Program - Unique Scientific and Technical Capabilities and Achievements

Robert F. Pfaff, Jr.
NASA/Goddard Space Flight Center

Abstract:

For over four decades, NASA's Sounding Rocket Program has been a jewel in the crown of the agency's spaceflight capabilities. The program rests solidly on 3 critical elements: (1) Unique, cutting edge science missions, (2) Platforms in space for the conception, testing, and development of new technology, and (3) Training ground for students, young researchers and engineers. Two additional important features of the program are its low cost and its rapid, quick response.

Sounding rockets carry scientific instruments into space along parabolic trajectories, providing nearly vertical traversals along their upleg and downleg, while appearing to "hover" near their apogee location. Whereas the overall time in space is brief (typically 5-20 minutes), for a well-placed scientific experiment launched into a geophysical phenomena of interest, the short time and low vehicle speeds are more than adequate (in some cases they are ideal) to carry out a successful scientific experiment. Furthermore, there are some important regions of space that are too low to be sampled by satellites (i.e., the lower ionosphere/thermosphere and mesosphere below 120 km) and thus sounding rockets provide the only platforms that carry out direct *in-situ* measurements in these regions. Astronomy, solar, and planetary science missions include sophisticated telescopes with optional joy-stick operated, sub-arc-second pointing of astronomical objects, including those too close to the sun for Hubble Telescope observations. Microgravity missions are carried out on high altitude, free-fall parabolic trajectories, which provide ideal microgravity environments without the vibrations frequently encountered on human-tendered platforms. In this presentation, an overview of NASA's Sounding Rocket Program will be provided with an emphasis on its technical and scientific capabilities and recent achievements.

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Session:	Invited Speaker
Presentation Method:	Talk
Presenting Author Title:	Government

Overview of the NASA Sounding Rocket Program:

Unique Scientific and Technical Capabilities and Achievements

Community Workshop on Science from Suborbital Vehicles

Canadian Space Agency

Robert F. Pfaff, Jr.

Project Scientist, NASA Sounding Rocket Program
Goddard Space Flight Center
Greenbelt, MD, USA

Toronto, Ontario, Canada

February 1, 2007

Outline of Presentation

- General Features of NASA's Sounding Rocket Program
- Sounding Rocket Vehicles, Payload Notes, Launch Locations
- Science Discipline Requirements and Examples of Accomplishments
  - -- Astronomy / Planetary / Solar
  - -- Geophysics
  - -- Microgravity
  - -- Special Projects (e.g., Re-entry tests, Aerobraking, etc.)
- SR Technology Roadmap -- Future Prospects
  - – Tailored Trajectories
  - – High Altitude Sounding Rocket
  - – Small Mesospheric Payloads
- Summary

NASA Rocket Program -- General Remarks

- For over 4 decades, NASA'S Sounding Rocket Program has provided an essential ingredient of the agency's exploration and science initiatives.

- Sounding Rocket Program rests solidly on 3 critical elements:
  - -- Unique, cutting-edge science missions
  - -- Platform for development and test of new technology
  - -- Education and training of students, young researchers, and engineers

- Two important features of the program:
  - -- Low Cost
  - -- Rapid, quick response

NASA Rocket Program -- General Remarks (cont.)

- Success of NASA Sounding Rocket Program *implementation* rests on a strong three-way partnership:

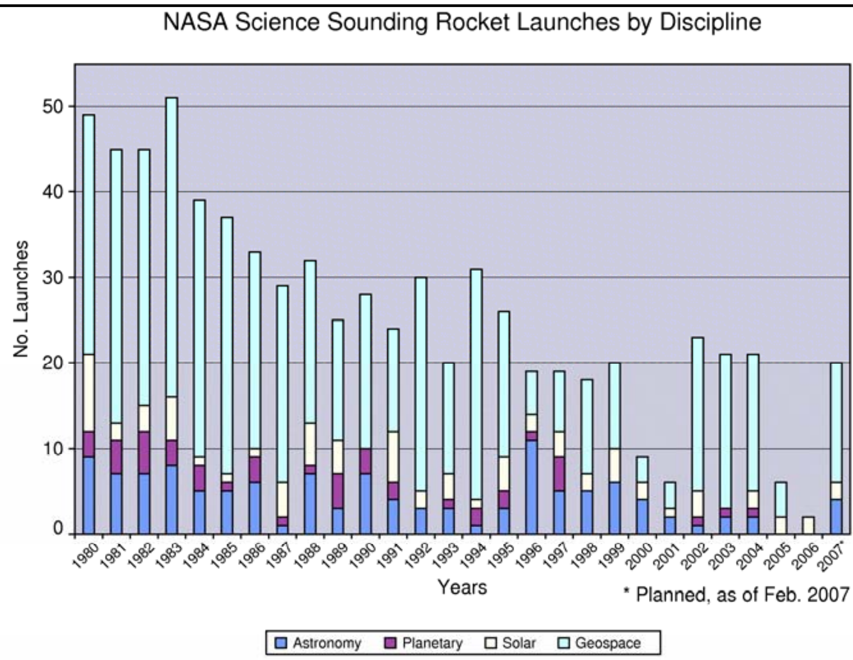
  P.I. • Sounding Rocket Program Office (Wallops) • NASA HQ

- An important aspect of the program is that **the P.I. is firmly in charge of the mission** -- from proposal to payload design to making the launch decision to the data analysis and publication of results.
  - -- Very appealing aspect of SR program to scientists.
  - -- P.I. must work within an agreed-upon science budget with no contingency.
  - -- Scope of project must stay within "envelope" outlined in proposal approved by both HQ and SRPO.
  - -- Excellent, "real world" training for P.I., particularly with respect to managing a scientific investigation.

NASA Rocket Program -- General Remarks (cont.)

Program serves numerous scientific disciplines:

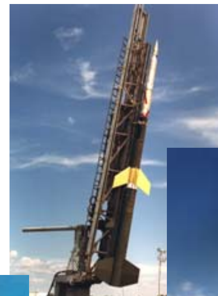
- -- Astronomy
- -- Planetary
- -- Solar
- -- Geospace (Magnetosphere/Ionosphere/Thermosphere/Mesosphere)
- -- Microgravity
- -- Special Projects (e.g., Aero-braking and Re-entry Studies)



Not included: Test rockets, student rockets, microgravity experiments, other reimbursable missions

Sounding Rocket Vehicles

Terrier Malemute



Nike Orion

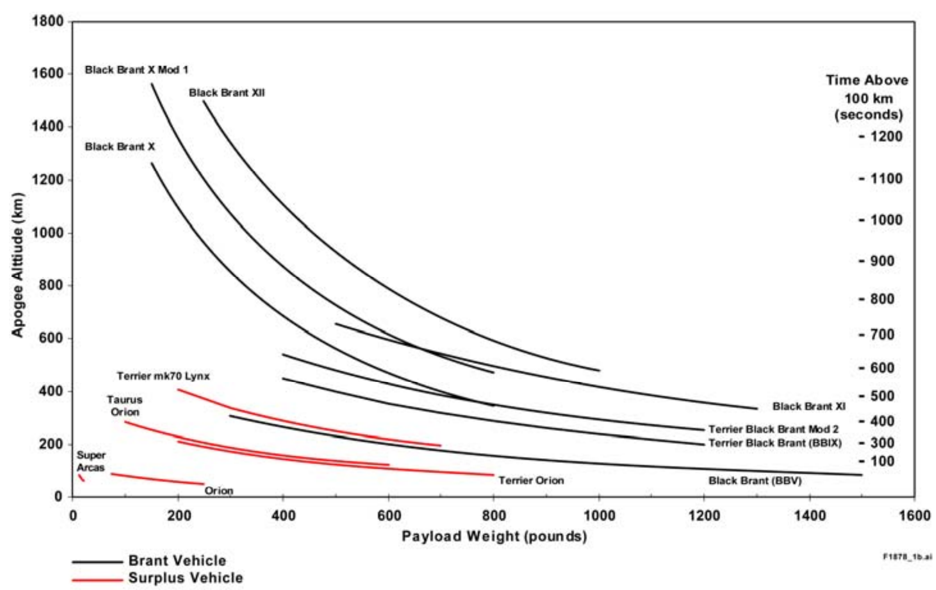
Orion

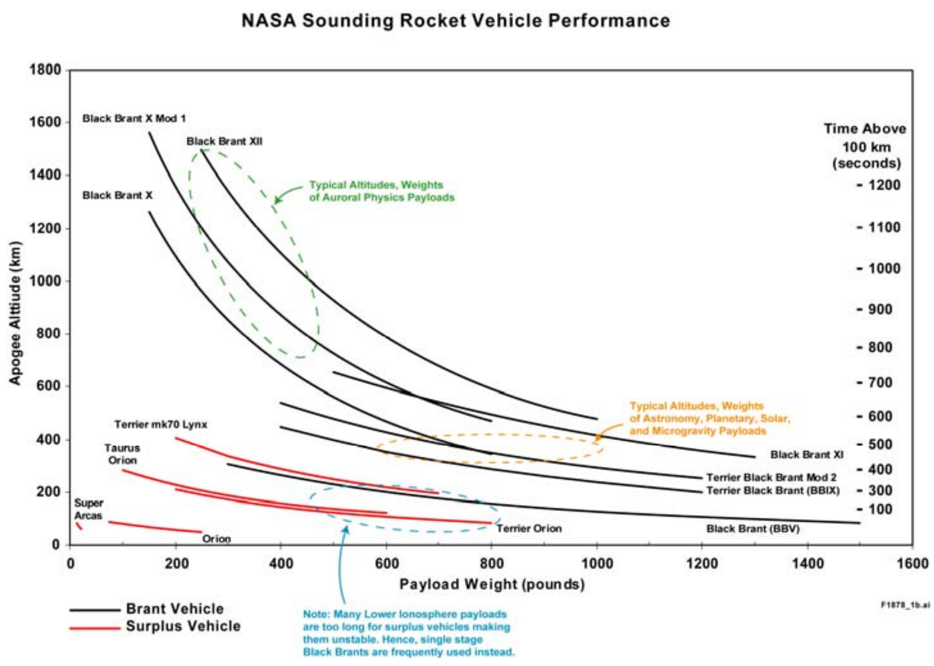
Terrier Orion

Black Brant IX

Black Brant XII

NASA Sounding Rocket Vehicle Performance





NASA Sounding Rockets: Use of Bristol Black Brant Vehicles

From 1994-2004, NASA Has Flown 264 Sounding Rockets:

223 Science Missions (including Microgravity)

-- 154 used a Black Brant Motor (or 69%)

41 Test, Student, DoD Missions

-- 4 used a Black Brant Motor (10%)

Overall: 60% of all NASA Sounding Rockets in this period have used a Black Brant Motor.

Basic Payload Design and Sub-systems

Mechanical

- Nosecones
- Diameters range from 4 to 22 inches
- Deployments
- Sub-payloads

Power

- +28 V, ±18 V, + 9 V typical
- 10-100 Watts typical (from batteries)

Telemetry, Timers, Commands

- Multiple links up to 10 Mbps typical
- Serial, parallel, analog data accepted
- GSP provides trajectory
- Uplink command for events, joy-stick control
- Timing typically with < 0.1 sec accuracy

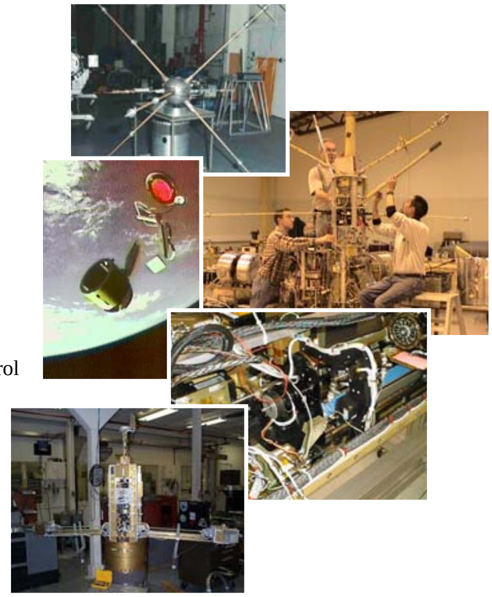
Attitude Control and Knowledge

- Coarse pointing along or perp to B or V
- Fine pointing to ~0.1 arcsec

Recovery sub-systems

- Land, Water, Air

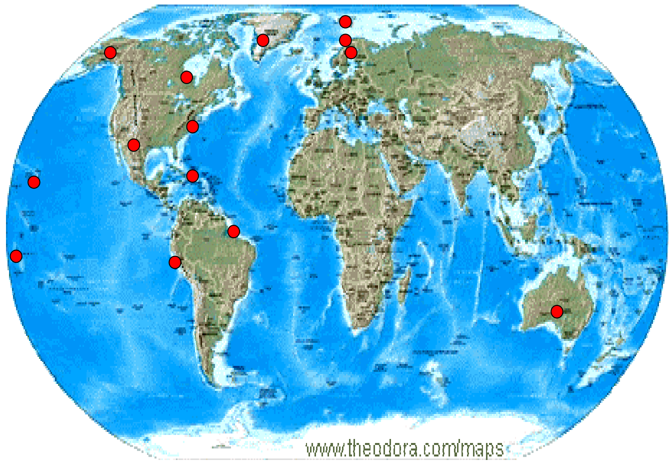
Trajectory and Performance Analysis



Sounding Rocket Launch Sites Used by NASA in last 25 years

- US Fixed
  - Wallops Flight Facility
  - White Sands Missile Range
  - Poker Flat Research Range
- Foreign Fixed
  - Sweden
  - Norway (Andoya & Svalbard)
- Mobile
  - Australia
  - Brazil
  - Puerto Rico
  - Greenland
  - Peru
  - Kwajalein

Sounding Rocket Launch Sites Used by NASA in the last 25 years



Map provided by www.theodora.com w/ permission

NASA Equatorial Sounding Rocket Campaigns

- 1964 India (Thumba) -- 4 rockets
- 1965 USS Croatan (off coast of Peru) -- 10 rockets
- 1970 India (Thumba) -- 6 rockets
- 1972 India (Thumba) -- 2 rockets (w/Germany)
- 1973 Brazil (Natal) -- 2 rockets (w/Germany)
- 1975 Peru (Punta Lobos) -- 19 rockets
- 1980 Kenya (Solar Eclipse) -- 5 rockets
- 1983 Peru (Punta Lobos) -- 18 rockets
- 1990 Kwajalein -- 7 rockets
- 1994 Brazil (Alcantara) -- 13 rockets
- 2004 Kwajalein -- 14 rockets

The ability to conduct experiments where the science is located is a fundamental aspect of the SR program.

Countries that build and launch Sounding Rockets

Countries that currently build and fly sounding rockets:

United States
Canada (?)
Germany
Norway
Japan
Brazil
India
Taiwan
Russia

Countries that exclusively build experiments flown on sounding rockets:

France
Peru
Canada (?)
Others ?

Sounding Rocket Mission Categories

Requirements

Examples of Accomplishments

1. Astronomy -- Planetary -- Solar
2. Geospace

Sounding Rocket Mission Categories

Disciplines: UV Astronomy, X-Ray, Planetary, Solar

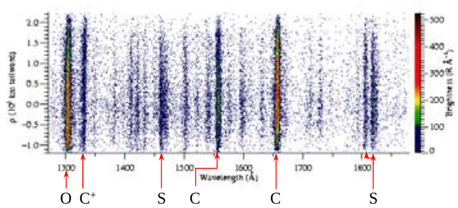
Remote sensing (Telescopes)

- Main requirements:
  1. Observing platform above earth's atmosphere
  2. Fine pointing of payloads (sub arc second usually required)
- Features:
  3. Real-time, joy stick uplink command positioning available
  4. Payload recovery/re-flights are routine (launches are at White Sands)
  5. Southern Hemisphere launch location (Australia) used on campaign basis
  6. Ability to observe sources close to the sun (e.g., comets, Mercury, Venus)

Strongest Ever Carbon Monoxide Production Discovered in Coma of Comet Hale-Bopp

Image of Comet Hale-Bopp, courtesy W. Johnasson.

Comet Hale-Bopp -- 6 April 1997
JHU-NASA Sounding Rocket 36.156 UG

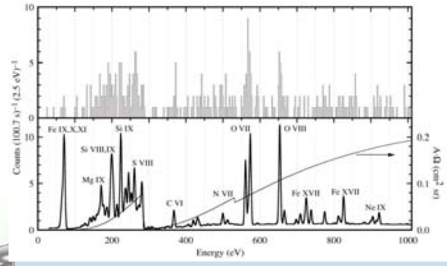


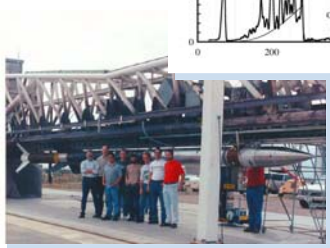
- **Remaining emissions are bands of the carbon monoxide Fourth Positive system.**

- Carbon abundances may simply result from photodissociation of CO.
- Observations gathered very close to perihelion; Comet was very active.

[Data: P. Feldman, Johns Hopkins Univ.; See also J. McPhate, *Ap. J.*, *521*, 920, 1999.]

New X-Ray Detector Developed on Sounding Rockets





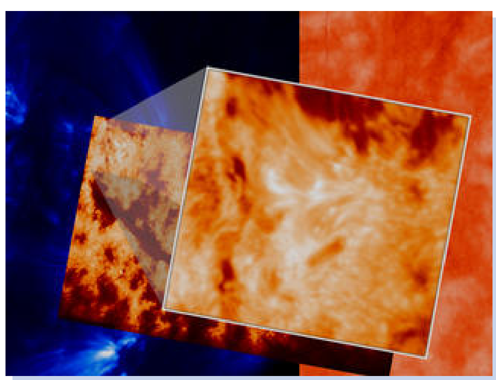
Scientists at the launch pad

Graduate student checks instrument

- **1st Detection of diffuse emission in 172 Å Fe lines**
- **Observations demonstrate soft X-ray background is thermally produced.**
- **Detector to be deployed on Astro-E2, Constellation-X, XEUS**

Data and photos: D. McCammon, Univ. of Wisc.

High Time and Spatial Resolution in Lyman α Reveal New Features of Solar Chromosphere



- **Highest Spatial resolution achieved to date (<0.3 arc sec)**
- **Simultaneous measurements with SoHo, TRACE enable different layers of the sun to be observed of the same region**

Very high Angular resolutions ULtraviolet Telescope (VAULT), Naval Research Lab

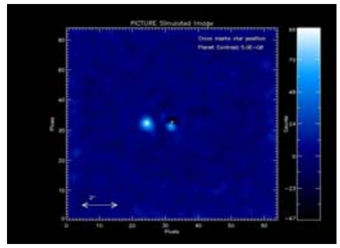
Data: C. Korendyke, NRL

Planet Imaging Concept Testbed Using a Rocket Experiment (PICTURE)

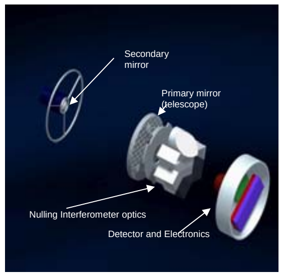
Goal 1: Directly image an extrasolar planet using telescope flown on a sounding rocket

Goal 2: Demonstrate nulling interferometer technology for future NASA missions

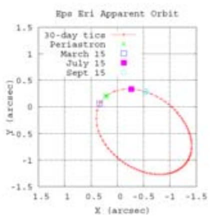
Development underway; first launch in summer '07



Expected Image

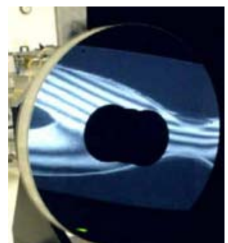


Experiment concept



Accurate pointing (< 0.1 deg) needed.

S. Chakrabarti, Boston University, P.I



Lightweight primary mirror; 0.5m dia, 4.5 kg

Carbon fiber telescope structure

http://newsroom.spie.org/x3847.xml

Sounding Rocket Mission Categories

Geospace (Magnetosphere, Ionosphere, Thermosphere, Mesosphere)

In situ measurements (generally)

- Main requirements/features:
  1. Access to altitudes too low for satellite *in situ* sampling (25-125 km region)
  2. *Vertical* profiles of measured phenomena (cf. satellite *horizontal* profiles).
  3. Slow vehicle speeds enable new phenomena to be studied; payloads "dwell" in regions of interest
  4. Launches are frequently in geophysical "Targets" (e.g., aurora, cusp, thunderstorms, ionospheric turbulence at equator, noctilucent clouds, electrojets, ionospheric metallic layers, etc.)
  5. SR Portability provides access to remote geophysical sites (high, middle, low latitudes)
  6. Launches in conjunction with ground observations (e.g., radars, lidars, etc.)

(Continued)

Sounding Rocket Mission Categories

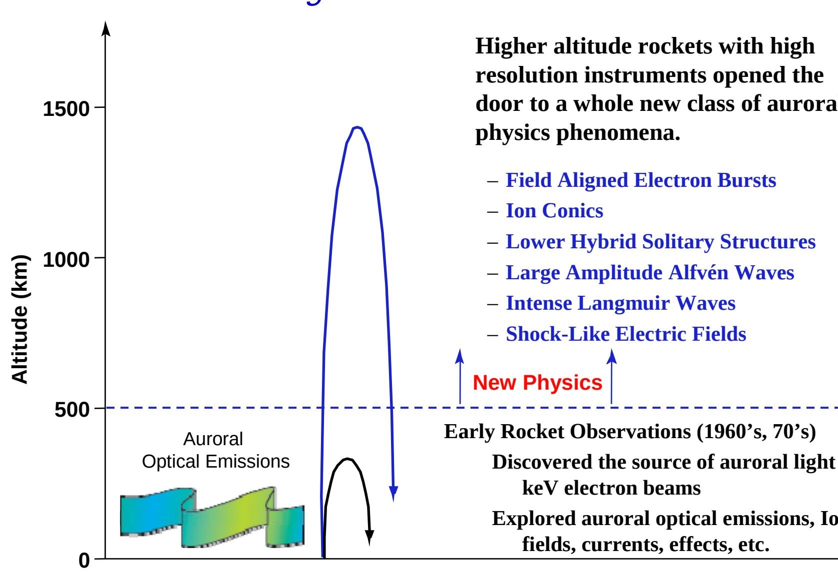
Geospace (Magnetosphere, Ionosphere, Thermosphere, Mesosphere)

In situ measurements (generally)

- Main requirements/features (continued):

  7. Multiple payloads (clusters) launched on single rocket
  8. Multiple, simultaneous launches (high and low apogees, different azimuths, etc.)
  9. Luminous trails to serve as tracers of geophysical parameters such as winds
  10. Flights in conjunction with orbital missions (e.g., Dynamics Explorer, TIMED)
  11. Tether capabilities (e.g., 2 km tethers between payloads have been flown)
  12. Collection of stratosphere/mesosphere samples (e.g., 24 underflights of UARS)

Auroral Physics on Sounding Rockets: Understanding Particle Acceleration in Nature



Higher altitude rockets with high resolution instruments opened the door to a whole new class of auroral physics phenomena.

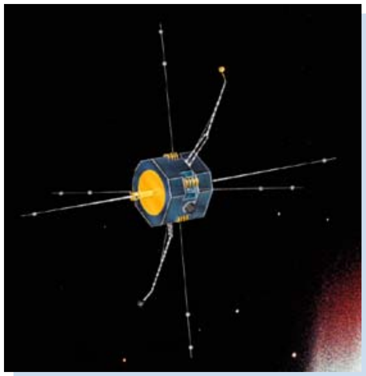
- **Field Aligned Electron Bursts**
- **Ion Conics**
- **Lower Hybrid Solitary Structures**
- **Large Amplitude Alfvén Waves**
- **Intense Langmuir Waves**
- **Shock-Like Electric Fields**

Early Rocket Observations (1960's, 70's)

Discovered the source of auroral light is due to keV electron beams

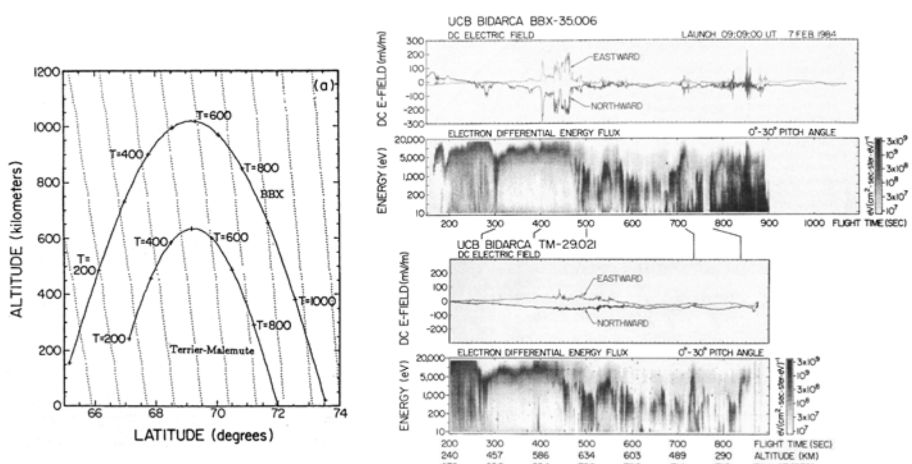
Explored auroral optical emissions, Ionosphere fields, currents, effects, etc.

Auroral Zone Rocket Discoveries Formed the Springboard for NASA's FAST Satellite



- **Auroral physics discovered on sounding rockets formed the basis of FAST Small Explorer Satellite**
- **FAST in-situ instruments were developed on rockets (e.g., "Top Hat" electrostatic detectors, plasma wave Interferometers)**
- **FAST experimenters, including P.I., had extensive prior experience with sounding rockets**

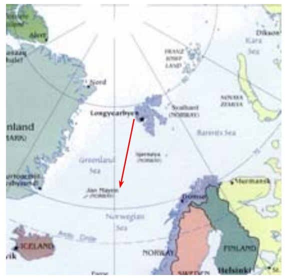
Dual-Rocket Observations of Electrostatic Shocks in the Auroral Zone

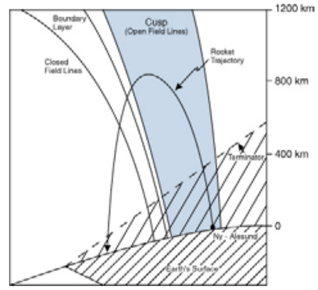


[Boehm et al., JGR, 1990]

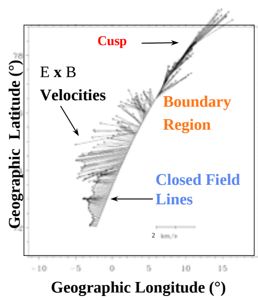
Direct Measurements in the Cusp from Spitzbergen

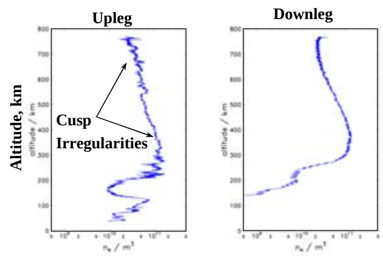
Experiment Location and Geometry:





Electric field, plasma density reveal complex electrodynamics at open/closed magnetic field line boundary.



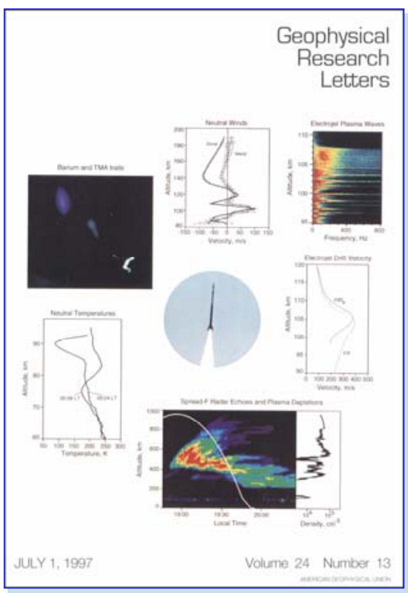


Plasma Density

Data: R. Pfaff, GSFC

NASA Guará Campaign

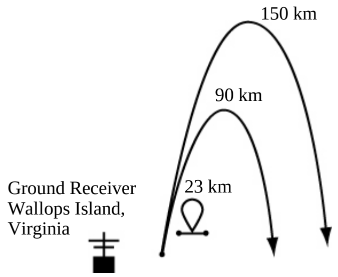
13 Rocket Launches at the Magnetic Equator in Brazil

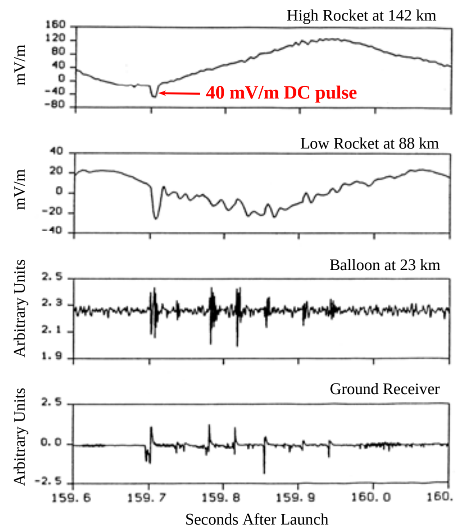


Observations include several significant "Firsts":

- **Polarization DC electric field that drives the equatorial electrojet**
- **High altitude (>800 km) DC and wave electric fields gathered in a Spread-F plume**
- **Neutral wind gradients associated with enhanced E-fields at sunset**
- **Gravity wave breaking in the equatorial mesosphere**
- **Primary two-stream wave spectra and phase velocities in electrojet.**

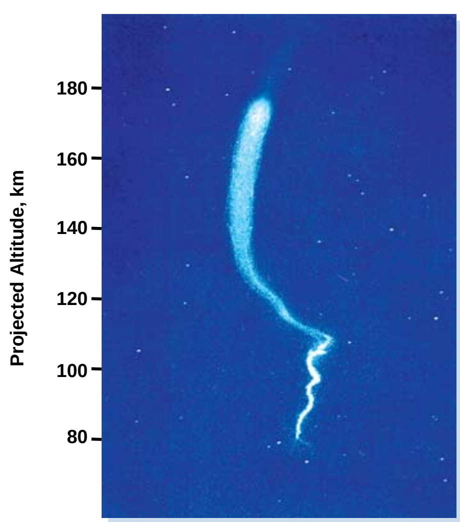
Direct Penetration of Lightning Electric Fields in the Ionosphere: Dual Rocket Experiment





[Kelley et al., <u>JGR</u>, 1985]

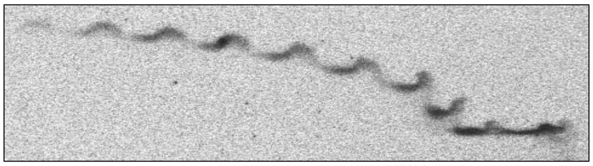
Luminous Trails Reveal Ionospheric Neutral Winds, Vortex Structures, and Instabilities



Poker Flat, Alaska

[Courtesy of M. Larsen/Clemson Univ.]

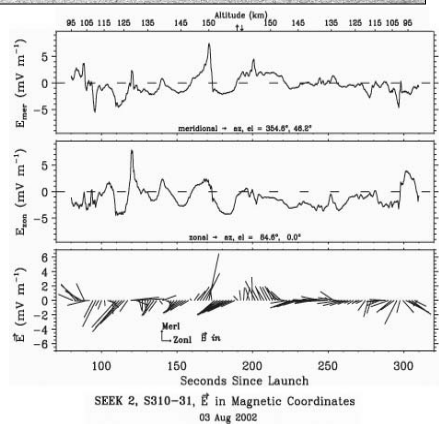
Luminous "Trails" and In-Situ Electric Fields Reveal Kelvin-Helmholtz Instability in Lower Ionosphere



Luminous trail reveals Kelvin-Helmholtz waves near 120 km, λ~5 km

Data from two Japanese rockets launched 15 min. apart.

P.I.s:
S. Fukao, M. Yamamoto, Kyoto Univ.

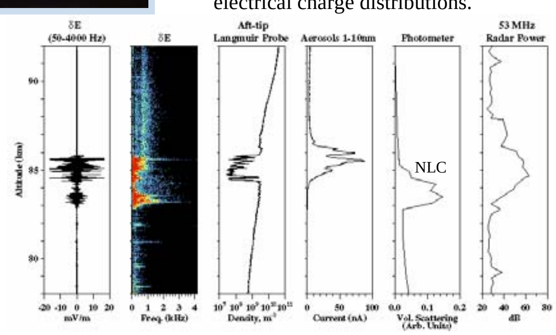


DC Electric field measurements show structure, similar wavelengths

Rocket Measurements of Noctilucent Clouds (NLC): A Near-Earth Icy, Dusty Plasma

- NLC located in high latitude summer mesosphere.
- Lowest neutral temperatures in atmosphere.
- Possible indicators of anthropogenic change
- Region of very intense radar echoes
- Complex aerosol chemistry, dynamics, electrical charge distributions.

Data from rocket flight into NLC with intense radar echoes from Andoya, Norway



[see Goldberg et al., GRL, 2001.]

Sounding Rocket Mission Categories

Microgravity

- Main requirements/features:
  1. Long periods of “zero-G” relative to airplanes, drop towers
  2. Recovery usually required (launches are at White Sands)
  3. Rockets provide very low acceleration, disturbance rates relative to STS, ISS

Special projects

- Aerobraking tests, re-entry technology testing, etc.

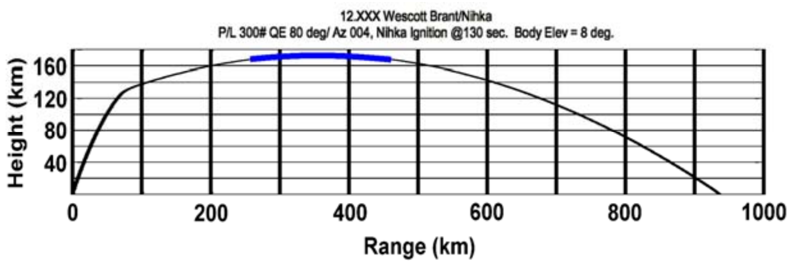
  Large descent velocities (afforded by high apogee) usually sought to simulate re-entry tests.

Technology Roadmap

Technology Roadmap developed jointly by WFF and the Sounding Rocket Working Group

- High Altitude Sounding Rocket
- Tailored trajectories
- Small Mesospheric “Dart” payload
- Air retrieval of sounding rocket payloads

NASA's first "Tailored" Trajectory
University of Alaska (Conde) HEX Mission



- The HEX project measured <u>vertical</u> winds by deploying a <u>near-horizontal</u> trail.
- This required actively re-orienting the rocket prior to 3rd-stage ignition. This was a first for NASA.
- HEX demonstrated that this maneuver can be performed successfully. Capability is now available for the program.

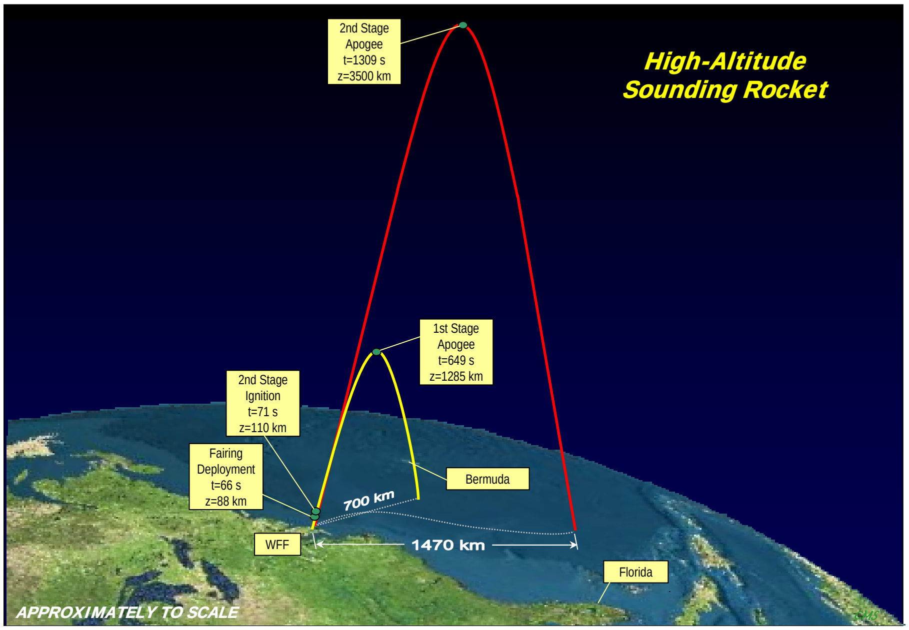
The Next Step…

High Altitude Sounding Rocket

(HASR)

- Total Payload Wt: 1000 lbs
- Science Instrument Wt: 700 lbs
- Payload Diameter: 50 in.
- Apogee Altitude: 3400 km
- Observation Time: ~40 minutes

Note: All numbers preliminary



Possible HASR Science Applications

- Astronomy / Planetary / Solar
  - Increased "hang time" and sensitivity -- observe for ~ 40 minutes with larger diameter (~ 1m) telescopes
  - Near-Sun observations of comets, inner planets
  - Observe temporal evolution of solar phenomena
  - IR observations (payload has time to cool down)
  - Observation of faint targets including "near-sun" observations of comets, inner planets
- Geospace Science
  - Penetrate the auroral and cusp acceleration region (> 3000 km)
  - Observe high altitude regions with constellations of well-instrumented sub-payloads
  - Observe magnetosphere-ionosphere coupling resonances and wave interactions with periods of 10's of minutes
  - Study inner radiation belt and slot region from Wallops
- Microgravity
  - Combustion experiments for considerably longer periods in "ideal microgravity"
- Exploration
  - 6-7 km/sec entry velocity available for planetary probe testing
  - Entry, Descent, and Landing Technology Demonstrations

Summary

- NASA Sounding Rocket Program provides a wide range of technical capabilites including unique launch vehicles, payload capabilities, and range operations.
- Commonality building on previous designs keep costs low.
- Missions are tailored to meet scientific needs of experiment.
- Program has served space science exceedingly well.
- Sounding rockets look forward to continued innovation and show great promise for the future.

Sounding rocket investigations of the polar mesopause region: achievements and perspectives

Franz-Josef Lübken
Leibniz Institute of Atmospheric Physics, Kühlungsborn, Germany

Presenting Author Name:	Franz-Josef Lübken
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Presenting Author Telephone:	49-38293-68100
Session:	Invited Speaker
Presentation Method:	Talk
Presenting Author Title:	Professor

Franz-Josef Lübken
Leibniz Institute of Atmospheric Physics, Kühlungsborn, Germany

Sounding rocket investigations of the polar mesopause region: some recent achievements and perspectives

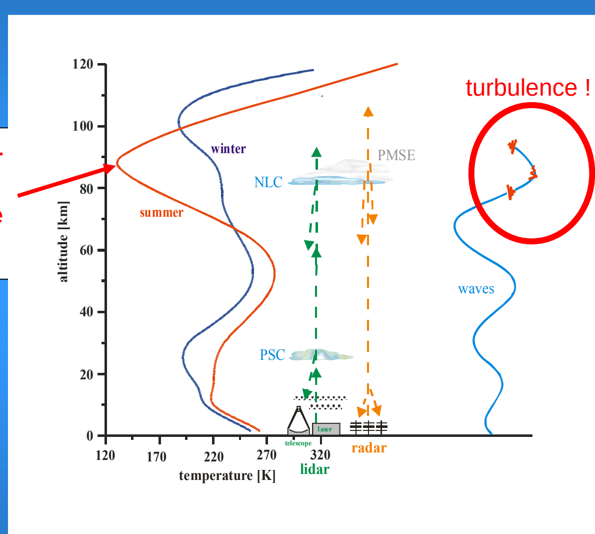
Outline:

- **Why rockets ?**
  - **very high resolution (e.g. turbulence)**
  - **plasma**
  - **basic parameters (temperatures, composition, winds, ...)**
  - **more (e.g. electric/magnetic fields, microgravity)**
  - **operational:**
    - **very short turn-around time (students !)**
    - **little management overhead**
    - **test facility for satellite instruments**
- **Example for synergy effect: PMSE**
- **Outlook and scientific perspectives**

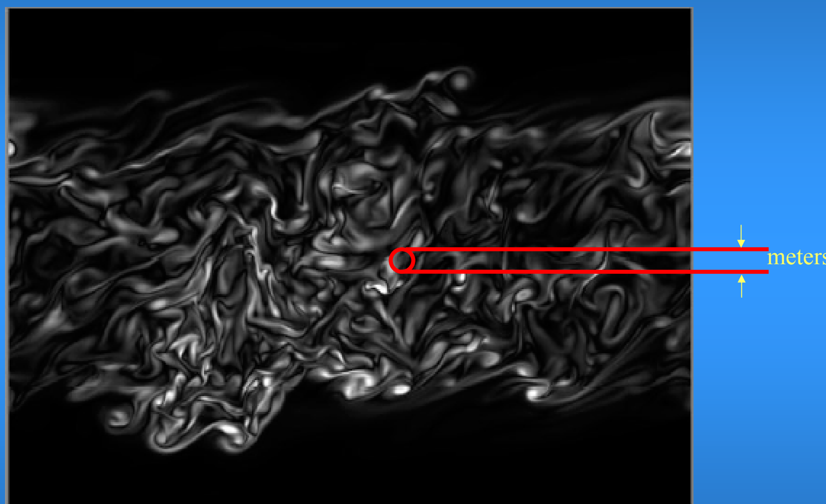
Resolution & Turbulence

Thermal structure, dynamics, and layers

summer polar mesopause: coldest place on Earth !



Turbulence acts on very small scales

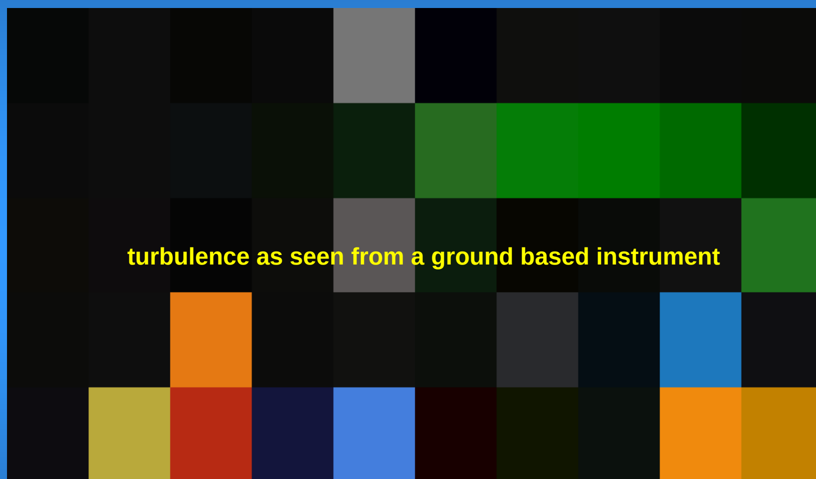


Werne & Fritts, 2001.

1000 x original resolution

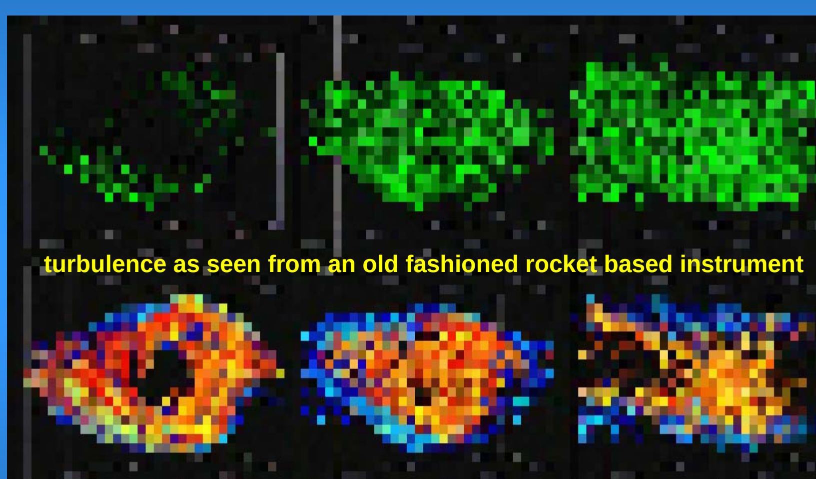
turbulence as seen from a satellite

100 x original resolution



Toronto, 1. February 2007 #8

10 x original resolution



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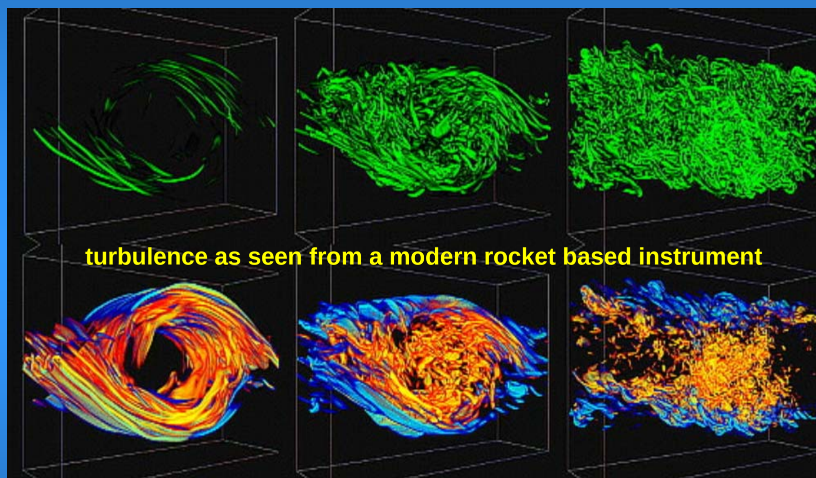
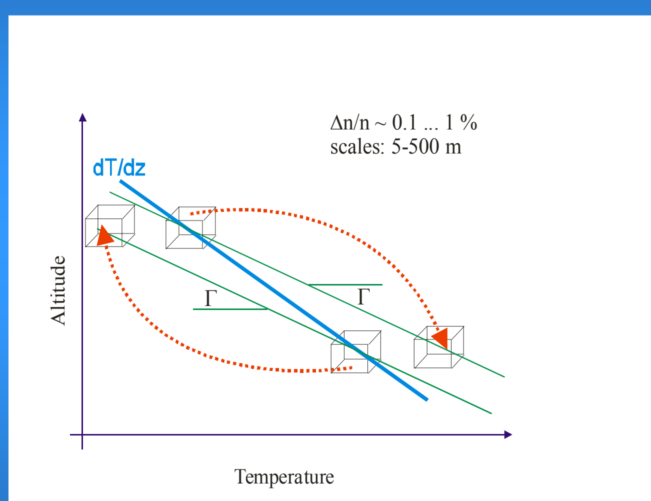
Original (model of KH instability)



Fritts et al., J. Geophys. Res., 2003.

Fritts-JGR03

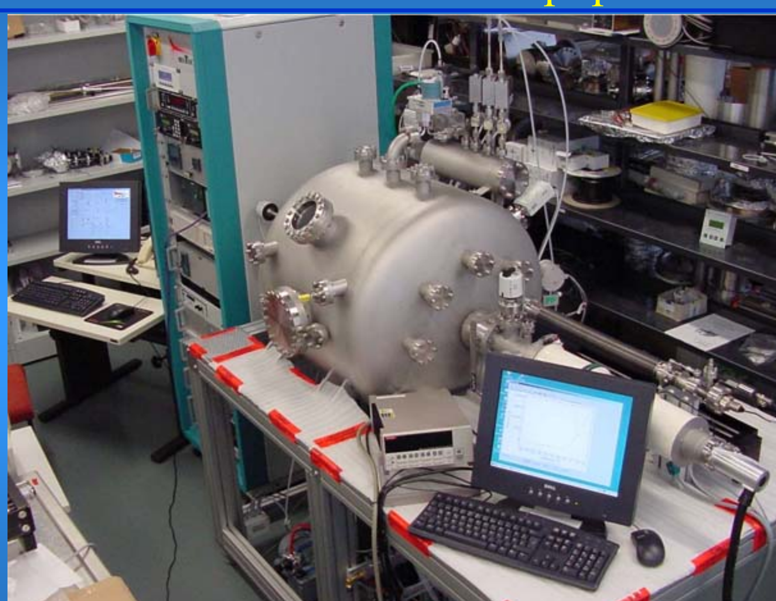
Density fluctuations due to turbulence



CONE rocket borne instrument

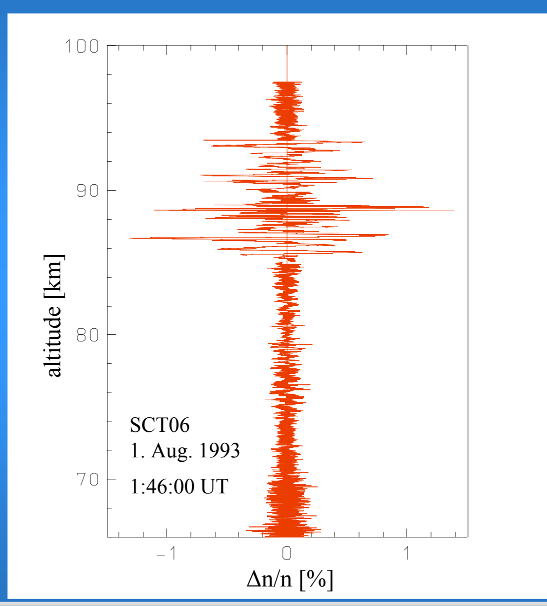
Toronto, 1. February 2007 #12

The IAP calibration test equipment



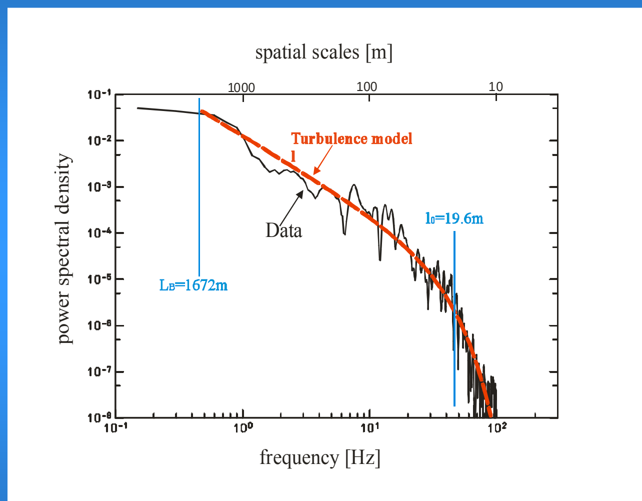
Toronto, 1. February 2007 #13

Relative density fluctuations (CONE)



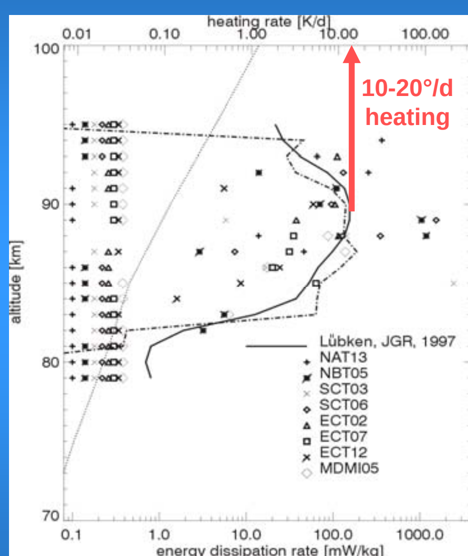
F.-J. Lübken
J. Geophys. Res.,
1997

Turbulence spectrum from CONE data



F.-J. Lübken
J. Geophys. Res.
1997

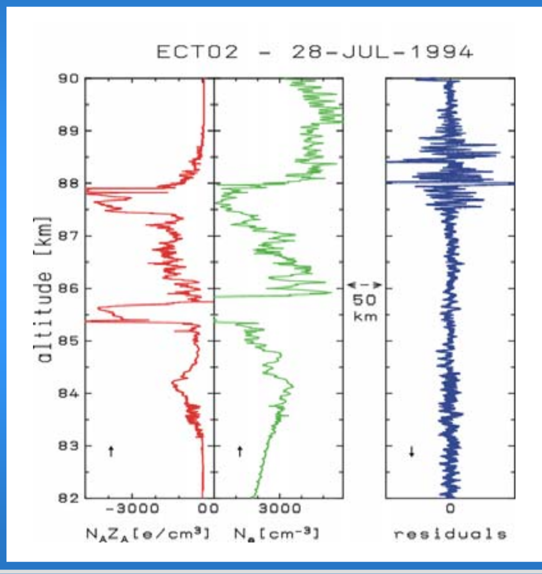
Neutral air turbulence in summer



Lübken et al., JGR, 2002.

at the coldest place on Earth !

Fluctuations in aerosols, electrons, and neutrals

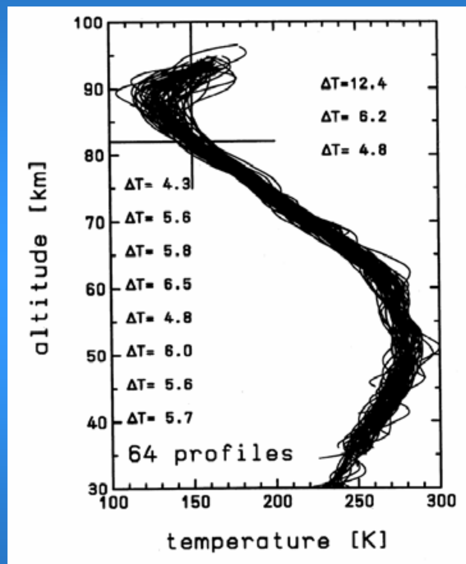


IAP, Kühlungsborn
FFI, Oslo
Tromso Univ.

Lübken et al., Geophys. Res. Lett., 1998.

basic parameters:
temperatures
winds
composition

FS temperatures in summer (69°N)

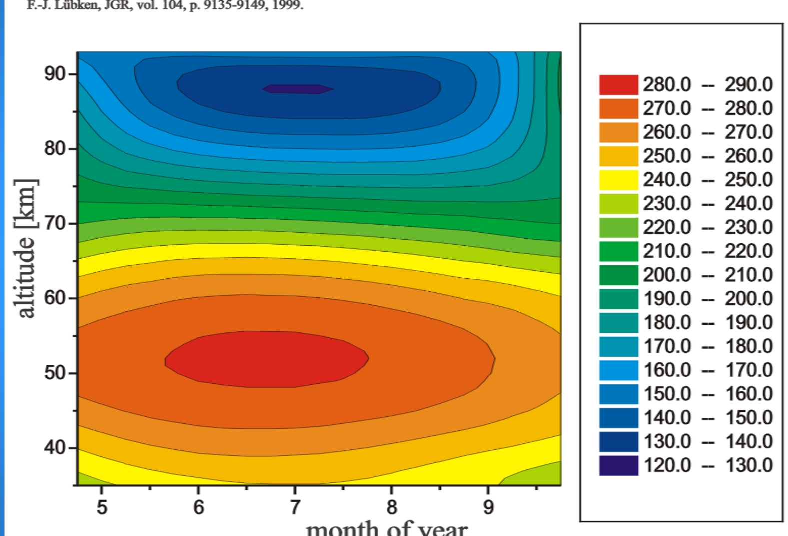


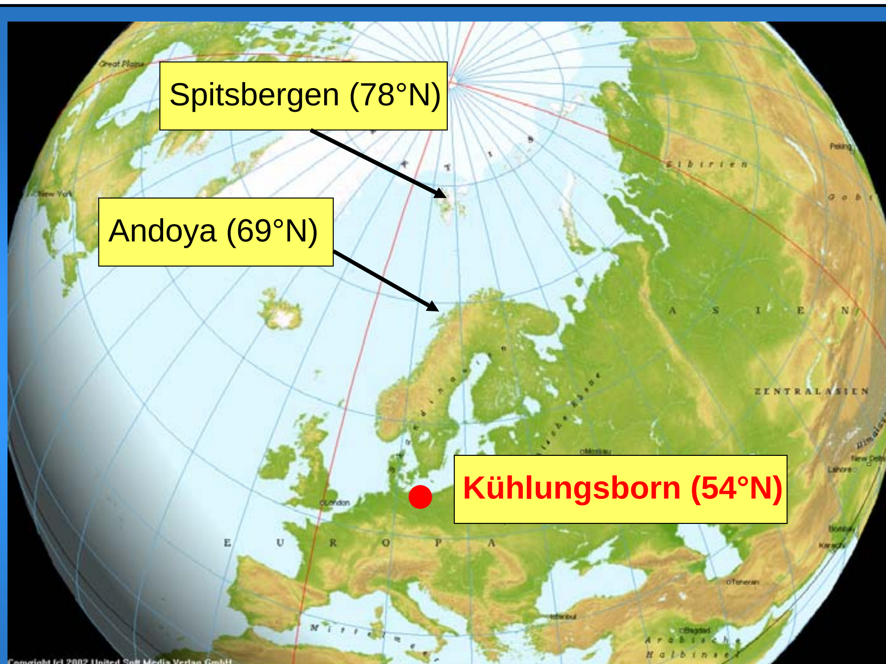
F.-J. Lübken,
J. Geophys. Res.,
1999

see also
Frank Schmidlin
J. Geophys. Res., 1991

Temperature climatology @ 69°N

F.-J. Lübken, JGR, vol. 104, p. 9135-9149, 1999.





Ostseebad Kühlungsborn

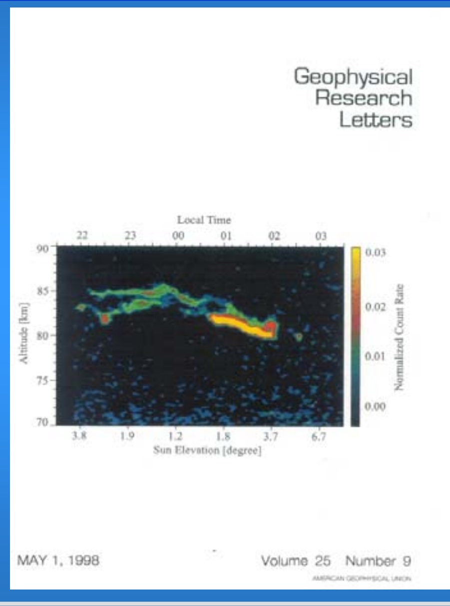
Toronto, 1. February 2007 #24

Kühlungsborn, 54°N, 10th July 1997, 2:00 LT

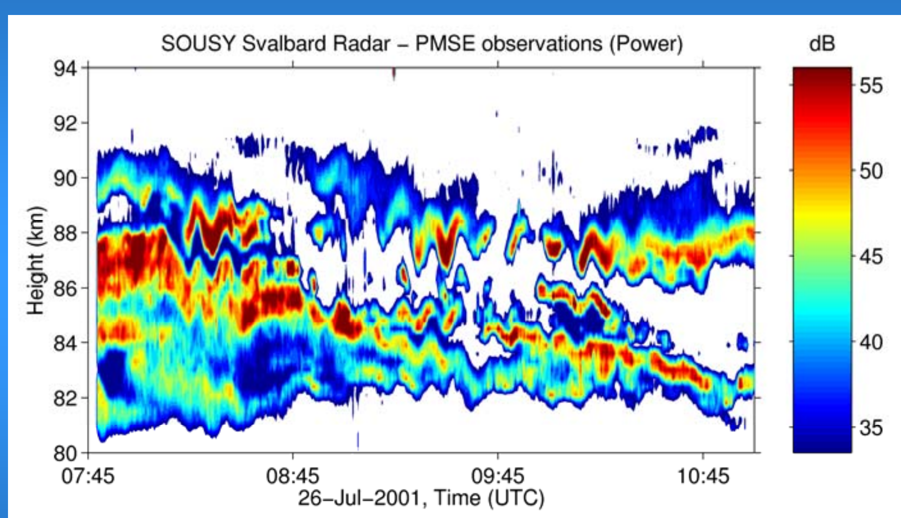
Toronto, 1. February 2007 #25

NLC at ALOMAR

ice clouds at 83 km observed by lidar at 69°N



Polar Mesosphere Summer Echoes in Spitsbergen

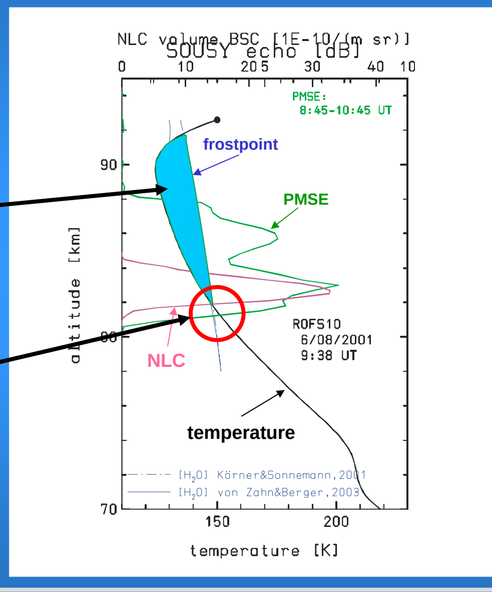


Courtesy of J. Bremer, IAP, 2004.

FS temperatures, NLC,PMSE (Spitsbergen)

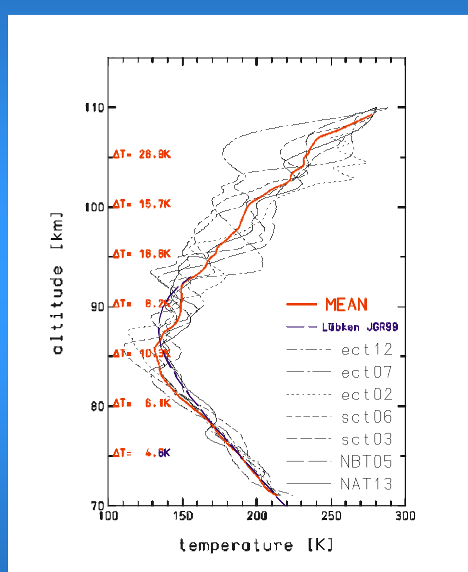
region where ice clouds can exist

perfact match !

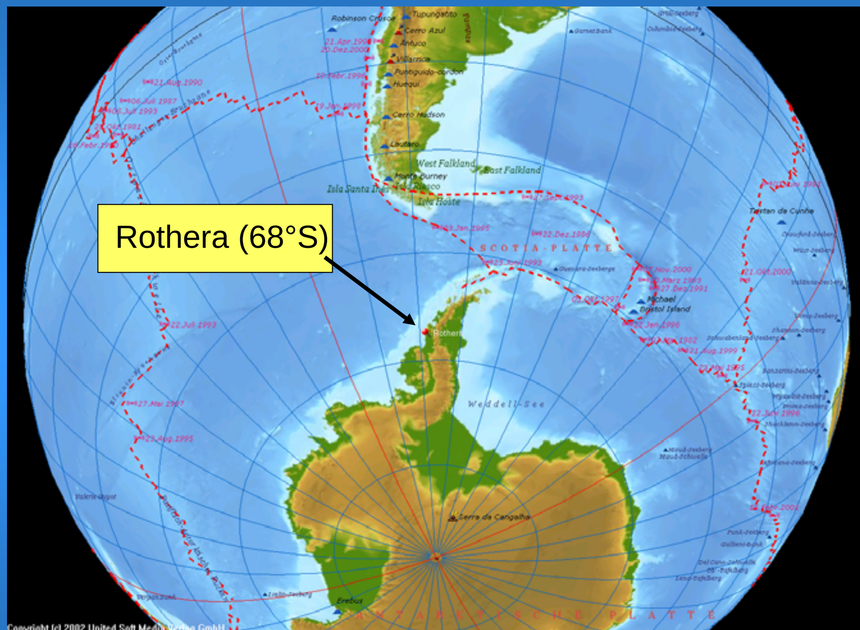


(Courtesy of IAP)

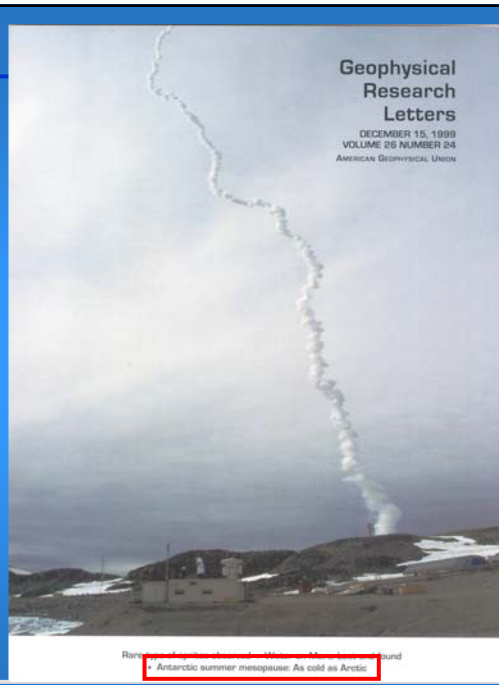
Small scale temperature profiles from CONE



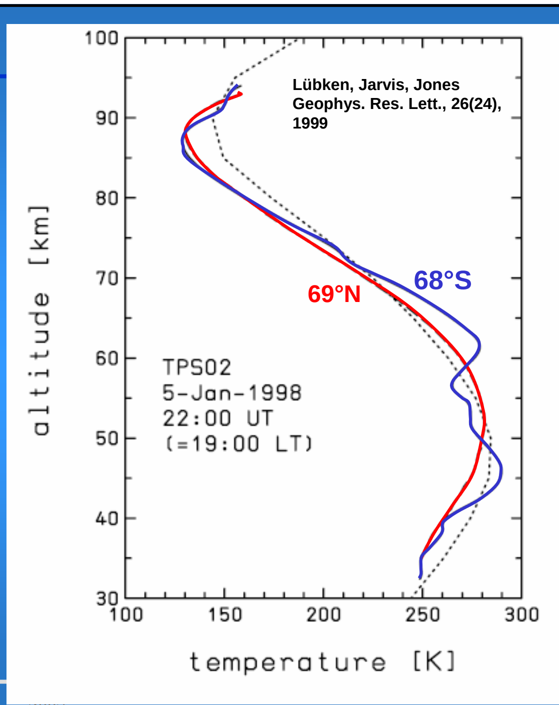
Rapp et al., J. Geophys. Res., 2003.



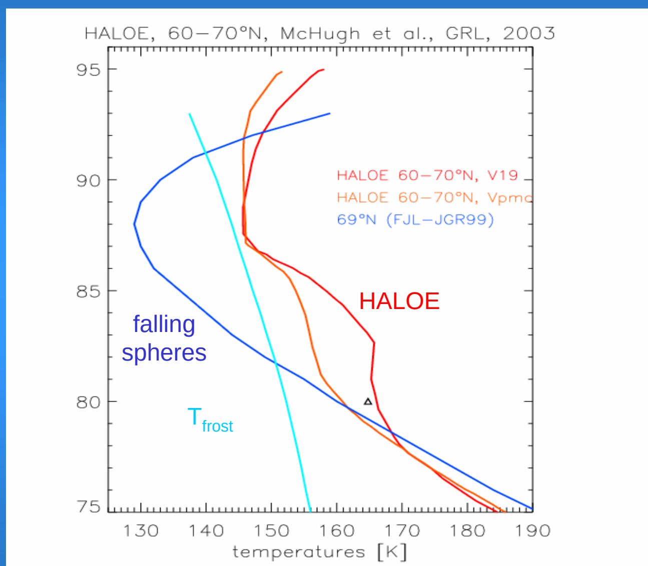
Toronto, 1. February 2007 #30



Toronto, 1. February 2007 #31

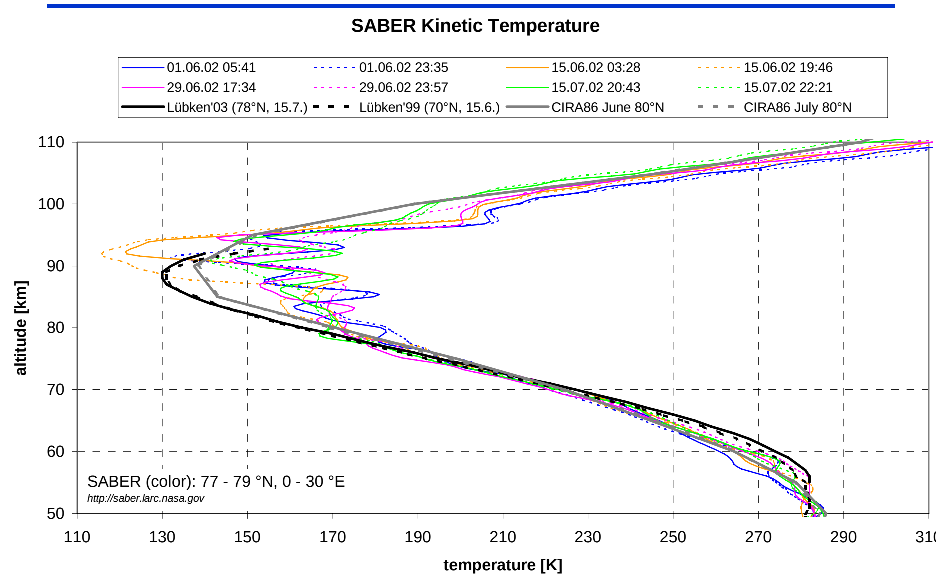


Toronto, 1. February 2007 #32



Toronto, 1. February 2007 #33

Courtesy of the SABER team



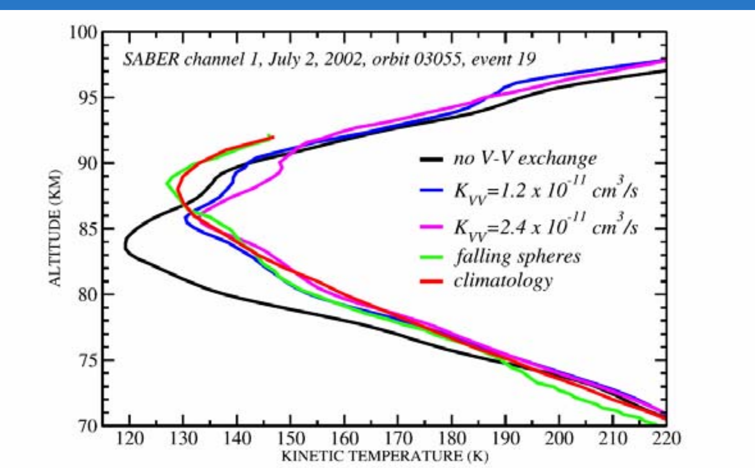
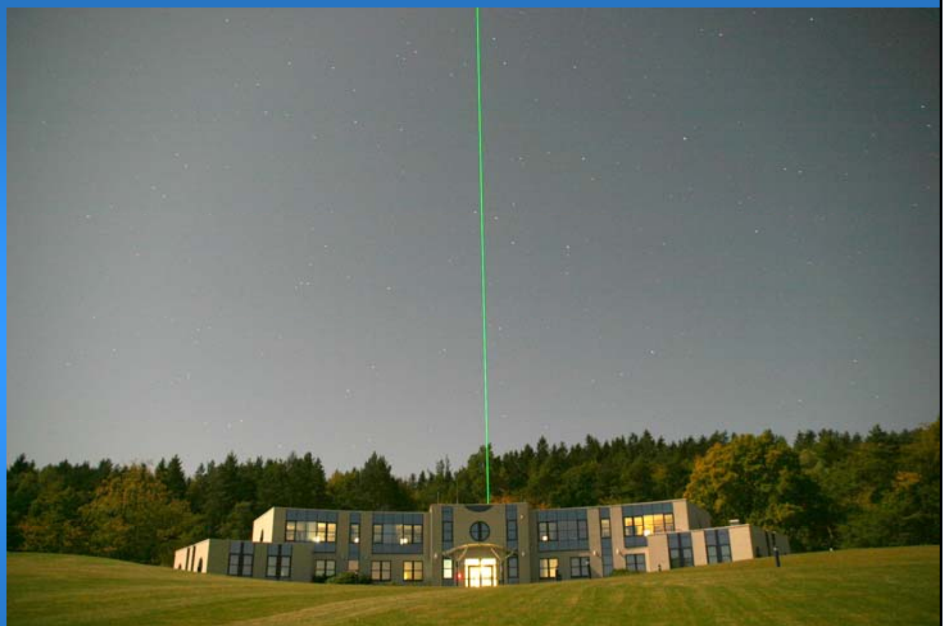
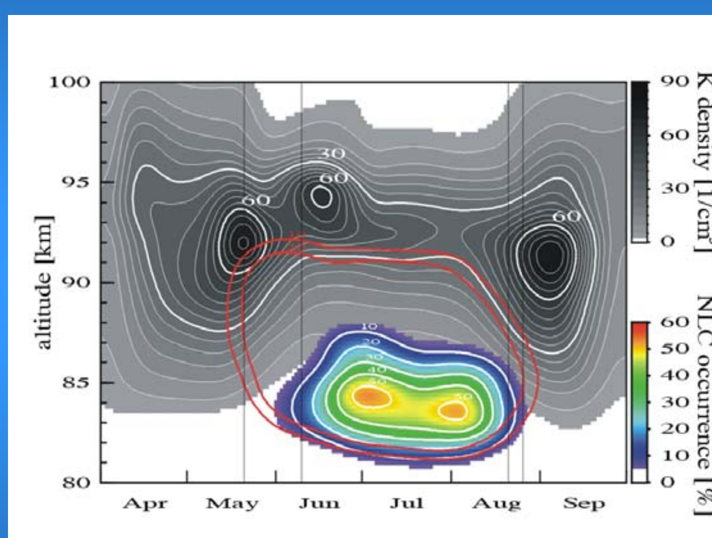


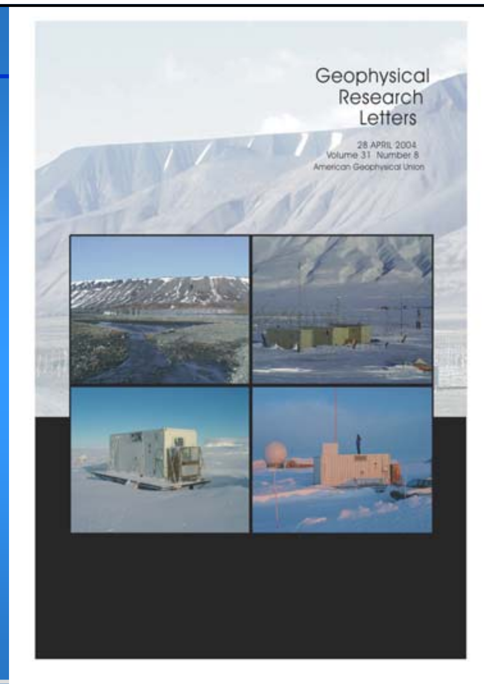
Figure 3. Temperature retrievals in polar summer MLT, SABER channel 1 (narrow 15 μm channel).

Kutepov et al., Geophys. Res. Lett., 2006

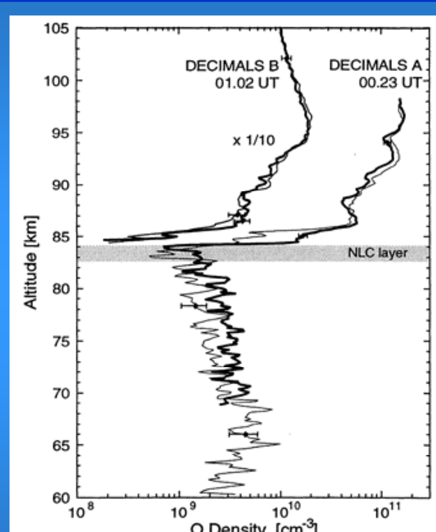




Lübken & Höffner, Geophys. Res. Lett., 2004



Atomic oxygen measurements from rockets

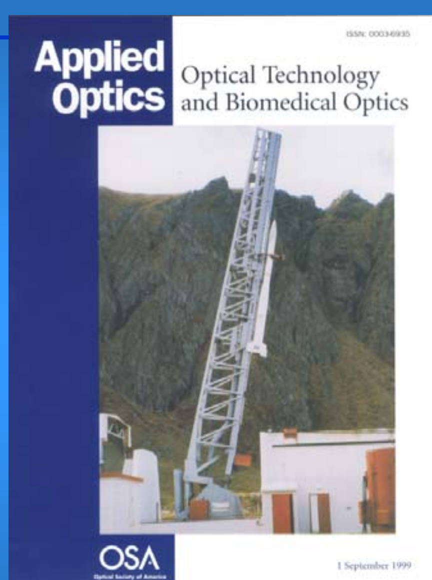


Gumbel at al., J. Geophys. Res., 1998.

MASERATI:

Middle atmosphere spectrometric experiment on rockets for analysis of trace gas influences

Lübken et al.,
Applied Optics, 1999

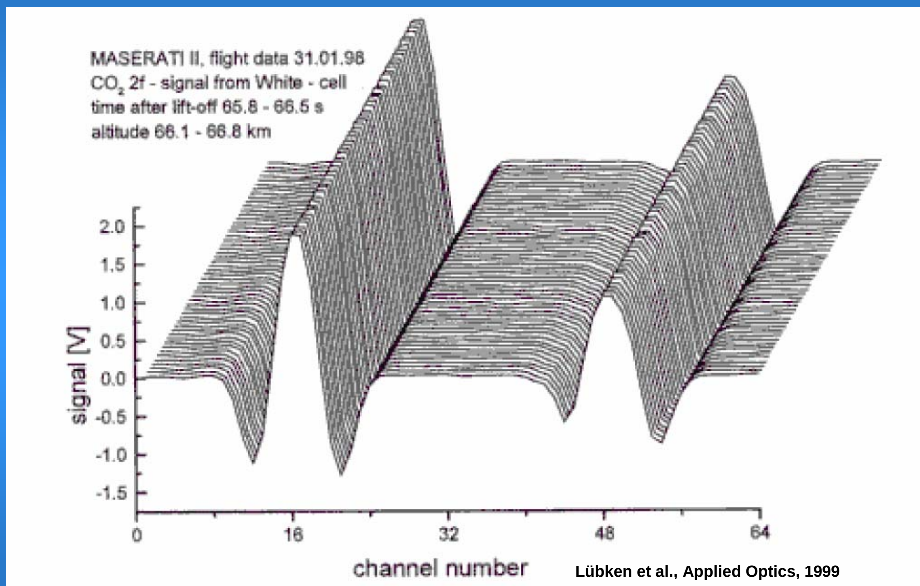


Lübken et al.,
Applied Optics
1999.

Idea delevoped during my post doc stay at York University in 1988/1989 (Harold Schiff, Don Hastie etc.)

MASERATI:

Middle atmosphere spectrometric experiment on rockets for analysis of trace gas influences



Lübken et al., Applied Optics, 1999

Chaff: high resolution winds

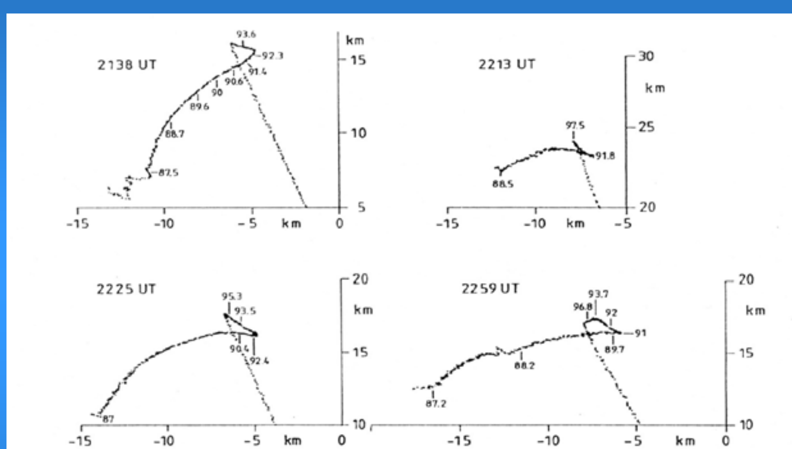


Fig. 10. Projection of the trajectories of high-altitude chaff (No. 7 and 8 of Table 1) onto the Earth's surface ('radar ground plot', to be read like a map, with north to the top). Distances given refer to the location of the tracking radar. Unsmoothed raw radar data. Quasi-straight line: Trajectory of the rocket. Immediately after release the chaff is blown away by the wind.

down to
1 g/m^2

H. Widdel, J. Atmos Terr. Phys., 1990

Polar mesosphere summer echoes:

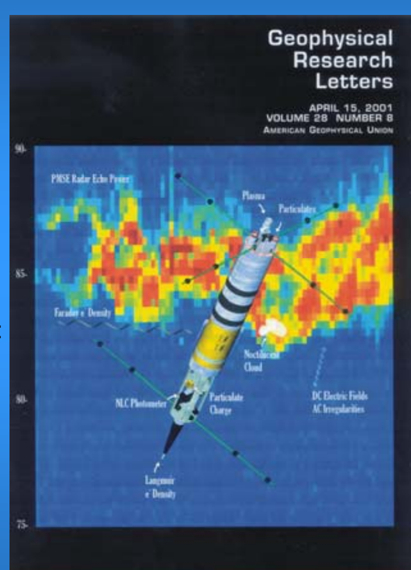
problem solved by combination of:

- insitu (rockets)
- ground based (radar,lidar)
- modeling

Toronto, 1. February 2007 #44

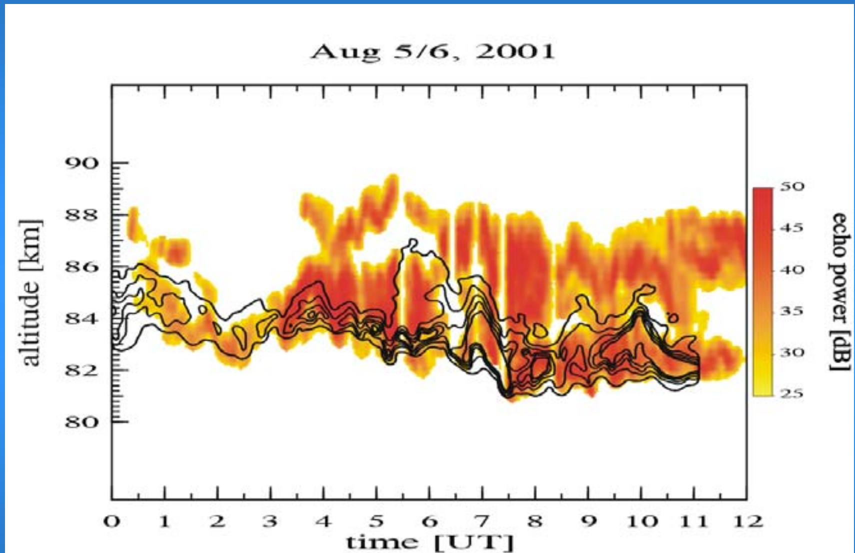
PMSE: polar mesosphere summer echoes

DROPPS campaign
at Andoya Rocket Range:
NASA, IAP, FFI, ...



Toronto, 1. February 2007 #45

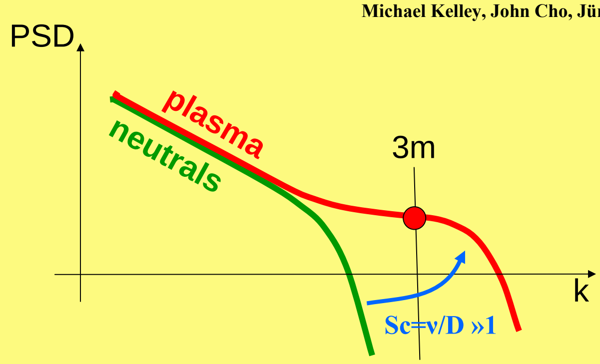
NLC/PMSE at Spitsbergen, 78°N



Lübken et al., J. Geophys. Res., 2004.

(polar) mesosphere summer echoes: main idea

Michael Kelley, John Cho, Jürgen Röttger



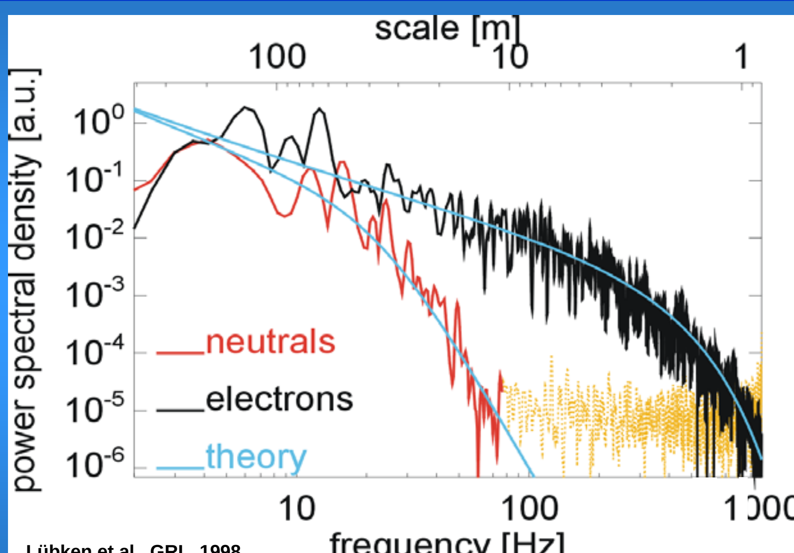
- `heavy‘ charged ice particles reduce diffusivity of electrons
- Schmidt number Sc=ν/D >> 1

PMSE theory: cows and flies

(after John Cho)

Toronto, 1. February 2007 #48

Effect of Sc>>1 on spectra (ECT02)



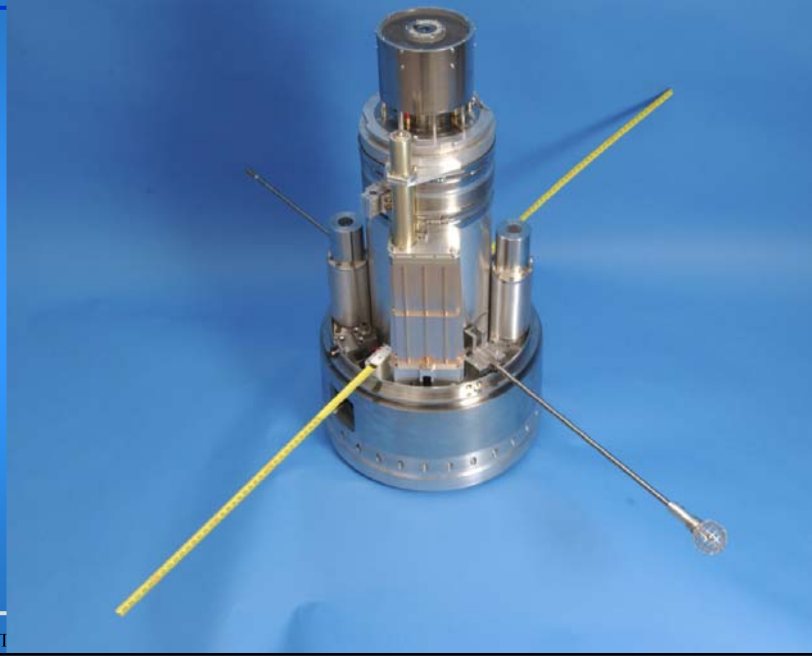
Toronto, 1. February 2007 #49

Outlook

Open questions:

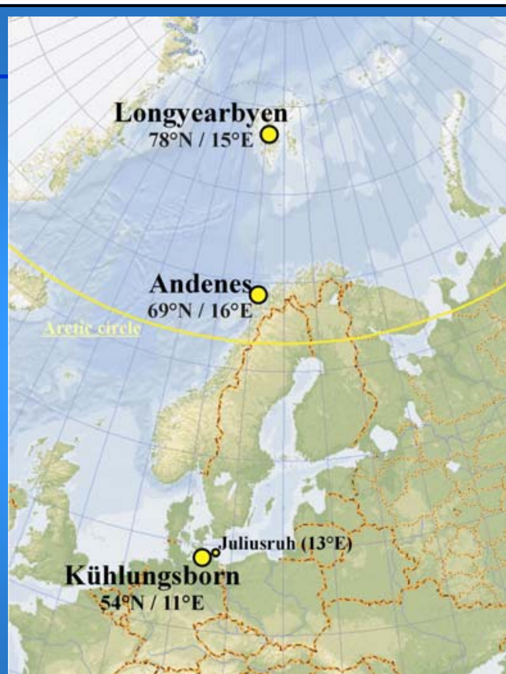
- **Do dust particles exist ?(ECOMA,MAGIC)**
- **Anisotropy, inhomogeneity, stationarity of turbulence**
- **Variability of turbulence on various temporal and spatial scales (e.g. variation with latitude)**
- **Role of turbulence for energy/momentum budget**
- **Variability of PMSE and NLC (geophys. control?)**
- **Effect of ice particles on composition ?**
- **Long term variations (solar cycle, trends...)**
- **Composition (e.g. atomic oxygen)**
- **... and more**

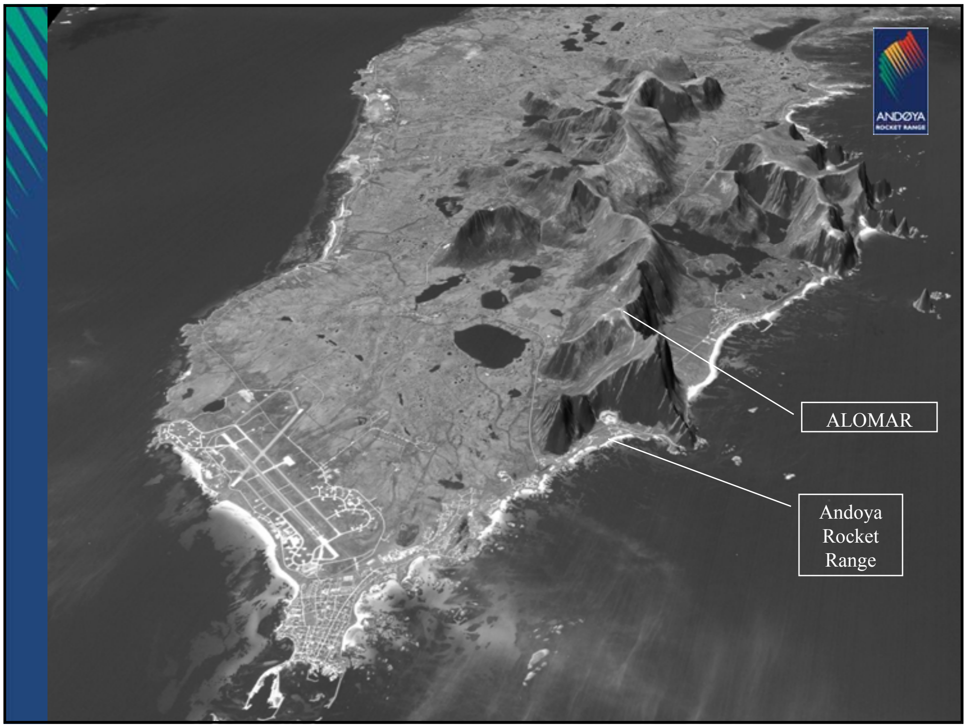
The IAP Particle detector: ECOMA



... in combination with ground based and satellite measurements ...

Andoya Rocket Range
&
ALOMAR





Andoya Rocket Range, 69°N

ALOMAR, 69°N

Toronto, 1. February 2007 #58

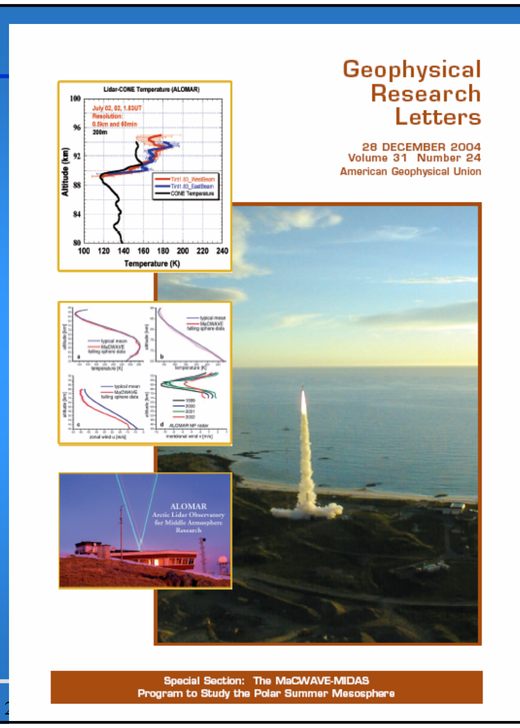
New MF radar at ALOMAR (narrow beam)

Toronto, 1. February 2007 #59

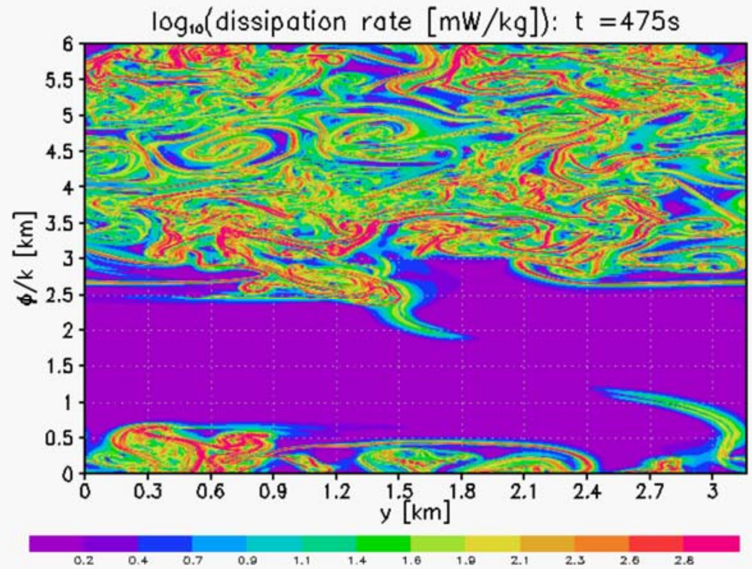
Mac/WAVE

Germany, Norway, USA

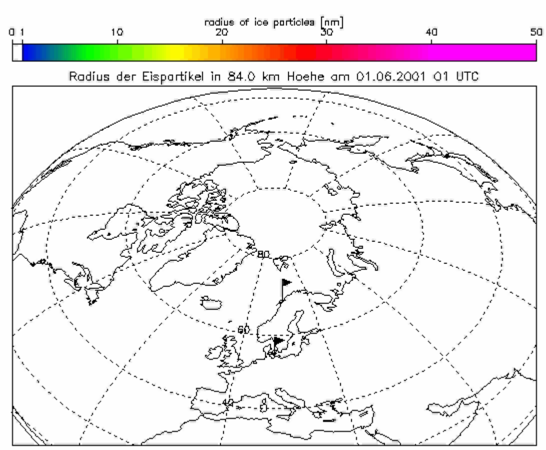
July 2002
from Andoya



... and modeling ...



after Achatz, J. Atmos. Sci., 2006.



Berger & Lübken, Geophys. Res. Lett., 2006

Conclusion:

rocket based instruments are an important tool for upper atmosphere science

The End

Thank you!

luebken@iap-kborn.de

Thanks to:

- Kim for invitation
- Andoya Rocket Range for rocket operation
- German Space Agency (DLR) for support of rocket programme
- many more ...

Development of the Suprathermal Particle Imager and the Role of Sounding Rockets

David Knudsen
Department of Physics and Astronomy
University of Calgary

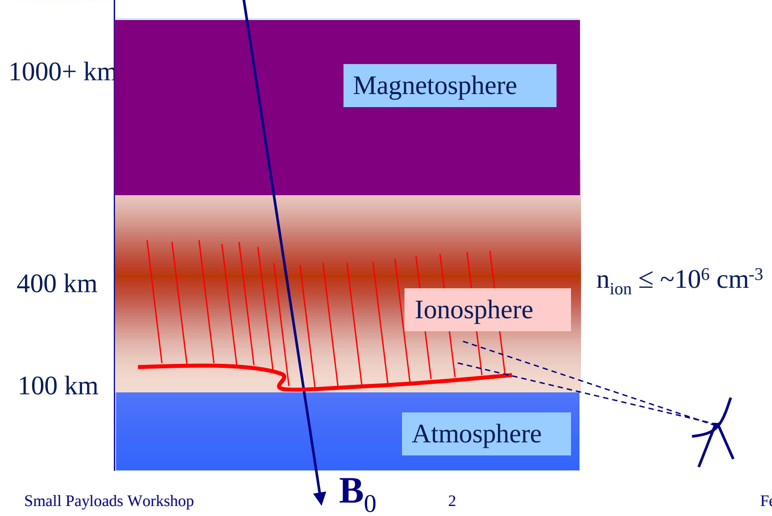
Abstract:

The Suprathermal Particle Imager began as a concept study in 1996 and has since evolved into a flight-proven research tool for measuring ionospheric temperature and flow velocity. Sounding rockets were the key to proving the concept and demonstrating the scientific potential of the SPI. This talk reviews the development of the SPI, highlights its scientific accomplishments, and asks whether a similar development would still be possible in today's Canadian research environment.

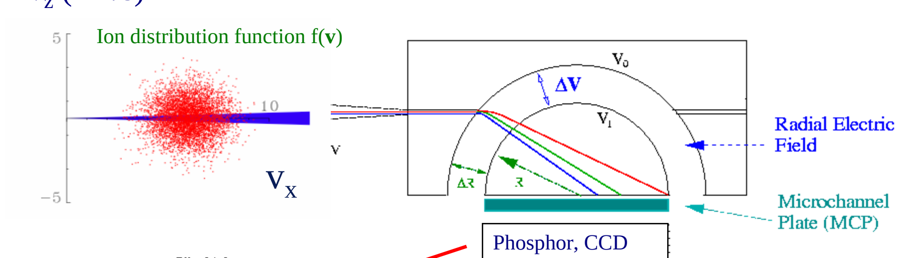
Presenting Author Name:	David Knudsen
Organization:	University of Calgary
Presenting Author Email:	knudsen@phys.ucalgary.ca
Presenting Author Telephone:	403-220-8651
Preferred Session:	Past projects and case studies
Presentation Method:	Talk
Presenting Author Title:	Professor

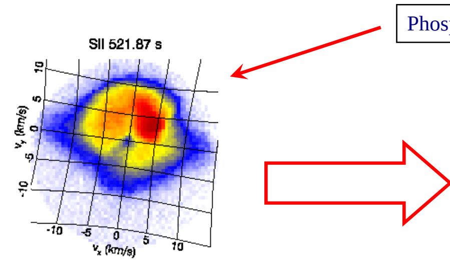
Development of the Suprathermal Ion Imager and the Role of Sounding Rockets

D. Knudsen, J. Burchill, L. Sangalli
University of Calgary



Ion Distribution Function Imaging

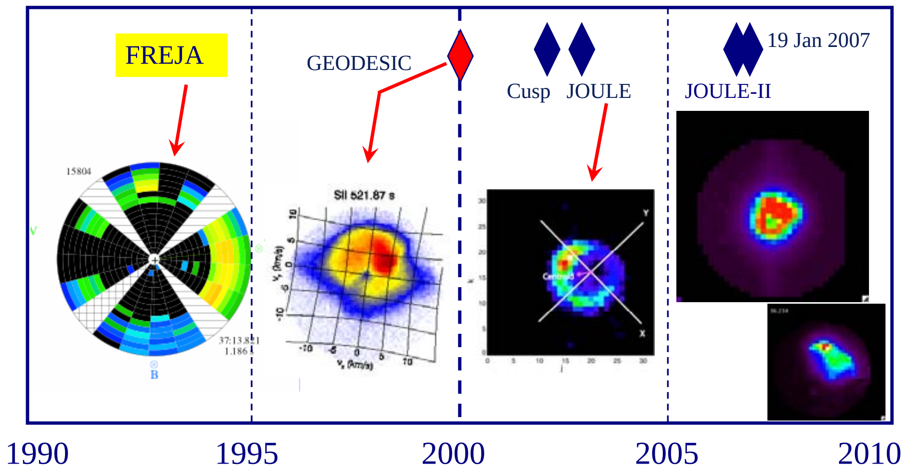




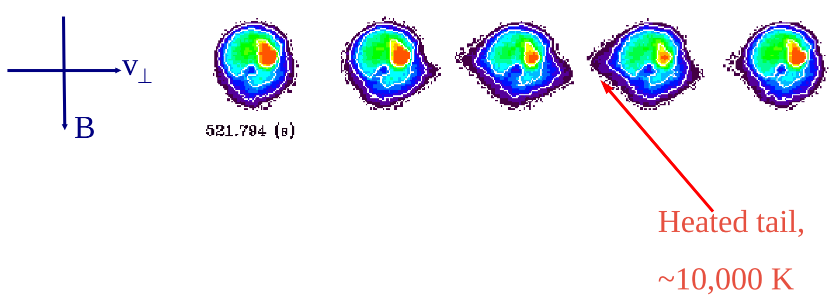
- velocity 2-D
  - **E** = -**v**x**B**
- temperature
- density

Burchill et al., J. Geophys. Res., 2004

Suprathermal Ion Imager Development



Rapid Imaging [GEODESIC example]



QuickTime™ and a YUV420 codec decompressor are needed to see this picture.

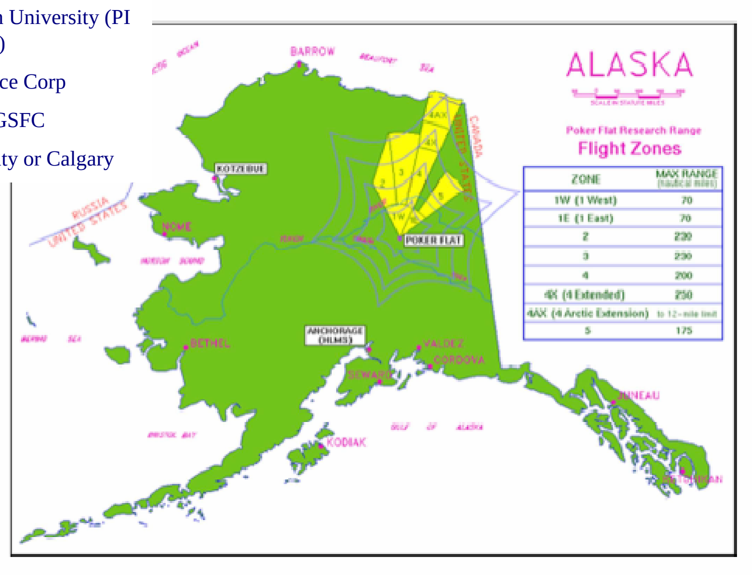
JOULE-I: Mar 2003 JOULE-II: Jan 19, 2007

Clemson University (PI Institute)

Aerospace Corp

NASA/GSFC

University or Calgary



JOULE-I Ion Drift: SII versus **ExB**

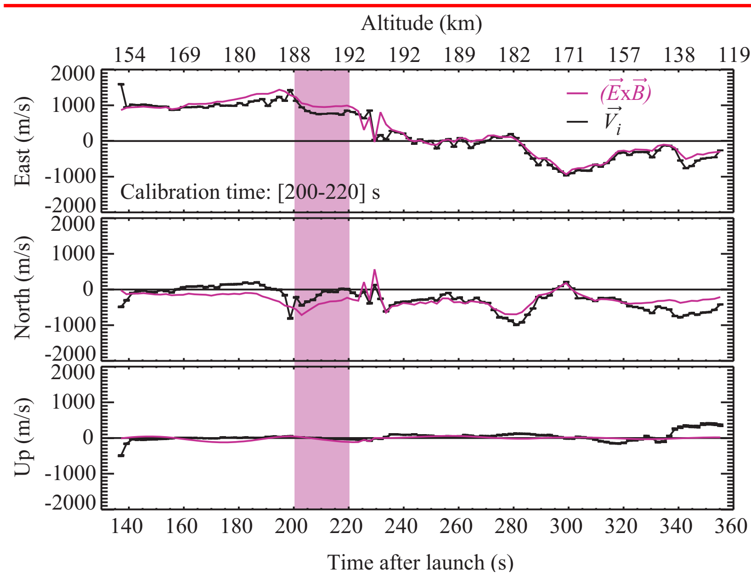


Figure: Laureline Sangalli

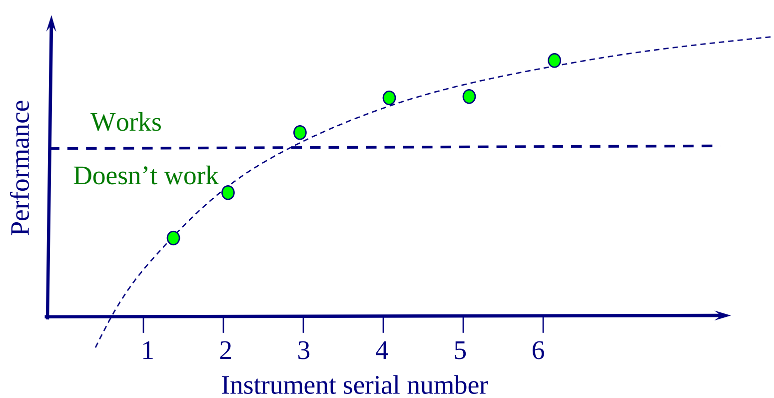
JOULE-I ion temperatures

(Arbitrary Units)

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

Figure: Laureline Sangalli

Development of a new instrument concept



O. Storey, "What's wrong with space plasma metrology?", *in Measurement Techniques in Space Plasmas*, 1998.

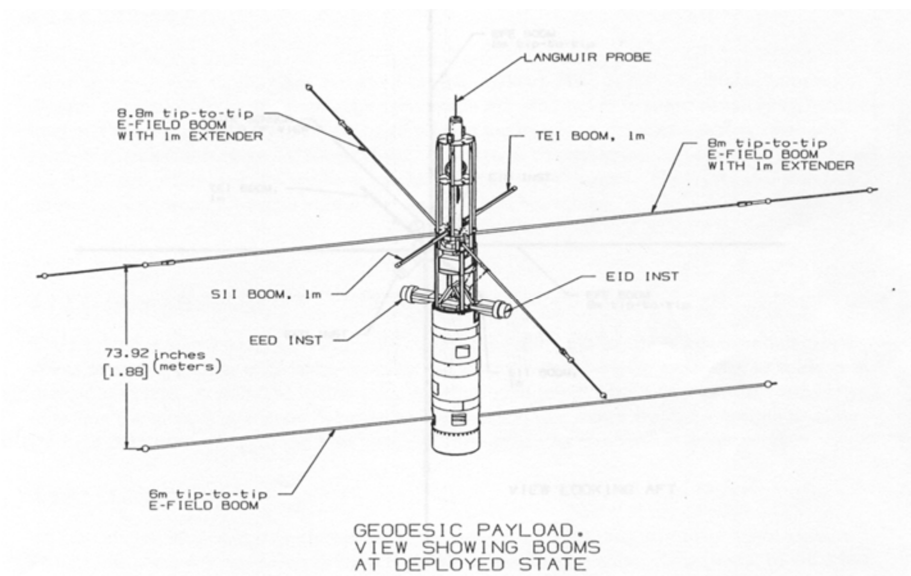
Thoughts

1) Hitch-hiking (Cusp, JOULE-I/II) has been fruitful and cost-effective (10% of GEODESIC's cost), but Canada must take its turn in the lead.

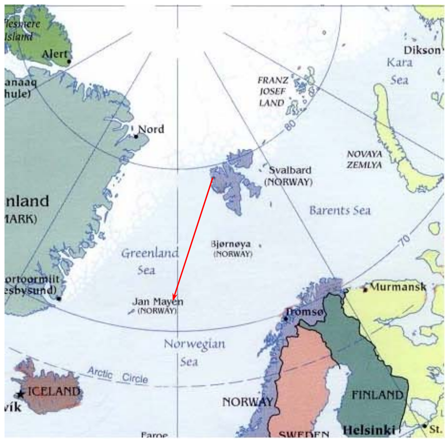
2) Canadian-led rocket missions :

- OEDIPUS-C (1995): 24 peer-reviewed publications
- GEODESIC (2000):
  - 5 publications to date (2 theses☐)
  - 5 follow-on missions (Cusp, JOULE-I/II, ePOP Swarm) resulting from concept demonstration.

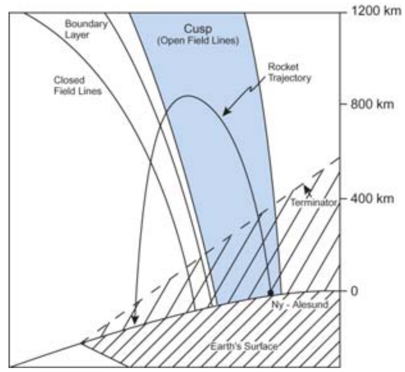
3) Note: Canadian industry remains willing and able to carry out Canadian-led sounding rockets.

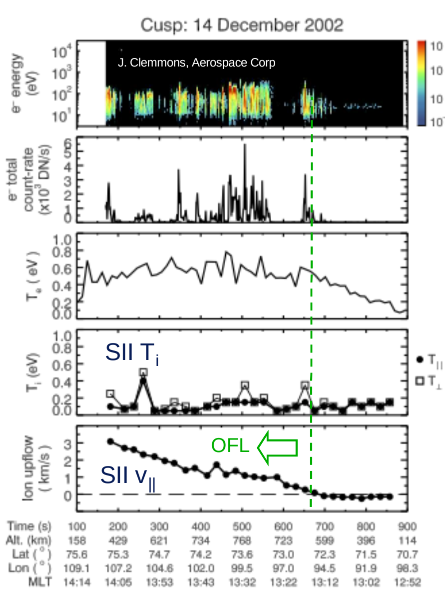


Cusp rocket: Polar wind cause & effect



14 December 2002



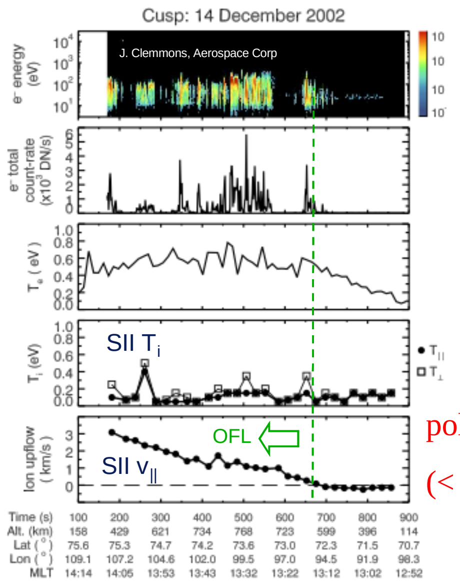


Burchill et al., GRL, submitted, 2005

Implied outflow mechanism:

Ambipolar $E_{||}$ from soft e- precipitation.

$\Rightarrow$ I.e. NOT photo-electrons in this case

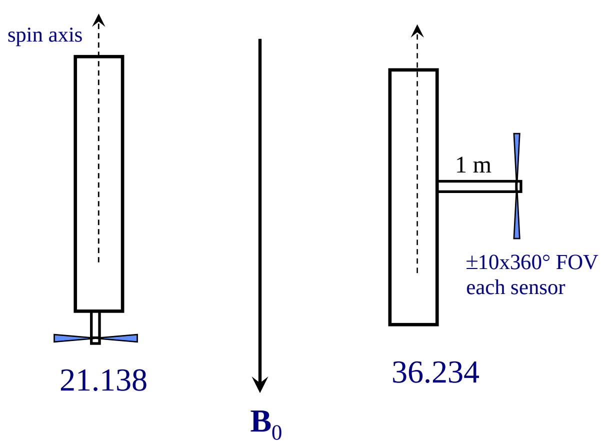


polar wind outflow

(< 0.75 eV!)

Burchill et al., GRL, submitted, 2005

JOULE-II: January 19, 2007, 0330 LT



The History of Canada's Black Brant Suborbital Rocket

Andrea Legary
Bristol Aerospace Limited

Abstract:

Canada's early space science program made great use of the research benefits offered by suborbital rockets. The benefits included the ability to take measurements at the altitude between the minimum altitude of satellites and the maximum altitude of balloons. Suborbital rockets provided a relatively fast response capability, permitting scientists to conduct their experiments at a time and pace of their choosing. Bristol's involvement in a typical suborbital rocket mission usually lasted approximately two years from project start to launch. Suborbital rocket programs were also considerably less expensive than satellite missions. While the rocket missions of the late-1980s and 1990s were becoming more complex and expensive compared to the missions of the 1960s, they were still less costly than a normal satellite mission. The Black Brant supported a wide variety of space science missions including, space physics, astronomy, and microgravity research, among others. Since its first launch in 1962, more than 1,000 Black Brant rockets were launched from 21 sites around the world. Although it has been years since the last Canadian-led sounding rocket was launched, Bristol still possesses the knowledge and expertise required for the support of these missions.

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Presenting Author Email:	Andrea.Legary@Magellan.Aero
Presenting Author Telephone:	(204) 775-8331 x.3146
Preferred Session:	Industrial capabilities and interests
Presentation Method:	Talk
Presenting Author Title:	Industry

Bristol Aerospace Limited

History of the Black Brant Sounding Rocket

Presented to The Community Workshop on Science from Suborbital Vehicles

Toronto, Ontario

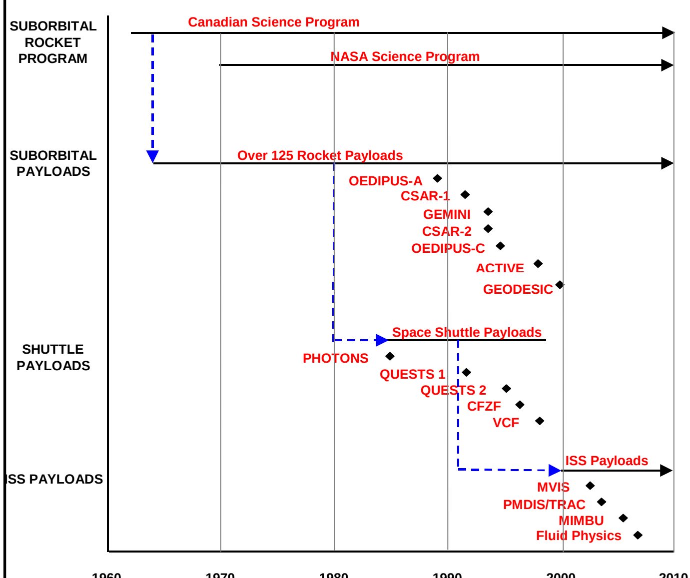
Thursday February 1, 2007
By Andrea Legary

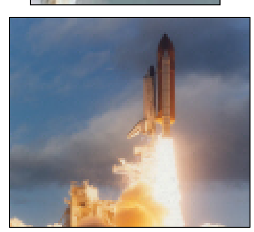
Magellan Winnipeg Corporate Information

Magellan Winnipeg: Bristol Aerospace Limited

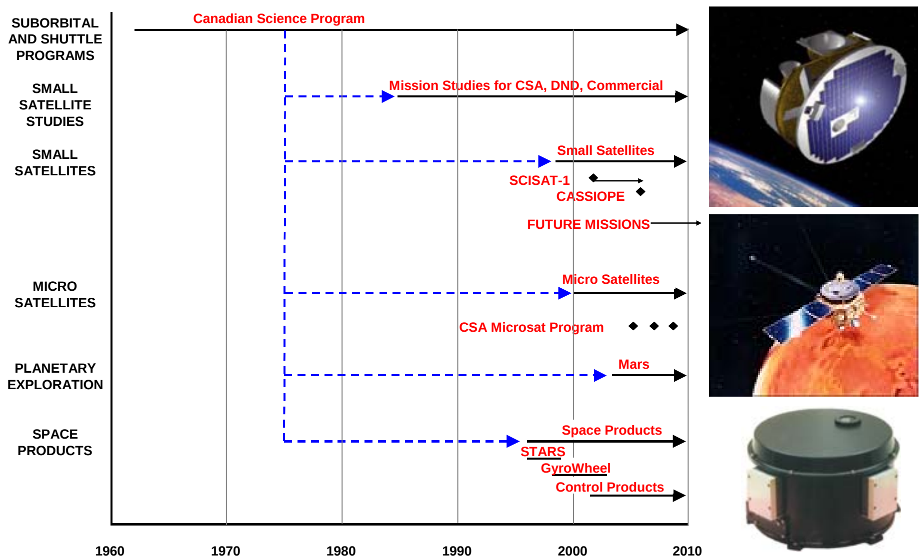
- Founded in 1930 as McDonald Brothers
- First involvement with aircraft -- fixing floats for bush pilots
- World War II support for Air Force -- built 2,000 Anson trainers
- Purchased by Bristol Aeroplane Co. in 1954
- Turned over to Rolls-Royce PLC in 1966
- Purchased by Magellan in 1997

Space Program Roadmap





Space Program Roadmap



Launch Vehicles

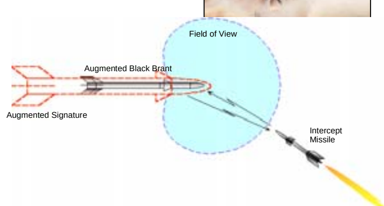
Black Brant

- Black Brant family of rocket vehicles are used for scientific research and/or TMD training
- Approximately 1000 BB vehicles flown from 20 sites around the world
- Overall Reliability Rate of 98.5%
- Key BB customer is NASA

  Goddard Contractor Excellence Award - 1998

Excalibur

- Suitable for civil meteorological research
- Simple two-man portable operation

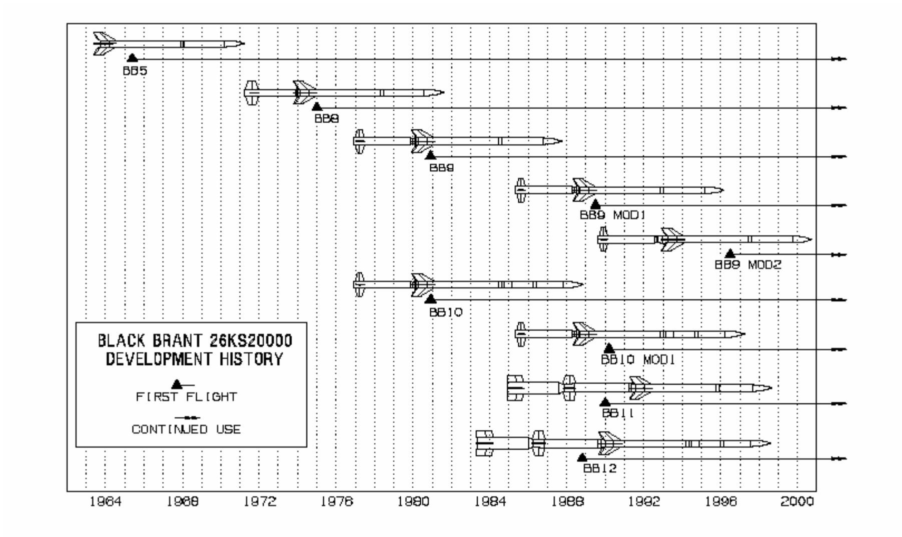


The Black Brant Sounding Rocket

History of the Black Brant

- Developed as the result of research at CARDE in the 1950's
- In 1957 CARDE contracted Bristol to develop a rocket fuselage for use on the Propulsion Test Vehicle for studies into high-power solid fuels
- Interest in using the vehicle as a sounding rocket developed and new lighter rockets were developed as part of the Black Brant Family
- The design continues to evolve today as design updates are made to improve performance

History of the Black Brant

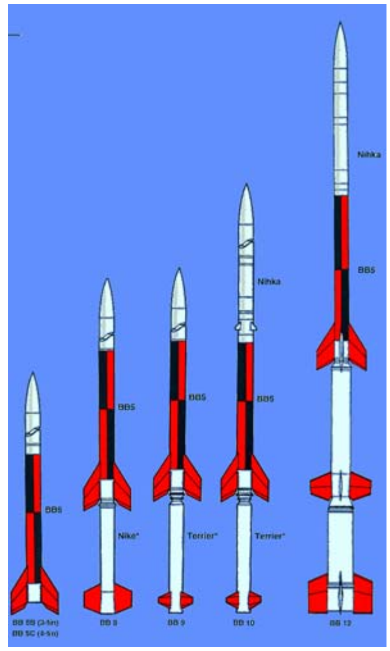


Civilian Uses of the Black Brant

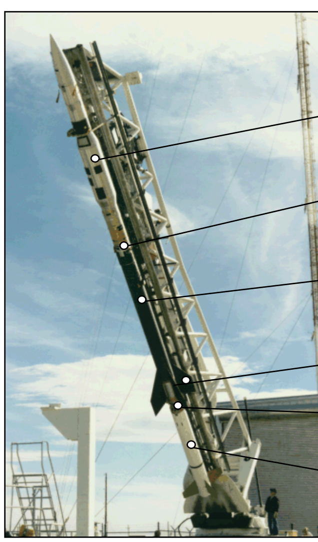
- Space science community is the largest user base:
  - Aeronomy
  - Astronomy
  - Plasma physics
  - Solar physics
  - Micro gravity
- NASA is Bristol's prime customer

Black Brant Vehicles

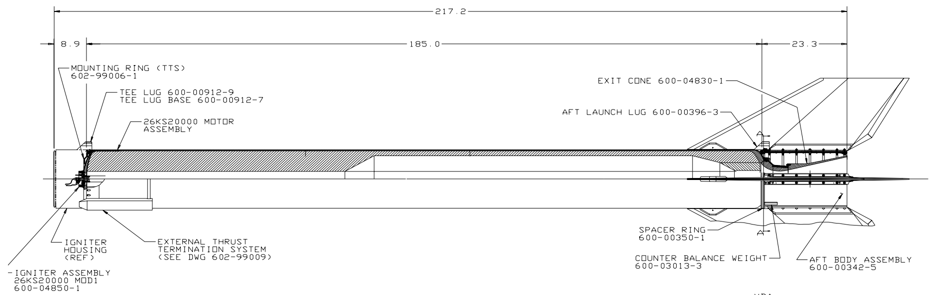
- Black Brant 5,8,9,10,11,12
- Building block approach with BB5 as core motor
- 1 to 4 stages
- Solid rocket motor technology
- Proven; 98% launch reliability

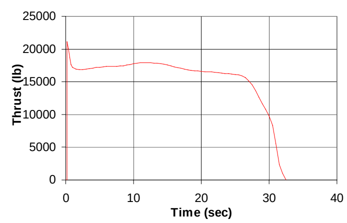


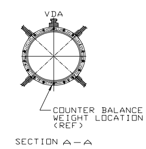
Basic Vehicle Components



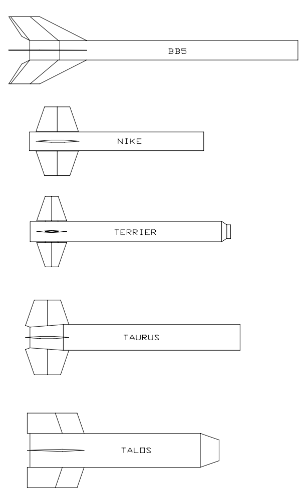
BB5 Motor







Booster Motor

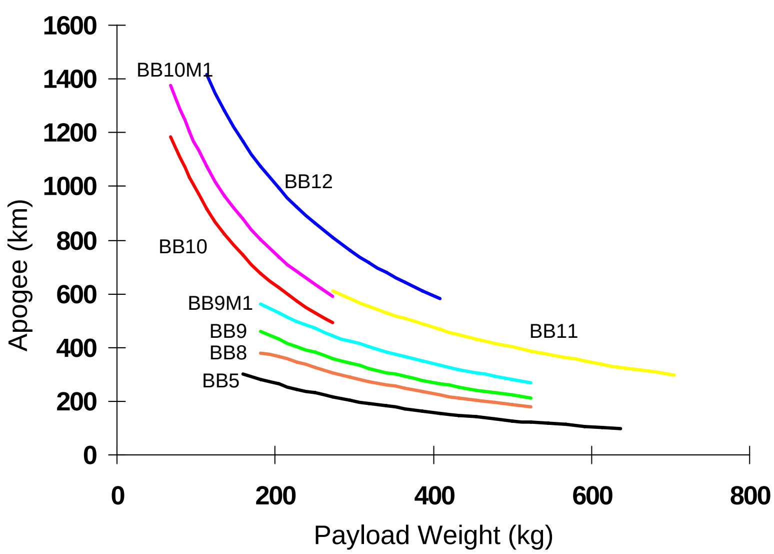


- Several different military surplus boosters are used:
  - Nike (Nike ABM systems)
  - Terrier (Terrier and SM2 systems)
  - Taurus (Improved Honest John)
  - Talos (Talos missile system)
- Integrated with BB5 to provide increased performance

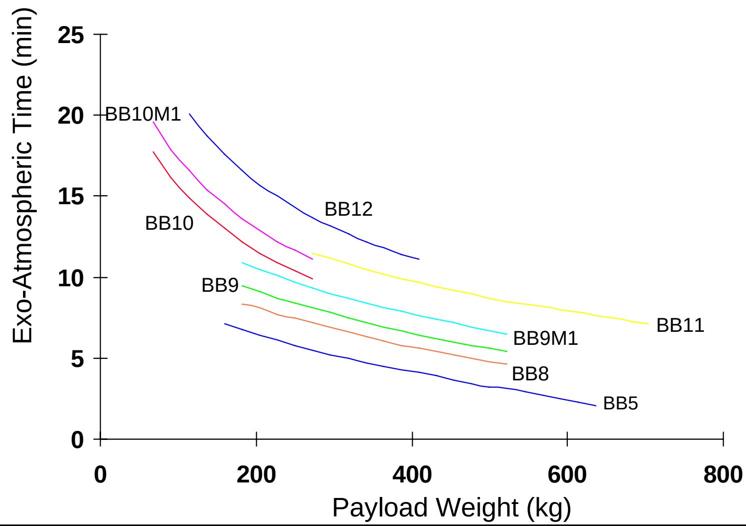
Payloads

- The payload is defined as everything forward of the forward most motor and varies from mission to mission.
- Payloads can range from 150lbs to 1900 lbs in weight and 81” to 310” in length.
- Payload diameters are typically 17.26” but payloads with parallel sections as small as 9” and as large as 23 inches in diameter have been flown.

Vehicle Performance



Exo-Atmospheric Time

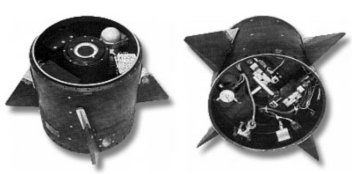


Vehicle Dispersion

- Black Brant Vehicles are designed to fly spin stabilized and unguided
- For missions where reduced vehicle dispersion is required, the guidance systems are added.
- Saab S-19 boost guidance system is presently used - 98% reliability in over 100 launches on Black Brant
- Usually use the S-19 system with a recoverable payload so that it can be recovered and refurbished

Flight Mode	3σ Dispersion Rad % of Apogee Alt	Flight Status
Unguided	40	Proven
S-19	7.5	Proven
LC-GCS	2	New

Saab S-19



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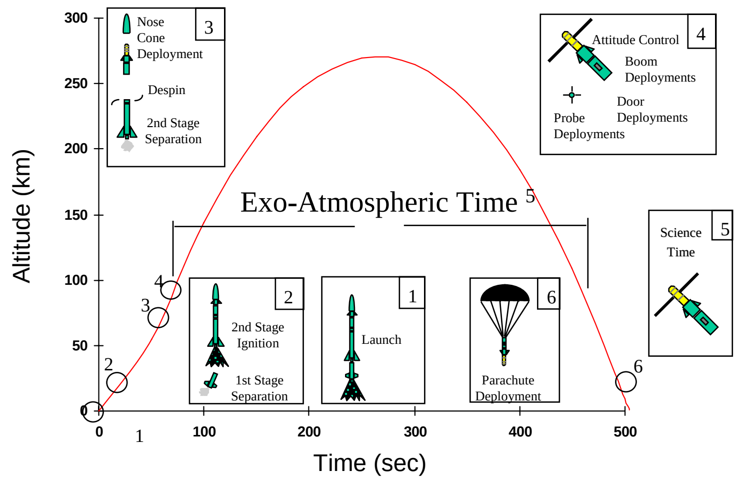
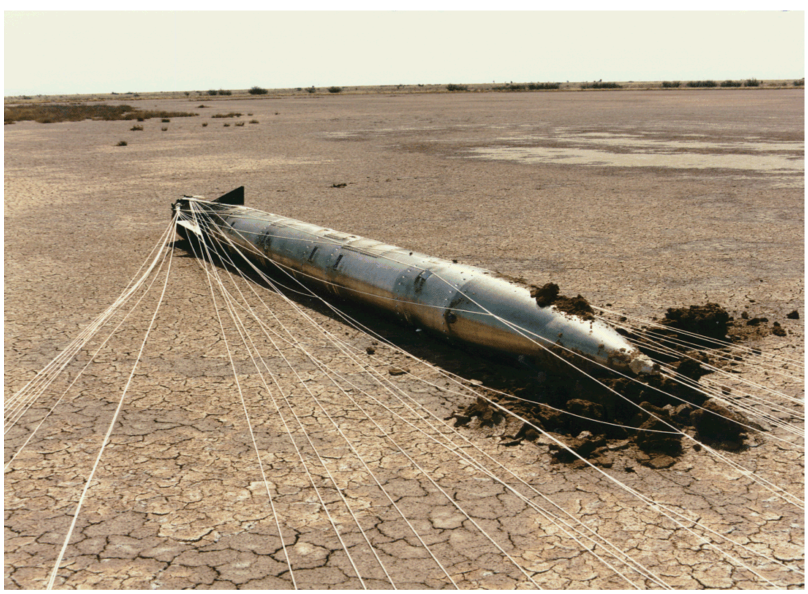
Typical BB9 Mission Profile



CSAR-1 Recovery Photo



Suborbital Programs

Canadian Suborbital Program

- Dates back to 1960
- Over 130 Canadian missions
  - Solar-terrestrial physics
  - Aeronomy
  - Astronomy
  - Microgravity
- Progression to more complex missions, heavier payloads, higher altitudes
- Last Canadian-led Sounding Rocket (GEODESIC) launched in 2000
- Launch sites all over the world

Benefits of Sounding Rockets

- Access to the Earth's mesosphere and lower thermosphere (40 - 120 km), as well as higher altitudes up to 1400 km.
- Low cost.
- Rapid response times (From 1-2 years, has been as fast as 6 months)
- Provision of several minutes of ideal, "vibration-free" microgravity.
- Ability to gather *in-situ* data in specific geophysical targets such as the aurora, the cusp, the equatorial electrojet, noctilucent clouds, thunderstorms, etc.
- Access to remote geophysical sites and southern hemisphere astronomical objects.
- Long dwell times at apogee.

Benefits of Sounding Rockets

- Slow vehicle speed with respect to the ambient medium (and much slower than that of orbiting satellites).
- Collection of vertical profiles of geophysical parameters.
- Ability to fly simultaneous rockets along different trajectories (e.g., with different apogees, flight azimuths).
- Ability to fly numerous free-flying sub-payloads from a single launch vehicle.
- Ability to recover and re-fly instruments from certain launch sites.

Bristol Experience

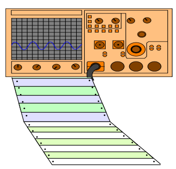
- Bristol was CSA's prime contractor for payload development;
  - design
  - Manufacture
  - integration and test
  - launch support
- Pre-Flight Mission Analysis
- Mission planning
- Support instrument development and test
- Launch Support
- Rocket Vehicle Analysis Support

Rocket Payload Capabilities

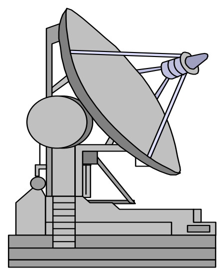
- Data acquisition and telemetry
- Sequencing/Control
- Power
- Tracking
- Environmental issues
- Support systems

Data Acquisition and Tracking

- Data rates to 10 Mbps
- Composite PCM downlinks
  - Analog data interface
  - Serial digital interface
  - Parallel digital interface
  - Counters
- Dedicated PCM links for instruments

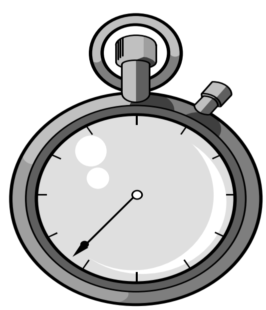


- TV links
- FM/FM multiplex systems
- Onboard data storage (recovered payloads)
- Multiple TM downlinks (5)



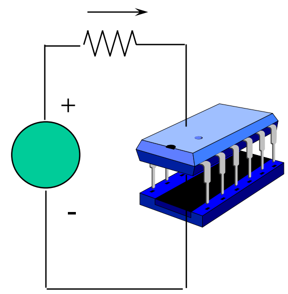
Sequencing/Control

- Centralized instrument and bus control, some autonomy
- Time based events
- Redundant implementation
- Vehicle control, pyrotechnics
- IMU based control, attitude
- Uplink control



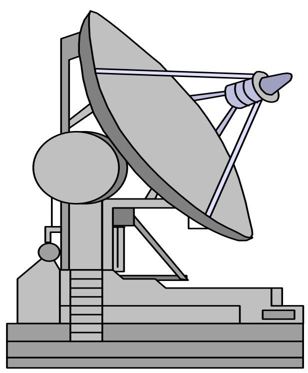
Power

- Bus normally provides all power
- Battery based system
- Standard +ve and -ve buses, shared, +28V, -18V
- Full protection, instrument to instrument
- Special requirements;
  - Low bus noise, dedicated sources
  - High power requirements; 15kW



Tracking

- Radar Tracking
  - Skin
  - Transponder
  - Not available everywhere
- TRADAT
  - Closed loop ranging
  - TM antenna pointing
  - Up to 0.1 km positional accuracy
- GPS
  - C/A code, < 100 meters



Payload Support Systems

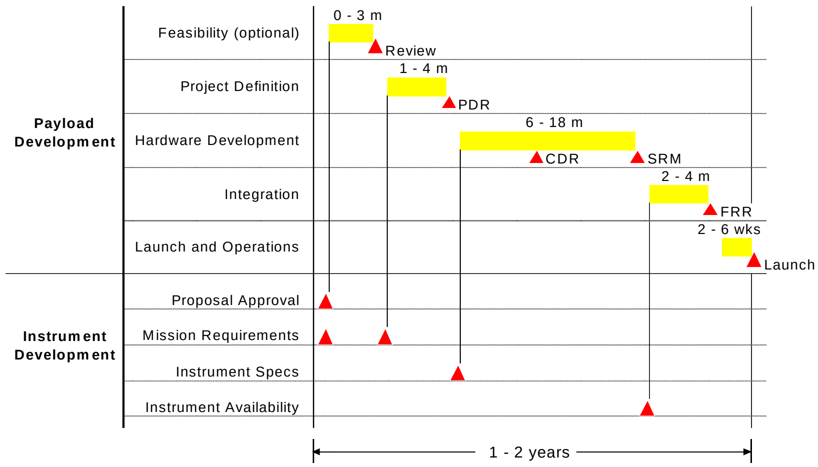
- Many different flight proven support systems are available to maximize payload effectiveness:
  - Payload Fairings
  - Payload recovery
  - Vehicle guidance
  - Payload attitude control
  - Deployable fairings and doors
  - Booms
  - De-spin systems
  - Bulbous sections to accommodate up to 22” diameter payloads (nominal 17.26” diameter)

Space Products - STARS

STandard ARchitecture Support system

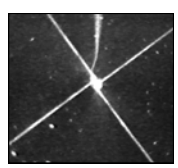
- An improved suborbital rocket payload architecture - Flight Qualified on GEODESIC
- Reduce sounding rocket mission costs by:
  - standardizing interfaces
  - reducing integration time
  - reducing payload mechanical layout time
  - reducing payload electrical design time
  - reducing range land line requirements

Typical Suborbital Project: Concept to Launch



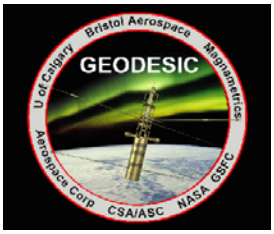
Previous Missions

- GEODESIC (2000)
- ACTIVE (1998)
- LAADEX (1996)
- OEDIPUS-C (1995)
- CSAR-2 (1994)
- GEMINI (1994)
- CSAR-1 (1992)
- COBRA (1990)
- OEDIPUS-A (1989)



GEODESIC

- Launched 26 February 2000
- PI – Dr. David Knudsen, University of Calgary
- Plasma Physics
- Most Recent Canadian-led Sounding Rocket
- Poker Flat Research Range, Alaska
- Used the STARS system for payload electrical support
- BB12, 990 km apogee, 17min of science data, payload weight 531lbs including structure & fairing

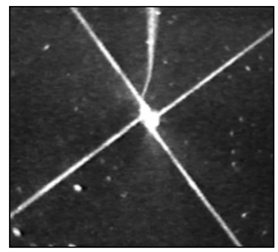


LAADEX

- Launched 13 June 1996
- US Navy customer
- Launched for as part of RIMPAC exercise
- Pacific Missile Range Facility (Hawaii)
- 227 kg payload
- BB5, 180 km apogee, 400 km impact range
- Passive radar reflector, tracking transponder
- First BB target payload

OEDIPUS-C

- Launched 6 November 1995
- CSA cooperative with NASA
- PI - Dr. Gordon James, CRC, DOC
- Solar-terrestrial physics
- Poker Flat Research Range, Alaska
- 255 kg payload
- BB12 vehicle, 843 km apogee
- Tethered subpayloads, RF propagation, RF effects on plasma



CSAR-2

- Launched 8 December 1994
- CSA project, commercial launch
- PI - Dr. R. Smith, Queen's U.
- Microgravity
- White Sands Missile Range, New Mexico
- 591 kg payload
- BB9 Mod2 vehicle, 247 km apogee
- 5 material science modules, 1 student experiment
- Recovered

GEMINI

- Launched 9 February 1994
- CSA cooperative with NASA
- PI - Dr. F. Harris, HIA, NRCC
- Aeronomy
- White Sands Missile Range, New Mexico
- 538 kg payload, 22” diameter section
- BB9 Mod1 vehicle, 243 km apogee
- Airglow characterization, wide spectral range, high spatial and spectral resolution
- Recovered

CSAR-1

- Launched 19 March 1992
- CSA cooperative with NASA
- PI - Dr. R. Smith, Queen’s U.
- Microgravity
- White Sands Missile Range, New Mexico
- 530 kg payload
- BB9 Mod1 vehicle, 227 km apogee
- 5 material science modules, 1 engineering test experiment
- Recovered

COBRA

- Launched 20 January 1990
- CSA cooperative with NASA
- PI - Dr. H. Gush, UBC
- Astronomy
- White Sands Missile Range, New Mexico
- 417 kg payload
- BB8C vehicle, 250 km apogee
- Cosmic background radiation mapping, liquid helium cooled detector
- Recovered

OEDIPUS-A

- Launched 30 January 1989
- CSA cooperative with NASA
- PI - Dr. G. James, CRC, DOC
- Solar-terrestrial physics
- Andoya Research Range, Norway
- 266 kg payload
- BB10 vehicle, 512 km apogee
- Tethered subpayloads, RF propagation, RF effects on plasma

Video of BB Return to Flight September 2006

Questions?

Development of a prototype Langmuir probe for the ICI-1 sounding rocket

Johnny Aase
Department of Physics and Astronomy
The University of Calgary

Abstract:

In this talk I will describe the development of a prototype Langmuir probe for the ICI-1 (Investigation of Cusp Irregularities) sounding rocket, which was my Master thesis work at the University of Oslo, Norway.

This instrument was designed to obtain an electron density profile of the polar cusp ionosphere over Svalbard in the Norwegian Arctic at altitudes between 90 and 300 km, and resolve HF backscatter targets in the F layer. The probe would measure large-, meso-, and microscale variations in the electron density, and also provide data for determining the rockets spin rate and attitude. Near apogee the spatial resolution would have been half a meter.

The probe was a hollow 30 millimeter diameter aluminium sphere. It was mounted on a deployable instrument boom. The electron-collecting hemisphere was biased with a +3.3 V voltage. The sampling frequency was 2 kHz. The rocket was launched from Ny-Aalesund on Svalbard in November 2003, but was lost 17 seconds after launch.

I will also briefly discuss the Norwegian cost-effective Hotel Payload concept being developed by Andoya Rocket Range.

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Preferred Session: Past projects and case studies
Presentation Method: Talk
Presenting Author Title: Research Associate

Development of a prototype Langmuir probe for the ICI-1 (Investigation of Cusp Irregularities) sounding rocket

- Johnny Grøneng Aase
- Master project
- University of Oslo
- University courses on Svalbard (UNIS)

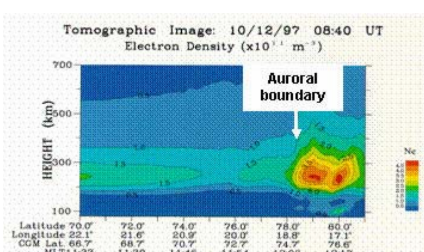
Overview

- Project description
- Background information
- Instrument
  - starting point
  - hardware and electronics
- Launch, Hotel Payload concept
- Results
- Improvements

Project description

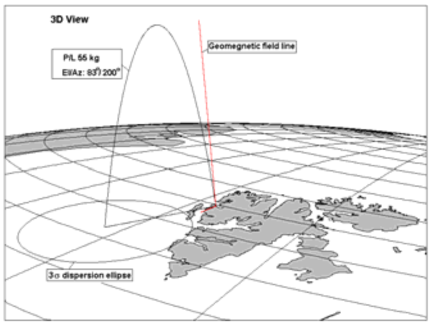
- Obtain a high-resolution electron density profile in the polar cusp ionosphere over Svalbard
- 90-295 km altitude
- Map layers and structures inside an ionospheric F-layer patch
- Determine rocket spin rate and attitude

Ionospheric patch



- Enhanced plasma density in polar cusp
- 100-1000 km
- Antisunward convection drift, 1 km/s

ICI-1 flight path

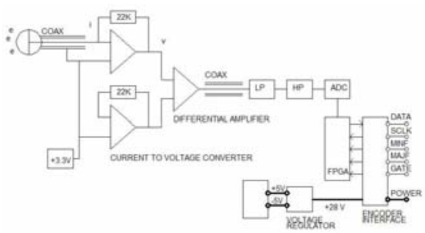


- Ny-Ålesund, 79°N
- Nike-Improved Orion
- 295 km apogee
- Langmuir probe deployment, 48 s
- 90 km

Starting point

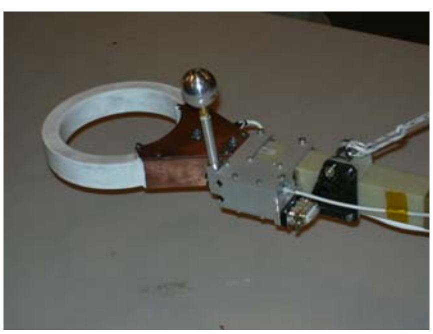
- Time: January - November 2003
- 200-300 mA, 28 V
- 16 bit resolution
- $I = 1/4 q N_e A \sqrt{(8kT_e/\pi m_e)}$
- $N_e = 10^{10} - 10^{12}\ m^{-3}$
- $T_e = 2000 - 5000$ K
- 10 nA - 100 μA

System overview



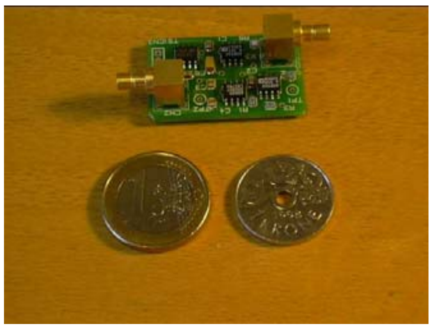
- Charge-collecting sphere
- Preamplifier
- Main electronics
- Encoder interface

Charge-collecting sphere



- Hollow Al sphere
- Diameter 30 mm
- +3.3 V bias voltage
- Covered with carbon during flight

Preamplifier



- Mounted on instrument boom
- IV-converter + amplification
- 3.3 V bias voltage
- 35 x 21 mm
- Only analog components

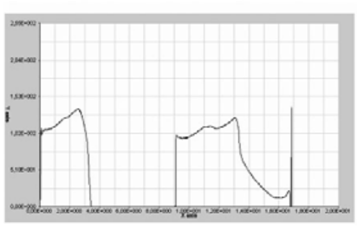
Main electronics

- 8-pole Sallen-Key Butterworth filter. fc_1 = 0.3 Hz, fc_2 = 2 kHz
- 16 bit ADC
- 2 kHz sampling frequency
- 50 cm spatial resolution at apogee

Launch...

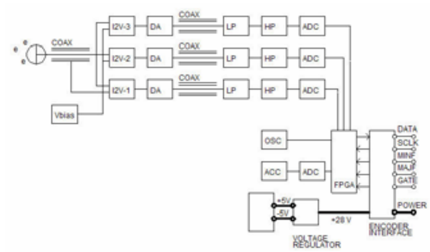
- Launch window: Nov 26 – Dec 8 2003, 0800-1200 UT
- Nike-Improved Orion
- Hotel Payload - 200 mm diameter
- 5 million NOK =
  950 000 CAD

…failure



- Lost contact after 17 sec
- Altitude 11-12 km
- No scientific data
- “Second stage and payload not stiff enough to withstand the high dynamic pressure (…)”

Proposed improvements



- 16 -> 10/12 bit
- 2 or 3 channels
- Accelerometer -> liftoff pulse
- Oscillator - > Sigma-Delta converter
- Larger probe
- Higher bias voltage

Case Study of a Hitch-hiker: The Thermal Suprathermal Analyzer (TSA) Instrument on the Japanese SS520-2 Rocket

Andrew Yau
University of Calgary
Department of Physics and Astronomy

Abstract:

The Thermal Suprathermal Analyzer (TSA) is a recent example of a Canadian instrument hitch-hiking on a foreign (Japanese) sounding rocket and subsequently evolving into a satellite instrument. The SS520-2 rocket was launched in December 2000 from Spitsbergen, for study of ion acceleration and outflow in the topside cleft ionosphere. The successful flight of TSA on SS520-2 has led to an opportunity to fly the Suprathermal Ion Imager instrument in an upcoming follow-on flight in 2007. We discuss our experience and lessons learned in the SS520-2 project, the benefits, drawbacks, and challenges of "hitch-hiking mode" sounding rocket experiments, and our vision of life in the hitch-hiker lane. In addition, we explore possible strategies to optimize or create future "hitch-hiking" and other flight opportunities.

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Preferred Session:	Past projects and case studies
Presentation Method:	Talk
Presenting Author Title:	Professor

The Thermal Suprathermal Analyzer (TSA) Instrument on the Japanese SS520-2 Rocket
or
“Life in the Hitch-hiker Lane”

Andrew Yau, University of Calgary

- TSA and SS520-2
- Life before and after
- Benefits, drawbacks and challenges of hitch-hiking
- Optimization and creation of opportunities

SS520-2

Science Objective: Microphysics of ion acceleration and outflow in polar cusp/cleft

Launch: Svalbard, December 4, 2000

Apogee: 980 km

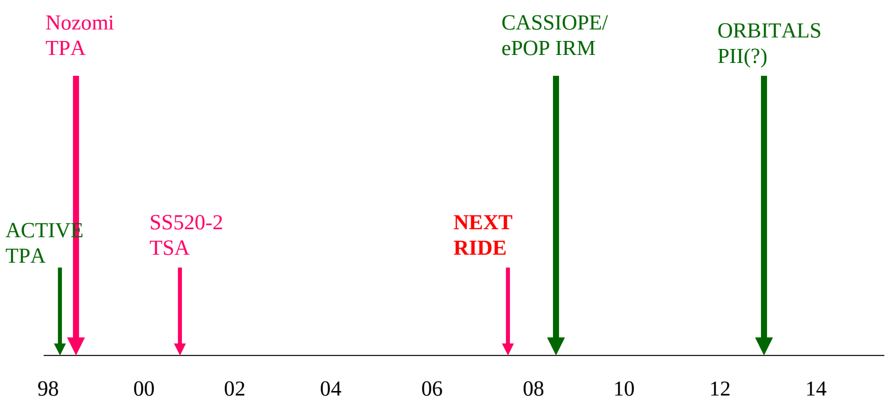
TSA

Thermal Suprathermal Analyzer

- **Hemispheric electrostatic analyzer; time-of-flight**
- **2-D ion velocity distribution**
  - **Fast, mass-resolved**
  - **20-ms resolution**
  - **1-100 AMU/q; H^+, He^+, O^+**
  - **0.5-20 eV/q (12 energies)**
  - **8 angles**

Feb 1, 2007 Community Workshop on Science from Suborbital Vehicles 4

Life Before and After TSA



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Hitch-hiking: Benefits

- Don't have to walk … really!
  – Instrument doesn't have to stay on the ground
- Low cost to CSA
  – <10% of 1 Black-Brant-X
- The experience
  – Learn from the other side, and enjoy the experience!
- Risk reduction
  – Help spread out risk and make program more sustainable

The TSA Experience

Hitch-hiking: Drawbacks and Challenges

- "Why the door bell has to ring during Happy Hour?"
  - Opportunity often inconsistent with CSA schedule
- "Don't call us; we will call you"
  - No NSERC/IOF type or NASA/MOO AO; and no Unsolicited Proposal
- "You first, Ma'am"
  - Agency A won't commit until Agency B has, and vice versa
- "We can only put you on standby"
  - No mechanism to work opportunity into CSA Work Plan
- When in Rome, do what the Romans do!
  - Adapting to multiple interface standards can be tricky or frustrating

Optimization and Creation of Opportunities

- "Opt in" or "opt out"
  - Both CSA and community must decide
- Be strategic
  - Develop small payload international collaboration strategy
  - Target at specific international partner
  - Establish community-based "Canadian" and bilateral SWG
  - Negotiate long-term collaboration programs with "like-minded" (and like-size) agencies

Talks – Day 2

Friday, February 2						
Chair	**Start**	**End**	**Duration**	**Session**	**Name**	**Theme**
	8:30	9:00	30	Coffee and Refreshments		
Marcotte	9:00	9:15	15	If I Had a Million Dollars	Earle	Aircraft
Marcotte	9:15	9:30	15	If I Had a Million Dollars	Grishin	Aircraft
Marcotte	9:30	9:45	15	If I Had a Million Dollars	Hegglin	Aircraft
Marcotte	9:45	10:00	15	Proposals	Brown	Aircraft
Marcotte	10:00	10:15	15	Proposals	Whiteway	Aircraft
Marcotte	10:15	10:30	15	Past/Case Studies & Proposals	Morrow	All 3
Marcotte	10:30	10:45	15	Past / Case Studies	Drummond	Balloons
	10:45	11:15	30	Posters / Refreshments	**See list below**	
Netterfield	11:15	11:30	15	If I Had a Million Dollars	Toohey/Wunch	Balloons
Netterfield	11:30	11:45	15	Proposals	Quine	Balloons
Netterfield	11:45	12:00	15	Proposals	Walker	Balloons
Netterfield	12:00	12:15	15	Proposals	Kruzelecky	Balloons
Netterfield	12:15	12:30	15	Proposals	van Kerkwijk	Balloons
Netterfield	12:30	12:45	15	Proposals	MacTavish	Balloons
Netterfield	12:45	1:00	15	If I Had a Million Dollars	Burchill	Rockets
	1:00	2:00	60	Lunch		
	2:00	3:30	90	Break-out sessions	Leads & Reporters: Whiteway & Hegglin, Quine & Walker, Knudsen & Burchill	Break-out
	3:30	4:00	30	Refreshments		
Strong	4:00	4:15	15	Report from aircraft session	Whiteway & Hegglin	Plenary
Strong	4:15	4:30	15	Report from balloon session	Quine & Walker	Plenary
Strong	4:30	4:45	15	Report from rocket session	Knudsen & Burchill	Plenary
Strong	4:45	5:30	45	General discussion		Plenary
	5:30			End		

A New Approach for Observing Ice Crystal Habit in Model Cirrus Clouds

M.E. Earle*: Department of Chemistry, University of Waterloo
T. Kuhn: Department of Chemistry, University of Waterloo
I.A. Grishin: Department of Chemistry, University of Waterloo
J.J. Sloan: Department of Chemistry, University of Waterloo

Abstract:

Physical and chemical information about cloud particles is of great importance to the understanding and prediction of climate change because the sizes and morphologies of cloud particles greatly influence light scattering and consequently the redistribution of solar energy in the atmosphere. In particular, ice crystals in cirrus clouds exhibit a variety of sizes, shapes and habits, depending on the ambient temperature and relative humidity during their nucleation and growth phases. The ability to predict the properties of the cloud particles and hence their effects on atmospheric radiative transfer is essential for climate modeling.

To this end, we have developed a means of imaging micron-sized ice particles in the laboratory under temperature conditions representative of those in cirrus clouds. The conditions are created within a cryogenic aerosol flow tube developed over the course of the past decade, comprising a temperature-programmable flow section capable of cooling to 150 K. Ice crystals formed from aqueous aerosols over a range of experimental temperature and flow conditions are then imaged using an optical microscope coupled to a CCD camera. The resulting images are of extremely high resolution (~ 1 um), allowing the structural details of the various ice crystal habits to be examined. Furthermore, the imaging results can be compared with the results from infrared spectra of ice particles obtained under the same conditions.

Here we will present our methodology within the framework of its feasibility for use in airborne aerosol measurements, and show examples of ice crystal habits obtained from micron-sized aqueous aerosols between 240 and 213 K. We will also discuss how imaging data have been used to validate our method of FTIR retrievals. In a companion presentation, we will discuss the image processing algorithms we have developed to determine the size and shape information from the images and present the results obtained from these algorithms.

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Preferred Session:	Proposals for future projects by graduate students and postdocs
Presentation Method:	Talk
Presenting Author Title:	Grad Student

A New Approach for Observing Ice Crystal Habit in Model Cirrus Clouds

- **Laboratory simulations of ice formation/growth**
- **Characterization of particles by FTIR**
- **Particle imaging using optical microscopy**
- **Adaptability of microscopy setup for airborne observations**

Mike Earle, Thomas Kuhn, Igor Grishin, and James J. Sloan
Waterloo Centre for Atmospheric Sciences
University of Waterloo
February 2, 2007

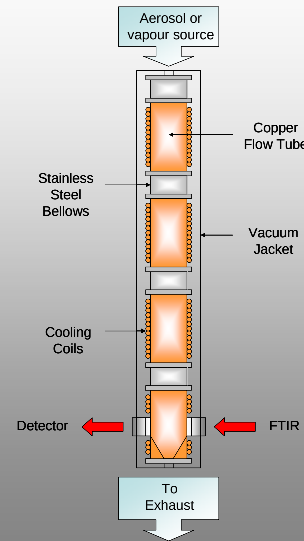
Introduction

- Cirrus clouds
  - Comprised predominantly of ice crystals under conditions of upper troposphere
  - Impact radiative balance
- Scattering of light dependent upon:
  - Particle size
  - Particle shape, or 'habit'
- Classification of habits
  - Hexagonal plates, columns, dendrites, bullets, etc.
- Climate models require detailed information:
  - Frequency of occurrence of habits

Images from T. Kobayashi & T. Kuroda, *Morphology of Crystals Part B*, ed. I. Sunagawa, Terra Scientific Publishing Co., 1987

Laboratory simulations

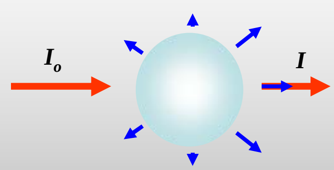
- Cryogenic flow tube apparatus
  - Four temperature-programmable sections
  - Chilled N_2 coolant
  - Control section temperatures between RT and -120 ºC (+/- 0.1 ºC)
  - Establish and maintain temperature profiles
- Aerosol generation
  - Ultrasonic nebulizer
  - Median particle diameter ~ 3 µm
- Observe resulting ice particles in bottom section using FTIR

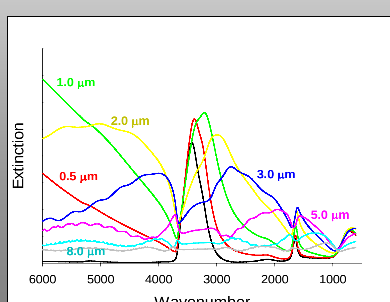


Ice particle characterization by FTIR

- Determination of aerosol properties:
  - Size distribution
  - Number density
  - Phase
  - Composition
  - Shape

Extinction = Absorption + Scattering

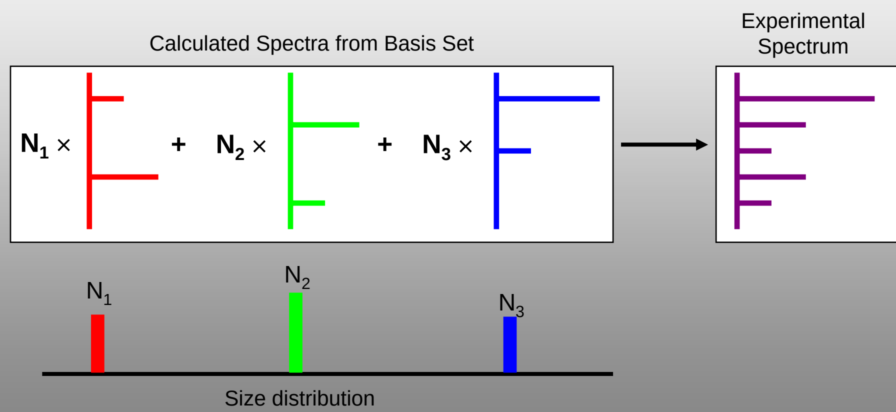




- Simulate extinction spectra
  - Mie theory
  - Spectral basis set
  - 96 radii (0.05 to 11.8 µm)

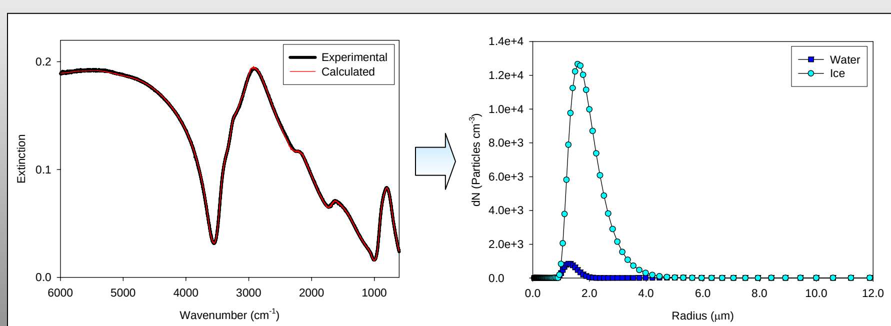
Ice particle characterization by FTIR

- Iteratively fit basis set spectra to experimental spectrum
  - Least-squares minimization



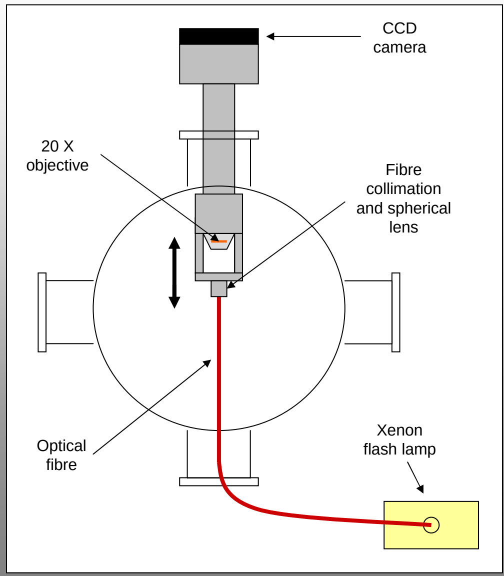
Ice particle characterization by FTIR

- Iteratively fit basis set spectra to experimental spectrum
  - Least-squares minimization



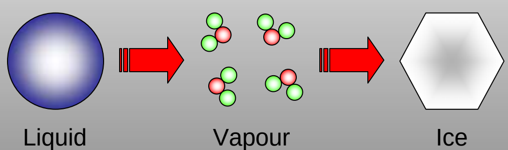
Particle imaging

- Illumination
  - Xe flashlamp driven by square wave (~ 100 Hz)
  - Maximum at 500 nm
- CCD
  - 1024 x 768 pixels
  - 4.65 µm pixel size
- 20X Objective
  - Working distance: 1 mm
  - 0.2 µm pixel size
  - 0.24 mm image width
  - Resolution < 1 µm



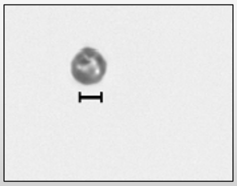
What happens in the flow tube?

- Freezing
  - Homogeneous nucleation of ice in supercooled water droplets
  - 1 in 10^4 or 10^5 droplets nucleate ice and freeze
- Mass transfer (deposition growth)
  - Vapour transfer from remaining liquid drops (higher vapour pressure) to nascent ice particles (lower vapour pressure)

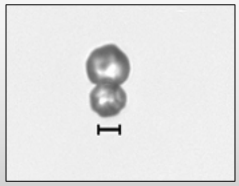


- Contact freezing (riming)
  - Freezing of supercooled water droplet upon contact with ice particle
- Simultaneous processes

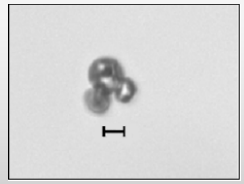
Crystal habit observations



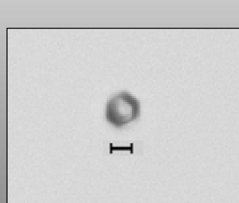
- Spherical frozen droplet



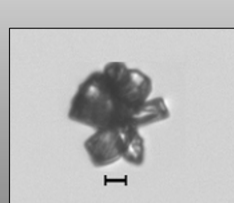
- Dimer (contact freezing)



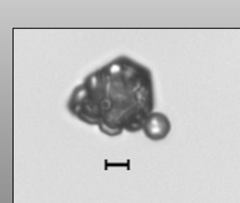
- Trimer (contact freezing)



- Hexagonal prism



- Mass transfer growth



- Mass transfer and contact freezing

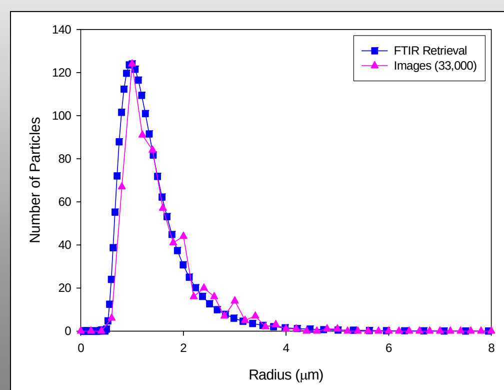
Scale = 7 μm

Comparison: Particle size distributions

- Compare size distributions from FTIR retrievals with those determined from particle images
    - Image processing algorithm (Dr. Igor Grishin)

- Obtained 33,000 images at RT
- Spherical water droplets
- Obtained FTIR spectra under identical conditions

- Verification of FTIR retrieval procedure



Adaptability for aircraft measurements

" We should put this thing on a plane and fly through clouds."

- Airborne imaging instruments - commercial
  - PMS (Particle Measuring Systems) Optical Array Probe – 2DC, PMS OAP-2DC
    - He–Ne laser, linear array of photodiodes
    - Resolution ~ 25 μm
    - Pattern recognition to classify particles
  - Cloud Particle Imager, CPI (SPEC, Inc.)
    - Pulsed laser, CCD
    - Resolution ~ 5 μm
    - Automatic habit classification for particles > 50 μm

Adaptability for aircraft measurements

" We should put this thing on a plane and fly through clouds."

- Airborne imaging instruments - prospective
  - Crystal Habit Optical Microscopy Probe (CHOMP)
    - Resolution < 1 μm
    - Discern fine details of crystal habit for micron-sized particles
    - Image processing algorithms to determine size, asphericity, and shape of particles
- Implementation
  - Key concerns:
    - Preserving cloud conditions (temperature, pressure)
    - Flow dynamics
    - Frosting/deposition of ice on optical components
    - Maximizing sampling volume
- If I had a million dollars…

Acknowledgements

- Dr. Strong and the organizing committee
- Sloan lab group
- University of Waterloo
- NSERC

- Thank you!!

Image Processing Method for Retrieving Ice Crystal Habits in Cirrus Clouds

I.A. Grishin*, M.E. Earle, T. Kuhn and J.J. Sloan
Department of Chemistry, University of Waterloo

Abstract:

Light scattering by ice particles in cirrus clouds depends on particle size, shape and habit, as determined by prevailing temperature and humidity conditions. The characterization of ice crystal habit in cirrus clouds is therefore an important step in establishing their effect on the Earth's radiative balance.

We have built an optical microscope assembly to record images of model cirrus cloud ice crystals created in a cryogenic flow tube under carefully controlled laboratory conditions. The details of this apparatus will be presented in a companion presentation. We have also developed image processing techniques capable of extracting size and shape distributions of the particles. These algorithms are based on the localization of contrast regions in the original image, followed by morphological analysis of the particle edges. Using this approach in combination with the method of moments, we can retrieve information about the particle size, aspect ratio (asphericity parameter) and compactness and relate this to the particle formation conditions.

The method was applied to the retrieval of size and shape distributions of water, sodium chloride and ammonium sulfate aerosols in the temperature range 213 - 243 K. Here we will illustrate the utility of these algorithms in characterizing ice particles in model cirrus clouds, and discuss the advantages and limitations of this approach.

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Presenting Author Telephone:	519 888 4713
Preferred Session:	Proposals for future projects by graduate students and postdocs
Presentation Method:	Talk
Presenting Author Title:	Postdoc

Image Processing Method for Retrieving of Ice Crystal Habits in Cirrus Clouds

Igor Grishin, Mike Earle, Thomas Kuhn and James Sloan

Department of Chemistry, University of Waterloo, ON, Canada

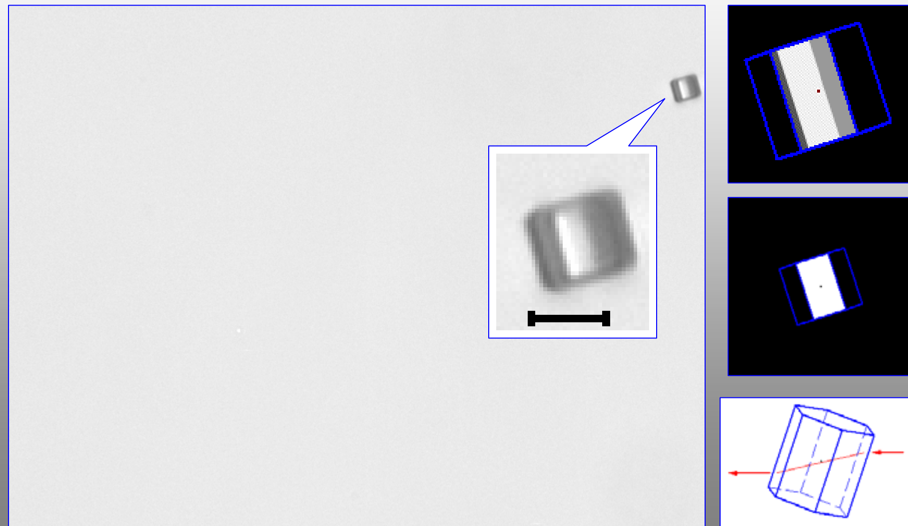
http://www.sciborg.uwaterloo.ca/wcas
http://www.sciborg.uwaterloo.ca/~sloanj

Objectives:

- observe the ice crystal particles by means of microscope
- develop the numerical technique for automatic image processing
- estimate the size and identify the shape of the particle
- describe the shape features of the particles by means of asphericity parameter

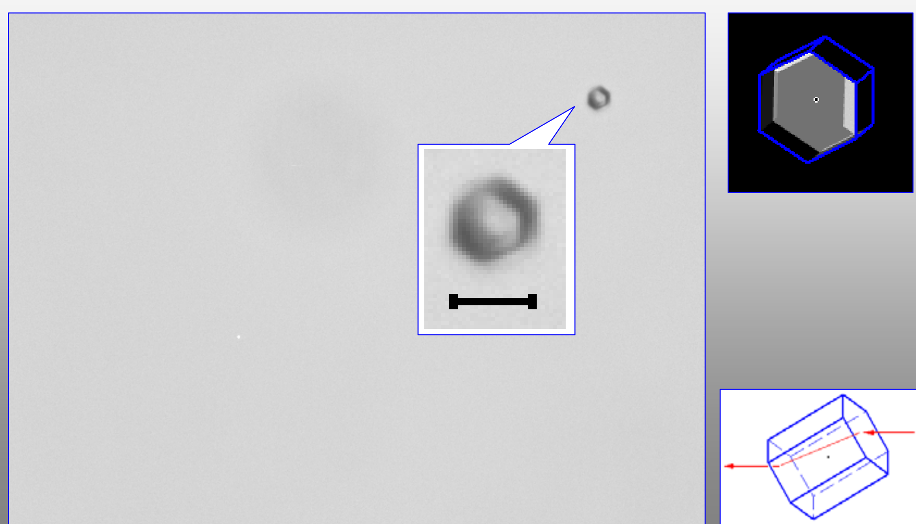
Light Scattering by Non–Spherical particles

Delta-transmission in prism crystal through *prism* facet:
size of the marker is 20 pixels (7.4 μm)



Light Scattering by Non–Spherical particles

Delta-transmission in prism crystal through *basal* facet:
size of the marker is 20 pixels (7.4 μm)



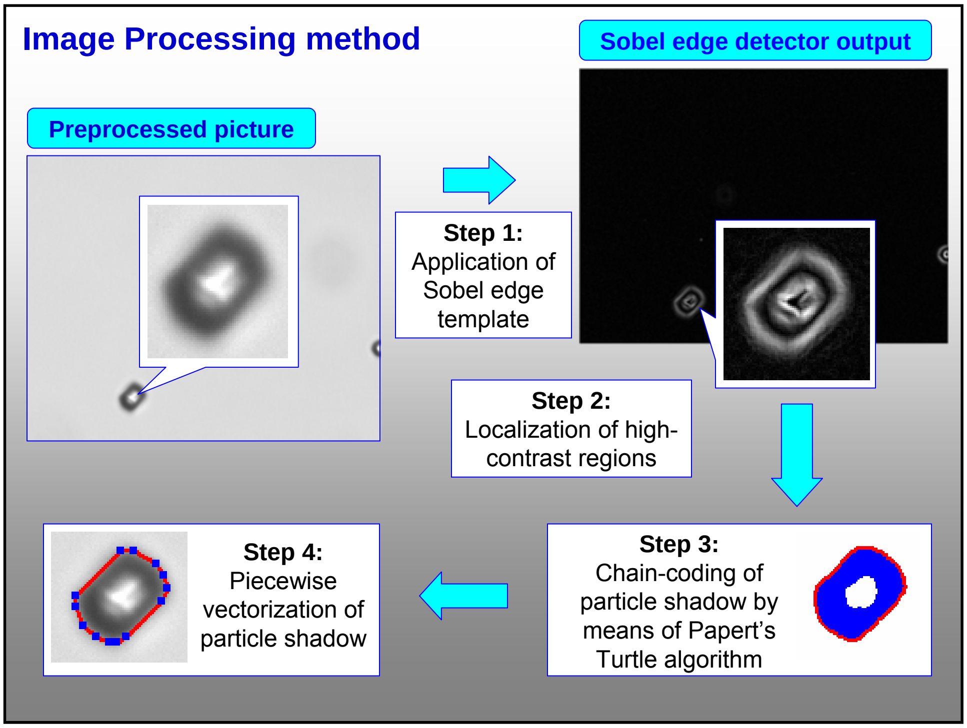
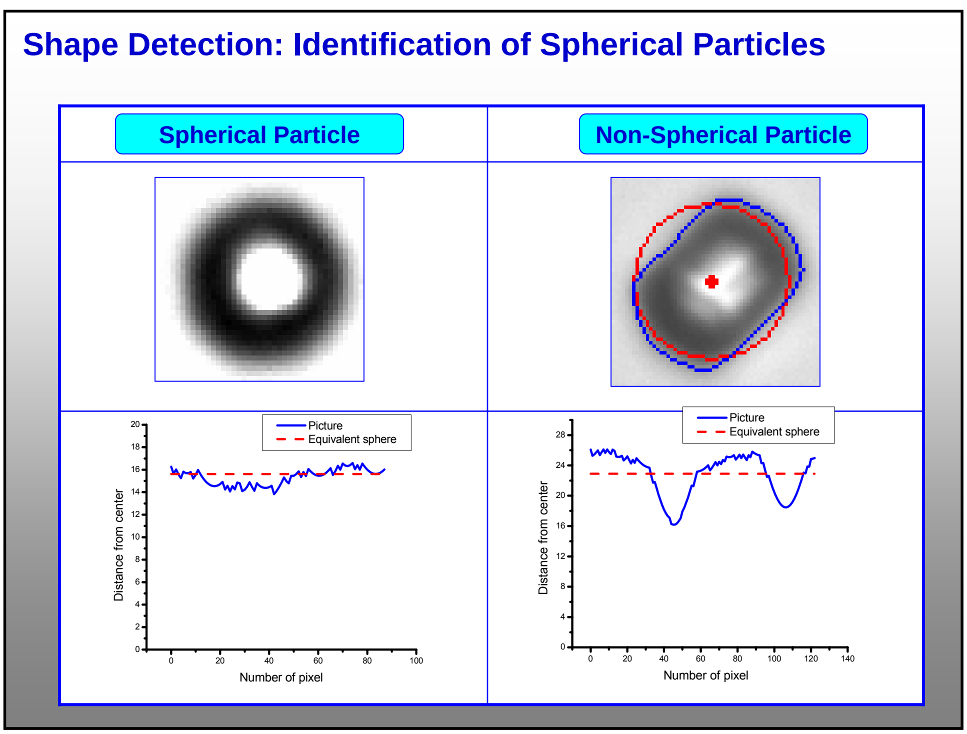
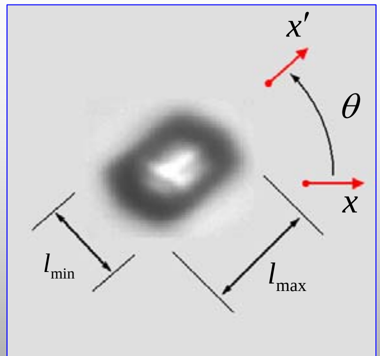


Image Processing method
Sobel edge detector output
Preprocessed picture
Step 1:
Application of Sobel edge template
Step 2:
Localization of high-contrast regions
Step 3:
Chain-coding of particle shadow by means of Papert's Turtle algorithm
Step 4:
Piecewise vectorization of particle shadow


Shape Detection: Identification of Spherical Particles
Spherical Particle
Non-Spherical Particle
Picture
Equivalent sphere
Distance from center
Number of pixel
Picture
Equivalent sphere
Distance from center
Number of pixel

Shape Characterization of Non-Spherical Particle



$$Q = \frac{l_{\max}}{l_{\min}}$$ - **aspect ratio**

$$\gamma = 1 - \frac{4\pi A}{p^2}$$ - **compactness**

where: *p – perimeter of the shadow,*
A – area of the shadow,
l_{max} – max dimension,
l_{min} – min dimension,
$(\bar{x}, \bar{y})$ – center of particle,
f(x,y) – shape-function

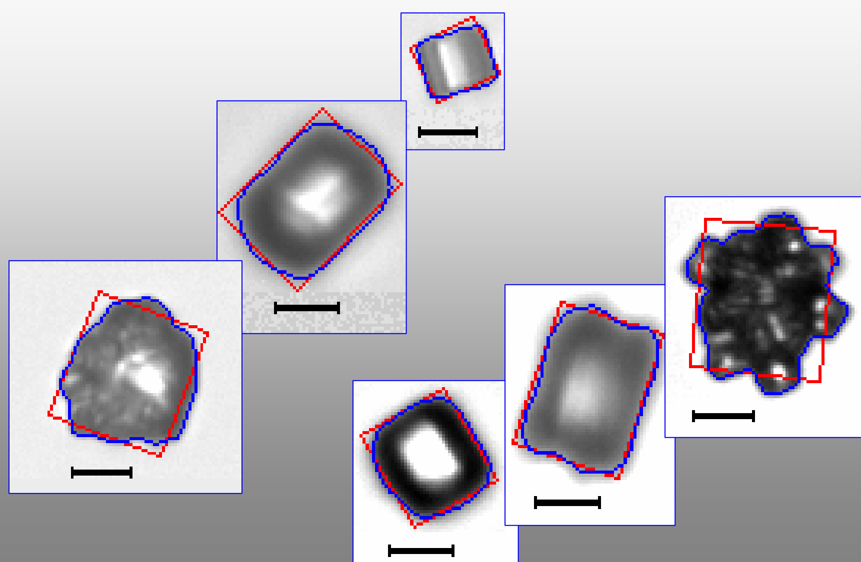
Position of new coordinate system (minimizing the moment of inertia):

$$\mu'_{20} = \max_{\theta} \mu_{20} \qquad \mu'_{02} = \min_{\theta} \mu_{02} \qquad \mu'_{11} = 0$$

$$\min_{\theta}\left(\iint_S dxdy\ f(x,y)\left[(x-\bar{x})\cos\theta - (y-\bar{y})\sin\theta\right]^2 \right)$$

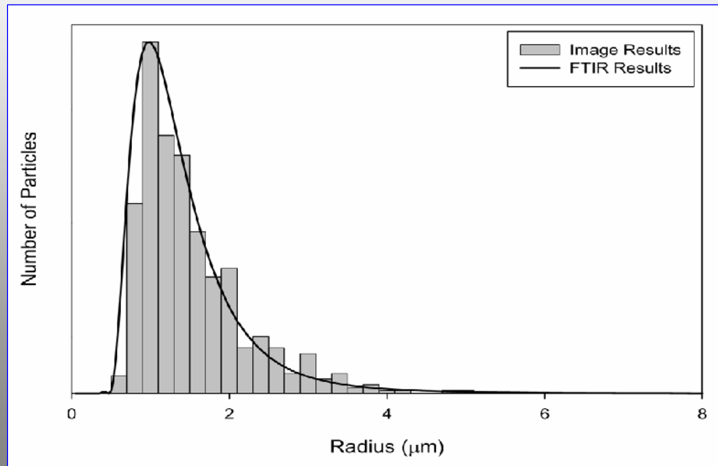
Some examples of Non-Spherical Particles

size of the marker is 20 pixels (7.4 μm)



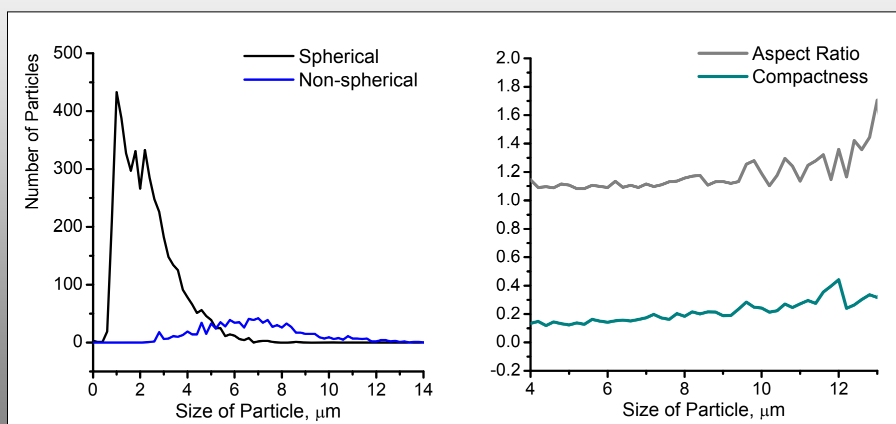
Size distribution Results

Comparison the results of image processing with FTIR measurements for water particles under room temperatures



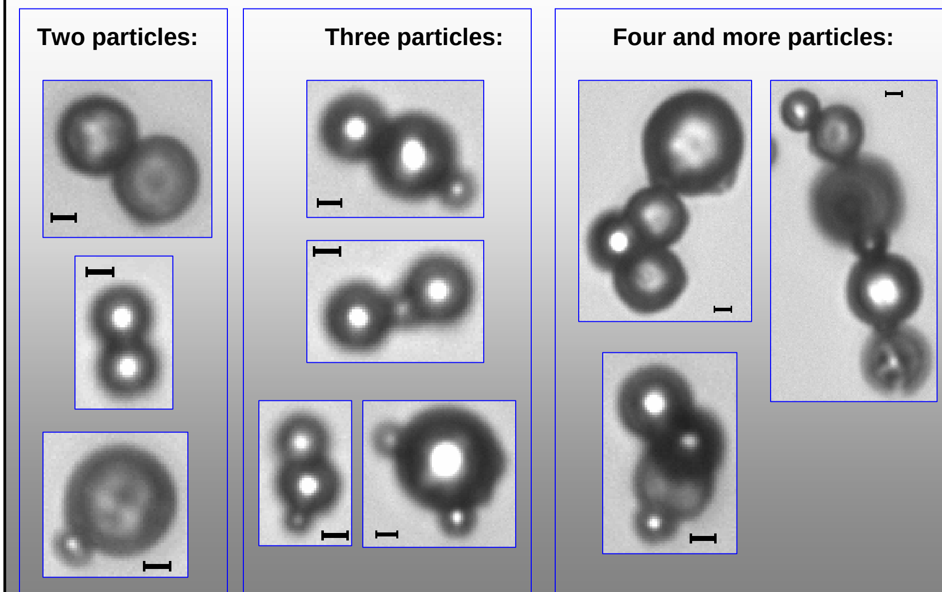
Size Distribution Results:

Temperature T = -37 C
Total number of pictures = 40 000
Total number of particles = 3220



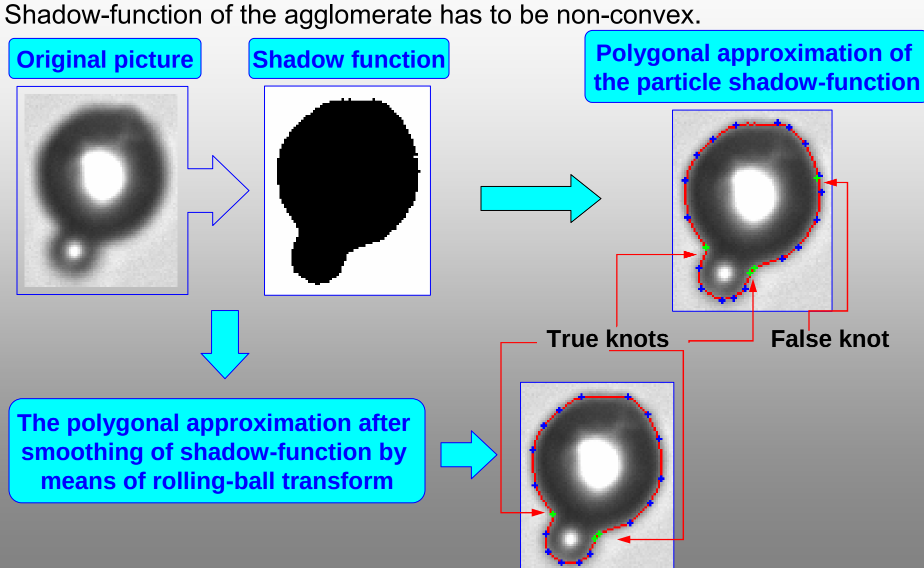
Some examples of agglomerates:

size of the marker is 10 pixels (2 μm)

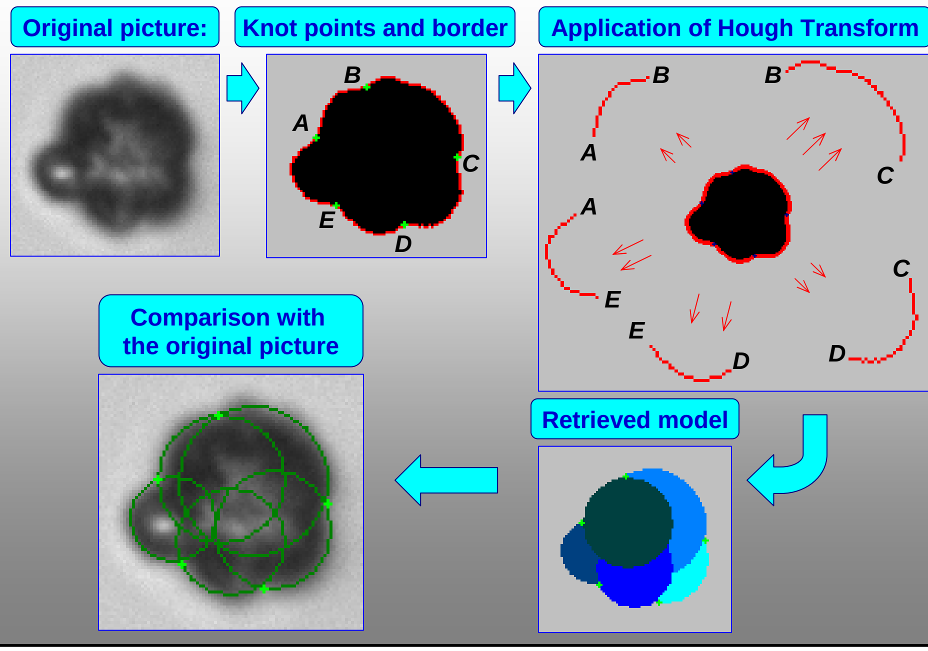


Identification of agglomerates among other particles

Criteria for identification**:**
Shadow-function of the agglomerate has to be non-convex.

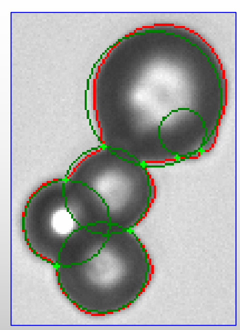


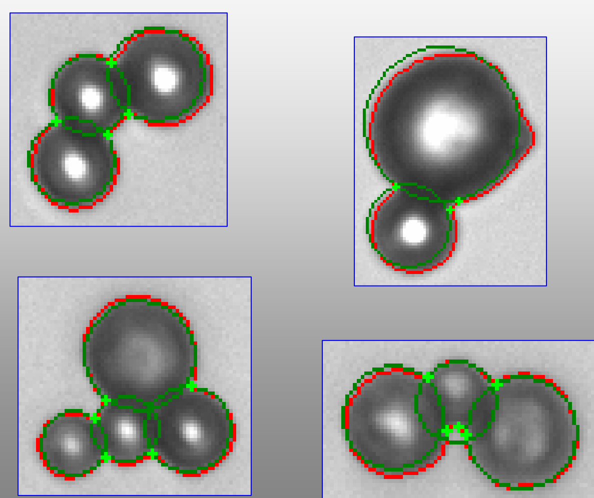
Retrieval of Components of Cluster

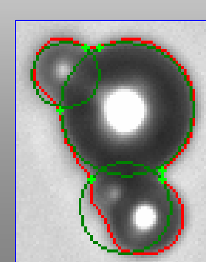


Some examples of agglomerates:

Red line – real detected border of the agglomerate
Green line – border of the approximation

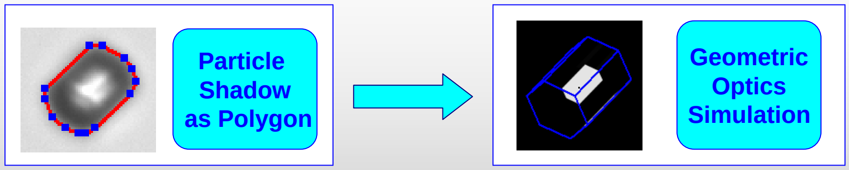




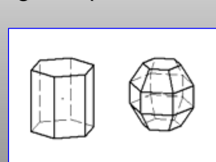


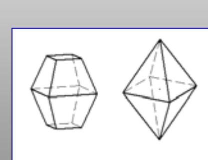
Future Plans:

- retrieve 3D shape of observed particles from 2D pictures



- identify pristine ice crystal shapes typical for hexagonal and cubic ice: hexagonal prism, octahedron, droxtal and etc





- correlate the shape properties of the ice particles with atmospherically relevant conditions

Thank you!

☺

The dream of a Canadian high-altitude research aircraft ...

Michaela I. Hegglin
University of Toronto

Abstract:

Why should the Canadian science community be interested in a high-altitude aircraft? What are the scientific questions related to the region between 8 and 16 km altitude commonly referred to as the upper troposphere/lower stratosphere (UTLS) region? What benefits would aircraft campaigns yield for the satellite community? These questions will be addressed during this presentation by using examples of past aircraft campaigns aimed at the study of tracer distributions in the UTLS region. It will further include a perspective on the use of aircraft measurements for satellite validation by showing comparisons between the SPURT aircraft data set and ACE satellite measurements.

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Preferred Session:	Proposals for future projects by graduate students and postdocs
Presentation Method:	Talk
Presenting Author Title:	Postdoc

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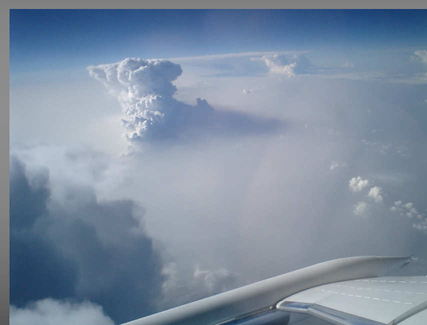
The dream of a Canadian high-altitude research aircraft …



Michaela I. Hegglin
Postdoc
University of Toronto

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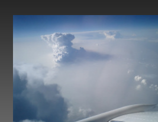
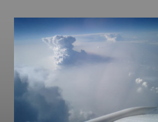
If I had a million dollars …



… I would have to forget about my dream …

… given the fact that a high-altitude aircraft costs between 10 and 100 M $.

BUT…



… I might rent one!

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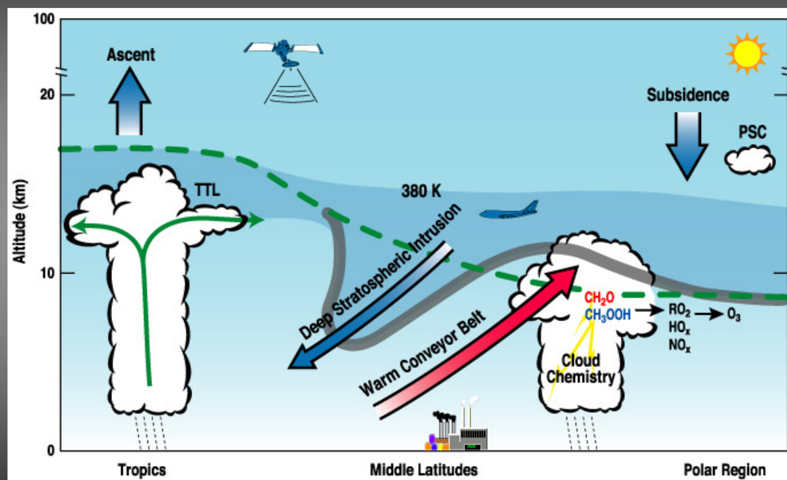
THE REGION OF INTEREST: UPPER TROPOSPHERE/LOWER STRATOSPHERE (UTLS)



Randel and Pan, SPARC Newsletter n°22, 2004

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SCIENTIFIC ISSUES RELATED TO THE UTLS

Changes in ozone, water vapor, cirrus clouds, and aerosols have a large impact on the Earth's radiation budget, especially in the tropopause region.

Transport influencing tracer distributions in the UTLS involves complex processes on multiple scales.

Relative contribution of different stratosphere-troposphere exchange processes are still not well quantified.

Particular scientific issues related to chemistry/microphysics:

- Lightning/aircraft produced NO_x.
- Heterogeneous processing on aerosols or ice particles.

Michaela I. Hegglin | *University of Toronto* | The dream of a Canadian high-altitude aircraft…

WHAT ARE THE CHALLENGES TO MAKE MEASUREMENTS IN THE UTLS?

Small vertical and horizontal length scales: The transition between the troposphere and stratosphere typically occurs over ~1km in the vertical and ~100km in the horizontal.

The unique characteristics of aircraft measurements (high resolution, high accuracy) are well suited to this region.

Neither nadir nor limb sounding can well represent the relevant structures (possibly advanced retrieval methods, e.g. tomographic, can help – though they would need to be validated).

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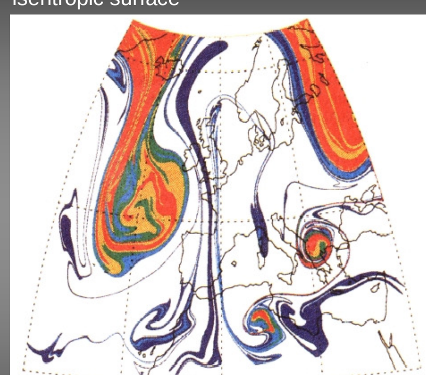
FINESCALE STRUCTURE IN THE HORIZONTAL

Meteosat water vapour

Contour advection from PV on 320 K isentropic surface



Appenzeller et al., JGR 1996

Fine scale structure can be predicted from large scale initial tracer data (e.g. from satellite) and large scale winds (stirring)

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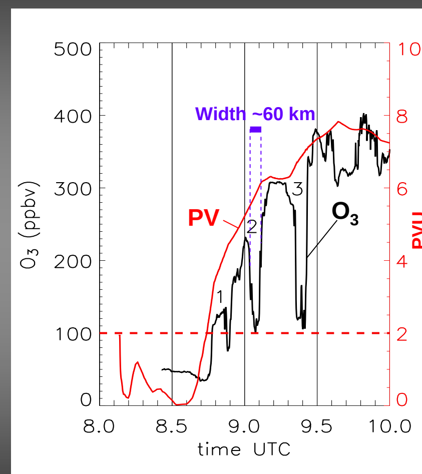
HIGH-RESOLUTION AIRCRAFT MEASUREMENTS CAPTURE HORIZONTAL STRUCTURES

Timeseries of O_3 during a flight of the SPURT campaign (Nov 2001). Filaments of tropospheric air masses have been observed in the deep stratosphere at 210 hPa.



Hegglin et al. ACP 2004

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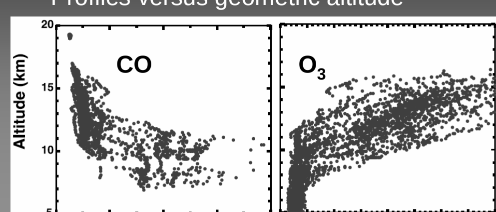
Michaela I. Hegglin | *University of Toronto* | The dream of a Canadian high-altitude aircraft…

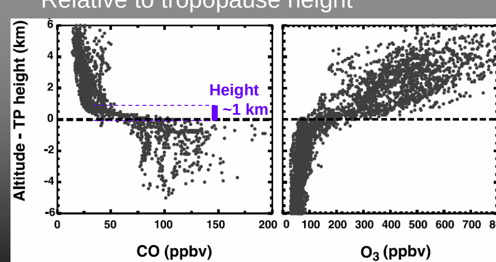
VERTICAL STRUCTURE OF THE UTLS DERIVED FROM AIRCRAFT MEASUREMENTS

The UTLS "shapes" the distribution of O_3, H_2O and related chemical species.

Profiles versus geometric altitude



Relative to tropopause height



CO and O_3 profiles near 65º N as functions of geometric altitude (top) and altitude relative to the thermal tropopause (bottom).

Pan et al., JGR 2004

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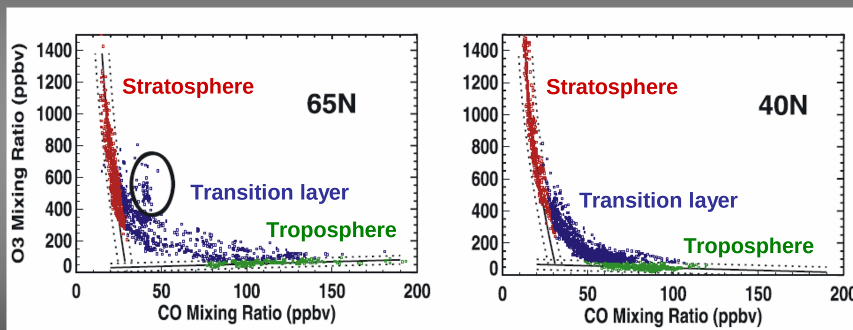
Michaela I. Hegglin | *University of Toronto* | The dream of a Canadian high-altitude aircraft…

TRACER-TRACER CORRELATIONS

From a chemical perspective, the tropopause has to be seen as a transition layer.



Pan et al., JGR 2004

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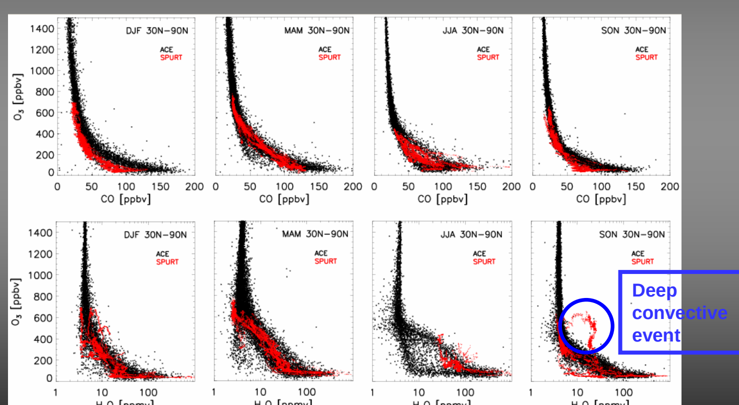
VALIDATION OF ACE SATELLITE MEASUREMENTS WITH SPURT AIRCRAFT DATA

ACE tracer-tracer correlations (2004-2006) match amazingly well with the SPURT data set (2001-2003). Note the different years of instrument deployment.



Hegglin, work in progress

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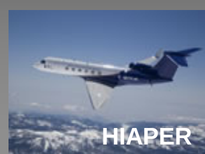
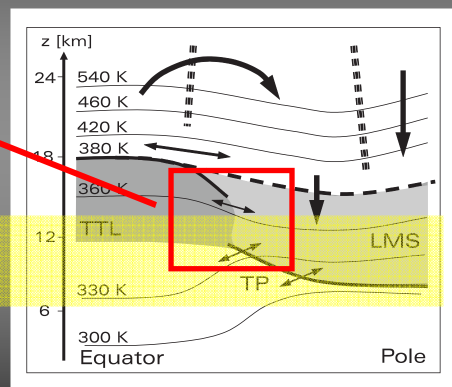
SO, BACK TO MY DREAM…

I'll make some friends in the US…
…and tell them I have a Swiss bank account ☺





LEARJET, FALCON, CESSNA

COMMERCIAL AIRCRAFT

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DREAM ON…

Capabilities of HIAPER (High-performance Instrumented Airborne Platform for Environmental Research)

- Ceiling Altitude 51,000 ft (15,545 m)
- Max Payload 7,900 lbs (3,583 kg)
- Max Range 6,900 miles (11,102 km)

Science goal: Study transport processes in the region of the subtropical jet.

Meteorological support: Forecasts for optimal flight planning.

Scientific payload chemistry:
- Long-lived: N_2O, NO_y, HCl, CO_2, CH_4, SF_6, O_3 and H2O (insitu/profiler)
- Intermediate-lived: CO
- Shortlived: NO_x, Acetone, Formaldehyde, PAN

Scientific payload dynamics:
- Temperature insitu/profiler
- Wind, turbulence, pressure

'Post-processing': Integrated, process-oriented studies using model data, satellite, and aircraft measurements.

SUMMARY

High-altitude aircraft measurements are valuable in many respects:

- Opening up new opportunities for instrument development at universities and collaboration with Canadian industry.
- Filling scientific gaps through accurate, high-resolution measurements of key chemical species and dynamical variables.

  Exchange processes with the TTL represents an emerging field of atmospheric research with implications for ozone and climate.

- Validating satellite measurements, which can then be used to extend the geographically and temporally limited aircraft measurements.
- Testing model performance (and maybe data assimilation systems).

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ACKNOWLEDGEMENTS:

SPURT project partners

Thomas Peter, Dominik Brunner, Johannes Staehelin (ETH Zurich, Switzerland)
Heini Wernli (University of Mainz, Germany)
Horst Fischer, Peter Hoor (MPI Mainz, Germany)
Cornelius Schiller, Mark Krebsbach (FZ Juelich, Germany)
Ulrich Schmidt, Andreas Engel (University of Frankfurt, Germany)

ACE Science Team

Chris Boone, Sean McLeod, Peter Bernath
(University of Waterloo)
Gloria Manney (JPL, California)

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THANKS FOR YOUR ATTENTION!

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NRC High Altitude Atmospheric Research Aircraft

Anthony P Brown*, John Aitken, Dave Marcotte, Camile Lebrun, Mike Pygas, Matthew Bastian and Roy Vestrum

Abstract:

The CT-133 of the Flight Research Laboratory of the NRC has recently been re-instrumented with high fidelity and ultra-fast response inertial and air data instrumentation systems, to provide a high altitude research capability for harsh atmospheric environments, such as turbulence (including wake vortices), jet aircraft engine exhaust (for emissions measurements) and ice cloud environments. The ruggedness, accuracy and reliability of the FRL Inertial Reference and Navigation System (FIRNS) has been demonstrated in FRL research aeroplanes at extreme Euler angles and very high rotation rates of 300 deg/sec. A unique air data system has been designed and fitted to the CT-133. It features sensors optimized for ultrafast response to changes in air direction, such as that occurring during flight in turbulence. Air and inertial data are measured and recorded at 600 Hz, which at high-altitude sampling airspeed, is equivalent to Nyquist sampling lengths of 0.5-0.6 metres along-track and, depending upon cross-track velocity, 1-2 cm across-track. Vectorial differencing enables the derivation of the 3D wind vector, also at 600 Hz. The systems installations were completed in spring 2006. Following airworthiness flight tests, air data developmental testing and calibration flights were conducted in May 2006. An initial wake turbulence measurement and verification flight was conducted on 26th May 2006, during which wake vortex flowfields of A310, A318 and B767-300 aircraft were surveyed in a stratified atmosphere amidst widespread thin cirrus. Vortex core traverses were conducted. The 600 Hz sampling provided flowfield insight not previously available in earlier NRC wake vortex flowfield surveying, in particular vortex core characteristics such as axial-flows and "super"-tangential velocities within the core. Initial data analysis and reporting has been conducted.

Underwing pods, for the carriage of microphysical and air chemistry instruments, have been designed and are presently being fabricated. The initial application shall be the airborne and runway measurement of aircraft emissions, under collaborative research agreements with Transport Canada (TC) and Environment Canada. For this purpose, the pods will carry air chemistry instruments, including an Lii200 black carbon sensor, Thermo NOx analyzer, CN aerosol counter and a flask air-gathering system. The emissions data shall be used in the deliberations of TC with ICAO and the international community on emissions standards. The FRL also has collaborated upon an IPY proposal to use the CT-133 for pyro-Cb emissions measurements in the upper-troposphere and tropopause, as one of a multi-aircraft experiment on the transport and transformation of Boreal forest fire emissions.

The capability of the NRC Falcon 20 complements that of the CT-133. The Falcon is a transport aircraft, and therefore is not as suitable for in-situ harsh environemnt measurements. However, it is a cabin-class aircraft, and as such is a suitable platform for near-field remote sensing, such as using LIDAR sensors. The aircraft is readily suitable for such modifications, in particular optical glass inserts could replace cabin windws, and mrror arrangements enable the LIDAR beams to be projected upwards and downwards, as requirements dictate.

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Preferred Session:	Proposals for future projects
Presentation Method:	Talk
Presenting Author Title:	Other

NRC High-Altitude Atmospheric Research Aircraft Capability (for Harsh Environments)

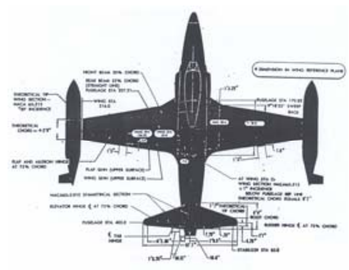
A Brown, D Marcotte, J Croll, C LeBrun, M Pygas
J Dillon and M Bastian
Flight Research Laboratory
Institute for Aerospace Research, NRC Canada

Presented to the Sub-Orbital Workshop
University of Toronto, 1st-2nd February 2007

***Outline*: high altitude atmospheric research aircraft capability programme summary:**

- what we have:- FRL Falcon 20 and CT-133
  - standing capability
  - basic instrumentation:
    - inertial
    - air data
    - DAS
  - applications:-
    - atmos airflow physics, microphysical, multiphase, air chemistry
    - remote sensing (e.g. LIDAR installations)
    - *in-situ* within harsh atmospheric environments:
      - jet wake, wake vortex & meteorological vortex domains (turbulence measurement)

CT-133 and FALCON CAPABILITY:



- Turbojet-powered
  - Falcon 20, CAR4b transport category (2.5g structure) aeroplane
  - CT-133, mil.trainer/light attack (*rugged* 7g structure) aeroplane
- 12.5 km height
- Performance:
  - speed, low-level, 150kts-505kts max (420 kts level) mid/high-level,
  - M0.3-0.8 max (0.75 level)
  - Slow speed (high alt.), c.150 ms^{-1}
  - 2.5 hrs endurance typical, mid/high, with reserves

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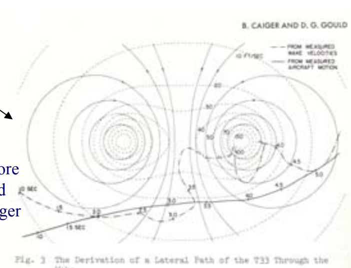
FRL CT-133 & FALCON 20 HISTORICAL RESEARCH APPLICATIONS (1960s to present):

- Atmospheric (CT-133)
  - turbulence
    - boundary layer
    - convective
  - cloud-seeding
  - wake vortex structures:- DC8, CV880
- Space (microgravity) research
- Flying qualities (Falcon / CT-133)
- Avionics systems:-
  - RVSM
  - TCAS



Identification of smaller, more intense vortices in near-field wake vortex structures (Caiger *et al*)

Inertial, Air Data, DAS Installation Locations – Falcon 20

32 Hz system (32 inertial, air data & derived wind samples /sec)

Inertial system,
air data processing,
data recording

FADS nosecone
α β sensing (5-hole);
p_S, p_T TAT a/c sys

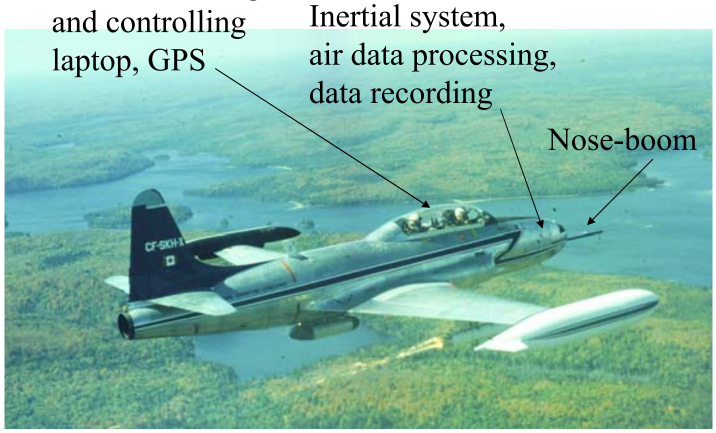
Inertial, Air Data, DAS Installation Locations – CT-133

600 Hz system

Data monitoring
and controlling
laptop, GPS

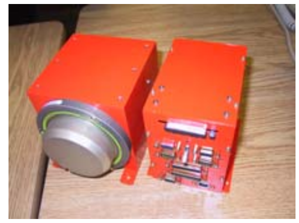
Inertial system,
air data processing,
data recording

Nose-boom



Inertial System Details

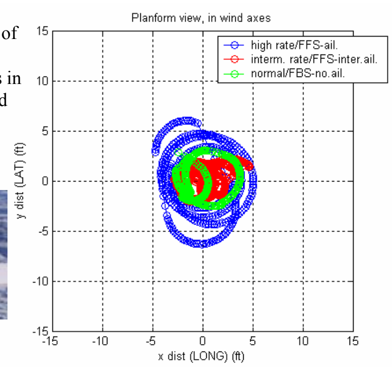
- Barrie Leach, Jeremy Dillon
- Honeywell HG1700 RLG IMU
- NovAtel GPS receiver
- DRP: PC/104 navigation computer performs strapdown navigation and INS/GPS integration (COTS)
- Proven technology – has flown on all other FRL aircraft & 4 additional flight test programmes
- Full set of navigation outputs
- Data rate up to 600 Hz over Ethernet
- DRP buildup system
  - Use as distributed data acquisition network nodes (CT-133:- inertial data, air data, two underwing sensor pods)

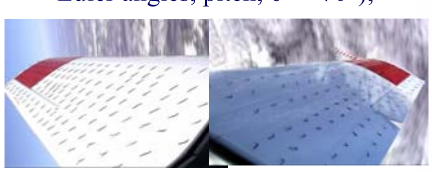


INERTIAL SYSTEM APPLICATION – NRC HARVARD LOW-α SPIN PROGRAMME:

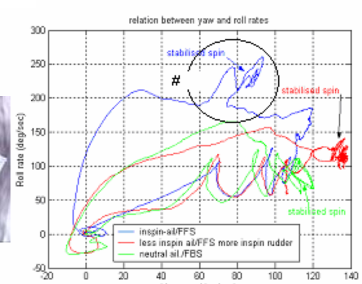
- A proven example of reliability in:-
  - ruggedness (vibrationary env.):-
  - high total rates (300°s^{-1}), extreme Euler angles, pitch, $\theta = -70°$);

Planform view of re-constructed spin flightpaths in freestream wind axes





wing-flow visualisation post-transition to low-α spin mode, **θ = -68.5°**



Correlation map of roll and yaw rates, during spin FQ flight test, showing non-linear dynamic bifurcations into a number of spin modes; # is the low-α mode;

CT-133 Air Data System Details (for 600 Hz):-

Kulite miniature pressure transducers for α, β sensing (in.)

Weston Aerospace pressure transducers for p_S , P_T sensing

- **Air data sensing:-**
  - Noseboom
    - very fast response P_T and p_S sensors;
      - 200 MHz clocking (<Pa)
    - air temperature:-
      - Rosemount 102DJ
        - for very fast response: film, wire
        - KT19.99 pyrometer
    - novel very fast response α and β non-lifting cylinder sensors
    - 600 Hz sampling, providing at high altitude sample speed, a Nyquist measurement eddy scale size, along-track, of 0.7metres at M0.7, across track, order of 1.5cm;

CT-133 Air Data Processing:-

- From nose boom: α, β, TAT p_S P_T
- Air data DRP: PC/104 air data computer,
  - p_S and P_T square waveform counts, analogue temp.comp. sig.
  - α, β, TAT analogue signals, all temp. compensated
- Data recorded to Compact Flash card and output over Ethernet
  - Monitored/backed-up by cockpit monitoring computer:

CT-133 BASIC INSTRUMENTATION – will give us:

- **Vehicle for atmospheric flowfield (turbulence) measurement:-**
  - wind derivation:
    - $\underline{WV} = \underline{V}_A - \underline{V}_G$
      - Ian MacPherson, Twin Otter (BOREAS thermal vortex core penetration), Dave Marcotte/Mengistu Wolde – Convair
      - Matthew Bastian – Falcon, CT-133

High Altitude Atmospheric Research Aircraft

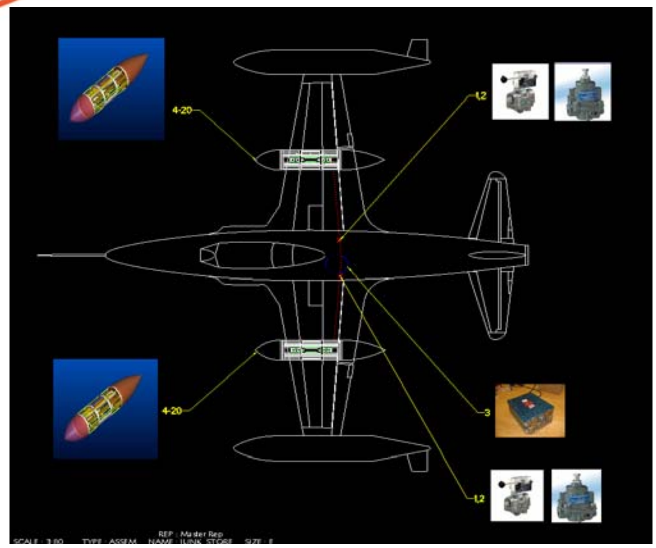
ROLE INSTRUMENTATION:

- **CT-133 pod-mounted (work-in-progress):-**
  - Two pods, one located under each wing:
    - pressurised (1 atm), temperature-controlled;
      - 22.5 inch dia x 60 inch instrument volume
      - air chemistry instrumentation, DAS
      - DRP node pick-up, Ethernet to nose compartment DAS
      - in-situ/remote sensors
        - initial:- aircraft emissions (42C, CN counter, Lii200, flask system), Transport Canada, EC; IPY:- EC, York U (NRC FRL, GTL, ICPET)
    - mounting points on pods for cloud microphysics instruments:
      - PMS and CVI probes

Sub-Orbital Workshop, University of Toronto, 1-2 Feb 2007

Instrumentation pods:-

– Camile LeBrun



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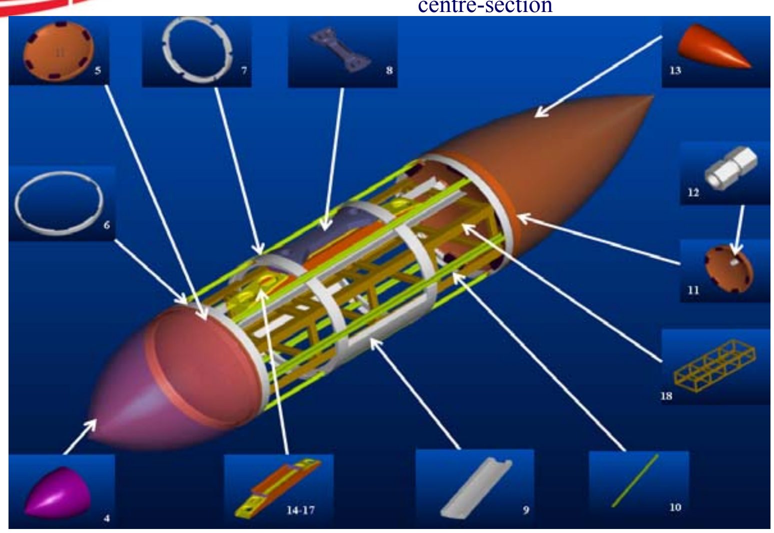
Pod cutaway:-

- nose/tail cones & pressurised centre-section



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FUTURE HIGH ALTITUDE HARSH ENVIRONMENT ATMOSPHERIC RESEARCH APPLICATIONS:

- ***enroute* wake vortex:-** fluid mechanics & dynamics, detection, addressing air transport safety (FRL successful pilot programme)
- **meteorological vortex flows (severe turbulence):–** boundary layer, orographic (rotors) and jetstream (horizontal vortex tubes), tropopause;
- **aircraft emissions:-** NOx, aerosol particle count (pod-mounted), black carbon, flask gaseous sampling;
- **contrail microphysics:-** PMS and CVI probes, pod-mounted;
- **high altitude flows, icing, mixed phase & high IWC:-** as for contrail microphysics;

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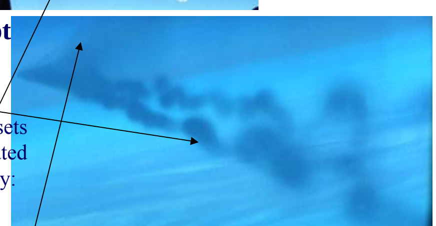

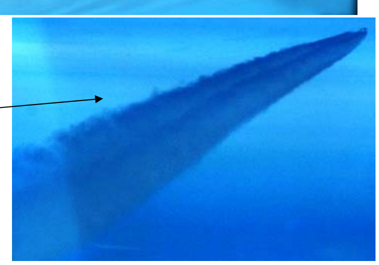

WAKE VORTEX/JET WAKE REGIME TECHNICAL ISSUES FOR RESEARCH (from FRL WV pilot programme):

- ***enroute* wake vortex:-**
  - NRC WV measurement programme: upsets in vortex instability encounters in regulated airspace (8/13nm), medium behind heavy: 300°s^{-1} roll accel. & 2.5g spikes
- **aircraft emissions:-**
  - jet wake regime (not co-located, but adjacent to the wake vortex regime);
  - ICAO emissions standards tech issues include transformation with wake length
- **contrail microphysics:-**
  - Jet wake condensation (to ice crystallisation) – transport and transformation in ambient cross-flow

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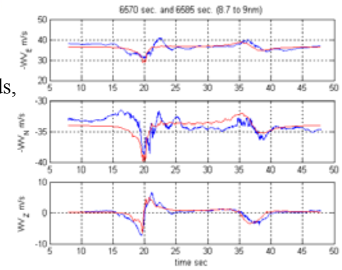
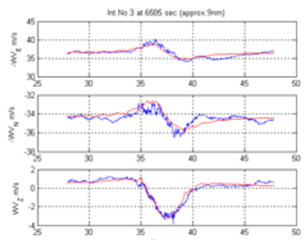
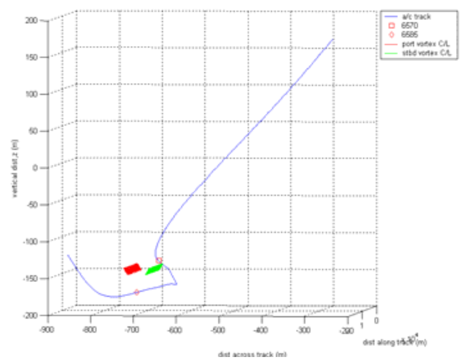
Blue, flight winds,
Red, line vortex
Model winds



FRL Wake vortex, 28th October 2004:

– **B747-400 outbound (polar):**
  – first perimeter:
  – Γ=665m²/s, source Γ=598m²/s at 8 nm





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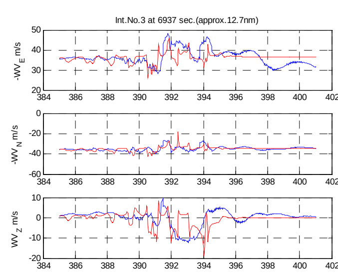
WAKE VORTEX/JET WAKE REGIMES:

Long-wave (Crow) Instability:

– Interaction with jet wake vortex sheets;
– Interaction with core (short-wave) instabilities & core funnel vortex type features
– Encounter loads, multiaxis, g spikes, lat/dir accels.

***B747 vortices (Falcon), 32 Hz*:**

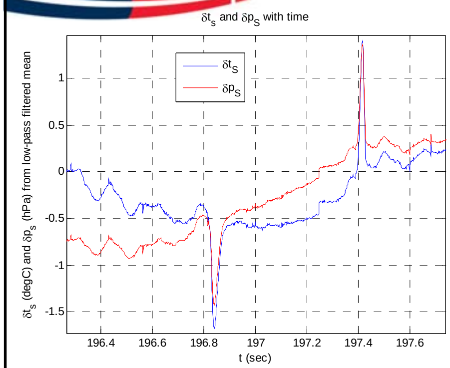


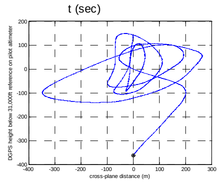
Γ≅480m2/s at 12.7 nm (72% source strength)
Trailing pair descent rate ≈500 fpm for a descent height of 750 feet by 13 nm wake length

High Altitude Atmospheric Research Aircraft

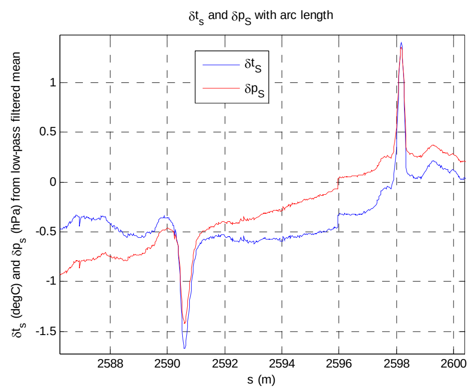
A310 vortex core passages (CT-133), 600 Hz:

– *scalars:-*





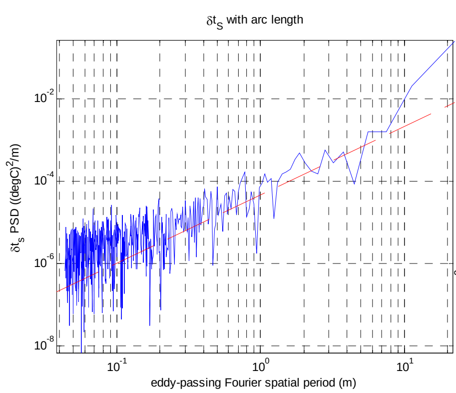
– *P & T:- crossplane arc length:-*



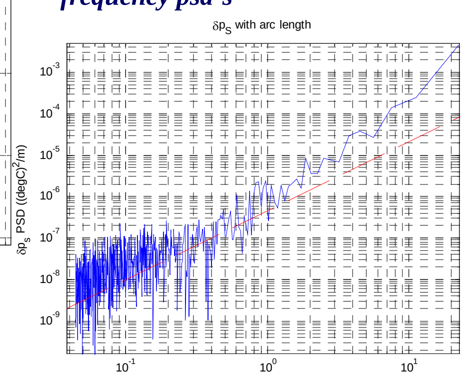
Wake Vortex Instability Flow-fields, Aircraft Encounters

A310 vortex core passages (CT-133), 600 Hz:

– *scalars:-*

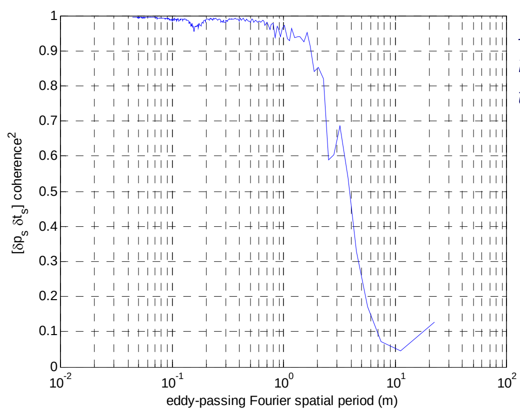


– *P & T crossplane spatial frequency psd's*



A310 vortex core passages (CT-133), 600 Hz:

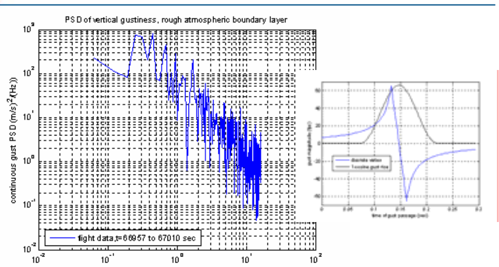
– ***scalars:- turbulent flowfield outside the vortex cores***

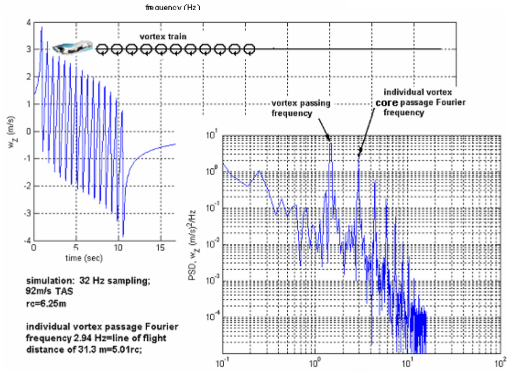


P & T coherence:- indicative of isotropic small eddy scale turbulence

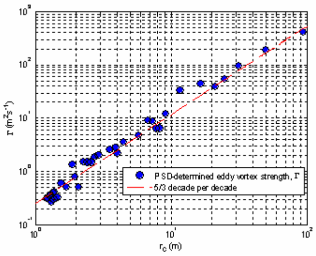
Deeply-developed turbulent boundary layer, Convair:-

– For reference & comparison to otherwise discrete gusts
– Engineering method for derivation:-
– Vertical gust psd
  – Mean 5/3 decade index observed, with many peaks and troughs
  – Frequency response converted to spatial scale by Fourier modelling of the observed induced wind during passage through core centres of a vortex train
    – Burnham-Hallock vortex model
    – $r_C \cong$ that for {*fft peak* harmonic scale size}/5

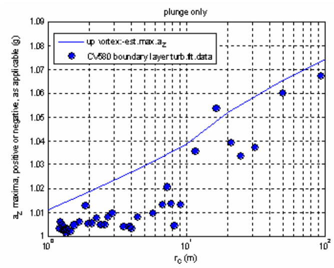




Deeply-developed turbulent boundary layer (cont.):-



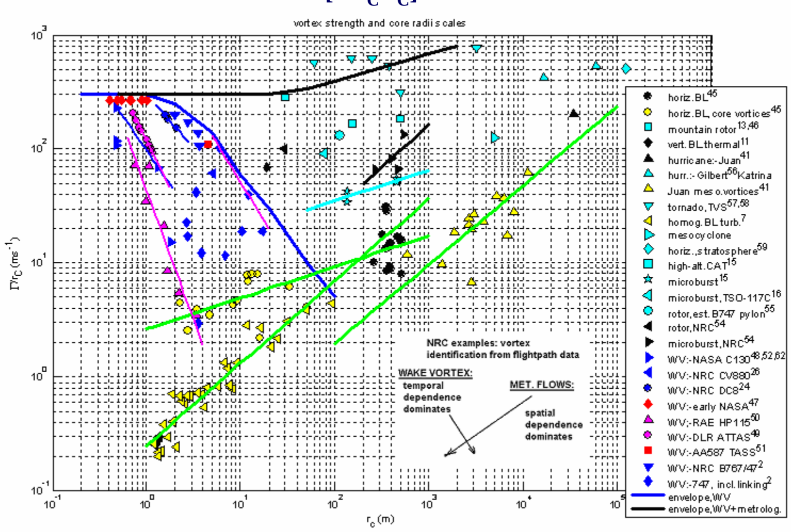
- Close-loop the unsteady loads modelling:-
  - Unsteady loads analysis
    - Potential line vortex gust shape
    - Wagner & Kussner functions for unsteady aero loads;
    - Rigid-body
    - Plunge only:-



- Above formulation can be used to discretise a timebase wavetrain to through a FFT spectrum to discrete vortices:
  - r_C from vortex core passage frequency
  - Γ from amplitude of V_{MAX}, from integration of PSD over individual peaks

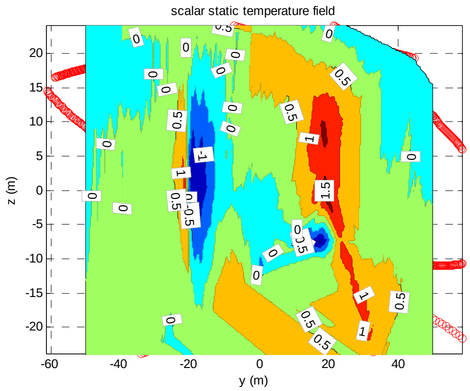
Discrete vortex parametric plot:-

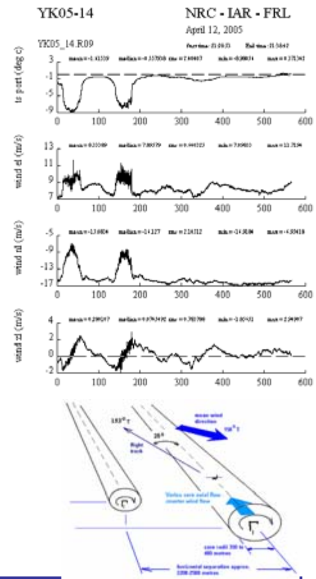
- $[\Gamma/r_C\ r_C]$



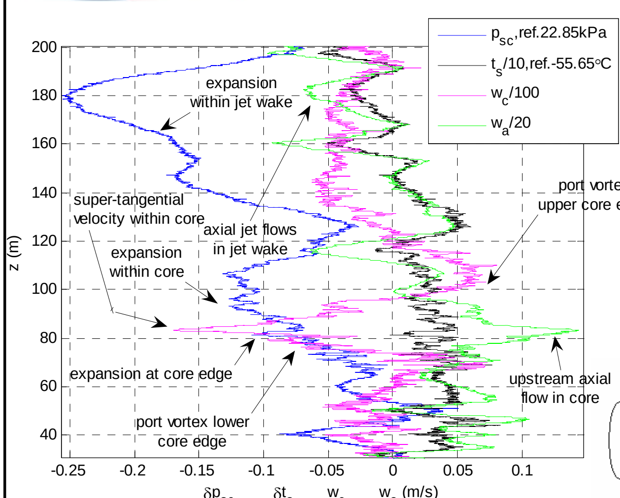
B763 Wake Vortex Scalar Fields

Ta – Heating correlated with compression above windward vortex; cooling correlated with expansion near vortex cores, 18.5° tilt between vortex centres:-

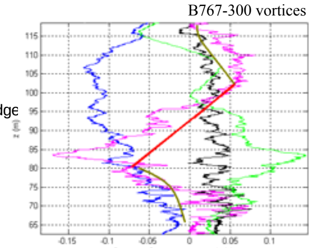


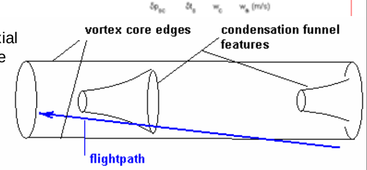


***Results & Discussion*:-** A310 Vortex Core Vertical Traverse Scalar Fields:- 600 Hz CT-133



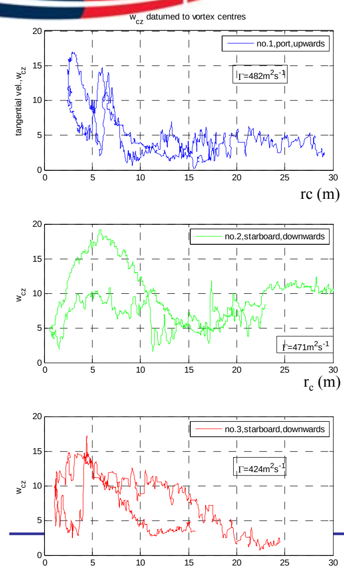
B767-300 vortices

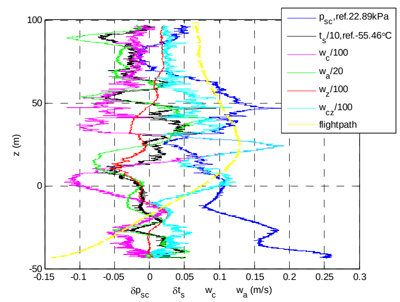


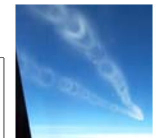


Wake Vortex Scalar Fields

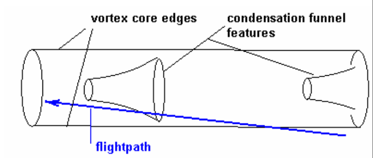
***Results & Discussion*:- B767 Vortex Core Vertical Traverse Scalar Fields:- 600 Hz CT-133**







B767-300 vortices



High Altitude Atmospheric Research Aircraft

CONCLUSIONS:

- ***AIRCRAFT CAPABILITY, CT-133 / Falcon 20***
- ***CT-133 RE-INSTRUMENTATION*:-**
  - accuracy, ruggedness, miniaturisation, dynamic response, high acquisition rate, 600 Hz;
- ***CT-133 UNDERWING PODS*:–**
  - Controlled environment (P & T), large volume, node DRP data acquisition and network transfer
- ***HARSH ENVIRONMENT RESEARCH AEROPLANES*:-**
  - Wake vortex flows & sensing, meteorological vortex flows (rotor, jetstream, HVT, boundary layer shear), IWC clouds, emissions, tropopause microphysics

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Government of Canada

Proposed airborne atmospheric research at York University

***Jim Whiteway and Brian Solheim**
Department of Earth and Space Science & Engineering
York University

Walter Strapp
Environment Canada

Abstract:

The airborne atmospheric research at York University mainly involves laser remote sensing (lidar) in combination with simultaneous in situ measurements. The focus of this research will continue to be placed on the tropopause region. This includes measurements of dynamics, composition, and cloud physics. The next step in this research program will be to achieve airborne lidar measurements of both water vapour and ozone in the tropopause region. Plans are currently being discussed for a proposal to install lidar systems in the Falcon aircraft operated by the Flight Research Laboratory at the National Research Centre (NRC). The Falcon will also be applied for testing instruments developed for remote sensing from earth orbit. This proposal will also involve applying the NRC T-33 aircraft for in situ measurements at heights up to 13 km.

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Presenting Author Telephone:	416-736-2100 ext 22310
Preferred Session:	Proposals for future projects
Presentation Method:	Talk
Presenting Author Title:	Professor

New Proposal in the works (CFI)

Jim Whiteway, York University
Walter Strapp, Environment Canada
Anthony Brown, Dave Marcotte, NRC

NRC Falcon with remote sensing

- **Ozone lidar**
- **Water vapour lidar**

T-33 with in situ measurements

- **Water vapour from York**
- **Cloud microphysics from EC**
- **Chemical measurements from EC**

Darwin or Costa Rica:

- **Convection and transport in the tropopause region**
- **Tropopause dynamics and generation of gravity waves**
- **UTLS Water vapour**

Ontario:

- **Cirrus clouds and effects of aircraft exhaust**
- **jetstream turbulence and mixing**
- **tropospheric ozone (lidar downward)**
- **convection, transport of pollutants and strat/trop exchange**
- **Testing of space instruments**

Rockies:

- **gravity wave breaking**
- **Strat Trop exchange**
- **Cloud Physics and water vapour**

North/Arctic:

- **Forest Fires**
- **Strat/trop exchange**
- **tropospheric ozone (lidar downward)**

Relation to CSA: Testing Instrument Concepts

1.) SHOW Spatial Heterodyne Observations of Water
Brian Solheim et al., York University

Validate capability of measurements in tropopause region
Quantify interference effect of cirrus clouds
Install on NRC Falcon looking out through window port
Combine SHOW remote sensing with in situ measurements

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Jim Whiteway et al., York University

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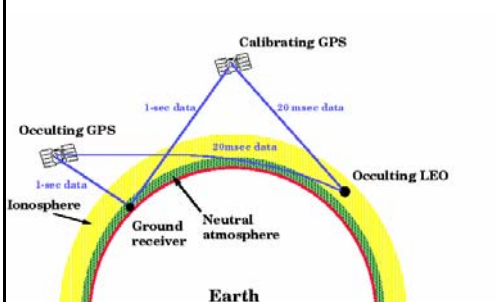

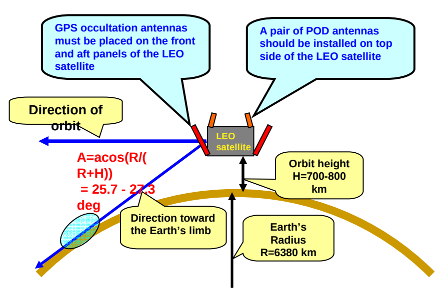

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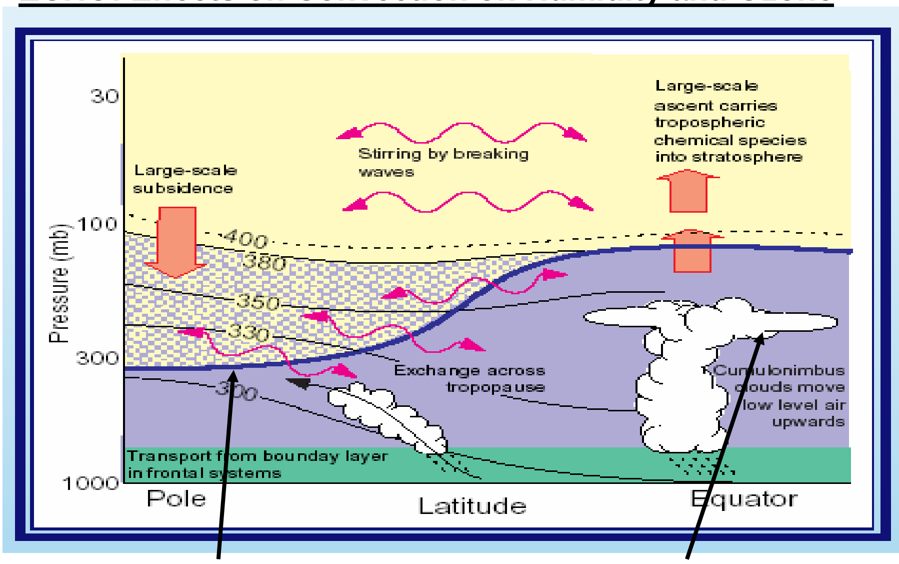
ECHO: Effects on Convection on Humidity and Ozone



Pyro-Convection
Forest Fires
Transport stratosphere

Convection and Climate
Outflow cirrus
Humidity
Ozone

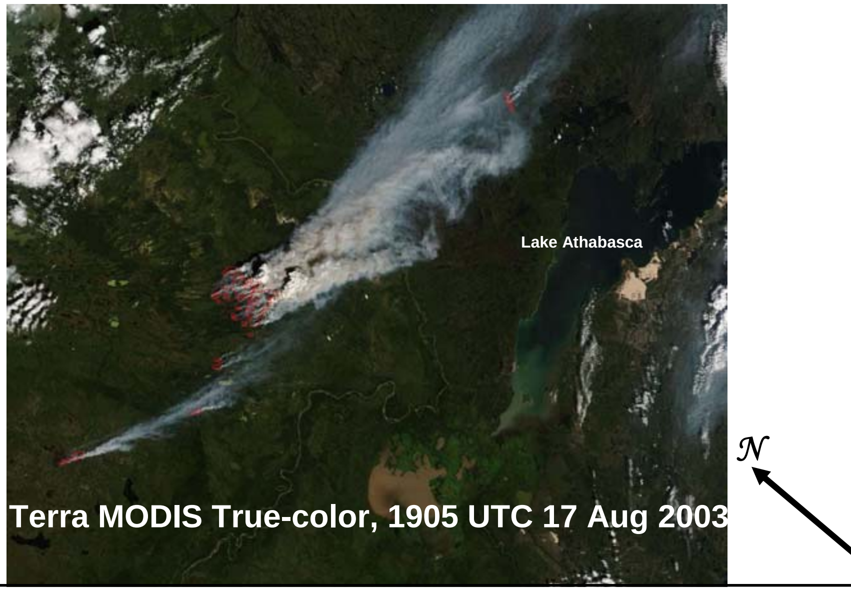
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 110, D08205, doi:10.1029/2004JD005350, 2005

Pyro-cumulonimbus injection of smoke to the stratosphere: Observations and impact of a super blowup in northwestern Canada on 3–4 August 1998

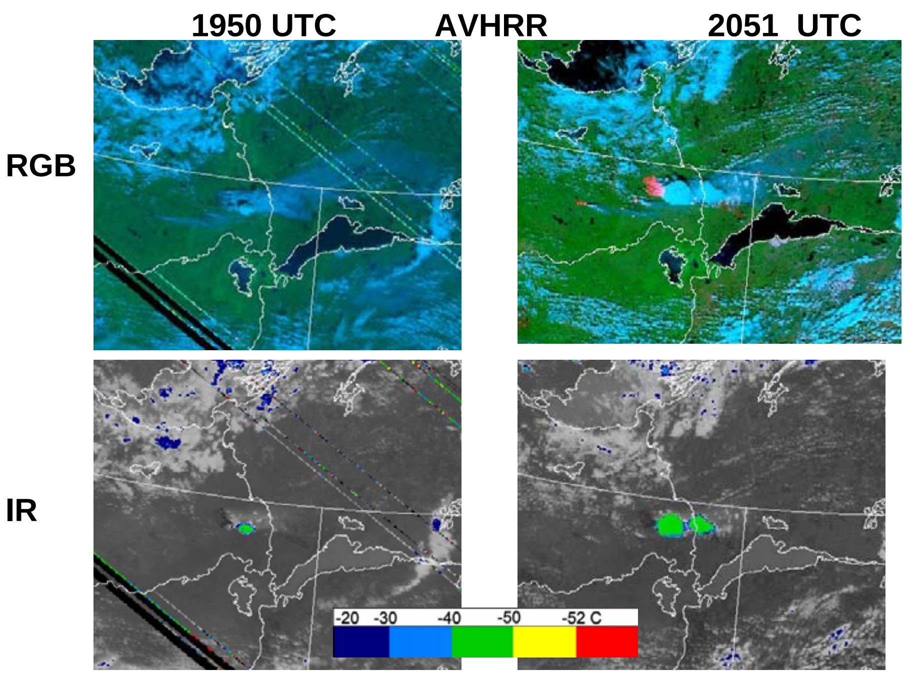
Michael Fromm,[1] Richard Bevilacqua,[1] René Servranckx,[2] James Rosen,[3] Jeffrey P. Thayer,[4] Jay Herman,[5] and David Larko[6]

Received 13 August 2004; revised 2 November 2004; accepted 11 February 2005; published 30 April 2005.

At 11 am local on 17 August,
pyro-convection is bubbling in northern Alberta.
(Provided by Mike Fromm, NRL)

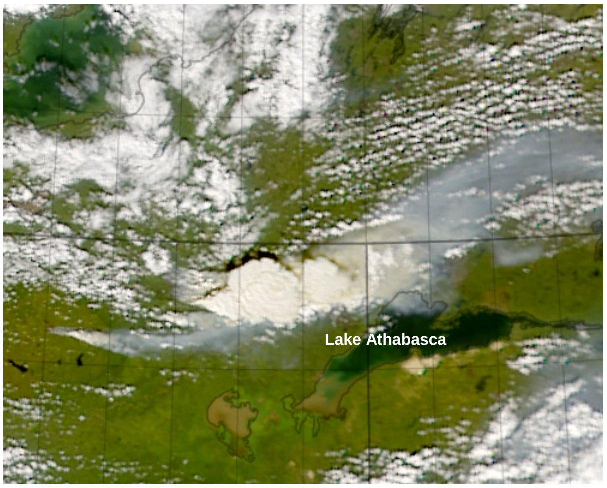


Anvil starts forming 10 before noon **Two anvils by ten of 1**



SeaWiFS True Color
2113 UTC 17 Aug 2003

Proof in living color: smoke in, on, and/or above anvil.

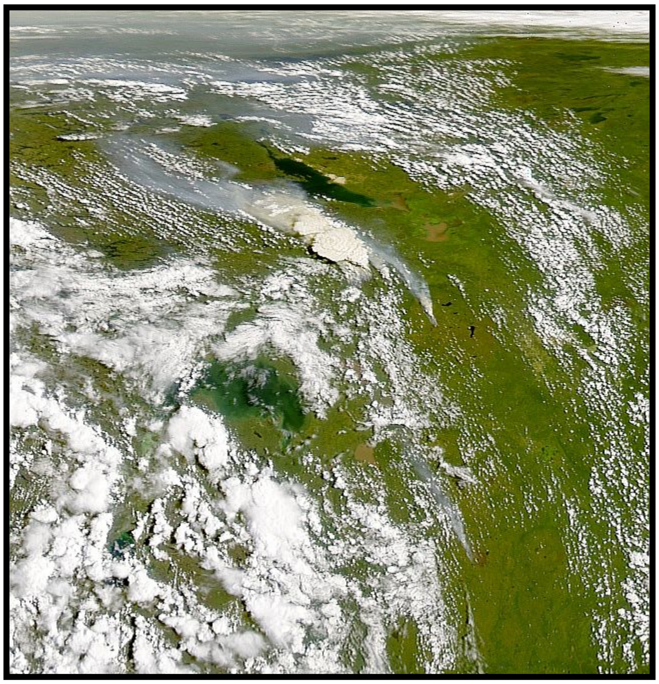


(Provided by Mike Fromm, NRL)

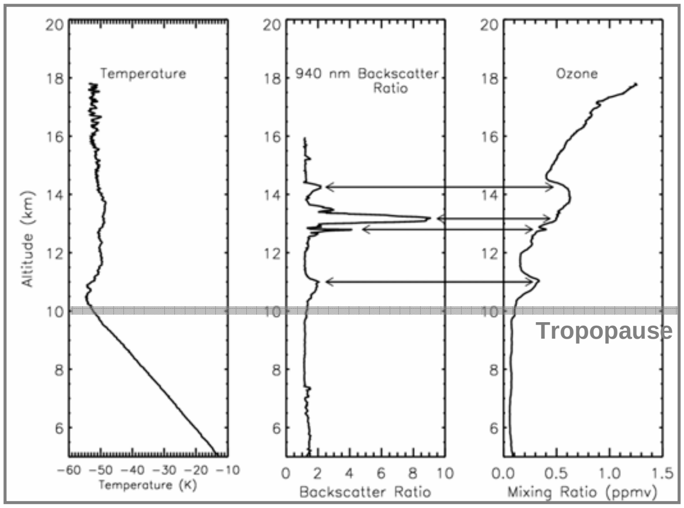
Same SeaWiFS, different perspective (and stunning!)

(Mike Fromm NRL)

N ←



23 August backscatter- and ozone-sonde near Saskatoon, Saskatchewan

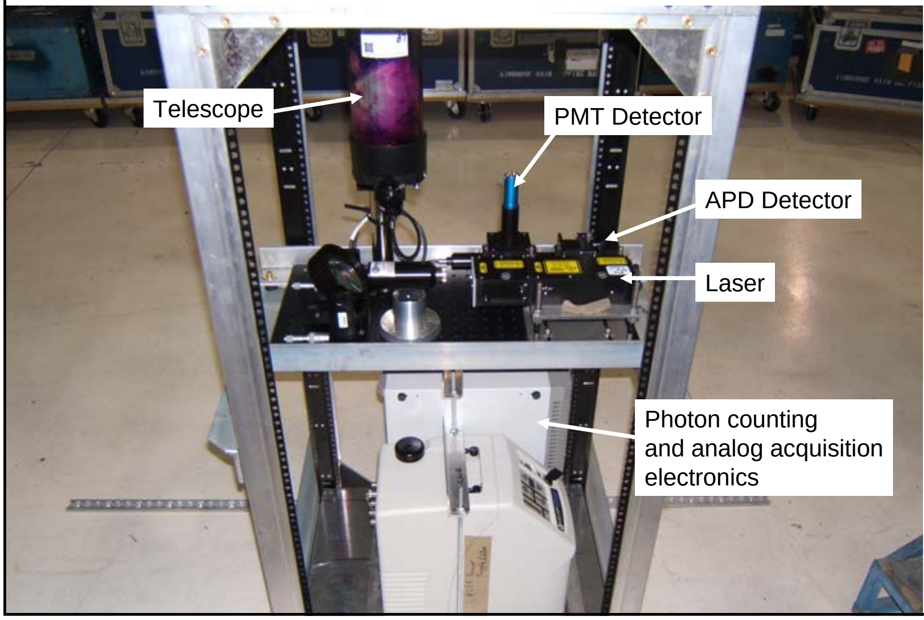


Does Pyro-Convection inject material into stratosphere?

York Lidar on Twin Otter
CFCAS funding: 50 hours, 30 days
Associated with POLARCAT IPY project

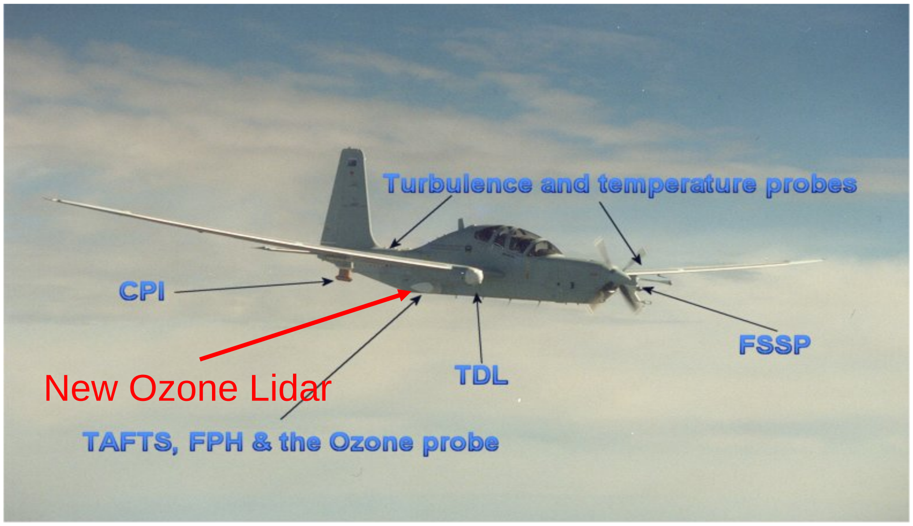
Figure 3. Photograph of the Twin Otter aircraft (left) and the new Phoenix Field Lidar (right) during installation on the Twin Otter at Grand Junction Colorado (base of Twin Otter Airborne Research).

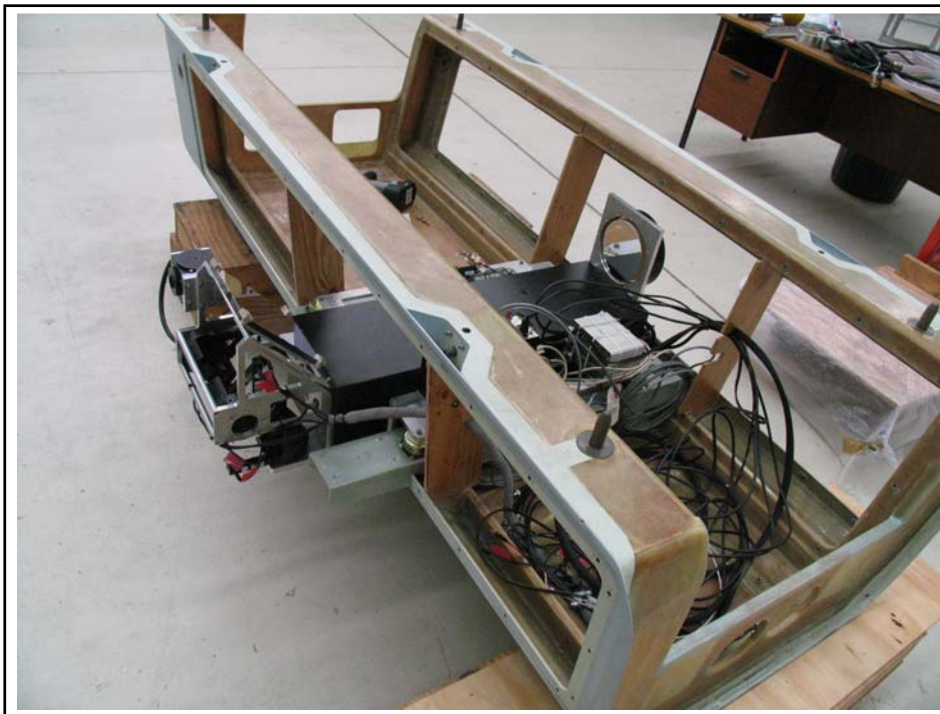
York Cloud/Aerosol Lidar
Installed on Twin Otter



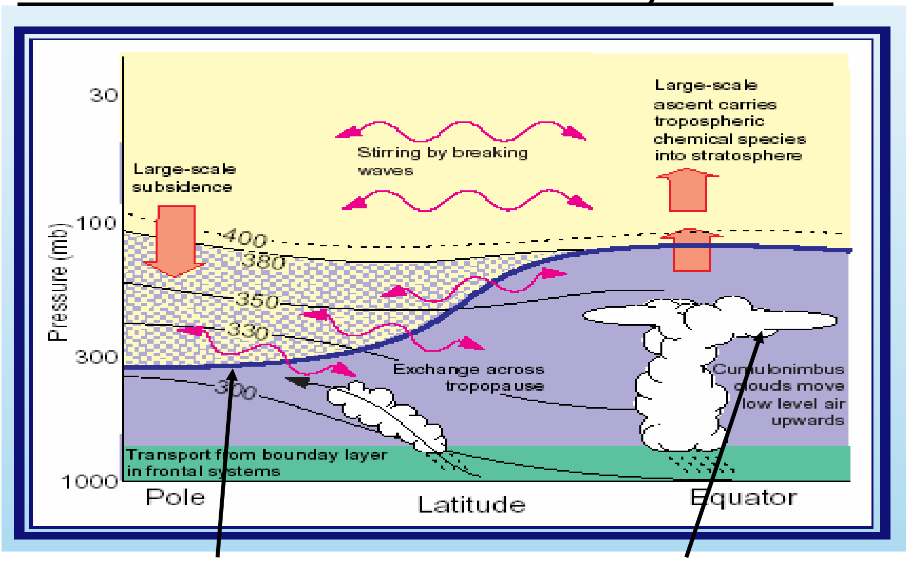
Ozone Lidar also on Twin Otter for Puro-Cb flights

Airborne Ozone Lidar





ECHO: Effects on Convection on Humidity and Ozone



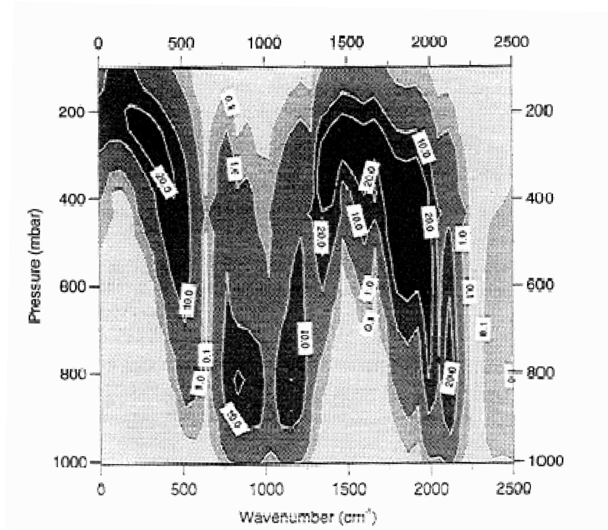
Pyro-Convection
Forest Fires
Transport stratosphere

Convection and Climate
Outflow cirrus
Humidity
Ozone

Q. J. R. Meteorol. Soc. (1996), **122**, pp. 799–818

The greenhouse Earth: A view from space

By J. E. HARRIES*
Imperial College, UK
(Presidential address: delivered 21 June 1995)

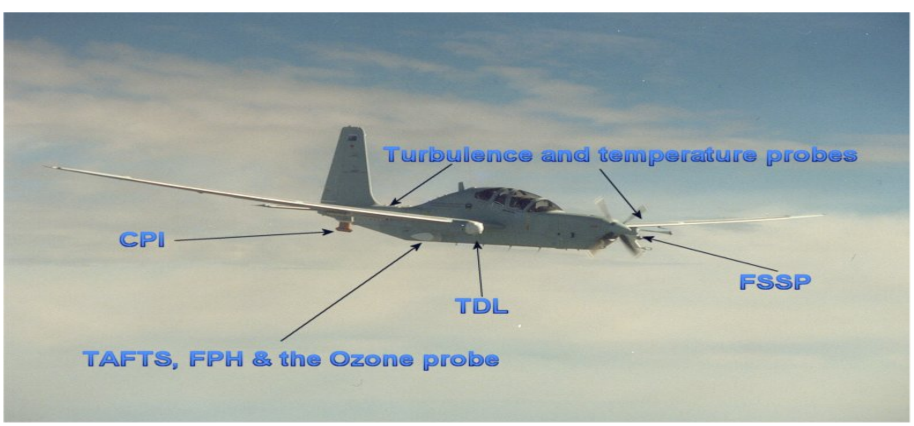


The Egrett

15 km

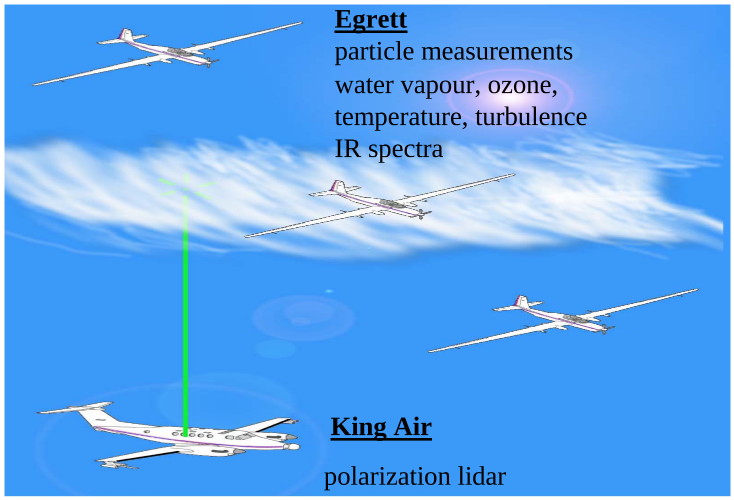
70-100 m/sec

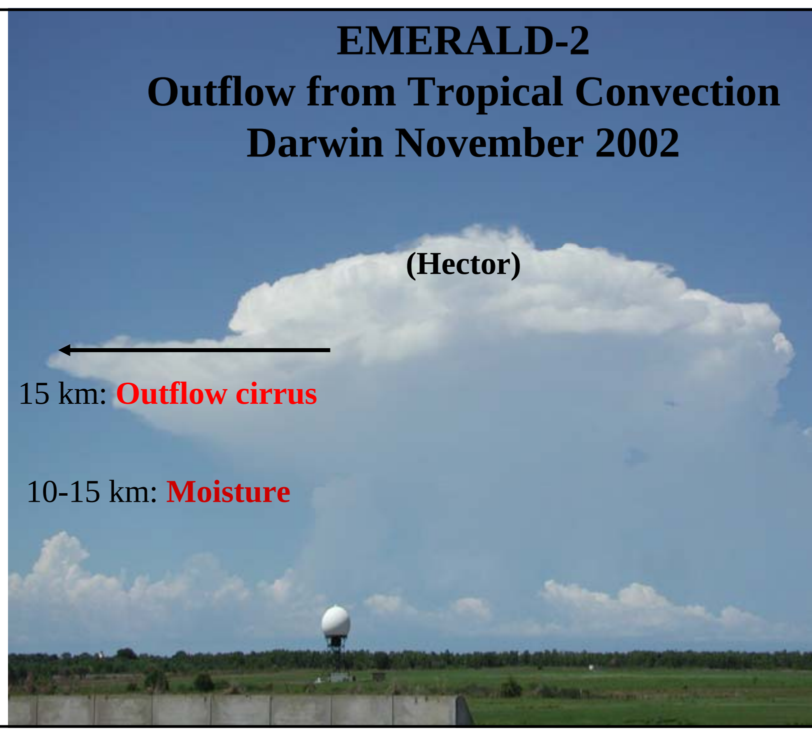
750 Kg



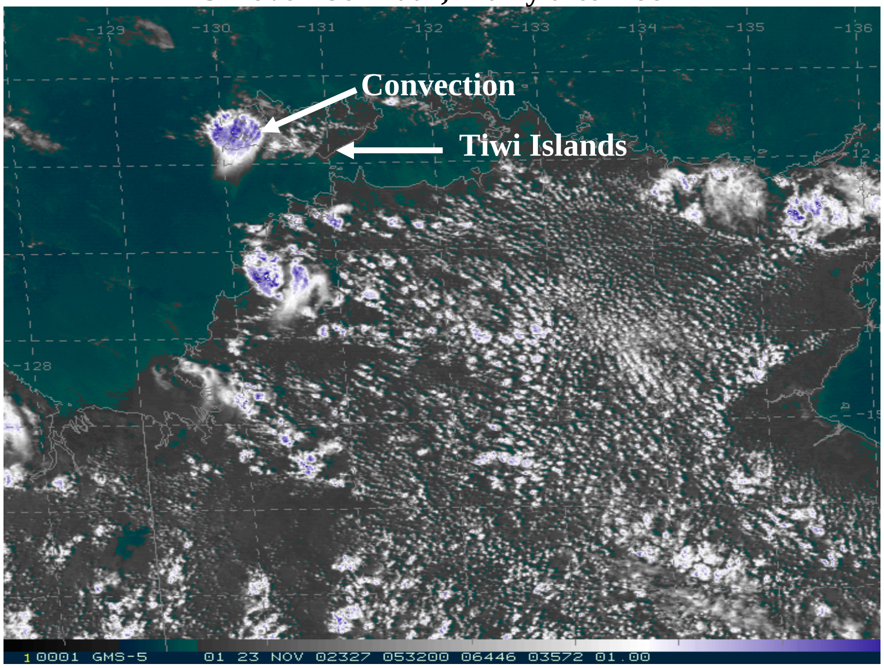
EMERALD

Egrett Microphysics Experiment with Radiation, Lidar, and Dynamics

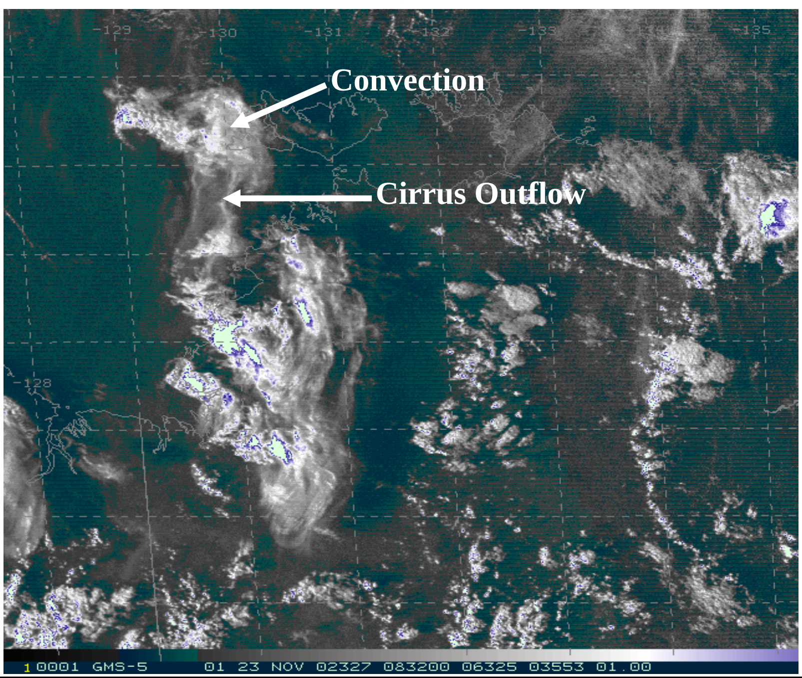




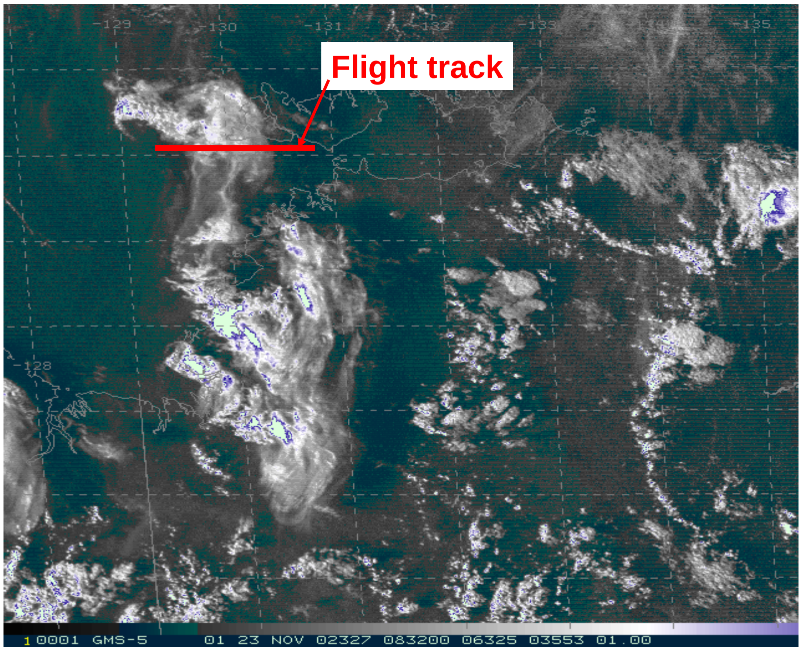
23 November 2002, Early afternoon



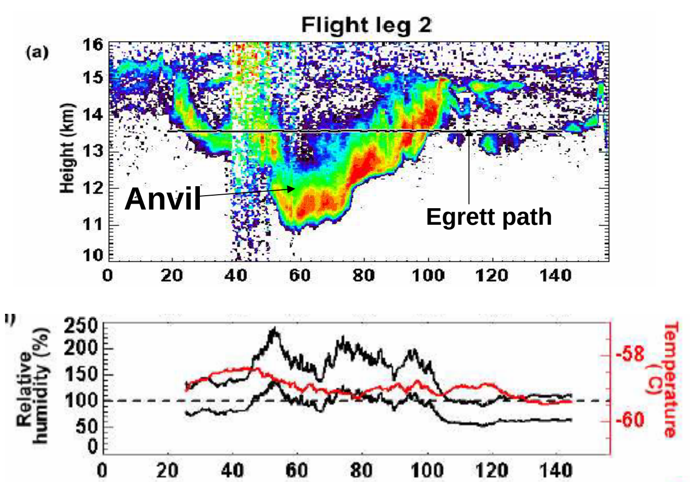
23 November 2002, Late afternoon



Flight leg across the outflow



Relative Humidity in the Anvil



Emerald-2 Water Vapour Measurements

Frost Point Hygrometer
R. Busen, DLR

Tunable Diode Laser
J. Whiteway, UWA

Both employ standard air inlets (Rosemount)

Interesting Result:

Extremely supersaturated air in anvil and core remnants?

Experimental consideration:
- Small portion of ice evaporates in inlet and sampled as vapour?

Next Egrett Campaign: Darwin 05/06
York U: Water vapour measurements with no inlet
Open path TDL installed on Egrett

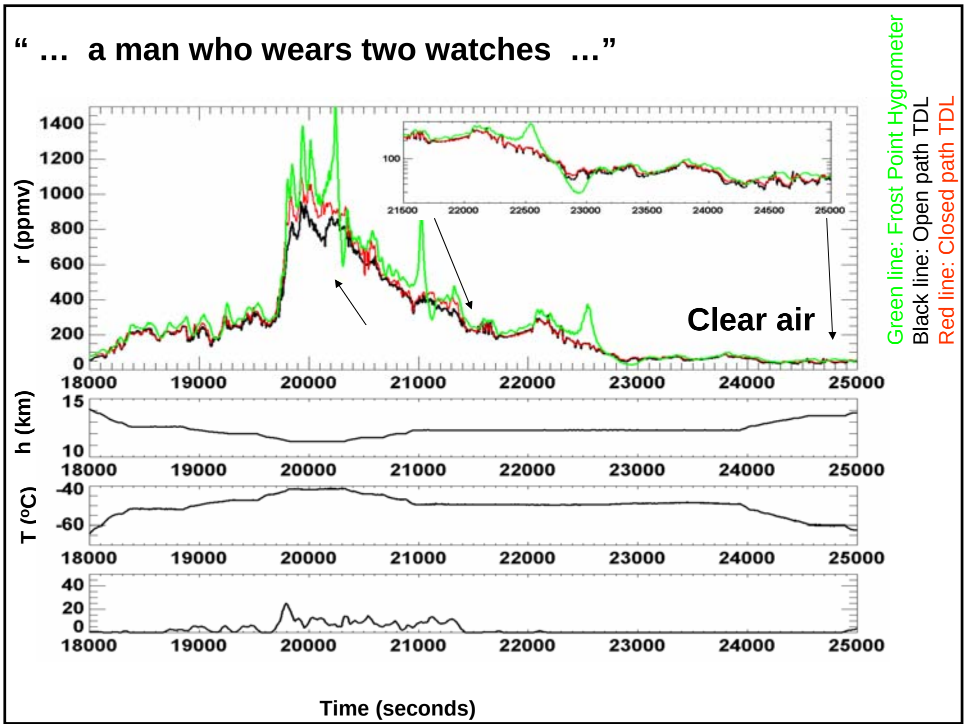
UK (ACTIVE): more microphysics and aerosol measurements

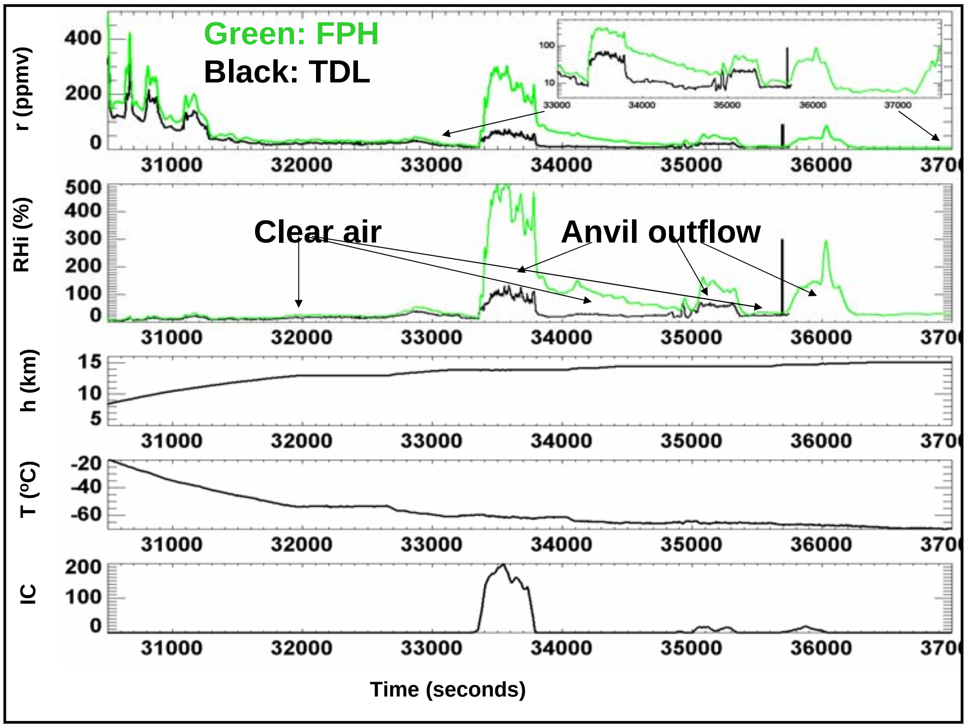
Addition of a third instrument for Water Vapour on the Egrett

Tunable Diode Laser with Open Path Herriott Cell

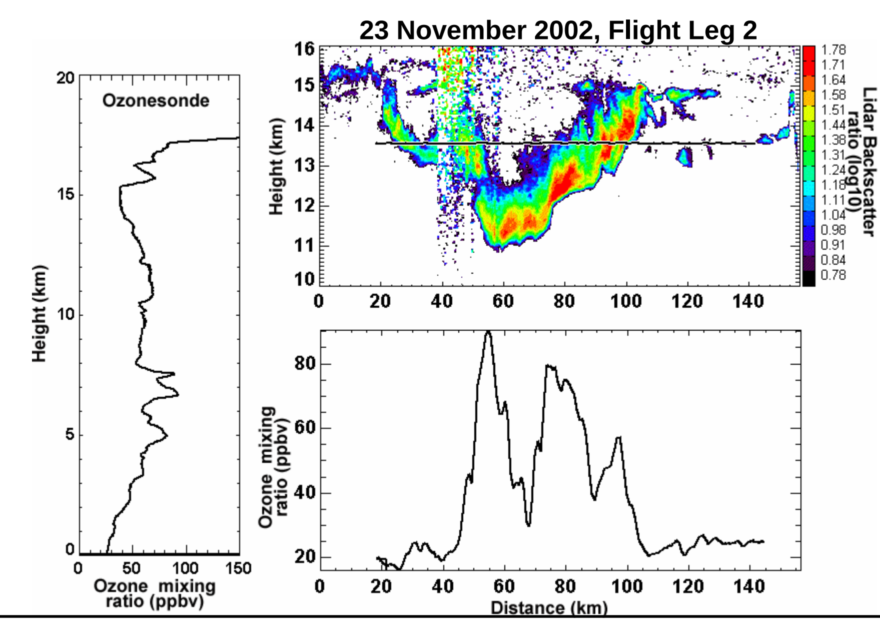
From York University (Built by R. May, MayComm)

" … a man who wears two watches …"





Ozone in Anvil outflow



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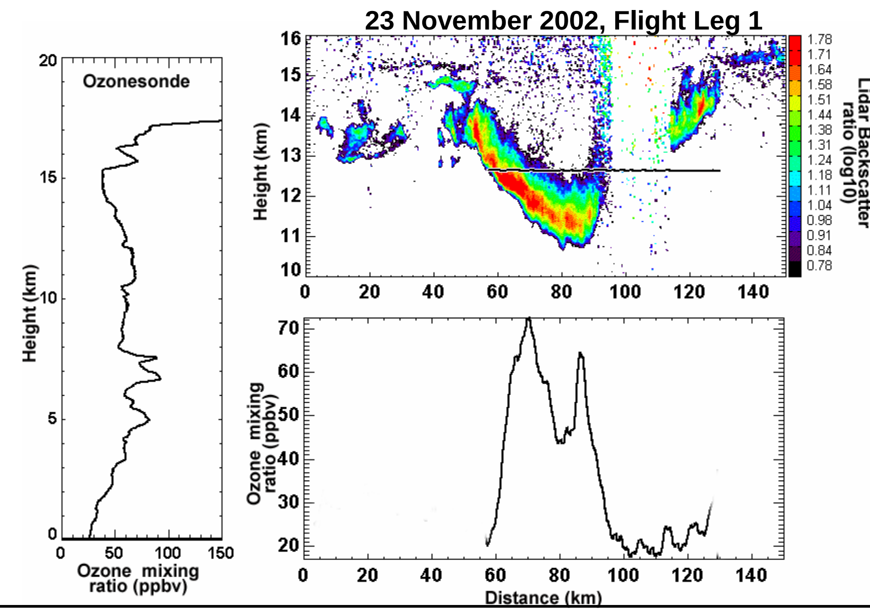
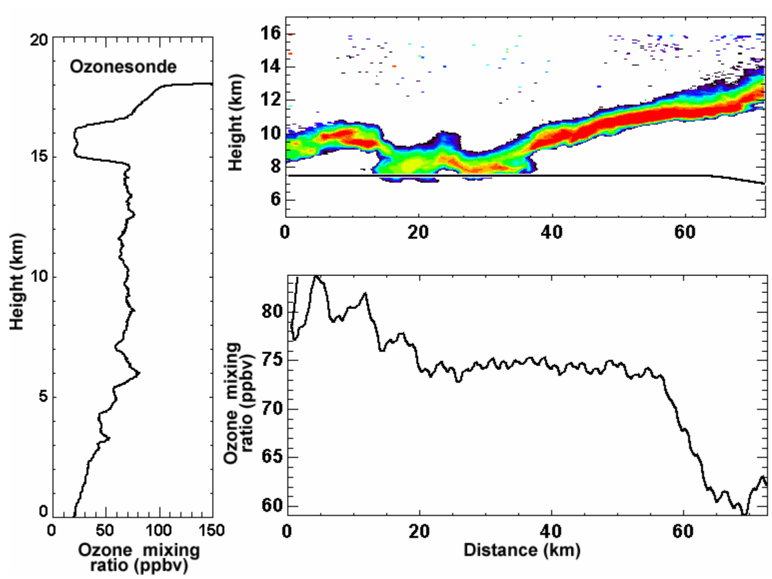
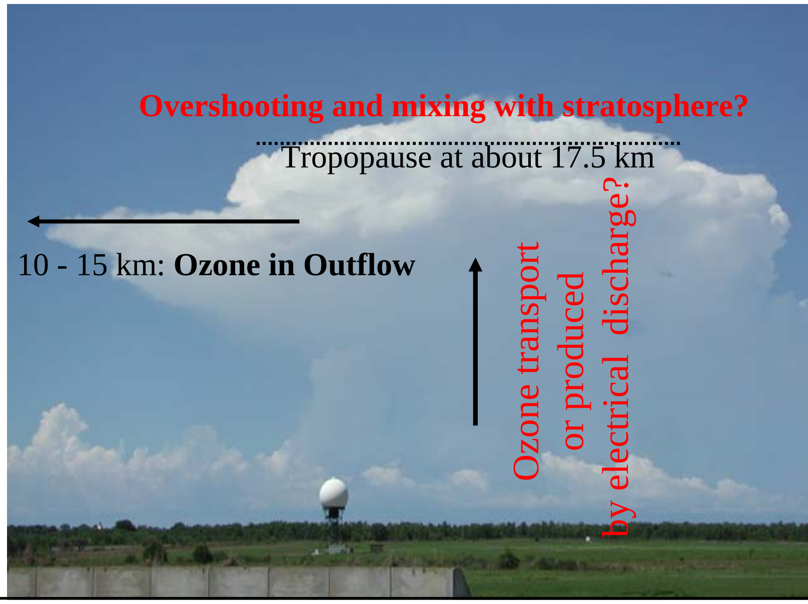


2 December 2002



Emerald-2 Campaign

Ozone in Anvil outflow



Interesting result 2:
More Ozone in the anvil than inflow and surroundings

Interpretation:
Transport from stratosphere
Transport from mid-Troposphere
Generation of ozone within the storm

Experimental consideration:
-Charging and discharge in inlet
-Water vapour variations interfering with Ozone measurement

Require: Ozone measurement with no inlet
Measurements after cloud dissipates

Next Egrett Campaign: Darwin 05/06
York U.: Water vapour measurements with no inlet
Open path TDL installed on Egrett

New Proposal in the works (CFI)

Jim Whiteway, York University
Walter Strapp, Environment Canada
Anthony Brown, Dave Marcotte, NRC

NRC Falcon with remote sensing

- Ozone lidar
- Water vapour lidar

T-33 with in situ measurements

- **Water vapour from York**
- **Cloud microphysics from EC**
- **Chemical measurements from EC**

Ontario:
Cirrus clouds and effects of aircraft exhust
jetstream turbulence and mixing
tropospheric ozone (lidar downward)
convection, transport of pollutants and strat/trop exchange
Testing of space instruments

Darwin or Costa Rica:
Convection and transport in the tropopause region
Tropopause dynamics and generation of gravity waves
UTLS Water vapour

Rockies:
gravity wave breaking
Strat Trop exchange
Cloud Physics and water vapour

Arctic:
Strat/trop exchange
tropospheric ozone (lidar downward)

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Brian Solheim et al., York University

Install on NRC Falcon looking out through window port
Validate capability of measurements in tropopause region
Combine SHOW remote sensing with in situ measurements
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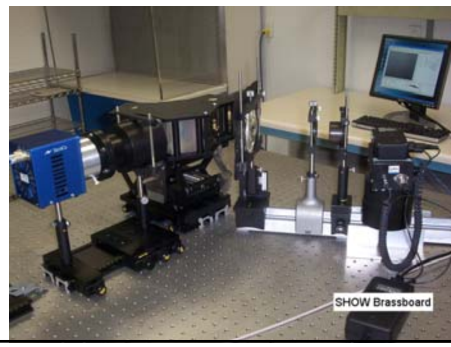

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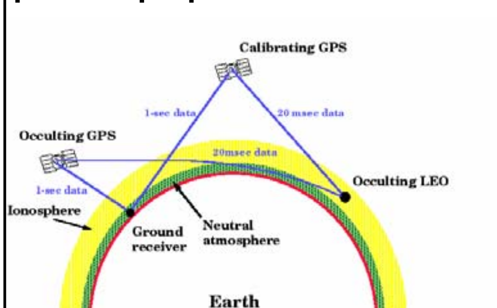

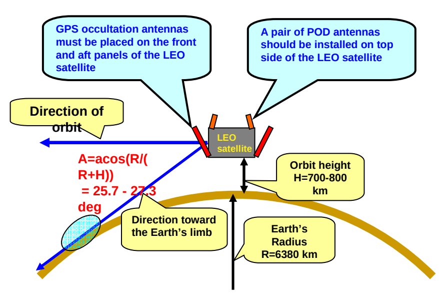

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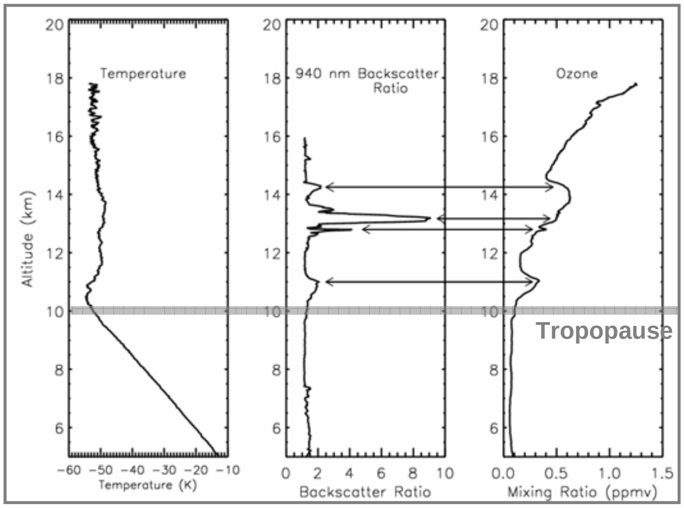


Resonance's Aircraft, Balloon and Rocket Payloads, Past and Future

Dr. William H. Morrow
President of Resonance Ltd.

Abstract:

This paper will review airborne, balloon and rocket flights with Resonance Limited's gas-sensing payloads. It will also discuss new initiatives for the use of unmanned airborne vehicles (UAVs) for the sensing of atmospheric gases.

Topics will include:

- Measurement of Mesospheric and Stratospheric AO with Resonance's rocket and balloon payloads (U of Tokyo).
- Flights of Resonance's miniaturized IR remote sensor (MicroMAPS) and on Burt Rutan's Proteus aircraft (NASA Langley Research Center).
- Resonance's CO in-situ sensor (Brookhaven National Laboratories).
- Future use of UAV-based sensors for gas flux measurements of volcanic plumes, pipelines and forests.

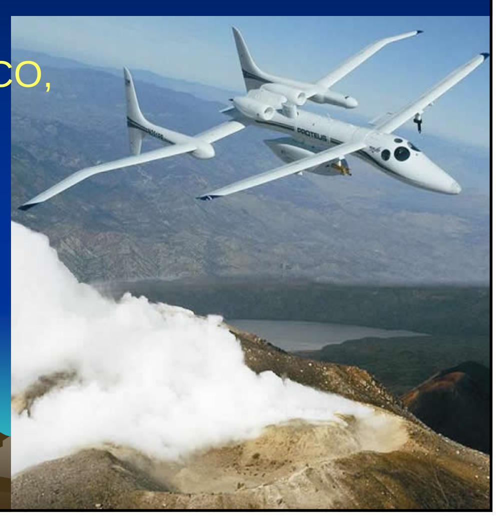
Presenting Author Name:	Dr. Bill Morrow
Organization:	Resonance Ltd.
Presenting Author Email:	bmorrow@resonance.on.ca
Presenting Author Telephone:	705 733 3633
Preferred Session:	Past projects and case studies / Proposals
Presentation Method:	Talk
Presenting Author Title:	Industry

Resonance's Aircraft, Balloon and Rocket Payloads: Past and Future

Bill Morrow
bmorrow@resonance.on.ca

http://www.resonance.on.ca

- Past:
  - Rocket and Balloon payloads for Atomic Oxygen
  - Aircraft payloads for CO, N_2O
- Future:
  - Unmanned airborne vehicles (UAVs) with miniaturized sensors



http://www.resonance.on.ca

AO measurements from sounding rockets and balloons-1990 to present

- Miniaturized lamp fluorescence technology
- Churchill flights in 1973, 1982.
- Apollo Soyuz project enhances technology
- Multi-gas rocket proposal accepted in 1984
- Canadian Rocket range shut down in 1985
- Our "great adventure" begins

http://www.resonance.on.ca

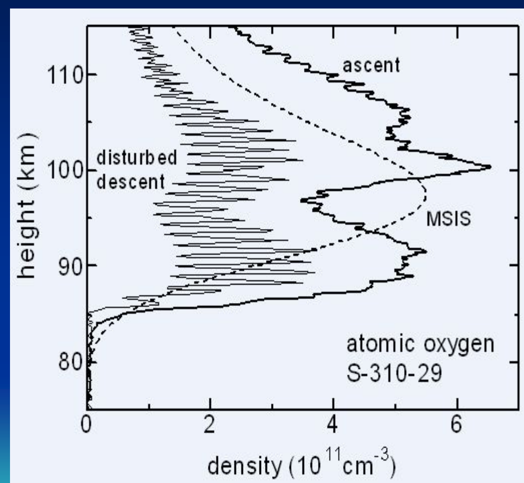
The "Great Adventure"

- Resonance goes to Japan in 1989
- Principal collaborators were Toshio Ogawa and **Naomoto** Iwagami from U of Tokyo
- 2 failed flights: 1989 to 1991
- 4 Successful flights of AO payloads from 1993 to present

http://www.resonance.on.ca

Results from Rocket work

- AO from 80 to 200 km using Canadian WINDO payloads on Japanese sounding rockets
- AO from 30 to 45 km with Canadian Tiny WINDO payload on a Japanese balloon
- Program continues



http://www.resonance.on.ca

Airborne (Tropospheric) Gas Measurements (Remote Sensors)

- Using GASPEC as a starting point, Bill Morrow and Ralph Nichols developed digital/filter wheel Gas Filter Correlation Radiometers (GFCR) in the mid 1980s.
- MAPS (1982-1996) was a GASPEC
- Resonance designed and built a miniaturized Space-Qualified MAPS (MicroMAPS) in the mid 1990s
- Hank Reichle Jr., Jerry Wallberg and Vickie Connors (NASA LARC and NCSU)

http://www.resonance.on.ca

MicroMAPS

- MicroMAPS orbit opportunity disappeared when the Clark Spacecraft was cancelled
- MicroMAPS found a home on Burt Rutan's Proteus
- MicroMAPS has been making airborne CO and N_2O measurements since 2004

MicroMAPS

http://www.resonance.on.ca

MicroMAPS

- CO/N_20 remote sensor with 3 gas channels
- 5 kg 16 watt sensor suitable for small vehicles
- 1/10 size, weight and power of MAPS

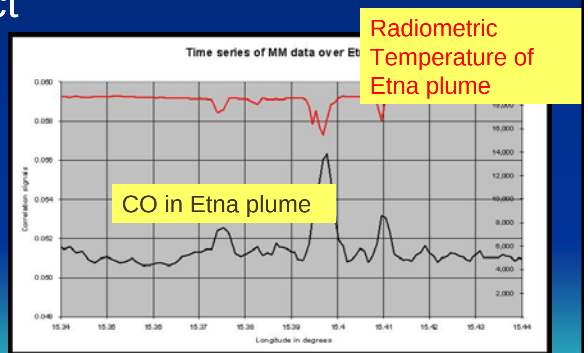
5 kg 3 gas channel space qualified MicroMAPS

Calibration at Resonance in June 05

http://www.resonance.on.ca

MicroMAPS on Proteus

- CO retrievals over N. America and Europe
- Volcanic plume observations
- Ongoing project



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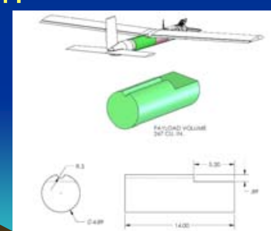
CO Sniffer with Brookhaven National Laboratories

- Fast response CO “sniffer”
- Uses VUV lamp fluorescence
- Low ppb level sensitivity
- Used by DOE for local and continental transport studies
- Collaboration with Steve Springston

http://www.resonance.on.ca

UAV based remote sensing

- Resonance develops mini-DOAS systems for plume and volcanology measurements with McGill (John Stix) starting in 2002
- Resonance sources UAVs (2004) for:
  - DOAS remote sensing
  - Gas imaging GFCR
  - Fluorescence-based spectrometers
  - Laser Fluorosensors



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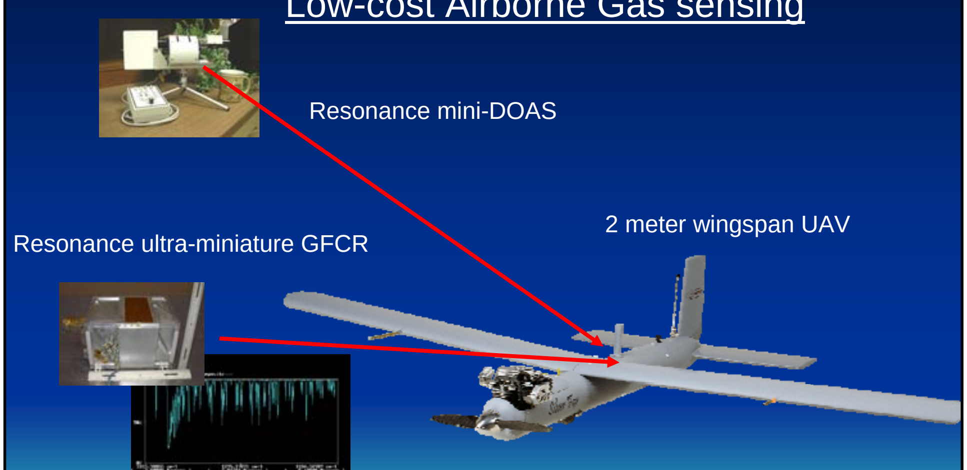
UAVs + Miniaturized Instrumentation = Low-cost Airborne Gas sensing



http://www.resonance.on.ca

What is Validation Anyway?

James R. Drummond
Department of Physics and Atmospheric Science
Dalhousie University

Abstract:

As satellites become more ubiquitous and more significant in our understanding and monitoring of earth systems, the reliability of satellite data becomes a matter of great importance.

The final step in the assessment of satellite data is validation and is especially significant for satellites because of the single-sensor nature of the measurements; the inaccessibility of the sensor for any troubleshooting and adjustment that was not anticipated at the design stage; and the often inherently complex methods of extracting the scientific data product from the raw measurements.

Since validation is often performed with sub-orbital instrumentation, this topic is of considerable interest in the context of this workshop. This talk will explore what we mean by validation: how it is achieved; how it should be achieved; the gap between the two; and what can be done to bridge the gap.

Presenting Author Name:	James Drummond
Organization:	Dalhousie University
Presenting Author Email:	james.drummond@dal.ca
Presenting Author Telephone:	902-494-2324
Preferred Session:	Past projects and case studies
Presentation Method:	Talk
Presenting Author Title:	Professor

What is Validation Anyway?

James R Drummond
Department of Physics and Atmospheric Science
Dalhousie University
James.drummond@dal.ca
902-494-2324

Validation

- The final step in the assessment of satellite data is "validation"
- Especially significant for satellites because
  - single-sensor nature of the measurements;
  - the inaccessibility of the sensor for any troubleshooting and adjustment that was not anticipated at the design stage;
  - the often inherently complex methods of extracting the scientific data product from the raw measurements.
- What do we mean by validation?
- How it is achieved?
- How it should be achieved?
- This talk is particularly related to atmospheric measurements

Definition

- "*The process of assessing, by independent means, the quality of the data products derived from system outputs".* (CEOS WGCV)
- *"Validation ensures that the quality of the products is properly assessed, via quantification of the uncertainties in Level 1b and Level 2 products.*
  - *A validated product is the output from the complete validated data generation chain."*
- *"Geophysical validation is the process of assessing, by independent means, the quality of geophysical data products derived from the system."* (CEOS 9/2006)

In (Ideal) Practice

- Validation is achieved by
  - Comparing the satellite to another instrument
  - The other instrument
    - Uses different techniques
    - Is known to be reliable by validation of its own technique
  - Systematically compared over a variety of scenarios
  - At a coincident time
  - At a coincident place
  - At the same spatial and temporal scales
  - Over the life of the satellite instrument

- In the ideal world validation is a valueless exercise
  - Because everything is perfect
  - And everything agrees
  - And there are no errors
  - And you don’t need a VISA card either
- But in the real world you need both a VISA card and validation…..
- The only people who want to skimp validation are those who believe that the world is perfect and they are….

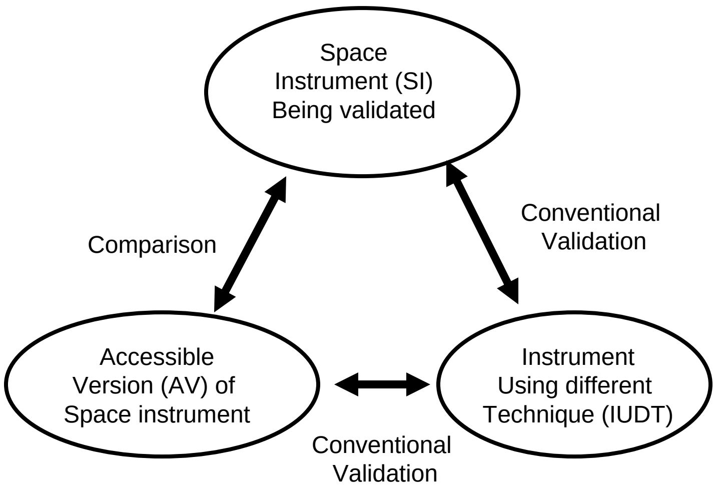
In (Real) Practice

- We do what we can afford!
- Compared to the cost of a satellite mission, the funds allocated to validation are often very, very, very, small
- But if it isn’t validated, then it isn’t reliable
- And if it isn’t reliable, the point of the exercise was……

Digging a Bit Deeper

- Comparing the satellite to another instrument using different techniques
  - Conventional wisdom
    - If we compare two similar instruments we could just propagate an error in the technique
      - Compare an infrared sounder to flask sampling – good
      - Compare an infrared sounder to an ultraviolet sounder – poor
      - Compare an infrared sounder to an infrared sounder – poorer still
  - But if validation fails, how do we sort it out?
  - Real life is a bit more complicated than theory

The Validation Triad



The presence of the “accessible version” (AV) of the space instrument significantly increases the possibility of resolving differences found in validation

Reliability

- One of the techniques has to be "reliable"
  - Reliability means that all the bugs have been worked out, or are at least known
  - Validation on a "campaign" basis is therefore difficult
    - Newly deployed instrumentation
    - Rarely used instrumentation
    - New instrumentation
    - All subject to problems
  - Validation needs to be done on a "program" basis
    - Long time scales
    - Well-trained staff

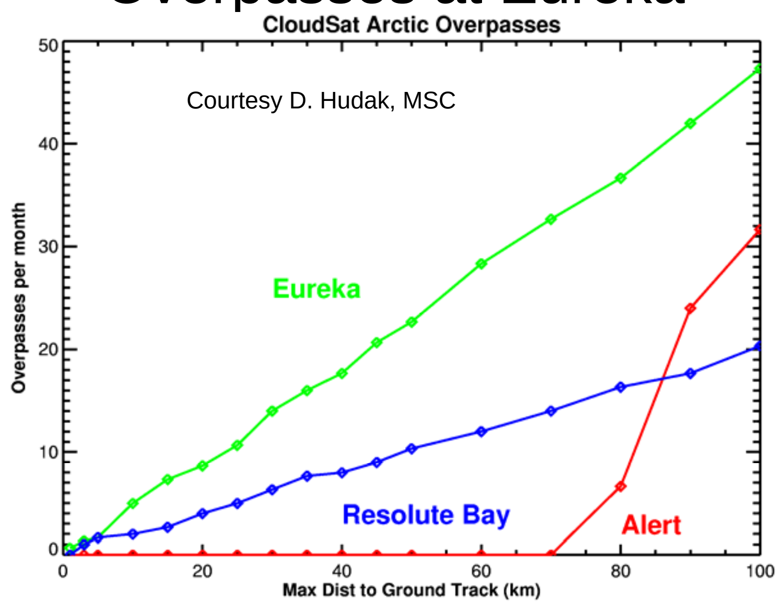
Systematic Comparison

- Tendency to try the "easy cases" with uniform fields
  - Helps with problems discussed earlier
- But the aim of the measurements is to work on difficult cases
- How do we know it works "on the edge"?
- But validation in difficult cases is costly….

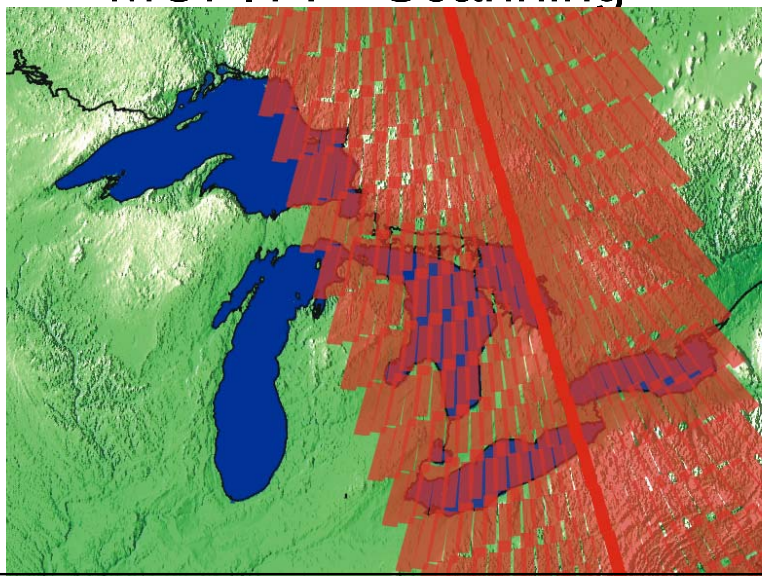
There Ain't no Such Thing as..

- The same measurement
  - All the work on averaging kernels (AKs) should convince us that no two instruments measure exactly the same thing (remember that AKs have a 3-D nature not just a vertical variation)
- In the same place
  - There is almost always a spatial scale problem
  - Satellite pixels are ~km, local instruments ~m
  - Satellites do not often pass over (or even near) any chosen point on the planet's surface
  - (But they often come over Eureka most frequently)
- At the same time
  - Satellites travel at 7km/sec – either all the techniques must be extremely fast or there is a temporal problem
  - Instrumentation has an annoying habit of failing at a critical time

Overpasses at Eureka



MOPITT - Scanning

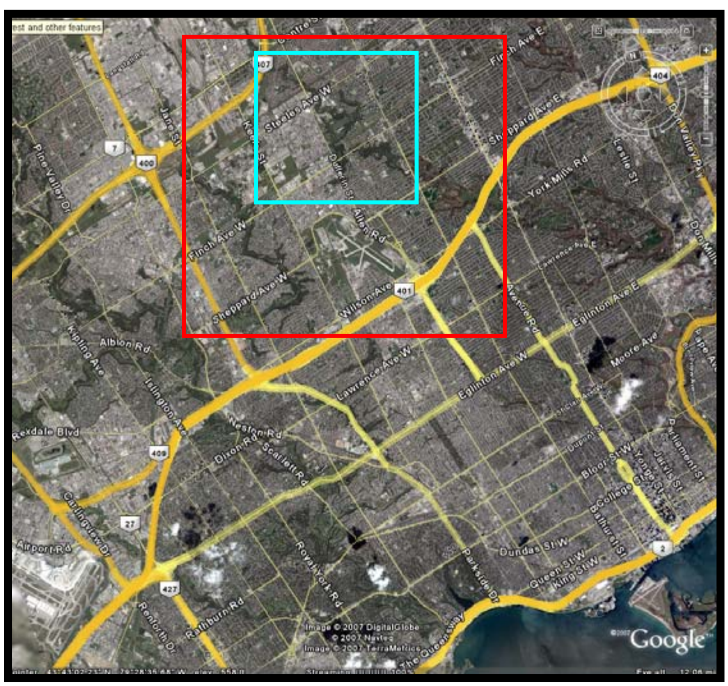


The black square is a 22km MOPITT Pixel

The red square is a 10km pixel

The Blue square is a 5km pixel

MOPITT measures a 22km square in 0.45 secs



A Useful Validation Concept (1)

- Before Validating the SI:
  - Validate one or more IUDTs
  - Validate an AV
  - Understand the relationship between the AV and the IUDTs
  - Identify and resolve
    - Spatial discrepancies
    - Temporal discrepancies
    - AK differences
  - Train all staff thoroughly
  - Perform “dry run” validations
  - Then you can launch the satellite!

A Useful Validation Concept (2)

- Validation Part 1
  - Start with “flat fields” to minimise spatial and temporal problems
  - Work out all discrepancies between the SI, AV & IUDT
- Validation Part 2
  - Use non-uniform fields to test robustness of SI/AV/IUDT matching
  - Much harder because all of AKs, spatial and temporal compatibility become an issue
  - Models may help, but they add a new component to the problem

A Useful Validation Concept (3)

- Post-Validation
  - There is no post validation
  - Validation needs to be performed regularly during the life of the mission because the SI may change and result in scatter or bias of the results.
  - This is especially important in the case of any instrument looking at "trends"

Closing Thoughts

- As satellite instruments become more accurate and we rely on them more, the need for validation increases
- Validation has been neglected, but can be neglected no longer
- If you are not going to validate a measurement properly, is it worth making the measurement in the first place?

"If I had $1M."

Matthew Toohey* and Debra Wunch*
University of Toronto

Abstract:

As student "veterans" of the MANTRA balloon campaigns, we have a unique perspective on the structure and effectiveness of the Canadian balloon program - especially as it relates to training and HQP development. We would propose to combine our respective millions to create a balloon program with two distinct parts, each satisfying a well-defined goal: one that consists of a set of "flagship" instruments, with the primary goal being scientific, and one that consists of small payloads that contain "development" instruments, with the primary goal being the training of HQPs. The scientific success of the flagship stream (modelled after, say, MkIV, BLAST or SAOZ BrO payloads) would encourage a commitment to ballooning which would be very valuable to students working on the developmental stream, since guaranteed launches with sufficient funding and support personnel are critical to timely and successful student education.

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Preferred Session:	Proposals for future projects by graduate students and postdocs
Presentation Method:	Talk
Presenting Author Title:	Grad Student

MANTRA: from the Student Perspective

Matthew Toohey, Debra Wunch
Suborbital Vehicles Workshop
February 2nd, 2007, Toronto, ON

Outline

- Background on MANTRA
- The student experience from MANTRA
- Advantages of MANTRA
- Disadvantages of MANTRA
- Major roadblocks to timely thesis completion
- Our proposed system
- Summary

Motivation: MANTRA

- Middle Atmosphere Nitrogen TRend Assessment
  - Series of high-altitude balloon launches from Vanscoy, SK in 1998, 2000, 2002, 2004
  - ~11 instruments on board payload
- Investigate changing chemical balance of mid-latitude stratosphere.

1. Measure trace gas profiles.
2. Determine historical trends.
3. Perform instrument intercomparisons.
4. Validate satellite data.
5. HQP training.

- Multiple PhDs, MScs, and a small army of undergraduates have participated in MANTRA in some way

Our Student Experiences

- Participated as summer students
  - First experience in field work
  - First instrument control computer program
  - First time using soldering irons/circuit boards/LN_2
- Participated as Master's students
  - First experience taking on some responsibility for an instrument
  - Basic data analysis
- Participated as a PhD students
  - First experience taking responsibility for an instrument, its development, flight-readiness, data analysis
  - Ability to see the "big picture" by participating in every aspect of the project

Advantages of Participating in MANTRA as a Student

- Opportunity for student research with high involvement
  - Provides hands-on opportunity for students
  - Rip instruments to pieces and put them back together again
- Experts are in the field with students
  - Opportunity to interact and learn from experienced scientists
  - Learn about context for your research
- Opportunity to be involved with instruments other than your own
  - New perspectives on atmospheric research
  - New technology/analysis techniques

Disadvantages of MANTRA

- Payload is complex
  - Pushed limits of our resources
- Need to satisfy (sometimes conflicting) technical needs of 11 instruments
  - Pointing, telemetry, power, space
- Too many single-point failures
  - Pointing system
  - Telemetry system
- Scientific requirement limits the participation by students
  - All student instruments considered "secondary" to expert-run instruments
  - Expert-run instruments allocated more resources
  - Stringent scientific requirements place limitations on instrument development

Major Roadblocks to Timely Thesis Completion

- Flights too infrequent (every 2 years)
  - PhD only lasts ~5 years – one failure significantly affects a thesis
  - Lose expertise, equipment corrodes between launches
- Funding arrives too late
  - Contracts approved in April or May for an August launch
    - Students sometimes work slowly!
- Infrastructure at Vanscoy dated
  - Increases risk

Split launches into two streams:

Flagship

- Primary goal: scientific
  - Satellite validation
  - Atmospheric chemistry/dynamics
  - Astrophysics
- Must have previously proven performance
  - Examples: MkIV, MAESTRO, PARIS-IR (eventually)
- Treated as a satellite program
  - $$$
  - Strict milestones and scientific deliverables
  - Frequent launches of these flagship payloads (i.e. at least once per year)

Development

- Primary goal: instrument development and HQP training
- Secondary goal: scientific
- Treated as student project
- Long-term goal: develop a flagship instrument

Our 5-launch student/HQP program

- Purchase 6 balloons of maximum 5 million cubic feet
  - Keep payload small
- Purchase support for 5 launches over program length
  - Occur near the same time as a flagship launch (within ~week)
  - Reduce extra infrastructure required of the launch provider
  - Access to expertise in the field
  - Possibility of piggy-backing on main payload for some instruments
- Maximum 2-3 instruments per payload
  - Not including sondes and GPS
  - Reduce risk by reducing infrastructure requirements
    - Telemetry, pointing
  - Focus scientific goals
- Two instruments should have a scientific goal
  - Example: U of T FTS with CO_2 sonde to validate OCO measurements

Our 5-launch student/HQP program

- Put the whole budget (~$5M) into a fund that can be distributed once the launch payloads are decided upon
  - At least one year before the scheduled launch
  - Require a status update 3 months before a launch to determine whether the students need more time to complete instruments
  - If instruments aren't ready, push back launch by 6 or 12 months (depending on the atmospheric conditions required and the date of the next flagship launch)
    - This doesn't eliminate an opportunity, but schedules it for a later date
  - More timely launches, and timely re-launch opportunities if launches fail
  - Flexible schedule, more frequent launch opportunities

Summary

- MANTRA has provided many students (including us) with invaluable experiences
- MANTRA was becoming too unwieldy, and conflicting requirements made it nearly impossible to both develop HQPs and return scientific deliverables
- Our proposal would be to put the two types of projects into separate streams: one with science goals and proven instruments; one designed to develop instruments and HQPs
  - The first stream would work like a satellite program, with strict deadlines and funding requirements
  - The second stream would work by having a limited number of more frequent launches, and providing sufficient funds at the beginning of the project

Argus Suborbital Flights

*__Dr. Brendan Quine__
Director of Space Engineering, York University, and Technical Director, Thoth Technology.
Rajinder Jagpal
Graduate Student, York University.

Abstract:

Argus is an advanced system to monitor greenhouse-gas emissions from space and represents a new generation of miniature remote sensing instrumentation. York University and Thoth Technology have worked together on the design and development of the 250 g Argus instrument to monitor greenhouse gases in the surface-to-lower-troposphere region. Operating in the infrared and in a nadir-viewing mode, Argus provides a capability for global pollution monitoring of specific targets at one-kilometer surface resolution. We will identify and measure sources and sinks of greenhouse gases, as well as find and track pollution plumes from large-scale, industrial activity. As part of the Can-X 2 microsatellite developed by UTIAS, the first launch of an Argus instrument is scheduled for 2007 on India's PSLV.

We seek flight opportunities on aircraft and balloon based platforms in order to validate and enhance this sensing capability. In one flight scenario, we propose validation flights of Argus instruments onboard one or more hand launched, high altitude balloons. We assume that payload stabilization and pointing control are not required and that missions do not require altitude control, eliminating a requirement for a ballast system and descent valves. The balloon payload will be suspended from the balloon with a pendulation of typically less than two degrees and with an expected revolution below one per minute. The Near Space environment is highly analogous to space environments with similar pressure and thermal regimes. Preflight qualification of integrated flight systems will be conducted at York University's new Space-Test Facility.

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Presenting Author Email:	ben@thoth.ca
Presenting Author Telephone:	416 736 2100 x 33483
Preferred Session:	Proposals for future projects
Presentation Method:	Talk
Presenting Author Title:	Professor

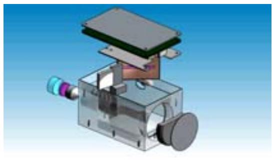
Argus: A spectrometer the size of a box of paperclips

Brendan Quine[1], Rajinder Jagpal[2]

[1]York University and Thoth Technology

[2]York University

Friday, Feb 2, 2007



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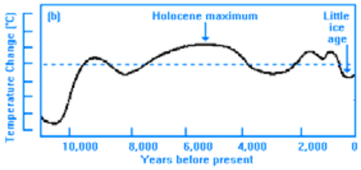
Climate change: natural or caused by me?

- Primary driver is variation in solar insulation power.

Orbit and solar variability = "natural variability"

- Previous history of planet indicates climate can exist in wide variety of quasi-static conditions characterized by different mean surface temperature.
- Scientific understanding of climate has advanced to stage that climate drivers can be quantified in terms of energy forcing on climate system.
- This comes with a realization that human activity is a driving factor on global climate.

SOHO, ESA



Hartmann

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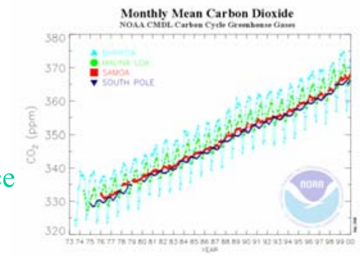
Climate change and Kyoto: a perspective

- Science has convinced wider society that anthropogenic modification of climate requires immediate and sustained action.
- Initiated economic change in previous "extraction cost only" paradigm to "resource use accountancy" model.
- Following Montreal Protocol, the Kyoto Accord defines economic methodology to account for greenhouse-gas emissions in the global economy.
- Engineers and scientists tasked to further explain, investigate, observe, advise to justify this significant economic action.



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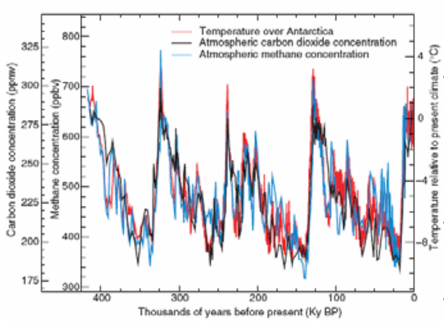
Measuring atmospheric composition



IPCC.

- IPCC model predictions indicate that CO_2 will likely double by 2050 even if Kyoto is adopted globally.
- Arguably, water (vapour, clouds, aerosols, ice) at least as important as GHGs for basic energy balance science.
- Also a long list of other species to be regulated.
- Understanding atmospheric transport also critical.
- Who are the polluters?

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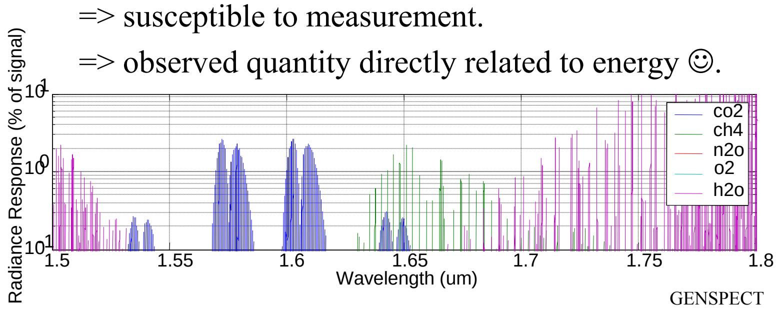
How do we support Kyoto?

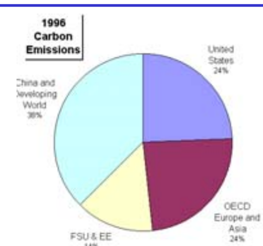
- Need to verify current production accountancy methodology and establish firm link between emissions control and the atmosphere.
- CO_2, like other GHGs, shows strong IR absorption features
  - => susceptible to measurement.
  - => observed quantity directly related to energy ☺.

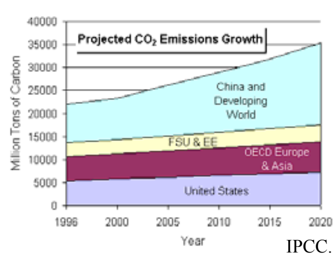


GENSPECT

Kyoto verification

- Identify atmospheric sources and sinks.
- High-spatial and temporal, near surface measurements of composition and co-measurement of other parameters to validate analysis.
- Physical models of atmosphere and instruments for use in inversion models.
- Province and country flux, inventories, emission events and trends as well as traditional physical parameter set.
- Canadian accord agreement = need for Canadian capability.





IPCC.

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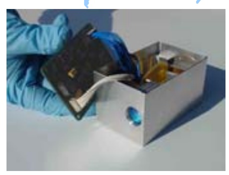
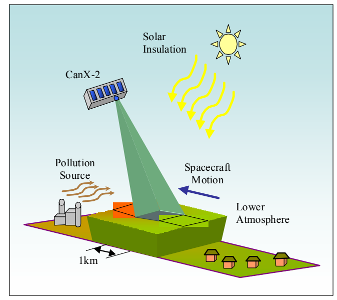
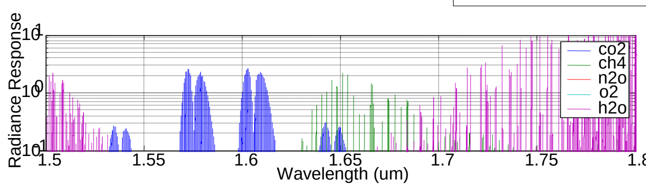
Argus: A Miniature Pollution Monitor

CanX2 (UTIAS) and Argus, Toronto Star.







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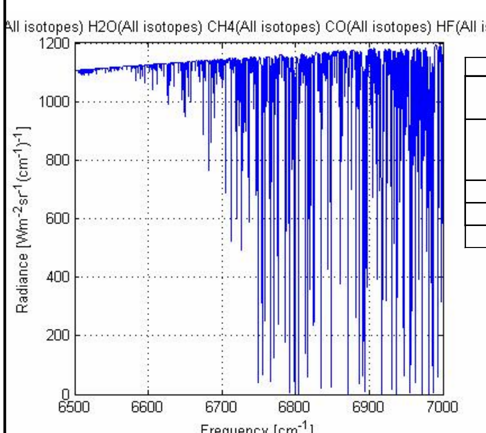
Data Retrieval Using Genspect



Gas	Observed Absorption
Carbon Dioxide (CO_2)	1.24μ m (10^{-23} mol.cm^{-2}) 1.42μ m (10^{-22} mol.cm^{-2})
Water (H_2O)	900nm (10^{-21} mol.cm^{-2}) 1.2μ m (10^{-21} mol.cm^{-2}) 1.4μ m (10^{-19} mol.cm^{-2})
Carbon Monoxide (CO)	1.63μ m (10^{-22} mol.cm^{-2})
Methane (CH_4)	1.67μ m (10^{-20} mol.cm^{-2})
Hydrogen Fluoride (HF)	1.265μ m (10^{-19} mol.cm^{-2})

http://www.genspect.com/

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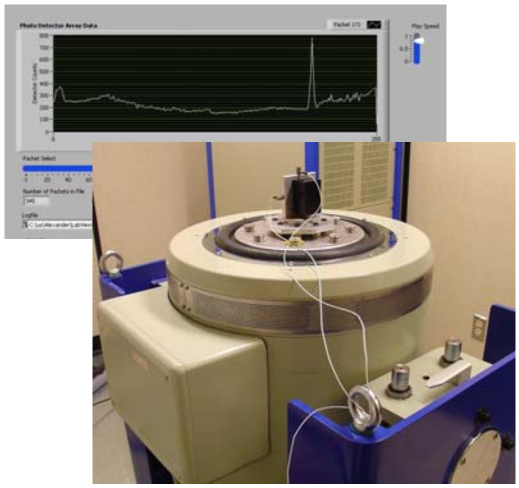
Instrument Qualification



- Argus qualified in YorkU Space Test Facility.
- Qualified to 10g random and sinusoidal excitation.
- Thermal-vacuum tested.

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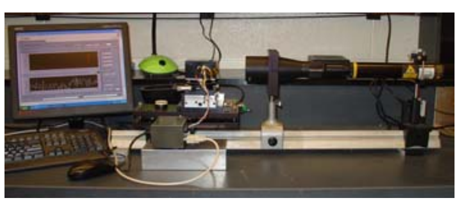
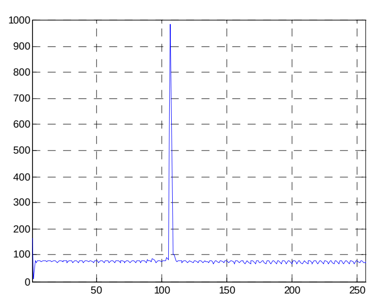
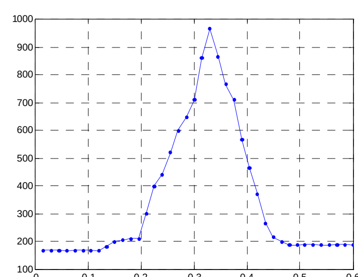
Preflight Calibration







Angular Sensitivity (degrees)

Laser Line Calibrations

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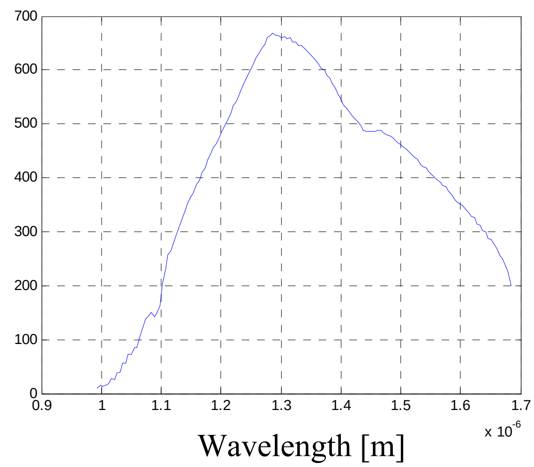
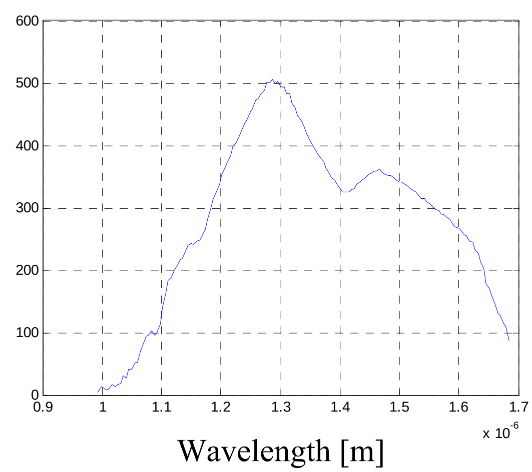
Spectral Response to 1 m (STP) CO_2 path



Tungsten source

Spectral Response (Natural Gas 1m STP path)



Tungsten source

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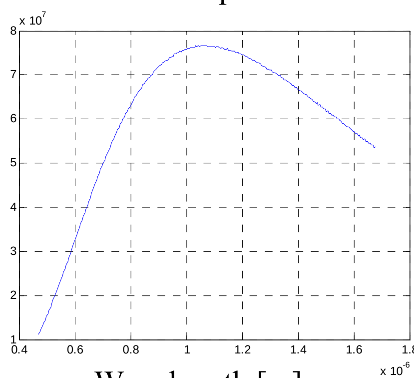
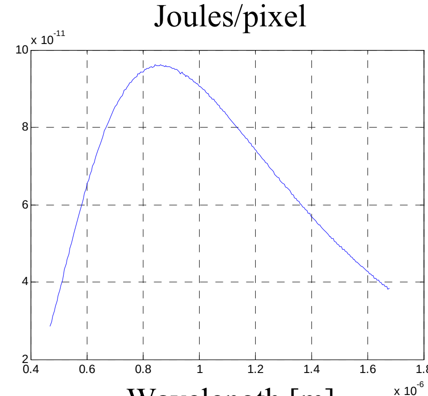
Radiometric Calibration (Preliminary)

Photons/pixel



Wavelength [m]

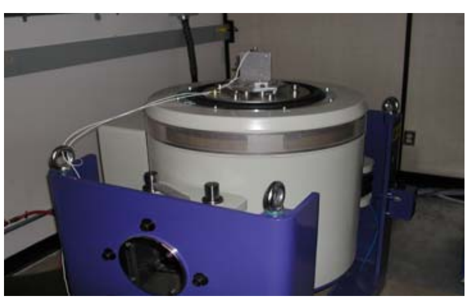
Joules/pixel



Wavelength [m]

CRESS: Space Engineering Laboratories

- Space and Suborbital payload test facility
- Simulates vibration of space launch
- 40 kW amplifier and vibration actuator
- Shake 150 kg at 10 times force of gravity



CSIL: What's inside?

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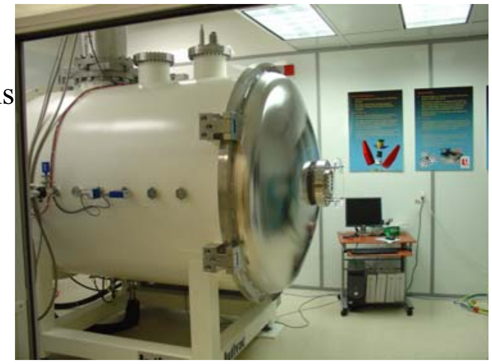
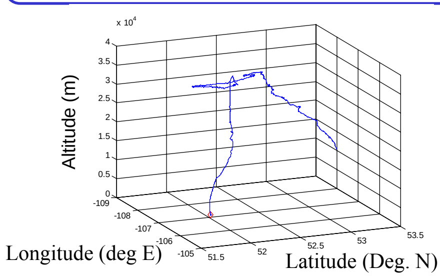
Thermal vacuum facility

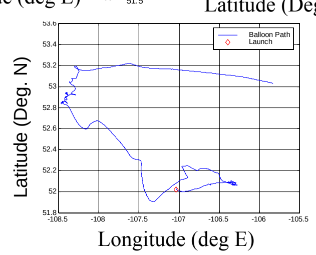
New YorkU Infrastructure

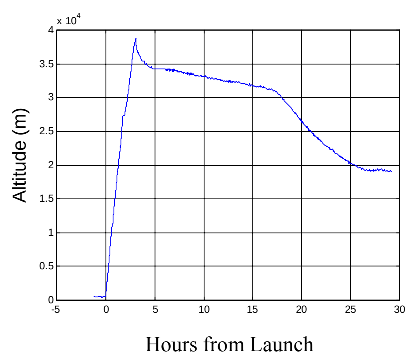
- Simulates Space Environment
- Hard Vacuum (10^{-6} torr)
- Extreme thermal conditions (–140C to +150C)



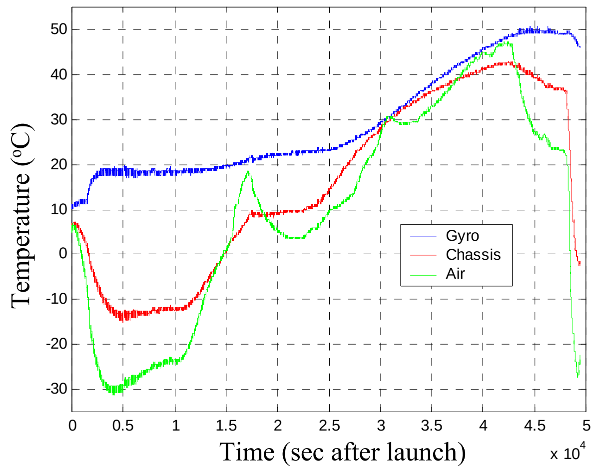
Free Flier: Typical Ascent, Decent Profile (Mantra 1998)







Environmental Considerations



MANTRA 2000

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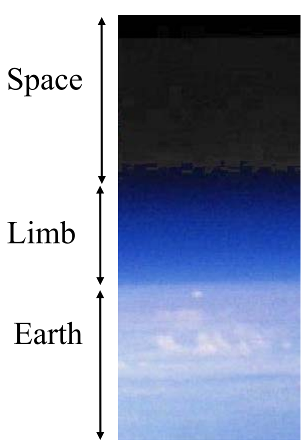
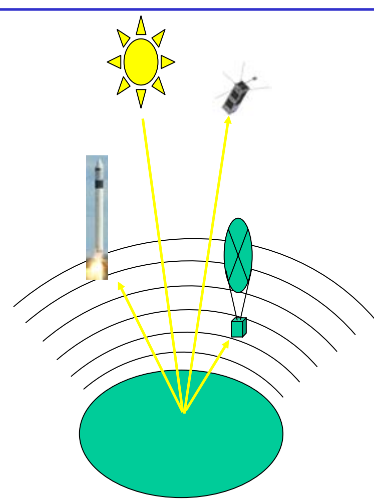
Alternate Viewing Geometries





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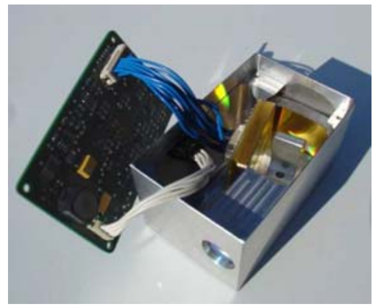
Argus: Looking for Flight Opportunities

- Argus is a low impact, low cost addition to payload suite.
- Measure upwelling radiation in 1.0-1.7um window => infer column composition CO_2, H_2O CH_4.
- Available in other spectral range derivatives: 1.3-2.5um
- 235g mass, 1W min. (3W optimal).
- 45x50x80 mm package.
- Serial data output (prime and redundant channels).



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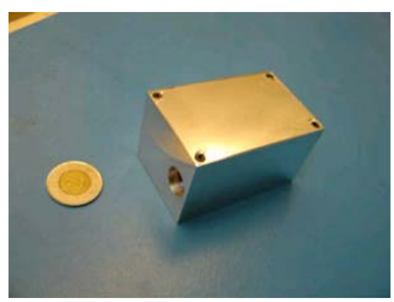
Summary

- Argus fully developed, qualified, ruggedized for suborbital and orbital flight
- One space flight opportunity with UTIAS CanX-2 platform (PSVL, June 2007)
- Looking for other opportunities to support validation, enhance global and temporal coverage
- Measure upwelling radiation, infer GHG compositions, look for plume enhancements caused by industrial activity, many other applications
- Web enabled data processing (in development)



Argus: fly one today!

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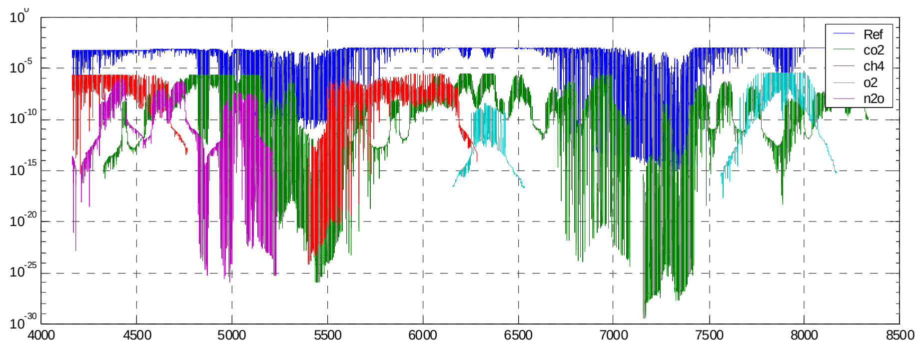
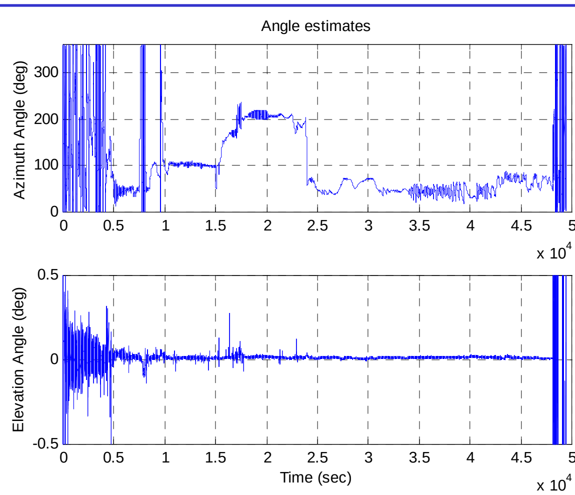
Observing Pollution Remotely



Atmospheric Sensitivity to 1% Change in Gas Composition Change by Spectral Region.

Rotation Pendulation (MANTRA 2000 Data)



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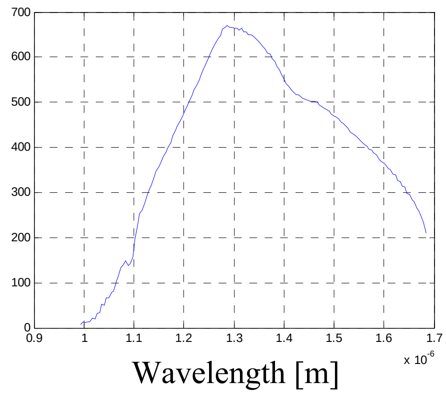
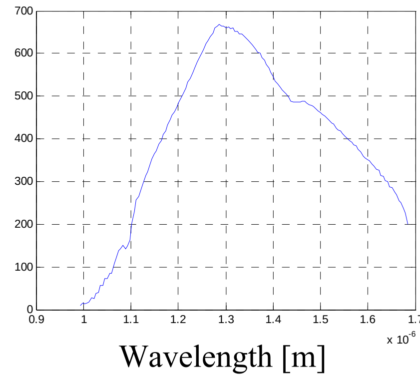
Spectral Response to 2 km CO_2 path





Tungsten source

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Bengal Leopard Kittens (six months old)

Magic

Bamber

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Kyoto: the challenge

- The Kyoto Accord requires signatory countries to commit to reducing GHG emissions by around 6% over a 10 year period and introduces a trading system for emissions tax credits.

Those who do not meet emissions quotas
pay more tax☹ and those who do pay less☺.

- It's not perfect:
  - likely current targets set for economic not scientific reasons 😐,
  - not tied directly to changes in the atmosphere ☹,
- but represents international cooperative action ☺.

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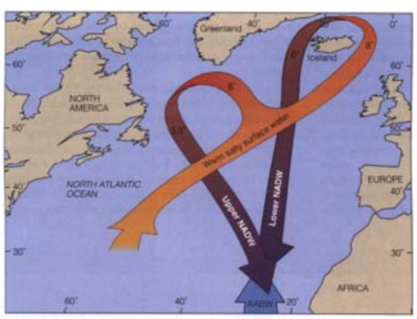
Climate science: What are the big effects?



Super-haline circulation system

Atmospheric circulation system

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Something old and something new: PARIS-IR and beyond

Kaley Walker
University of Toronto

Abstract:

This paper will discuss an existing balloon-borne instrument, the Portable Atmospheric Research Interferometric Spectrometer for the Infrared (PARIS-IR), that is used for studies of atmospheric composition by solar absorption spectroscopy. Based on the ACE-FTS on-board the Atmospheric Chemistry Experiment satellite mission, PARIS-IR is a high resolution (0.02 cm-1) infrared Fourier transform spectrometer (FTS) that has been developed for operation on the ground and on high altitude balloons and aircraft. It had a successful engineering flight during the Middle Atmosphere Nitrogen TRend Assessment (MANTRA) 2004 balloon mission. Possible mission scenarios for PARIS-IR will be described. Also, a brief outline will be given for a millimeter wave emission instrument for atmospheric studies.

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Presentation Method:	Talk
Presenting Author Title	Professor

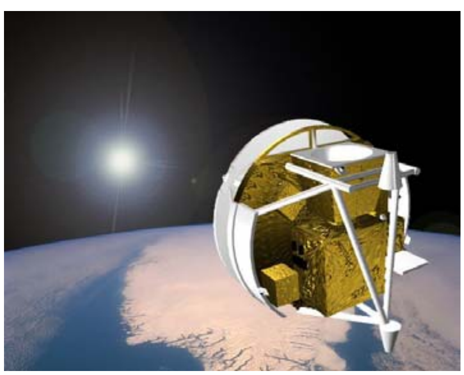
Something old and something new: PARIS-IR and beyond

Kaley A. Walker, Peter Bernath, Marc-Andre Soucy, Dejian Fu, Ian Young, Yony Bresler, Michelle Seguin, Chris Boone, Keeyoon Sung

Suborbital workshop – 2 February 2007

In the beginning…

- Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS) was in development by ABB-Bomem as primary instrument on SCISAT-1 satellite



Waterloo Atmospheric Observatory

CFI funding awarded to Peter Bernath to start atmospheric observatory at University of Waterloo:

- Develop a portable rugged high resolution FT spectrometer based on the ACE-FTS on-board SCISAT-1 with Bomem
- Flexible instrument to make measurements from both ground and airborne platforms
  - Perform ground-based observations from Waterloo and remote campaign locations (such as Eureka, Nunavut)
  - Adapt instrument for operation as part of high-altitude balloon payload

PARIS-IR

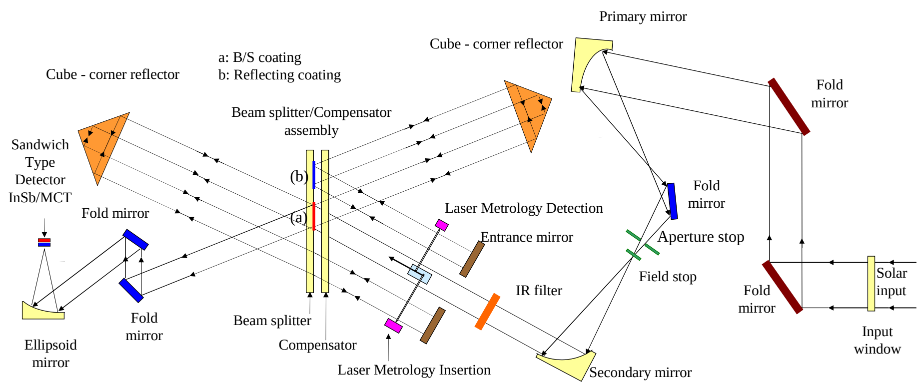
Portable Atmospheric Research Interferometric Spectrometer for the Infrared

Resolution : 0.02 cm^{-1} (max.)
Range: 750–4400 cm^{-1}
Scan Speed: 2.5 cm/s (max.)
Detectors : InSb/HgCdTe (sandwich)
Mass: 66 kg
Size: 61 cm wide x 60 cm deep x 42 cm high
Observation: Solar occultation

PARIS-IR on MANTRA 2004 gondola during early stages of integration

PARIS-IR in operation (with suntracker) at Waterloo Atmospheric Observatory

PARIS-IR Optical Layout



- Measure full spectral range from 750 – 4400 cm^{-1} every 20 seconds with PARIS-IR

Middle Atmosphere Nitrogen TRend Assessment (MANTRA 2004) Balloon Campaign

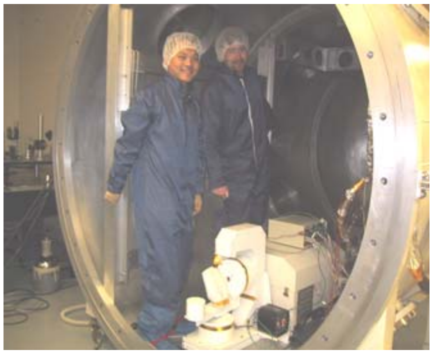
Vanscoy, Saskatchewan
(52° N, 107° W)
Campaign: Aug. 3 –
Sept. 16, 2004

Environment
Canada Balloon
Launch Facility

PARIS-IR on MANTRA 2004

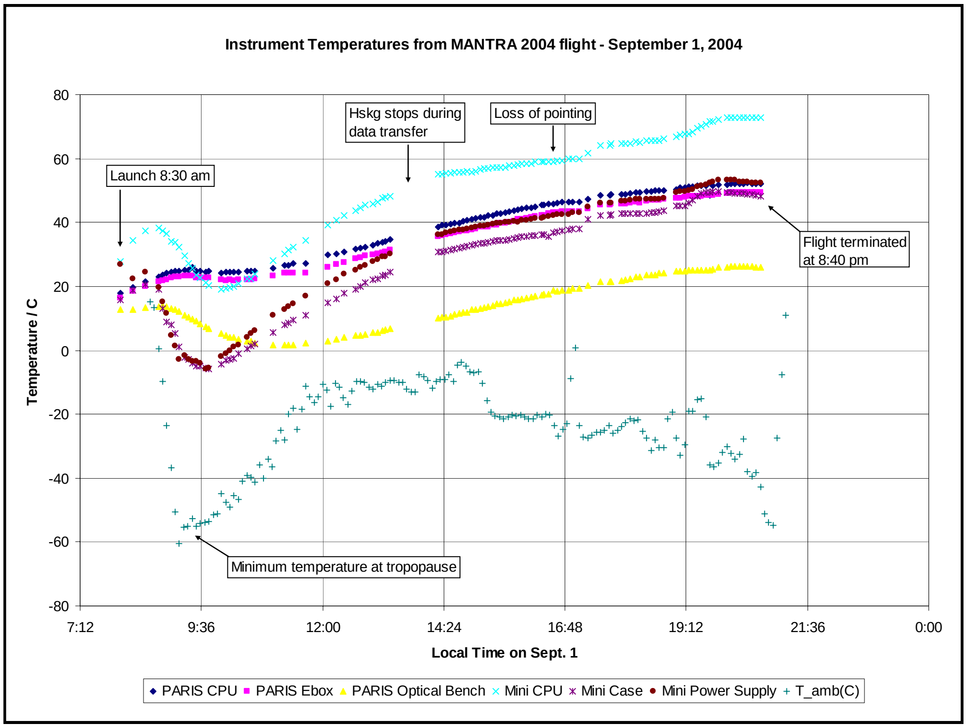
Instrument was delivered 10 months before balloon campaign…

- Design and implement remote control system to operate autonomously and be able to command PARIS from ground
- Perform vacuum testing to verify that it could survive and operate at 40 km altitude
- End-to-end testing of system was done at Waterloo as well as on-site during campaign



MANTRA 2004 Measurements

- Flight data
  - No useful spectra obtained during Sept. 1 flight – only engineering data
- Proved that instrument could fly and autonomous control system functioned
- Need improved sun tracker and minor modifications to the on-board computer



Future for PARIS-IR

- Needs to be flown again to demonstrate science capability
  - 0.02 cm^{-1} is best suited to balloon measurements
- New sun tracker is in development (C. Midwinter)
  - Designed for balloon-borne as well as ground-based use

Next step: Science Test Flight

- Fly with another FTS (DU FTS or UofT-FTS)
  - Want to verify PARIS-IR performance versus instrument with flight "heritage"

Possible Projects with PARIS-IR

- Fly PARIS-IR and MAESTRO-B to simulate measurements on SCISAT-1 satellite
  - Create controlled test of simultaneous observations
- Focus on lower stratospheric species
  - Recent measurements by ACE-FTS of CH_3OH from aged biomass burning plumes
- Isotopologues of O_3, H_2O, CH_4…
  - Will be a challenge but this has been done using ACE-FTS
  - Could be possible with PARIS-IR?

In the further future…

- Millimeter wave or microwave emission measurements for atmospheric composition studies
  - Cloud, ice, snow and water studies already done in Canada
- Strong water vapor and O_2 emission limit measurement of weaker features from the ground
  - Aircraft or balloon platforms can help overcome these limitations
- Region between ~300 – 700 GHz used by several groups: including ASUR (Bremen), SLS (JPL), BSMILES (NICT) for studies of O_3, HCl, HO_2...

Identified during the 5th Atmospheric Environment Workshop as an area "we would like to move into" for future missions

Summary

PARIS-IR solar absorption instrument

- Instrument has had successful engineering flight and needs science test flight (with new suntracker)
- Will be ready to participate in small payloads program
  - Need regular opportunities to maintain continuity

Millimeter wave – sub-millimeter wave emission instrument

- Idea at present which needs to be studied to see what science goals could be achieved and possible future applications

Acknowledgements

- Luc Levesque, Frederic Doyon, Leon Rousseau, and Ginette Aubertin and the ABB-Bomem team

Funding for PARIS-IR is provided by:

- Canadian Foundation for Innovation, Canadian Space Agency, Natural Sciences and Engineering Research Council of Canada (NSERC), Environment Canada
- NSERC-Bomem-CSA-MSC Industrial Research Chair in Fourier Transform Spectroscopy (at U. of Waterloo)
- Canadian Space Agency – Small Payloads Program

Skycam Tethered Aerostat for the Inukshuk Landed Rover Canadian Mission to Mars

Roman. V. Kruzelecky*, Brian Wong, Emile Haddad, and Wes Jamroz,[1] Ed Cloutis,[2] Nadeem Ghafoor[3]

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Abstract

The Inukshuk mission addresses key science themes of CSEW4; focusing on the search for hydrated mineralogy and subsurface water sites that can provide evidence of past or present life using an innovative landed rover. Mission cost effectiveness is achieved through a synergistic instrument suite based on advanced but mature patented MPBC miniaturization technologies that enable high IR spectral measurement performance with minimal mass and power. New exploration and science will be accomplished using an innovative tethered combination of a small rover and a self-elevating Skycam aerostat with VIS imager.

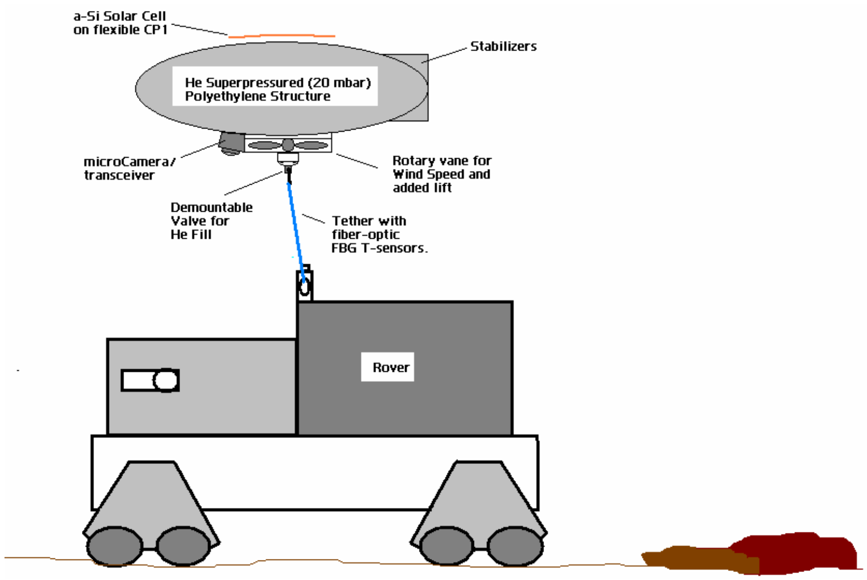
The Mars Skycam elevating aerostat, at 5 to 10 m altitudes, will provide an informative high-resolution 2-D view of the rover below and surrounding terrain to greatly assist the semi-autonomous navigation of the rover around obstacles and the selection of sites for more intensive subsurface investigations using the Inukshuk MDA robotic driller to depths of about 1 m.

Balloon designs proposed for planetary missions have involved a number of approaches. One is the solar Montgolfiere hot-air balloon where the envelope is made from a material that traps heat from sunlight, or from heat radiated from a planetary surface. Another approach is a "reversible fluid" balloon. This type of balloon consists of an envelope connected to a reservoir, with the reservoir containing a fluid that is easily vaporized. The balloon can be made to rise by vaporizing the fluid into gas, and can be made to sink by condensing the gas back into fluid.

The first planetary balloon mission was successfully performed by the Russian space agency in collaboration with the French space agency CNES in 1985 using spherical super pressure balloons. A small balloon, similar in appearance to a terrestrial weather balloon, was carried on each of the two Soviet VEGA Venus probes, launched in 1984. The first balloon was inserted into the atmosphere of Venus on June 11th, 1985, followed by the release of second balloon on June 15th, 1985. Each of the balloons operated for about two Earth days until their battery power was consumed.

The Inukshuk skycam aerostat will employ a refillable superpressure structure about 1.5 to 2 m in diameter with a He reservoir on the rover that can be used to periodically replenish the aerostat He fill. For buoyancy, the blimp must displace a volume of the Mars largely CO_2 atmosphere with a mass exceeding the combined weight of the blimp, interior He gas and the

tether. The available lift for a Mars blimp is about 12 g/m^3 for a pressure near 7 mbar and air temperature near 0^{o}C. The operating Mars conditions are similar to those encountered terrestrially at the higher 30 to 40 km altitudes. The skycam will employ a-Si solar cells on flexible CPI to provide about 1 Watt peak power for the onboard VIS imager(s) and other miniature sensors with an RF data link to the rover.



Preliminary schematic of Skycam aerostat tethered to rover.

The added science that can be accomplished using the Sycam aerostat includes measuring the near surface atmospheric conditions such as the temperature distribution between the rover and skycam using a serial string of miniature FBG temperature sensors along the tether. Near-surface wind conditions can be monitored using an opto-isolated miniature rotor for wind speed measurements at the Skycam altitude.

Near surface atmospheric studies between the rover and aerostat will be accomplished using the MPBC tuneable fiber laser to provide very high spectral resolution measurements of CO_2 and CH_4 in the bands near 1600 nm, and their isotopic composition, with about 5-10 pm wavelength resolution. The CH_4 is of high interest from a planetary biology perspective.
Near end of mission, it is hoped to release the Inukshuk Skycam to provide a sojourn across Mars with data link to the rover or an overhead communications satellite.

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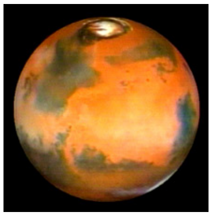

Skycam Tethered Aerostat for the Inukshuk Landed Rover Canadian Mission to Mars.

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MDA Space Missions (Nadeem.Ghafoor@mdacorporation.com)

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Presentation Outline

- Introduction
- Inukshuk landed-rover Mars Mission (Phase 0 Study)
- Skycam Elevating Platform
- Conclusions

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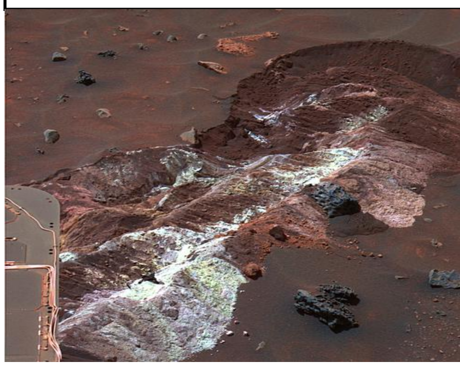
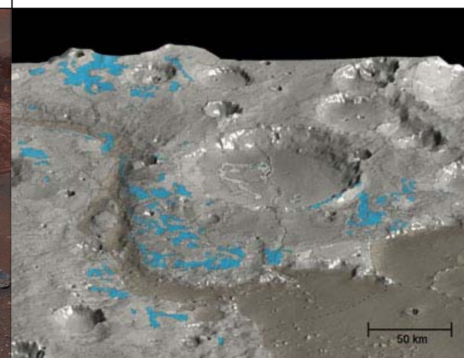
Evidence that the geology and environment of the near subsurface of Mars may differ dramatically from the more accessible and visible uppermost surface.

(Image: Bibring et al. (ESA/MGS/NASA/Science))

Image of bright presumably sulfate-rich soils exposed in the wheel tracks of the Spirit rover at Columbia Hills (image Sol721A_P2538_L257F-A721R1_br.jpg).	View of the Marwth Vallis area mapped by OMEGA on Mars Express with water-rich minerals indicated in blue. (Image: Bibring et al. (ESA/MGS/NASA/Science)).





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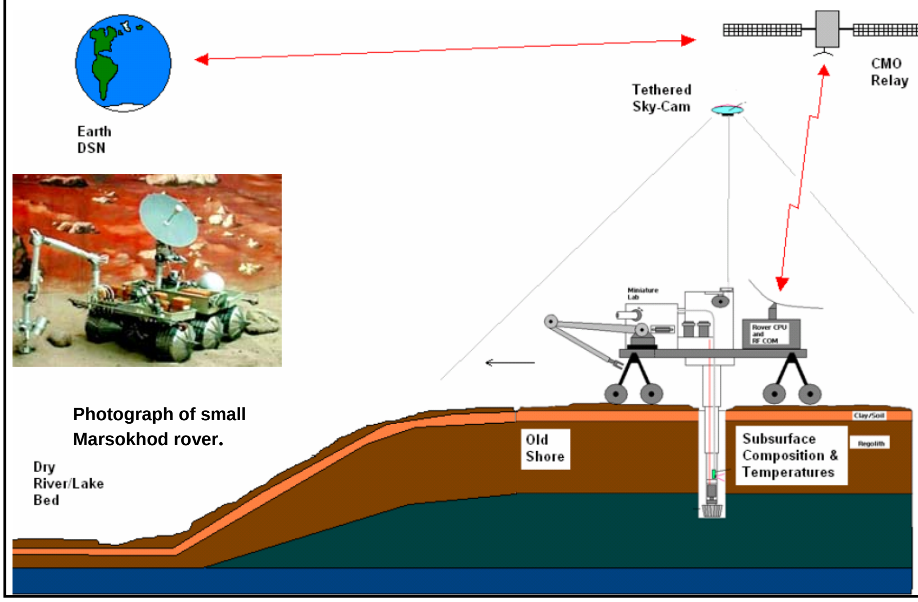
Inukshuk Canadian Mission to Mars



Photograph of small Marsokhod rover.

Inukshuk Preliminary Science/Payload Team

Prof. Edward Cloutis	U. of Winnipeg	Mission P.I. Planetary Mineralogy
Dr. Kathleen Londry	U. Of Manitoba	Planetary Microbiology
Prof. Kimberly Strong	U. of Toronto	Mars near-surface atmospherics.
Prof. James F. Bell III	Cornell University	Lead PI on the imaging cameras for the Mars Exploration Rovers.
Prof. John Mustard	Brown University	Mars Express Omega Instrument
Dr. Nadeem Ghafoor, Sean Jessen	MDA Space Missions	Mars Rover and Driller Robotics
Dr. Roman V. Kruzelecky	MPBC	Miniaturized instrumentation. Skycam Aerostat.

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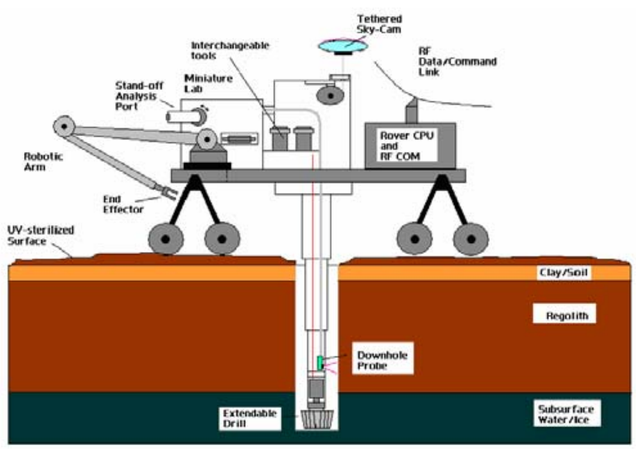
Science Objectives

- Select suitable old terrain landing site with Patm > 6 mbar and evidence of previous surface aqueous activities as suggested by detected clays and water-eroded morphology (fluvial system, lake shore).
- Use stand-off measurements from rover and elevated Skycam to select suitable sites for detailed subsurface investigation.
- Conduct detailed (1 mm vertical spatial resolution) imaging and spectroscopic data acquisition to a depth of 1 meter in situ of the subsurface at various locations using a rover-mounted drilling unit.
- Search for evidence of organic molecules/biological activity using spectroscopy-based techniques.
- Measure stable isotopic ratios of key molecules (O, C, S, H) using spectroscopy-based methods.

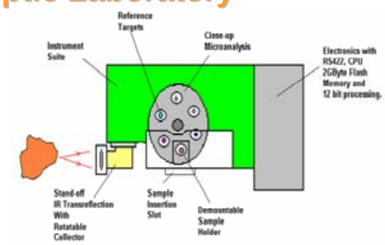
Preliminary Schematic of Inukshuk Rover

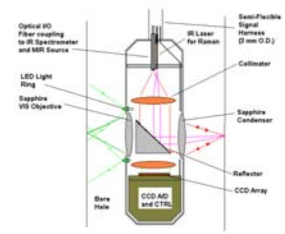
- Select suitable sites for drilling using Skycam and standoff sensors.
- Pretest for suitable layer cohesion to preserve the borehole and stratigraphy.
- Alternate between drilling and insitu bore hole sample analysis.
- Shield the bore hole against degradation by the incident UV.



Miniature Integrated-Optic Laboratory

- IR reflection line imaging between 0.8 and 4.0 µm at 4 nm/pixel as provided by optically coded IOSPEC Miniature IR spectrometer
- VIS microimager with selectable filters and pixel resolution below 5 µm for microorganisms.
- Complimentary IR Raman spectroscopy using compact MPB fiber-optic laser technology.
- Compact tuneable fiber laser for high-resolution CO_2 and CH_4 (microbiology) NIR spectral measurements.
- Switchable between coarse stand-off analysis and insitu bore-hole probe measurements.
- Integral reference targets for spectral and instrument calibration.





Miniature Bore-hole Probe

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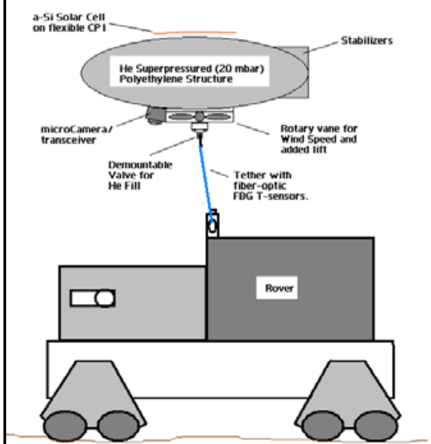
Preliminary Mars Skycam Concept



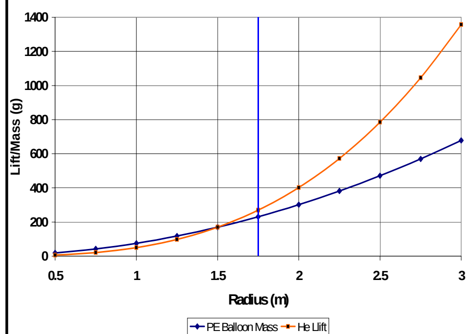
- 5 to 10 m altitude
- Provide downward 2-D mapping of rover surroundings to assist navigation and selection of drill sites.
- Measure air temperature distribution between rover and blimp using strand of WDM-multiplexed FBG sensors.
- Measure wind speed at blimp altitude.
- High resolution 0.01 nm spectra of CO_2 (1575 nm) and CH_4 (1670 nm) using tuneable laser signal reflected off Skycam blimp.

Mars Aerostat Considerations

- Mars atmosphere mainly composed of CO_2
- P(atm) of 6 to 10 mBar for potential landing sites - similar to terrestrial high-altitude balloon at 30 to 40 km.
- Near surface wind speeds: 4 to about 60 km/hr (Viking 1)
- UV radiation
- Tethered, refillable He superpressurized structure (12 to 20 mbar).
- Selection of balloon material:

Polyethylene	5.7 g/m^2 at 0.25 mil.	110-135°C mp
Mylar	8.9 g/m^2 at 0.25 mil.	254°C mp
Kapton	11.8 g/m^2 at 0.3 mil.	>350°C operating temperature.
Coating	Control α_S/ε, solar heating of balloon	UV protection Balloon equilibrium temperature

Preliminary Balloon Requirements for $P(CO_2)$= 6 mbar



Coated 0.25 mil PE Blimp (R=1.75 m)	6 g/m^2	231 g
s.s. microtubing tether	1 g/m	10 g
SM Fiber-optic cable with 4 FBG T-sensors and wind sensor		3-4 g
2.4 GHz RF transmitter		2 g
A-Si solar cells on CP1	2 W/g	1 W, 0.5g
Micro-camera (x2)		2 to 10 g
Total:		257 g
Buoyancy at 6 mbar CO_2:		About 270 g at 273K

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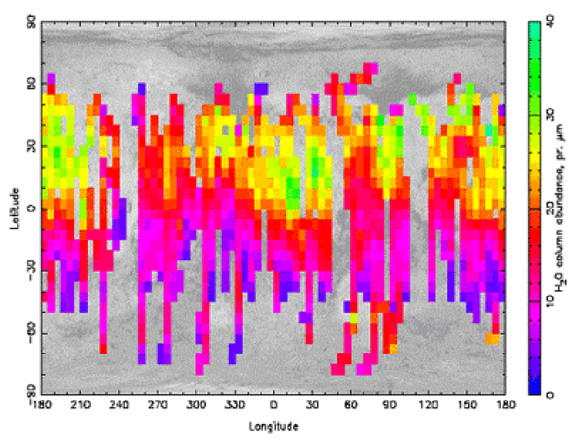
Mars Express Planetary Fourier Spectrometer (PFS) mappings of H_2O vapour distribution.

- Still very weak H_2O cycle concentrated over some areas (green shade)
- $P(CH_4)$ shows some correlation with $P(H_2O)$



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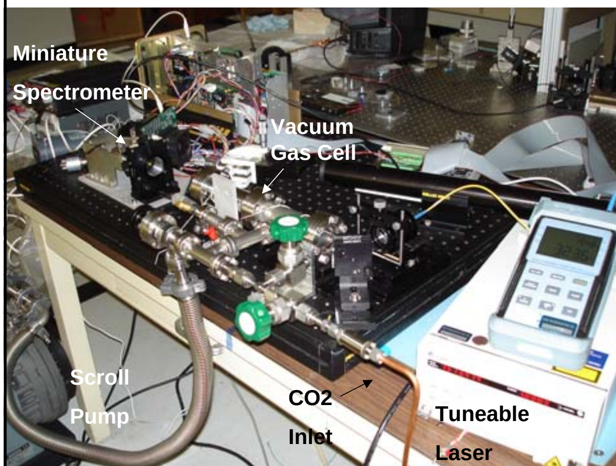
Photograph of Lab. CO_2 Measurement Test Set-up



MPBC Fiber Sensor Demonstrator payload for ESA's Proba-2 with dual tuneable fiber lasers (<1.3 kg with microprocessor and 16 bit DAQ, 2007 launch)

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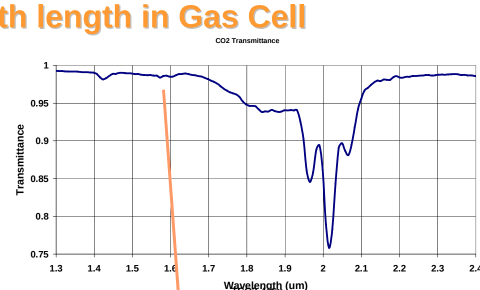
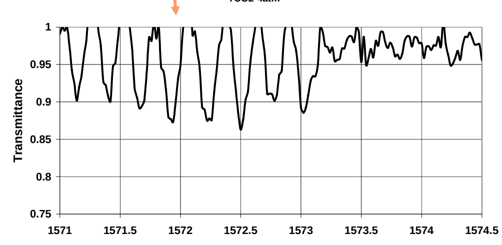
Measured Spectra of CO_2 by IOSPEC at 4 atm. using 25 cm path length in Gas Cell

Coarse resolution broad-band spectrum og CO2 at at 8 nm/pixel:



High resolution tuned laser spectrum at 0.01 nm/pixel of 1572 nm CO2 band:



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Presentation Outline

- Introduction
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- Conclusions

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Conclusions

- Inukshuk seeks to answer the central themes of CSEW4 - search for evidence of near surface H_2O, its state, and past/present microbiological activities.
- Unique tethered combination of medium sized rover and elevating platform using refillable He for buoyancy.
- Skycam elevating aerostat can improve the rover navigation and assist in site selection for detailed subsurface analysis.
- Skycam can provided added near surface science using retroreflected tuneable laser signal to facilitate high-resolution spectra between 1550 and 1670 nm for CO_2 and CH_4 studies to assist planetary microbiology.
- Inukshuk's broad-band MIR spectrometer can be tilted upwards to provide AM1 measurements of incident solar radiation for further information on near-surface atmospheric conditions.

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A Balloon Borne Planet Finder

Barth Netterfield (UofT), Carrie MacTavish (CITA), *Marten van Kerkwijk (UofT), Mike Shao (JPL), Martin Levine (JPL), Ben Lane (MIT), Supriya Chakrabarti (Boston Univ.)

Abstract:

With orbits and masses of hundreds, and radii of tens of planets around other stars known, the logical next step is to obtain an actual image. This requires extremely high contrast, especially if one wishes to detect the planet when it is least like a star, with its emission dominated by reflected light. Such high contrast is difficult if not impossible to achieve from the ground, since it would require correction for seeing due to atmospheric turbulence beyond current or near-future capabilities. Thus, space missions have been considered, using either a coronograph or a nulling interferometers to remove or cancel most of the host star light. It should not be necessary to go to space, however: from a stratospheric balloon, with only 1% of the atmospheric column one has from the ground, seeing is not an issue any more. What might be a problem, is accelerations due to changing winds, which cause pointing instabilities and mirror deformations. With periods longer than a second, these are relatively slow, however, and it should be possible to correct for them using active optics.

Our proposal is to fly a prototype nulling interferometer on a balloon to test the feasibility of obtaining very high contrast imaging, using a slightly updated instrument built for the PICTURE sounding rocket experiment, matched to a telescope with an aperture of 1.25 m. We prefer the nulling interferometer over a coronograph since it allows for high contrast closer to the host star, and thus requires a smaller telescope for a given star-planet separation.

The main goal of the mission would be to test the feasibility of observing from a balloon, and determine whether the next step should be space, or, whether in fact a mission with a larger mirror (up to 3 meter) is possible. Such a mission would be especially interesting if the next generation of ultra-long duration balloons becomes available (or, even better, stratospheric zeppelins).

While the main goal is to test feasibility, the observations might lead to interesting science on their own. Specifically, among the known extrasolar planets, the one around Epsilon Eridani should be detectable, and other obvious targets would be the debris disks detected around a large number of stars.

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Preferred Session:	Proposals for future projects
Presentation Method:	Talk
Presenting Author Title:	Professor

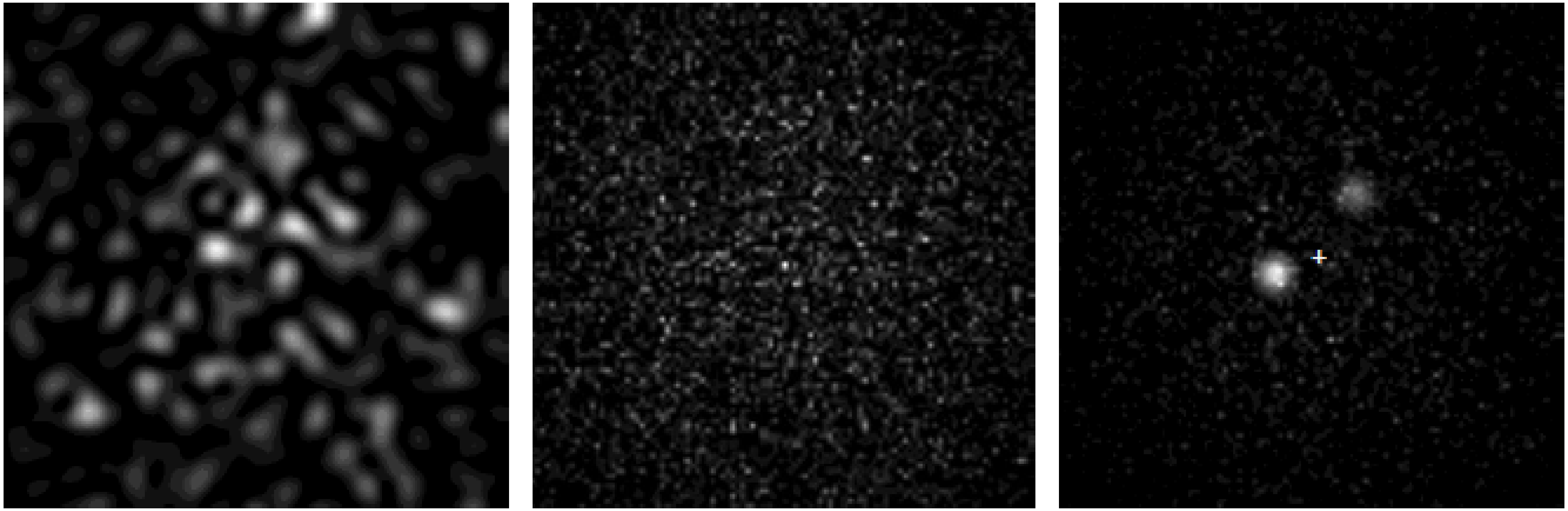
Balloon Borne Planet Finder

Marten van Kerkwijk, Barth Netterfield, Carrie MacTavish

(UofT, DAA & CITA)

in collaboration with

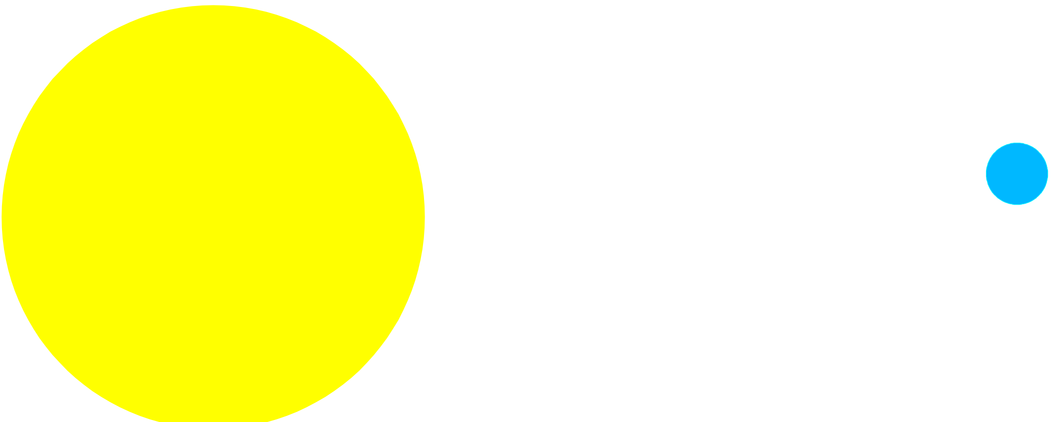
Mike Shao (JPL), Martin Levine (JPL),
Ben Lane (MIT), Supriya Chakrabarti (BU)

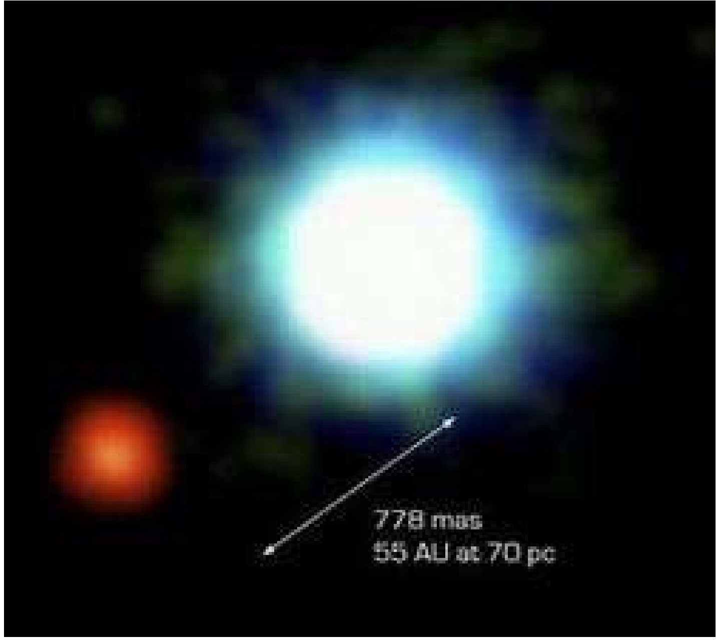


OPD, Menneson et al., Proc. SPIE 4860, 32

Detection:

1. Direct imaging -- the race is on!





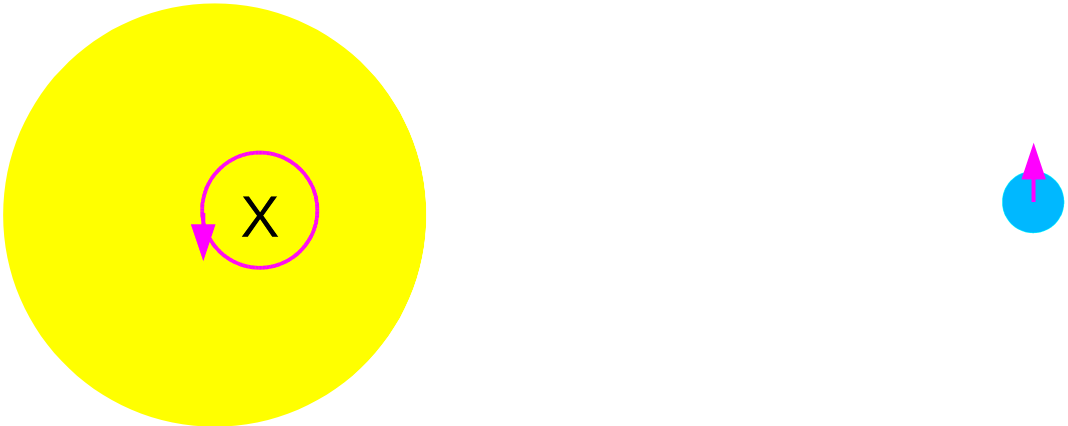
the brown dwarf 2M J1207... and its planetary mass companion.

Angular separation: $$0.1\,\mathrm{arcsec}\left(\frac{a}{1\,\mathrm{AU}}\right)\left(\frac{d}{10\,\mathrm{pc}}\right)^{-1}$$

Contrast (reflected light): $$\frac{\pi R_p^2}{4\pi a^2} \simeq 10^{-8}\left(\frac{a}{1\,\mathrm{AU}}\right)^{-2}\left(\frac{R_p}{1\,R_J}\right)^{2}$$

Contrast (thermal radiation): $$\frac{\pi R_p^2}{\pi R_s^2}\left(\frac{T_p}{T_s}\right)^4 \simeq 10^{-6}\,\text{(for Jup.)}$$

Detection:
2. Stellar motion
– working very well (~200 planets)



A) Pulsar timing:

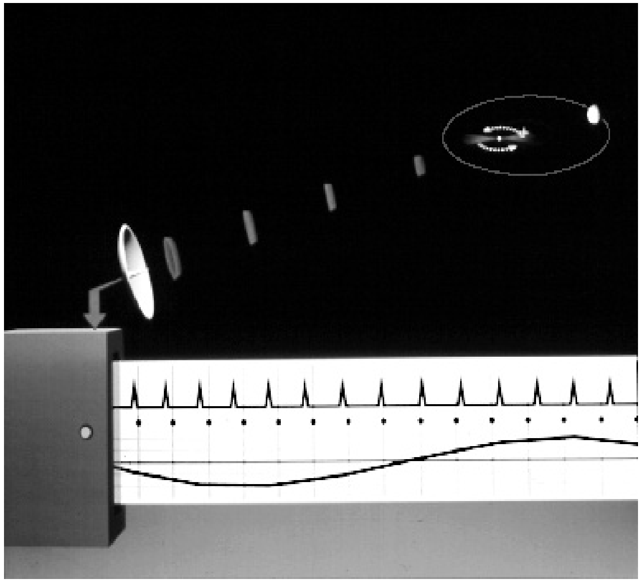
$$\Delta t \sim 0.5\,\mathrm{s}\left(\frac{a}{1\,\mathrm{AU}}\right)\left(\frac{M_p}{1\,M_J}\right)$$

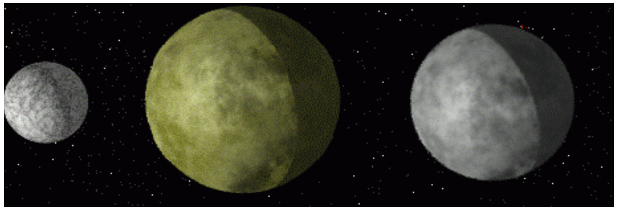
B) Radial velocity:

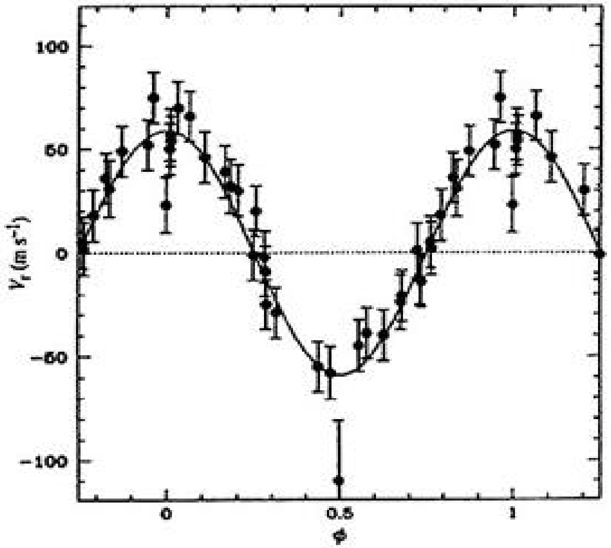
$$\Delta v \sim 30\,\mathrm{m\ s^{-1}}\left(\frac{a}{1\,\mathrm{AU}}\right)^{-1/2}\left(\frac{M_p}{1\,M_J}\right)$$

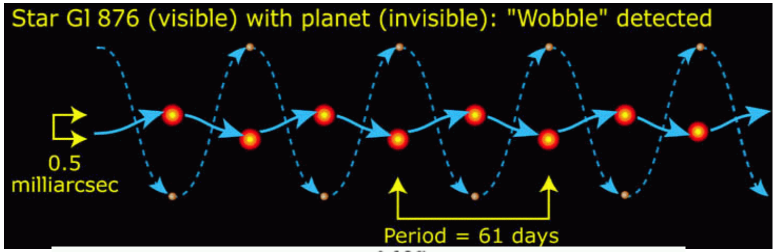
C) Astrometry:

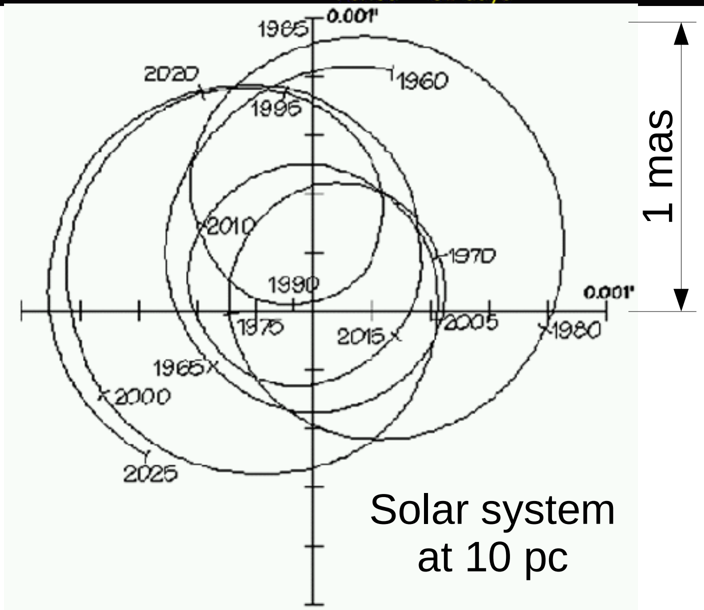
$$\Delta \theta \sim 0.1\,\mathrm{mas}\left(\frac{a}{1\,\mathrm{AU}}\right)\left(\frac{M_p}{1\,M_J}\right)\left(\frac{d}{10\,\mathrm{pc}}\right)^{-1}$$





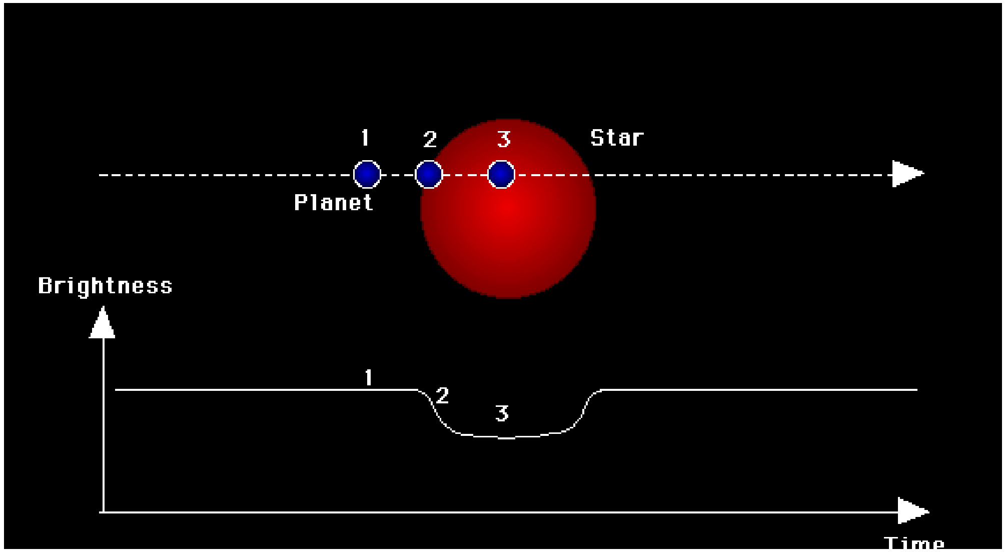




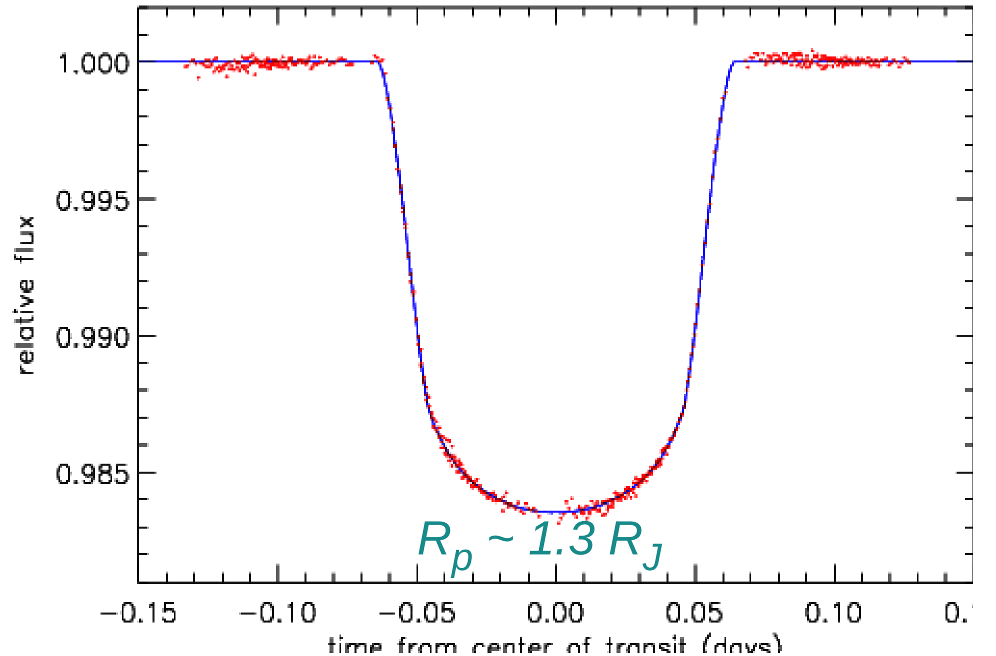


Detection:

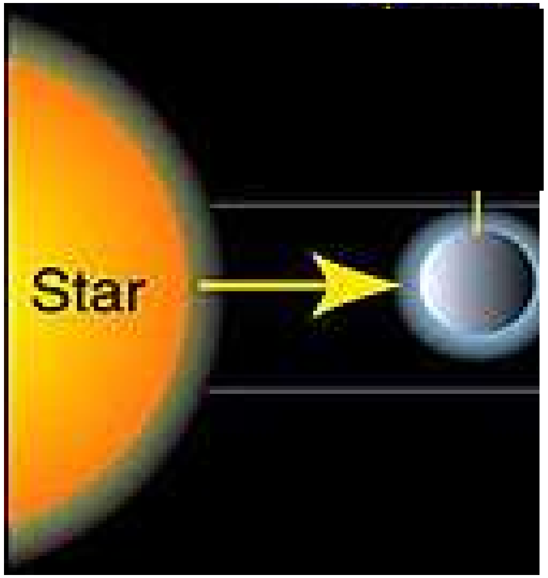
3. Transits – working well
(~10 planets)



HD209458b 1st transiting planet

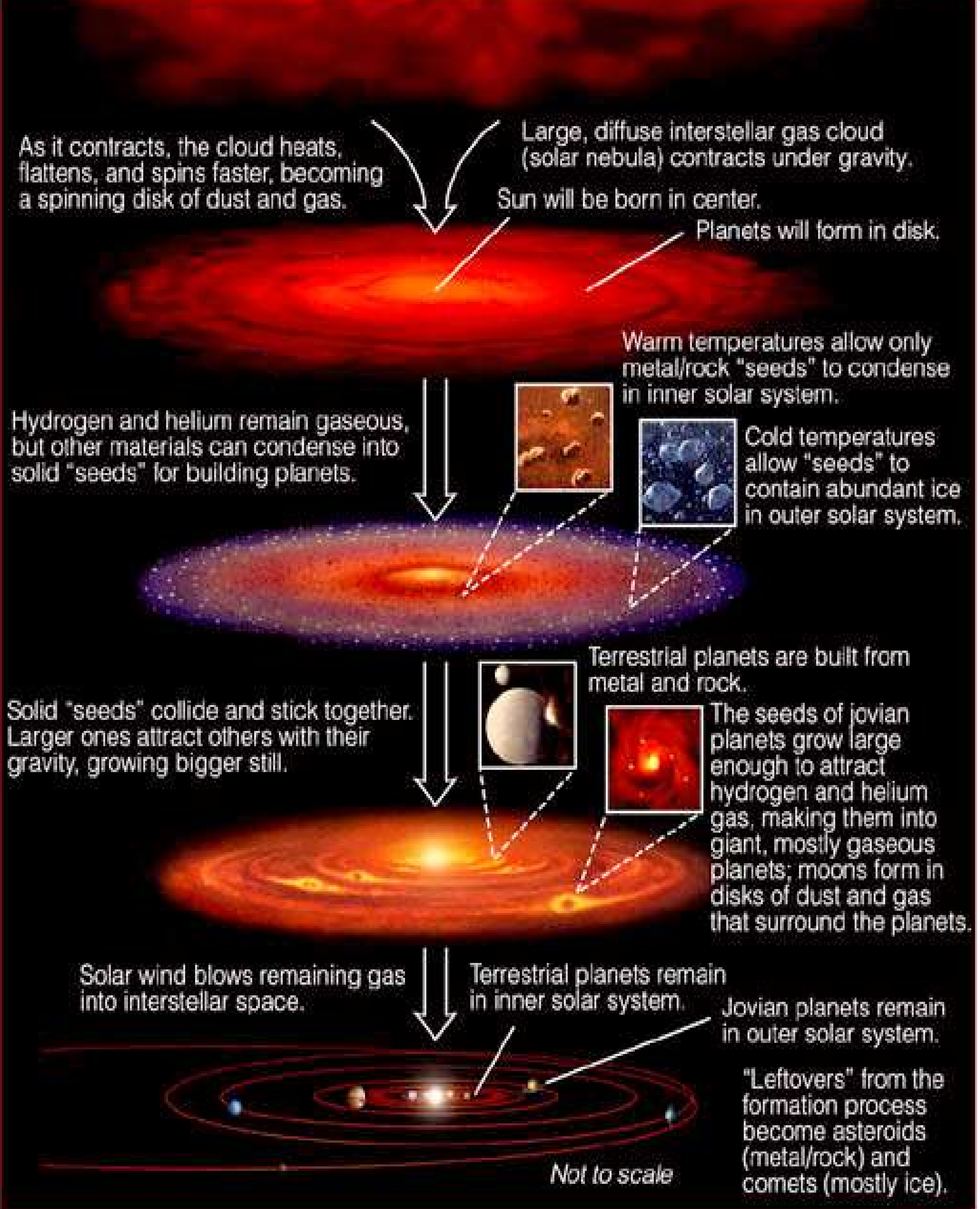


It has got sodium & is evaporating



Eclipse depth: $\frac{\pi R_p^2}{\pi R_s^2} \sim 0.01 \left(\frac{R_p/R_J}{R_s/R_S}\right)^2$

Probability: $\sim \frac{R_s}{a} \sim 0.05 \left(\frac{R_s/R_S}{a/0.1\,\mathrm{AU}}\right)$



Two Main Expectations from the Solar System

1) Formation in “proto-planetary disk,” hence circular orbits.

2) Near Sun, too hot for ices to condense, hence Rocky planets close to Sun; Gas giants far from Sun.

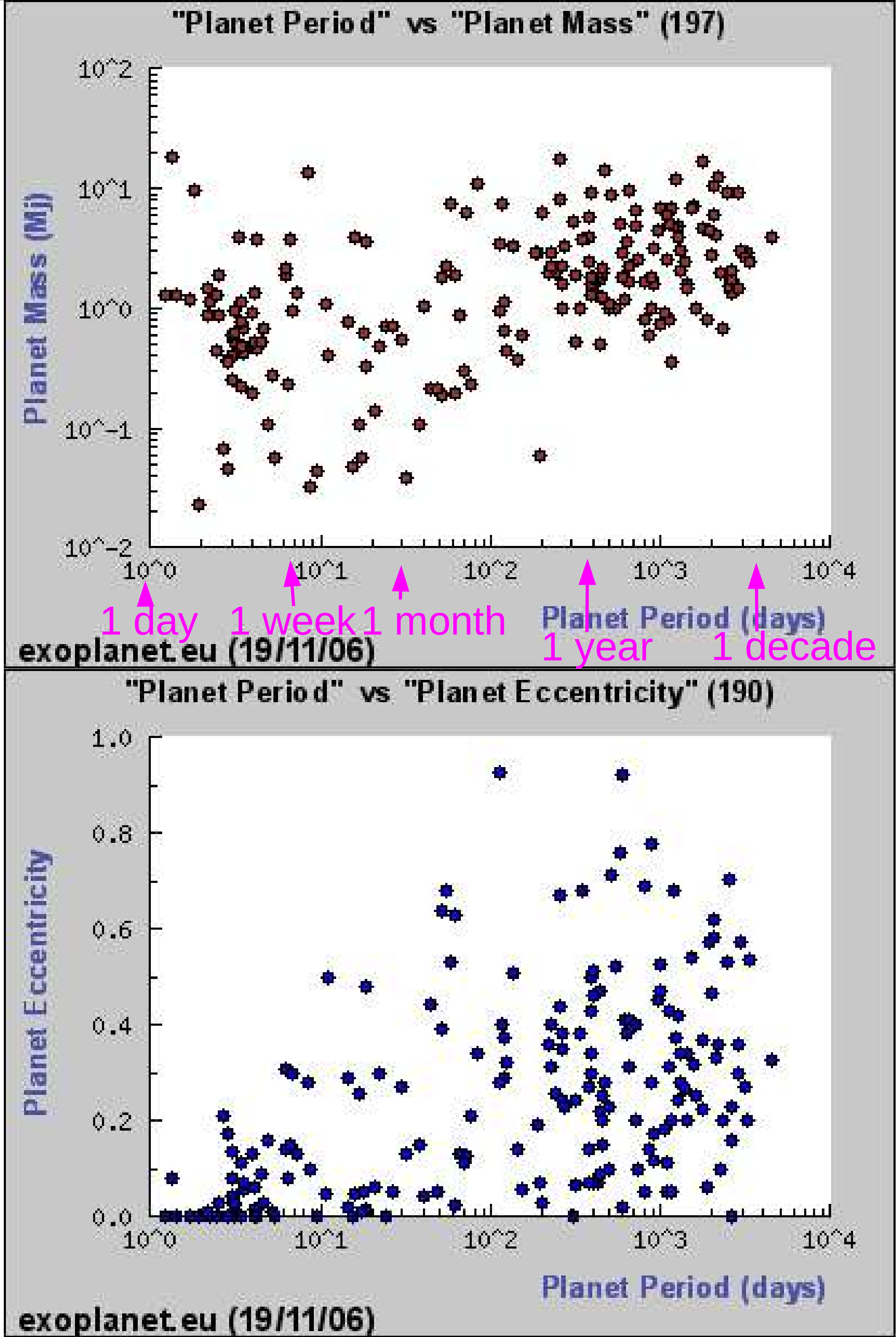
Properties of exoplanets:

RV studies show
Unexpected variation!

1) Large range of masses
   low masses: limited by sensitivity;
   high masses: real cut-off at ~10 M_J.

2) Large range of periods
   short end: hot Jupiters! (but note bias)
   long end: limited by sens./time cov.

3) Large range of eccentricities
   Circular at short periods -> tides;
   no preference for circular at long P
   (though slightly less eccentric than
   binary stars)



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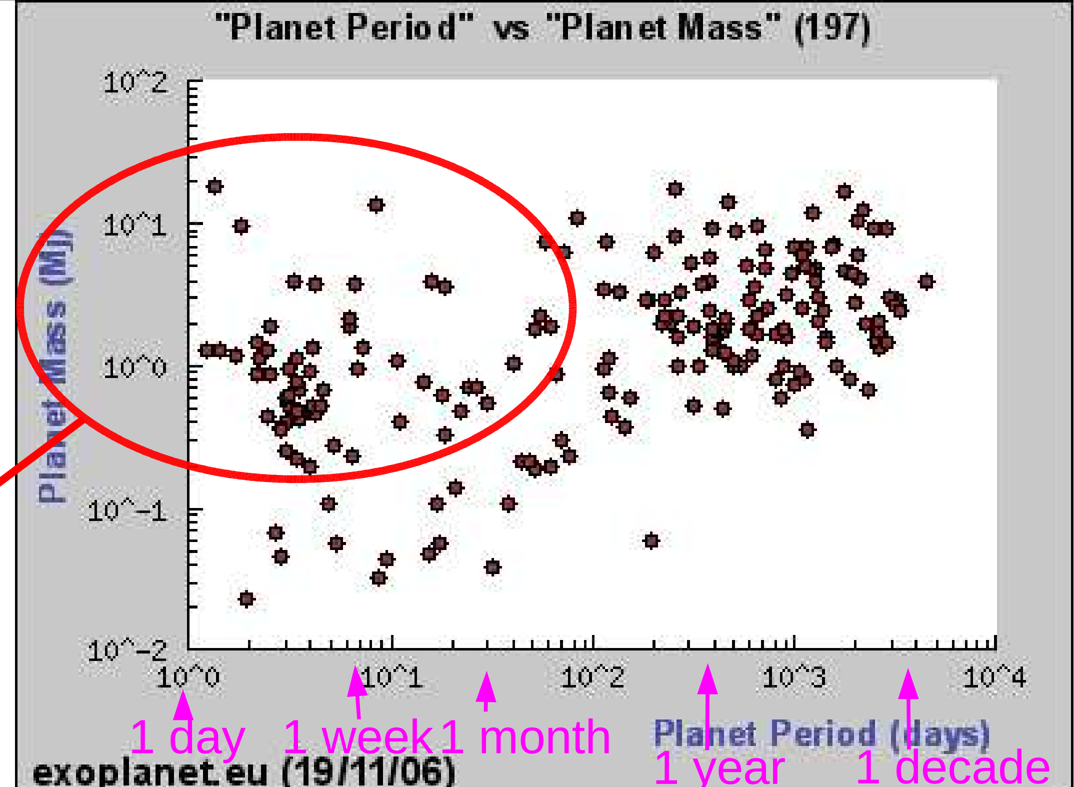

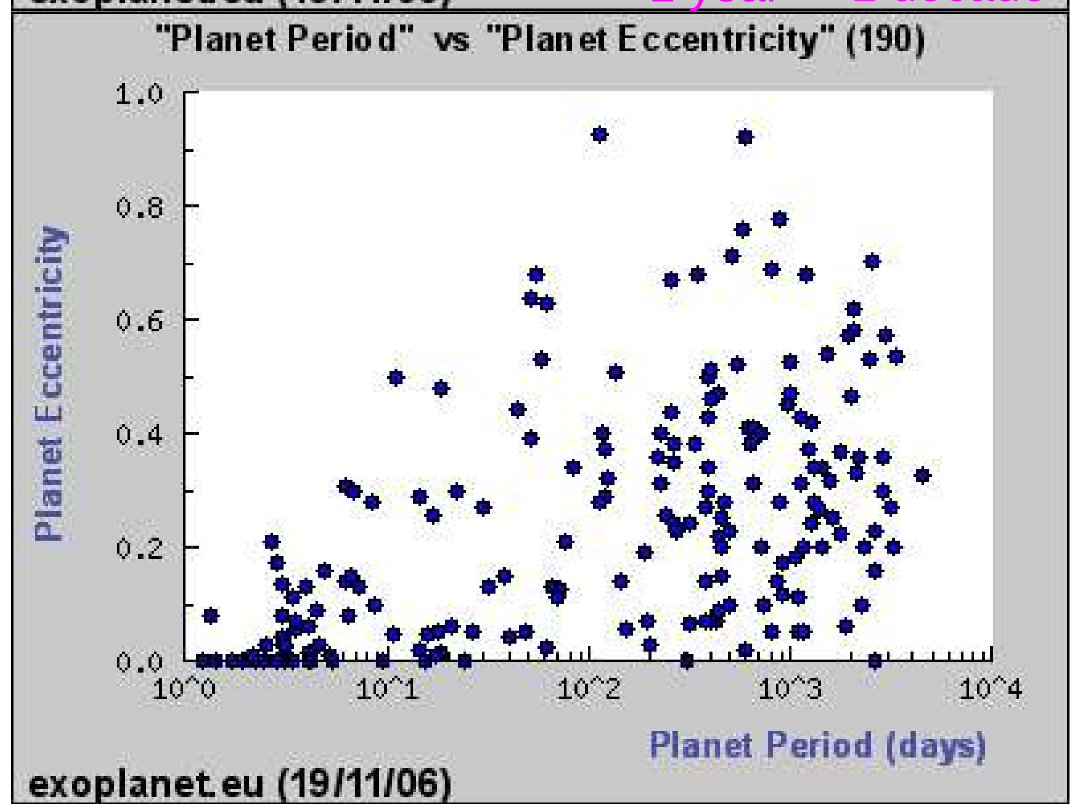

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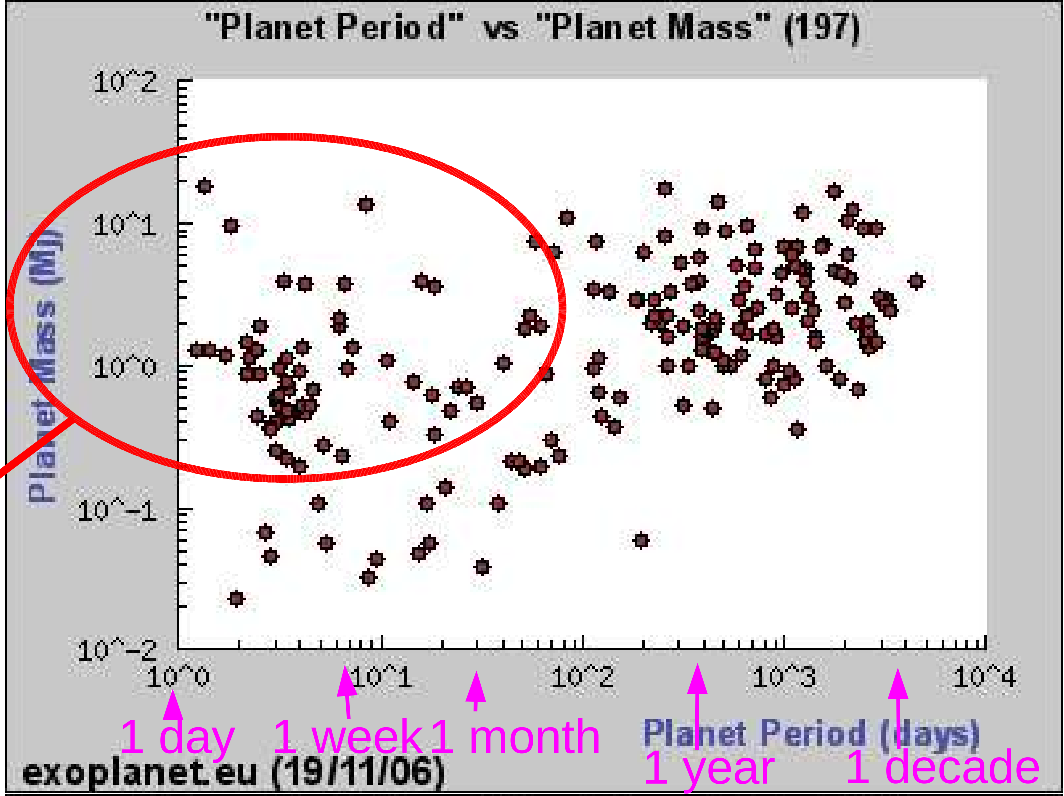
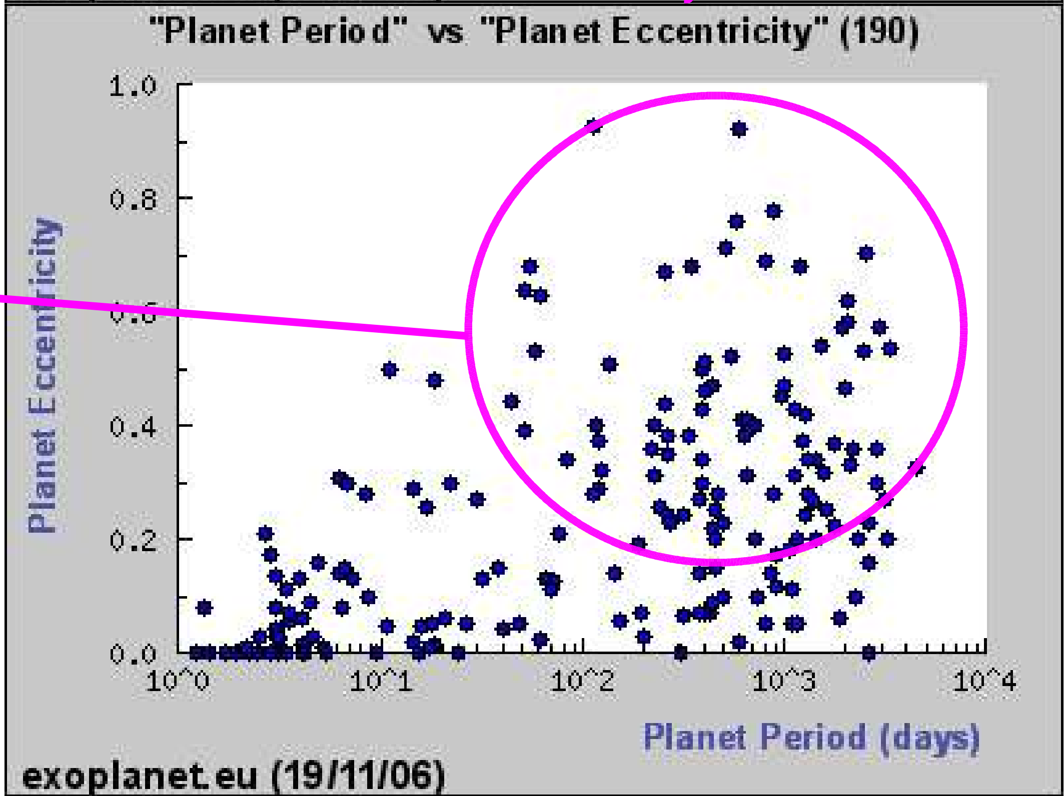




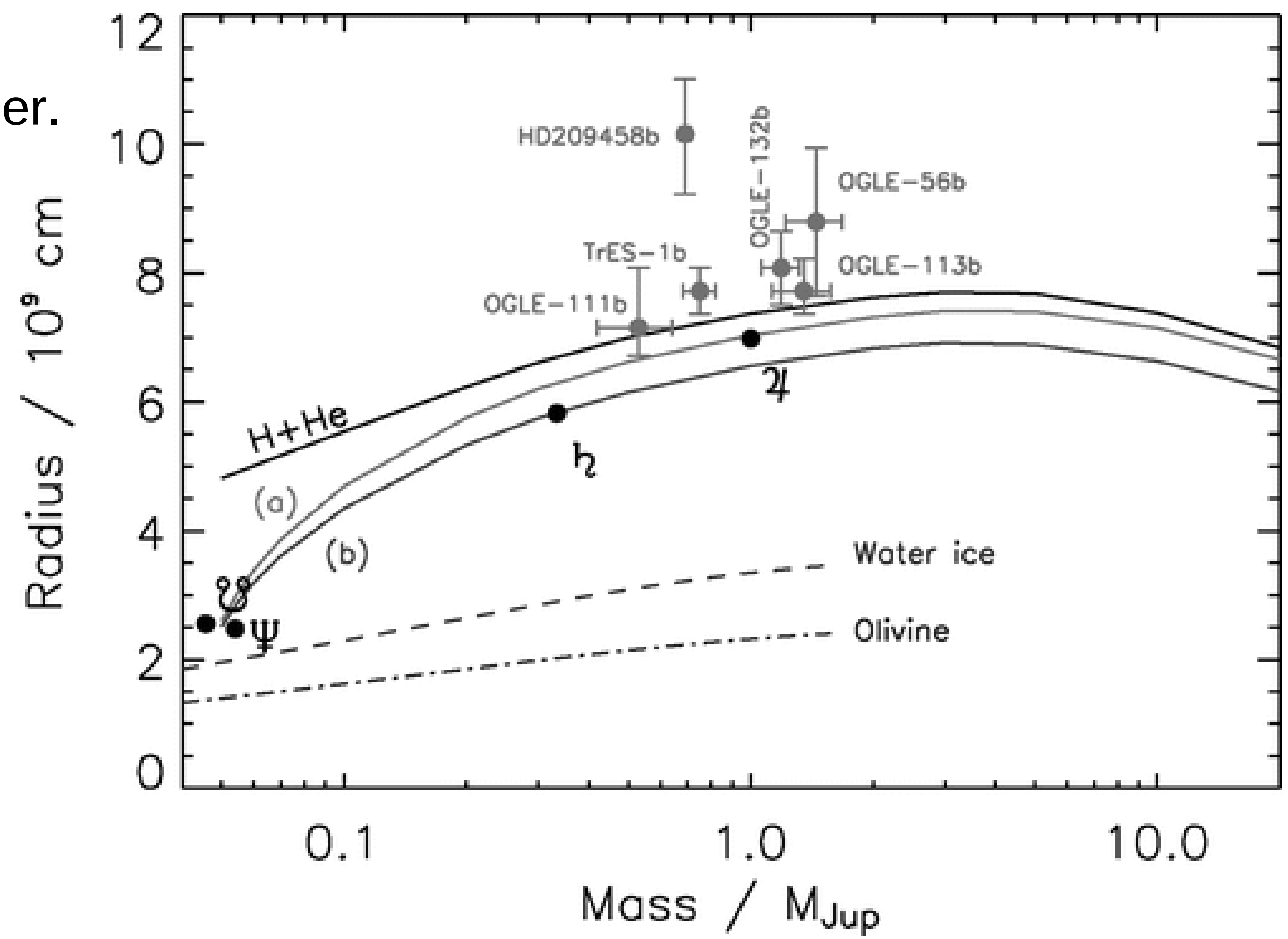
Properties of exoplanets:

Transit studies show
Unexpected variation!

Large range of radii

Some planets have sizes similar to Jupiter, but others are significantly bigger.

- Bloated? But hard to "inflate" a giant planet!
- Never shrunk? But how to get a planet close to the star sufficiently fast?
- Why the variety?



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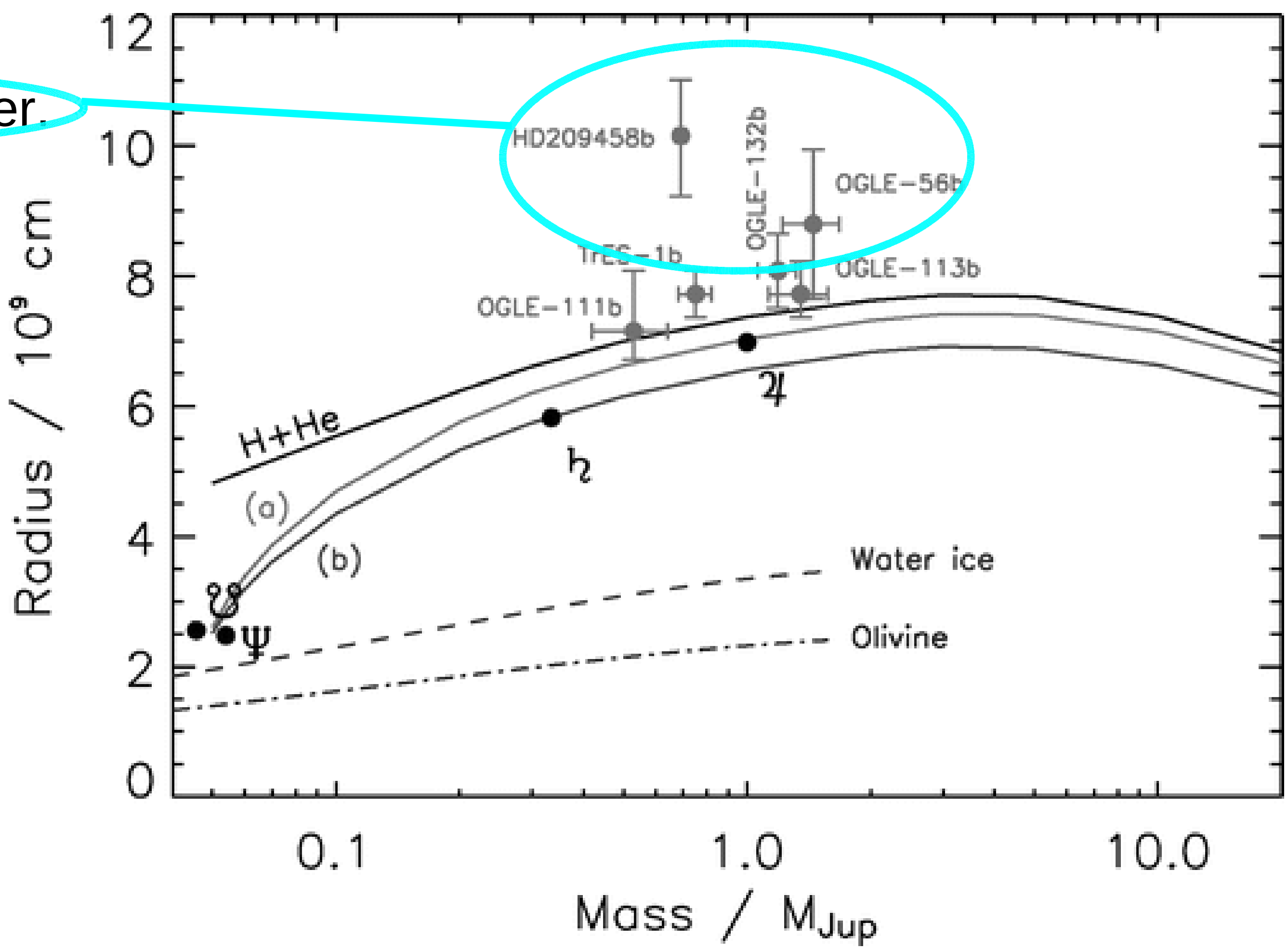


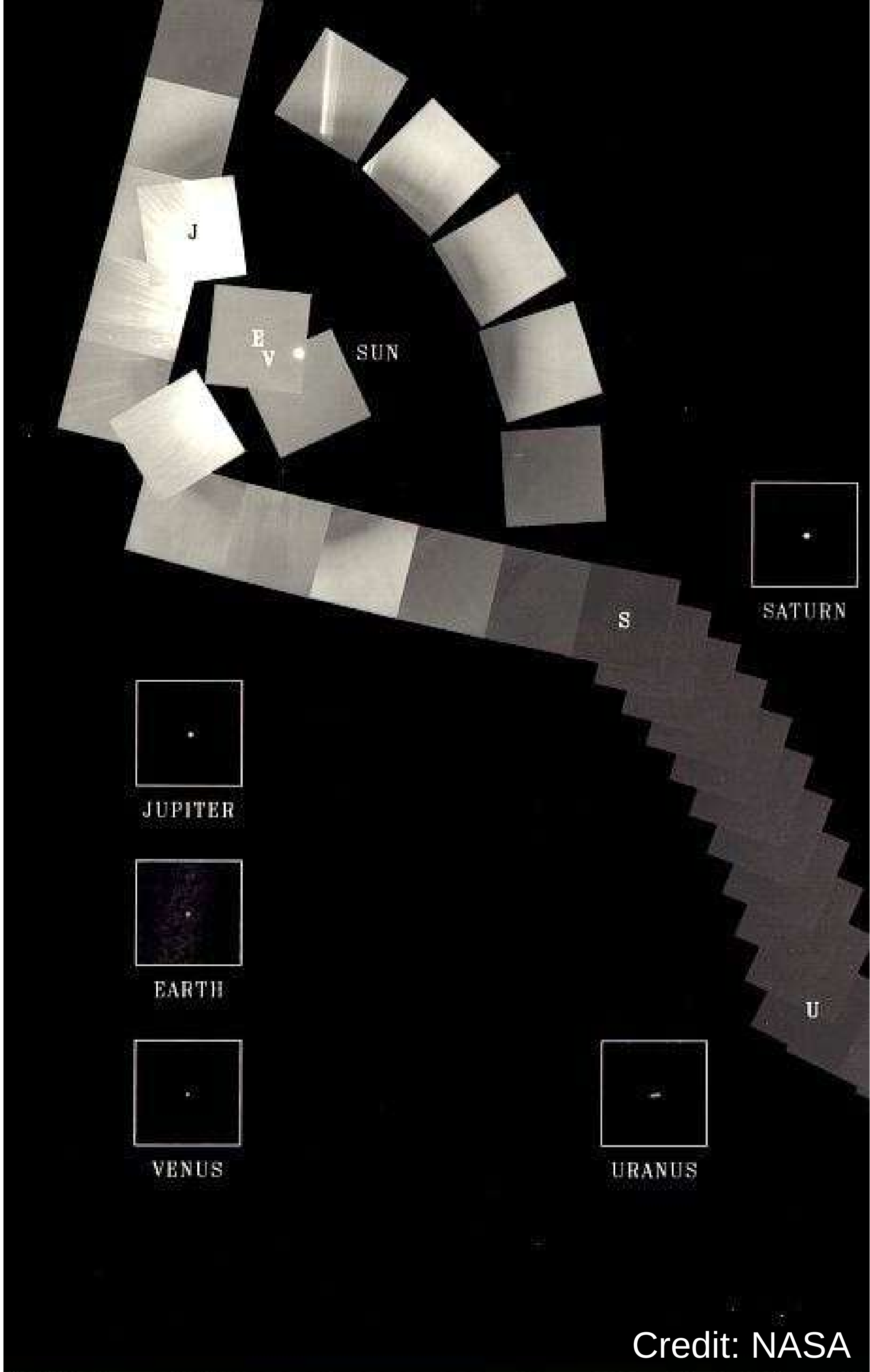
What is a planet?

Shines by reflected light

What is an *interesting* planet?

Non-equilibrium chemistry

Credit: NASA



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What is a planet?

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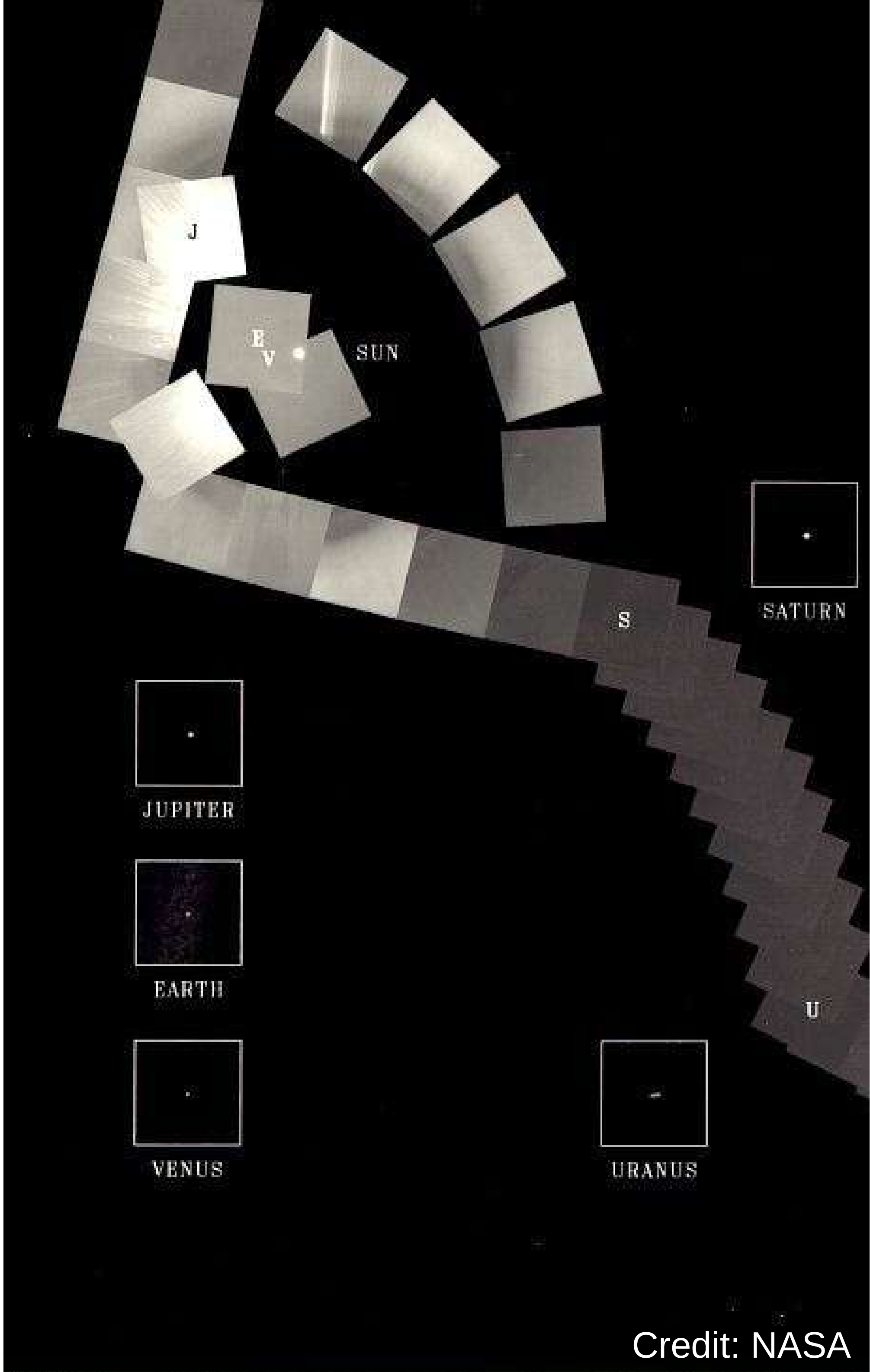
LIFE

Non-equilibrium chemistry

Credit: NASA



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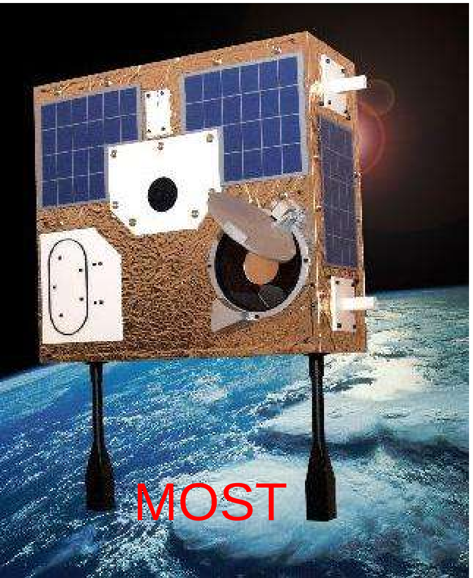
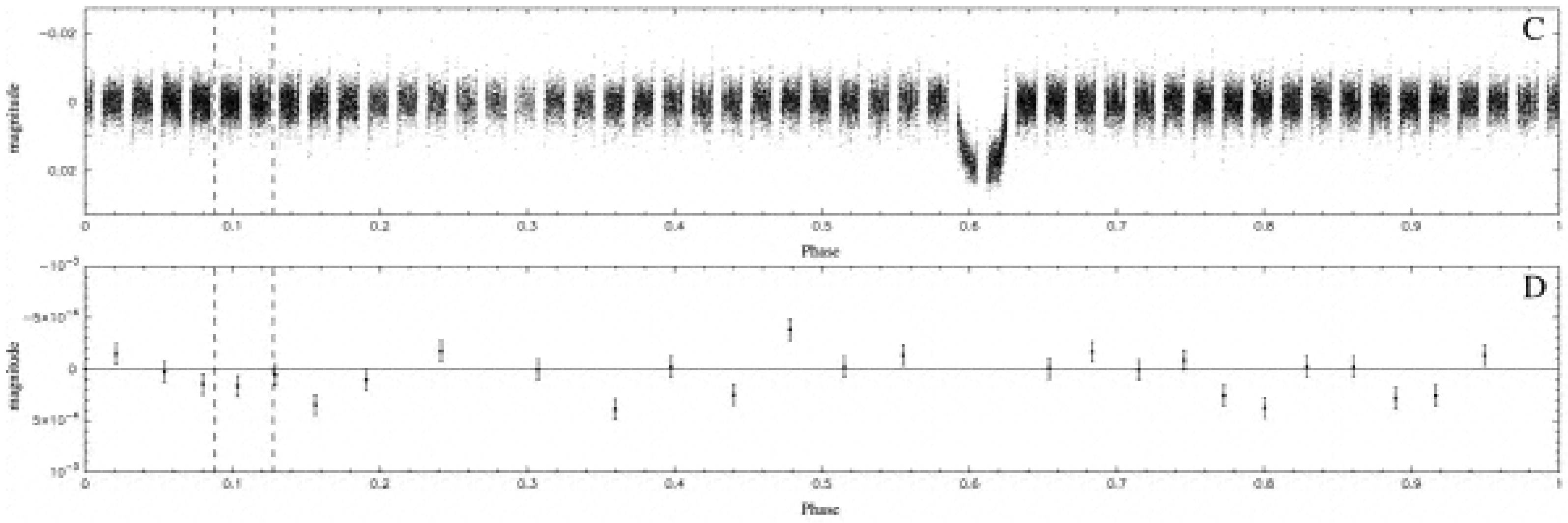
Advantages of space

1) No transparency variations
- Finding transits (HST, CoRoT, Kepler)
- Atmospheric transit spectra (HST)
- Reflected light (MOST)
- Planet occultations (Spitzer Space Tel.)

2) No point-spread function variations ("seeing")
- Better astrometry (HST, GAIA, SIM, Darwin)
- Easier to remove star light (TPF-C, TPF-I)





Advantages of space

Balloon?

1) No transparency variations

- Finding transits (HST, CoRoT, Kepler) — Yes
- Atmospheric transit spectra (HST) — Yes
- Reflected light (MOST) — Maybe
- Planet occultations (Spitzer Space Tel.) — Yes

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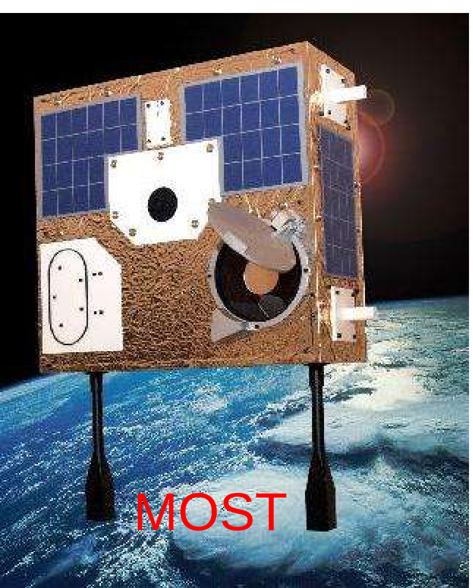
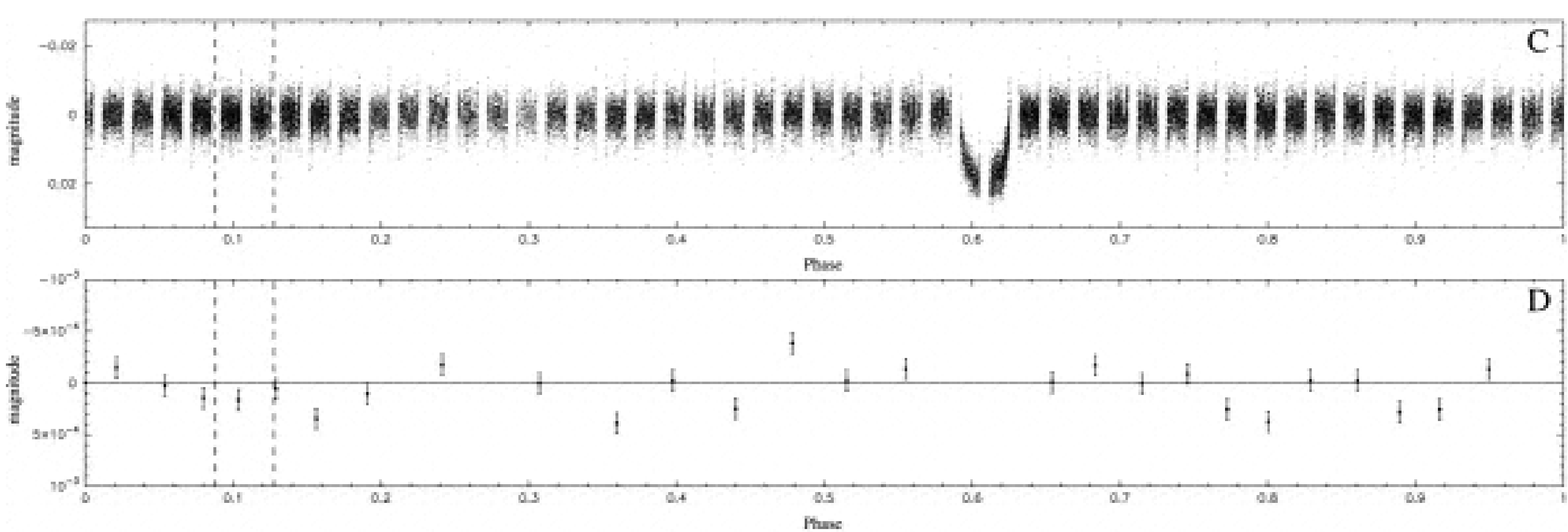
- Easier to remove star light (TPF-C, TPF-I) — Yes





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Astronomy perspective: Balloons are great!

But: Almost all astronomy missions need (U)LDB

So: A Canadian ballooning facility is not very useful
(at least without agreement with Russia or the ability to avoid it)

Also: CSBF does it **very** well. Why duplicate?

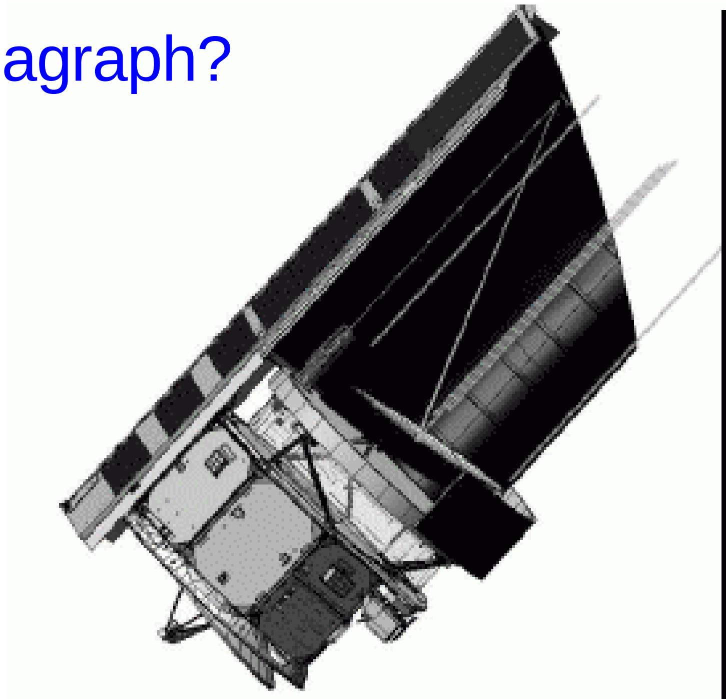
Direct imaging requirements

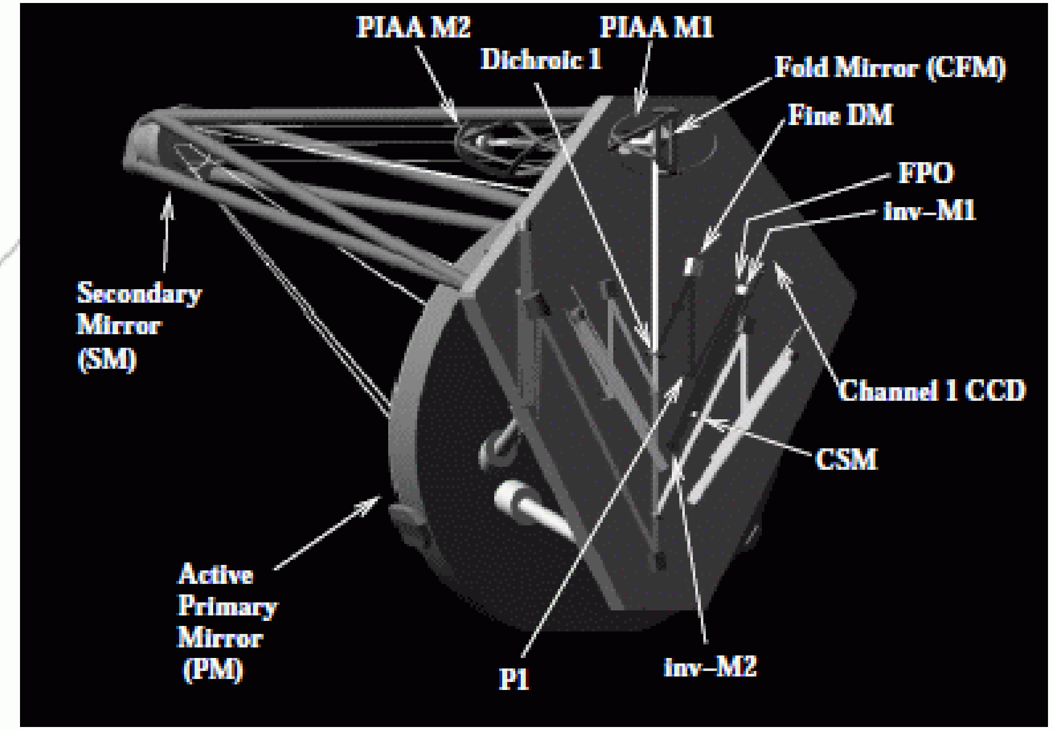
Angular separation: $0.1\,\text{arcsec}\left(\frac{a}{1\,\text{AU}}\right)\left(\frac{d}{10\,\text{pc}}\right)^{-1}$

Contrast (reflected light): $\frac{\pi R_p^2}{4\pi a^2} \simeq 10^{-8}\left(\frac{a}{1\,\text{AU}}\right)^{-2}\left(\frac{R_p}{1\,R_J}\right)^2$

Hence, need excellent suppression of the light of the star!

Coronagraph?





TOPS, Guyon et al., astro-ph/0606397

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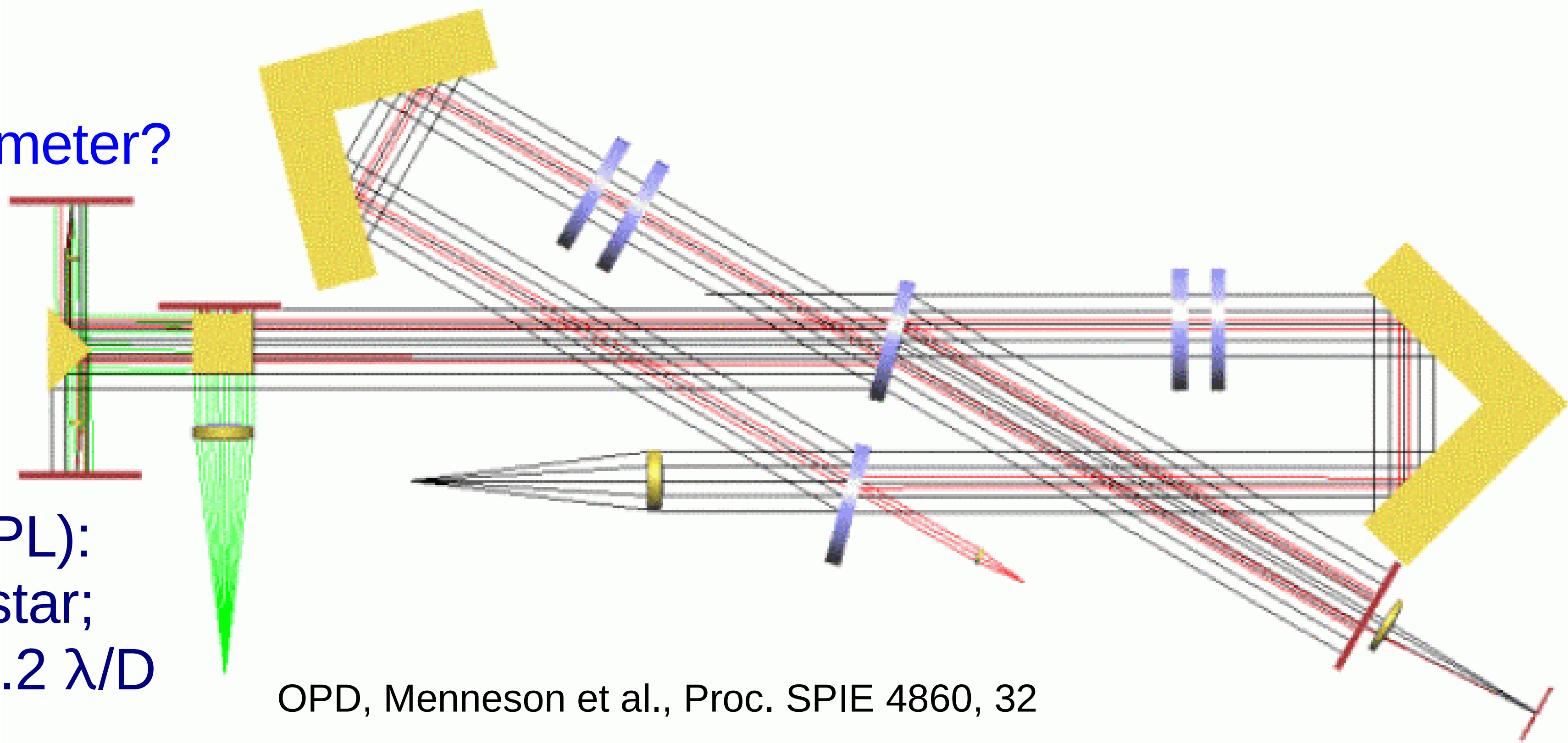
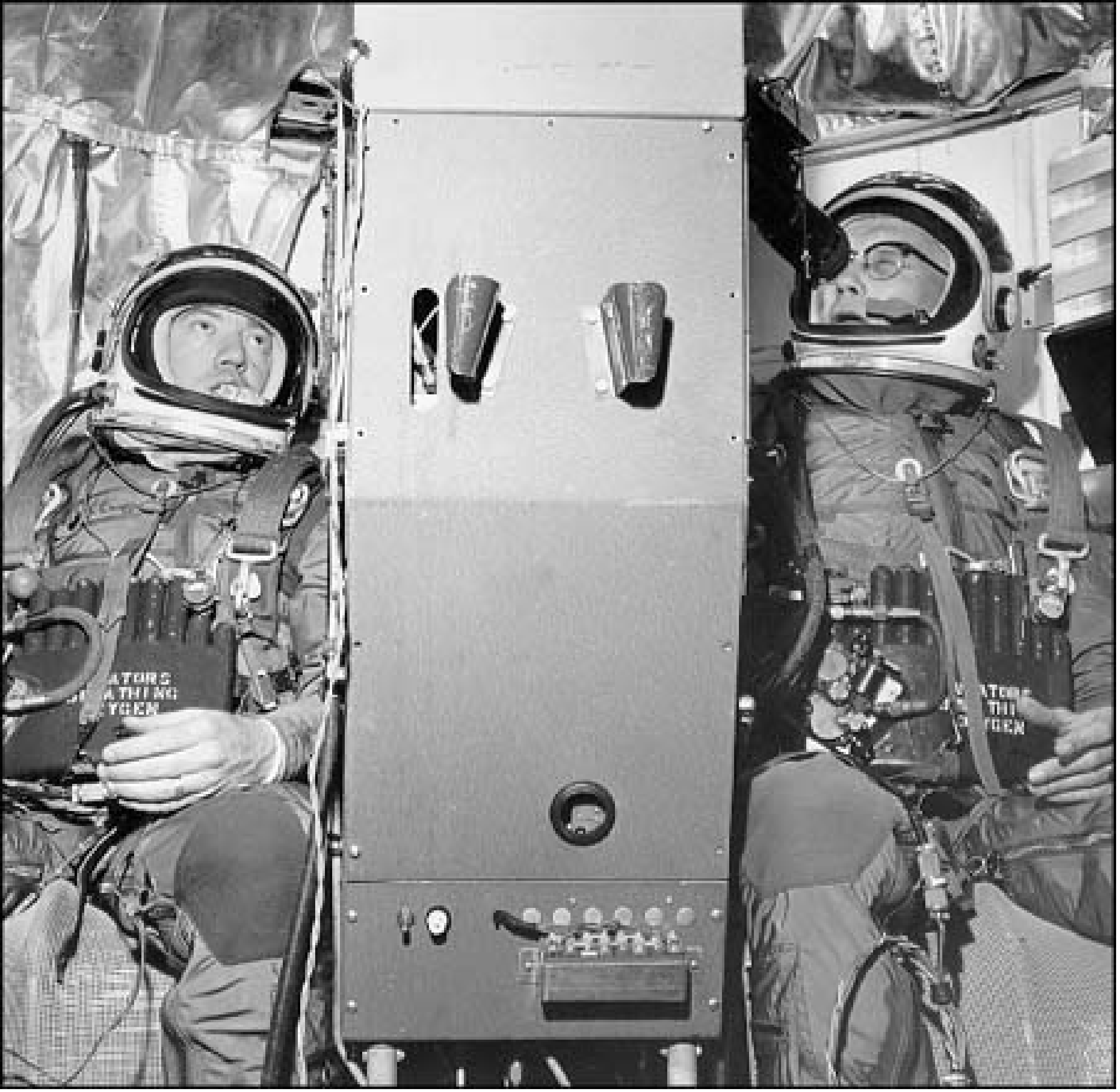
Nulling interferometer?



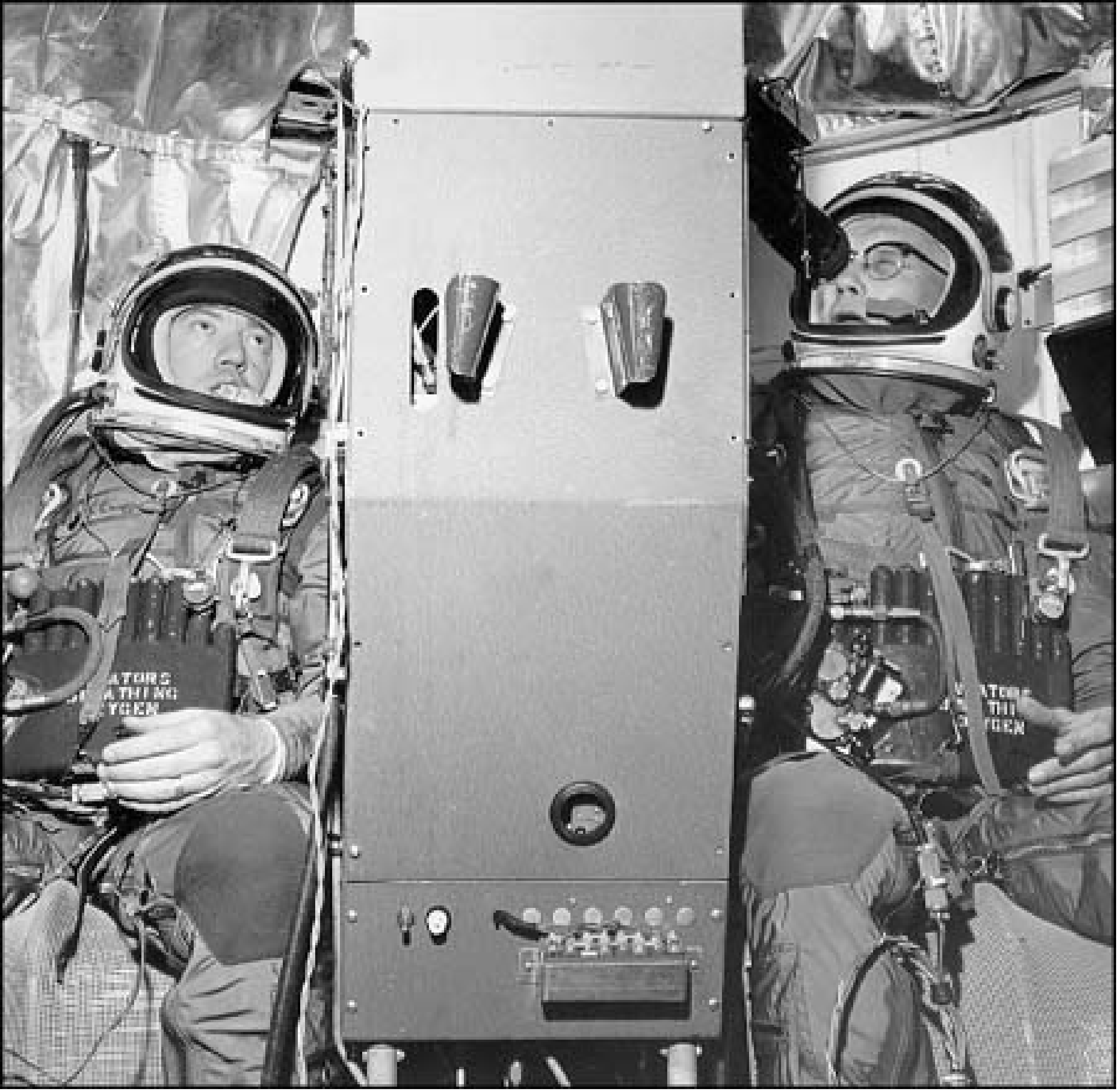
In lab (JPL):
10^{-6} on star;
10^{-8} at 1.2 λ/D

OPD, Menneson et al., Proc. SPIE 4860, 32



Credits: US Air Force

Project Stargazer

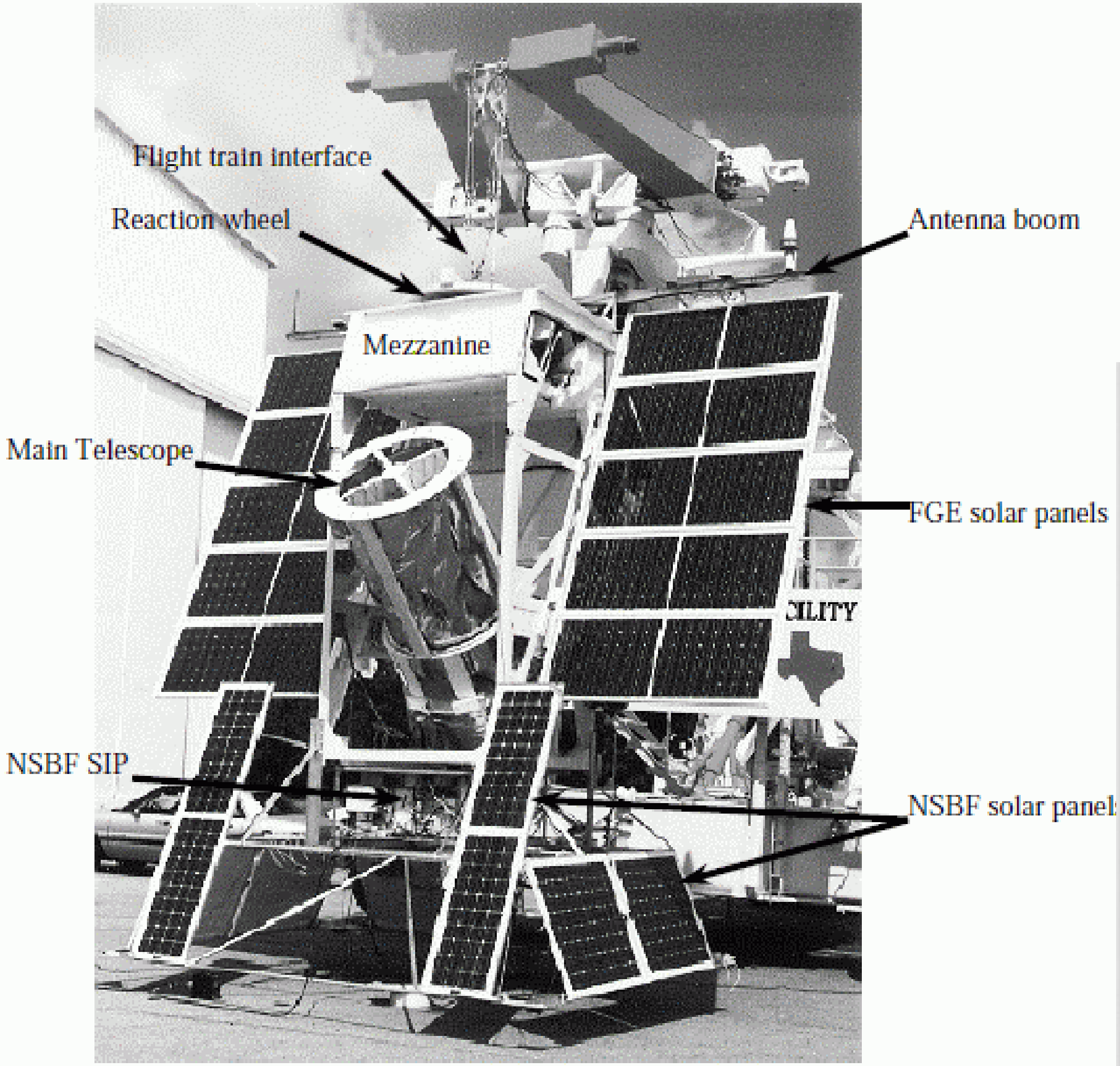


Credits: US Air Force

Project Stargazer

Stratoscope II

Credits: Smithsonian Nat'l Air & Space Museum



Bernasconi et al., 2000, Proc. SPIE, 4014, 214

Flare Genesis Experiment

Stratoscope II

Credits: Smithsonian Nat'l Air & Space Museum

Balloon-borne Planet Finder

Requirements

1) Dark sky

Night flight; Antarctic not possible

2) Ultraprecise and stable pointing

Frame to <10", tip-tilt+active optics, <0.01" mas

3) Good control of thermal deformation

Active optics

4) (Ultra-)Long duration

Multiple nights

Balloon-borne Planet Finder

Time line

Aug. 2007: launch of precursor mission PICTURE (on sounding rocket)

Apr. 2007: Proposals to be sent in for precursor mission with ~1.25m telescope + nulling interferometer ROSES (NASA), Small Payload (CSA)

~2009/10: Test and science flights of precursor mission

~2011-15: Mission with larger, ~3 m telescope?

~2020s: Satellite, huge balloon???

If I had $1M (or a little more...)

For optical and infrared astronomy,
the stratosphere is high enough,
but it needs long duration flights.

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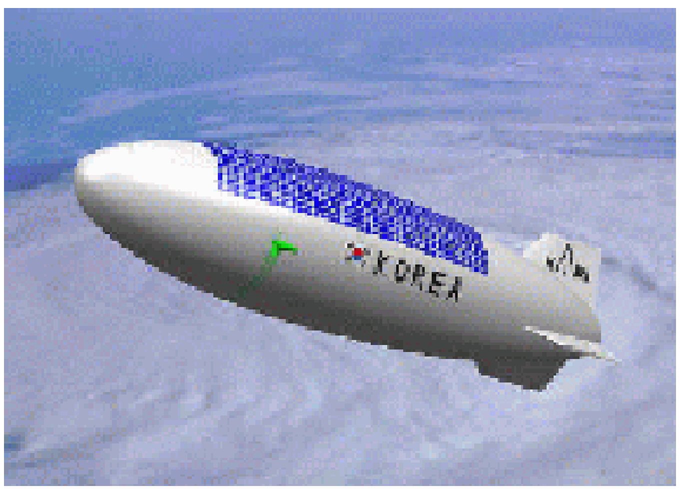
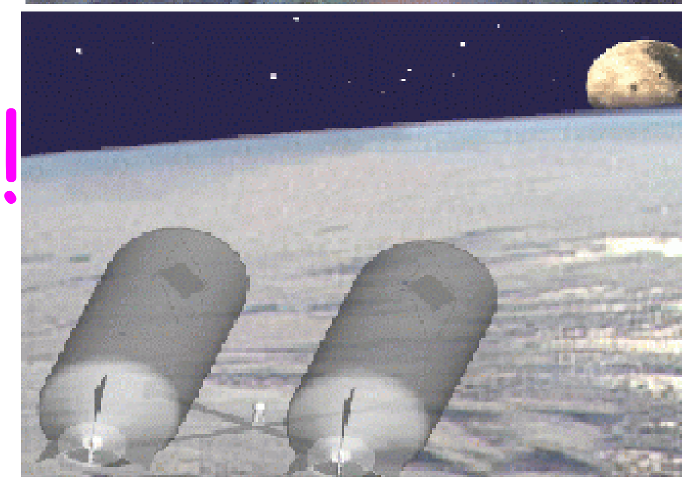
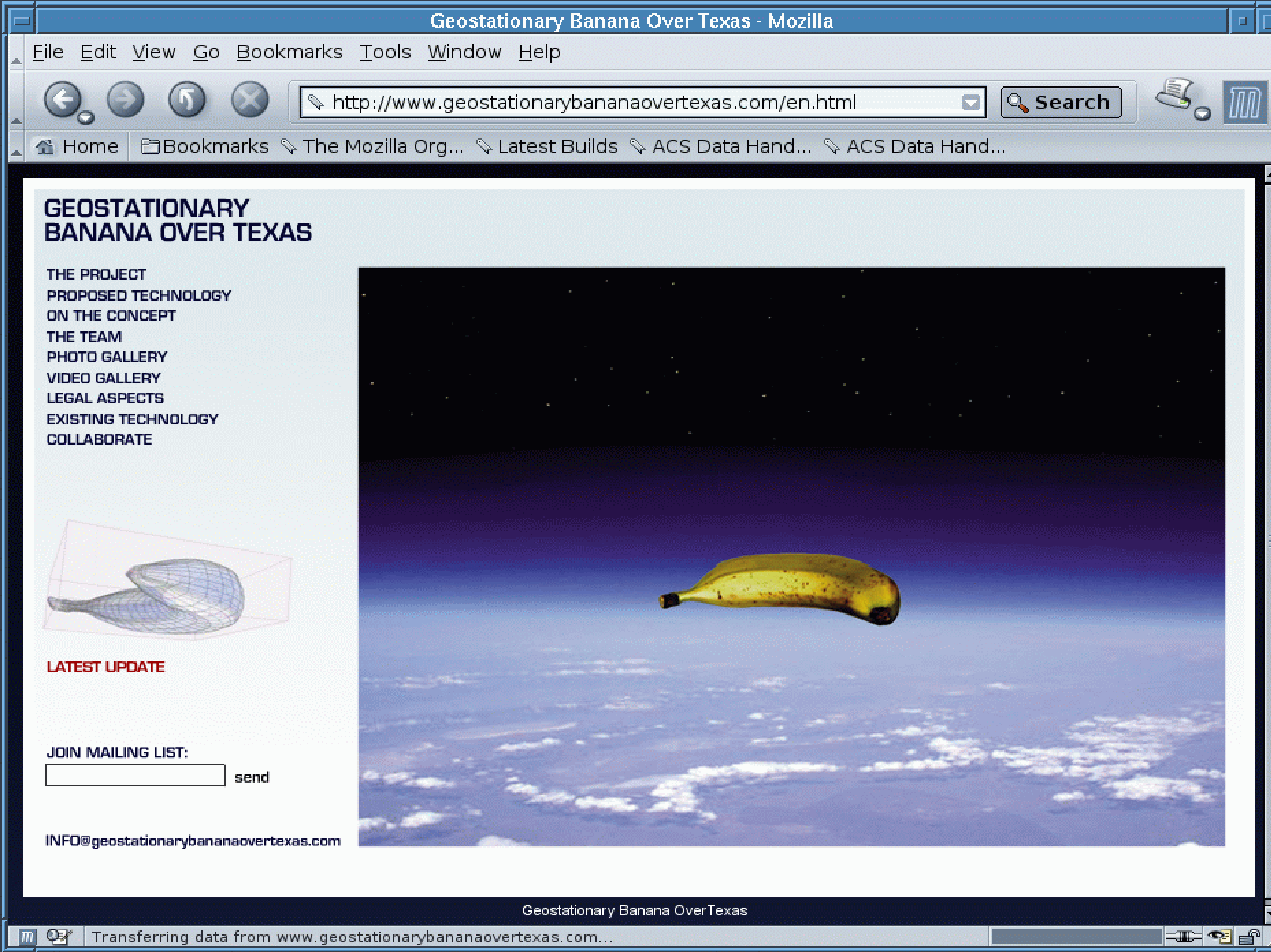


Zeppelins!



All images taken from Fesen, astro-ph/0606383



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SPIDER: A Balloon-Borne Polarimeter for Measuring Large Angular Scale CMB B-Modes

Carrie MacTavish for the SPIDER collaboration

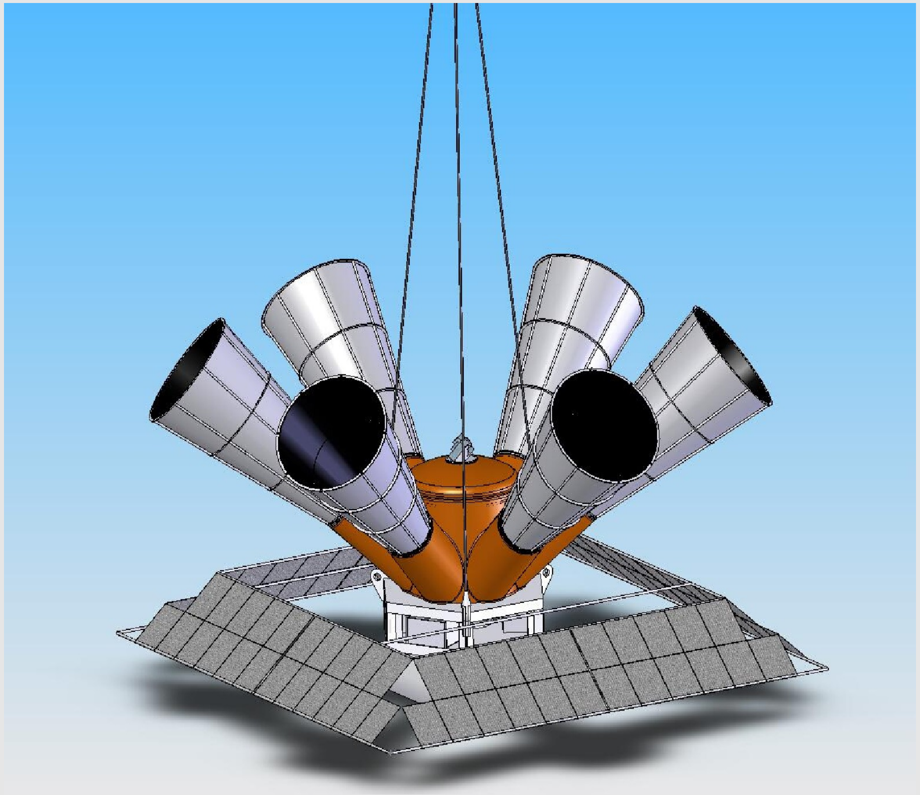
Abstract:

SPIDER is a balloon-borne polarimeter that is designed to measure CMB B-mode polarization. The experiment is scheduled to launch from Alice Springs, Australia in December of 2009 and will target large angular scales where the B-mode signal from primordial gravity waves dominates. In a mid-latitude, around the world, 25 day flight SPIDER will map out roughly 50% of the sky. The instrument will observe in five frequencies ranging from 80 GHz up to 275 GHz enabling accurate characterization of the interstellar dust foregrounds

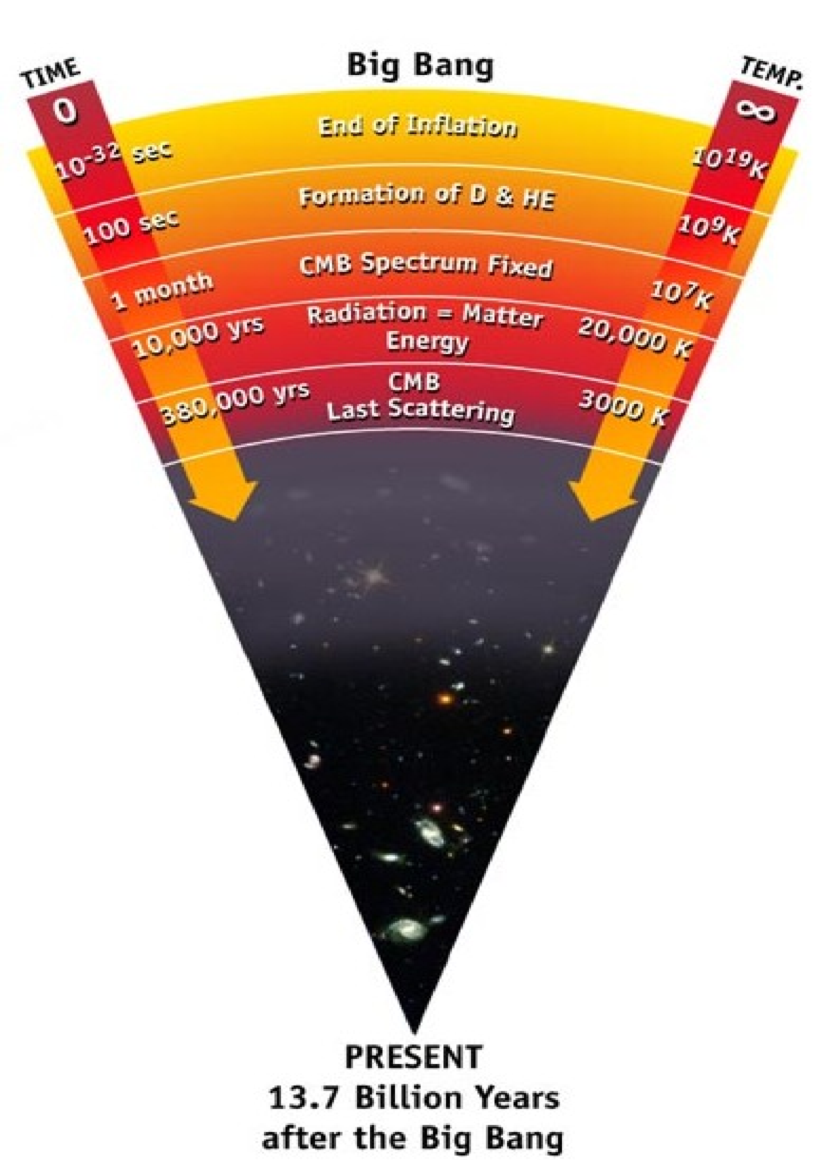
Presenting Author Name: Carrie MacTavish
Organization: CITA
Presenting Author Email: cmactavi@cita.utoronto.ca
Presenting Author Telephone: 416 978 8194
Preferred Session: Proposals for future projects
Presentation Method: Talk
Presenting Author Title: Postdoc

SPIDER:

A Balloon-Borne Polarimeter for Measuring Large Angular Scale CMB B-Modes



What Will Spider Measure?



The cosmic microwave background Radiation's "surface of last scatter" is analogous to the light coming through the clouds to our eye on a cloudy day.

--> Cosmic Microwave Background (CMB) a remnant of the Big Bang

--> Universe expanding, in the past hotter and denser

--> So hot and dense that matter radiation in equilibrium

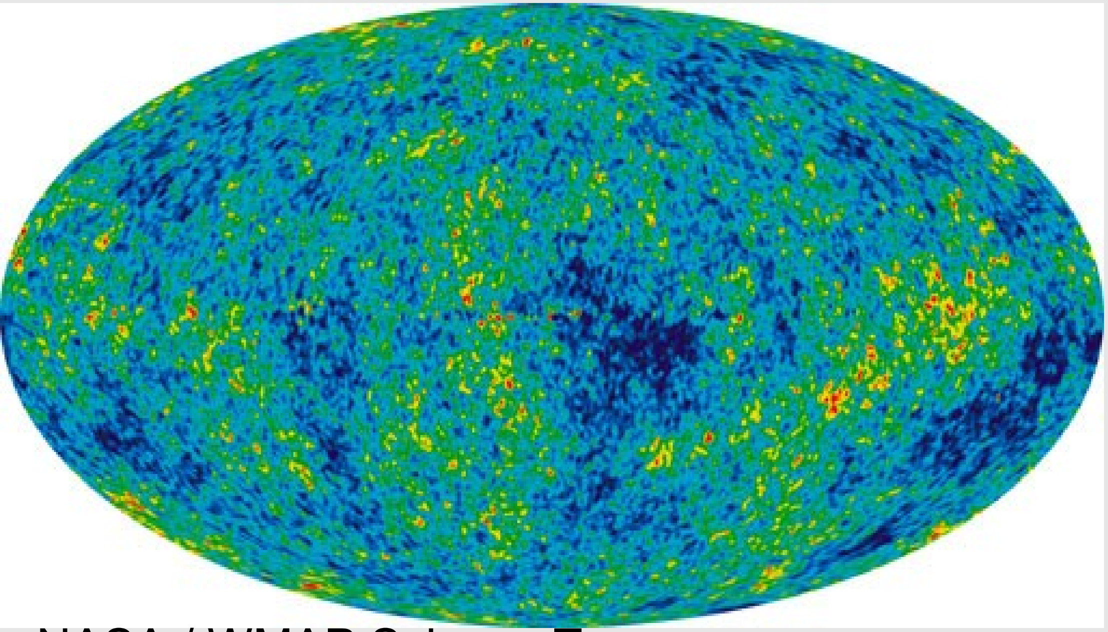
--> Universe ~400,000 years old cooled sufficiently so that matter & radiation decoupled

--> Surface of last scattering

--> Photons move freely; CMB a snapshot of the early Universe

Figure from WMAP web page: http://map.gsfc.nasa.gov/m_uni/uni_101bbtest3.html

CMB Intensity Measurements

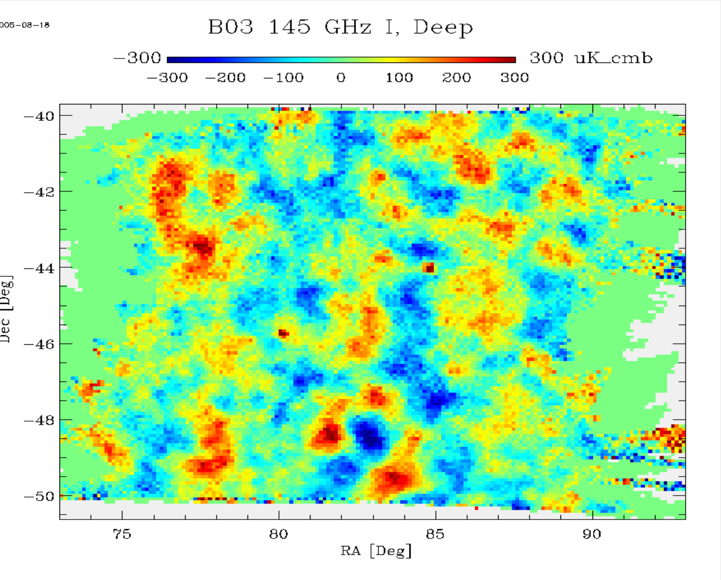


NASA / WMAP Science Team

--> Precision large/small angular scale maps of CMB intensity

--> WMAP satellite: full sky at 0.3 degree resolution

--> BOOMERANG balloon-borne: 1800 square degrees at 10 arcminute resolution



--> Intensity fluctuations at part per million level

--> Used to constrain Age, Geometry and Content of the Universe

SPIDER Probing Deeper: CMB Polarization

--> Characterize the CMB polarization field by E-mode and B-mode polarization

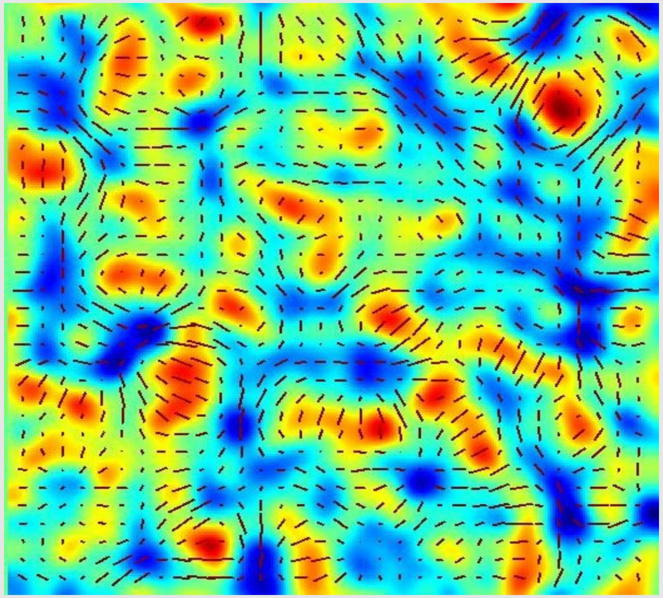
--> Electromagnetism analogy

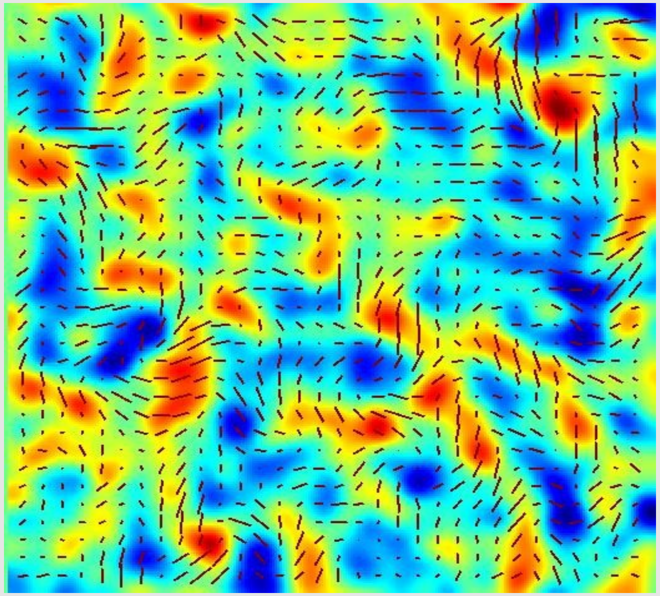
--> E-mode = curl-free component (electric-field like)

--> B-mode = curl-like component (magnetic-field like)

--> **B-mode signal predicted to be factor ~1000 times smaller than CMB intensity fluctuations--yikes!**

Pure E-mode





Pure B-mode

Colour plates from: Seljak and Zaldarriaga, 1998,astro-ph/9805010

Why Go After B-modes?

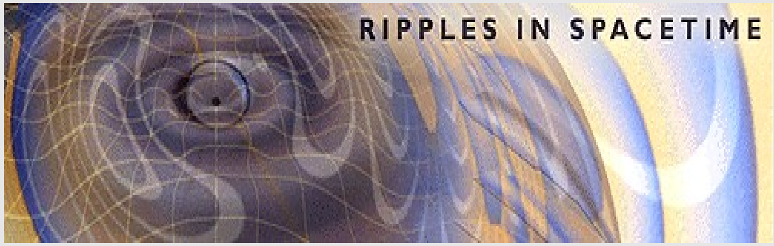
--> Puzzles remain: Why is the Universe so isotropic?
Where did initial matter fluctuations originate?
What is the energy scale at earliest times?

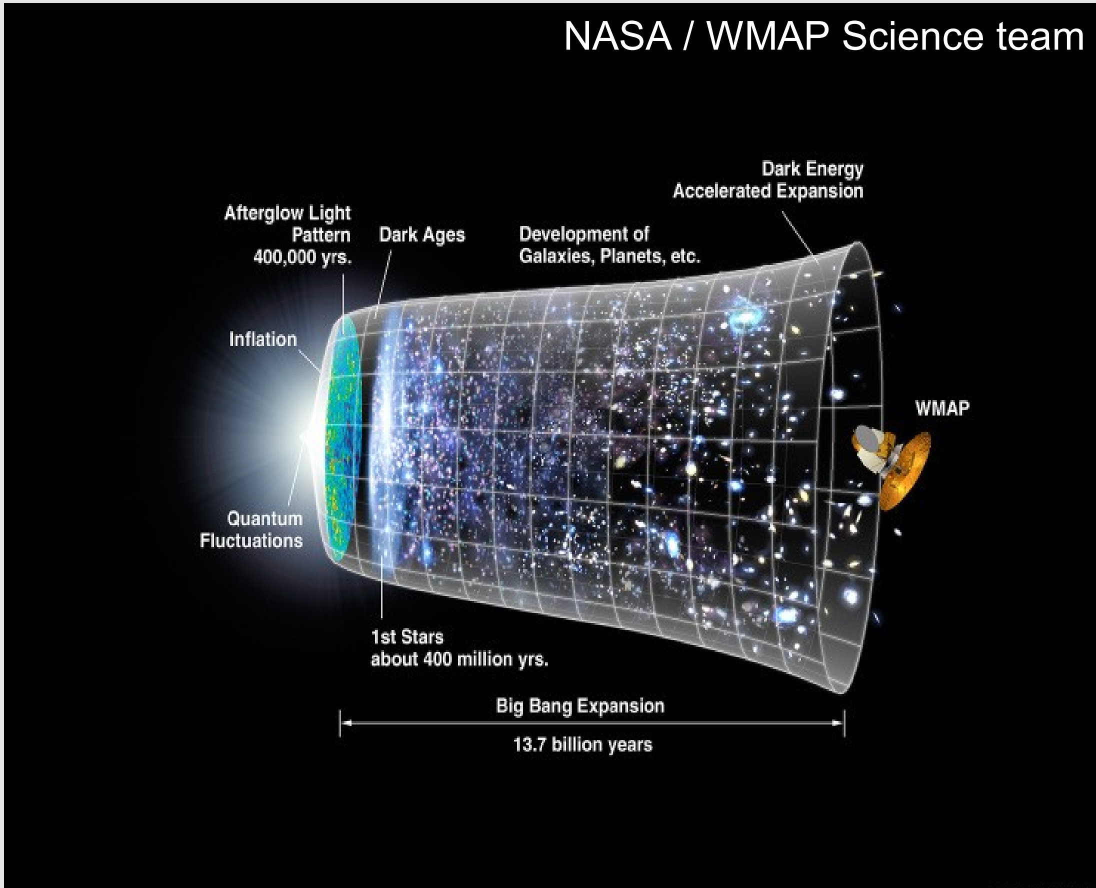
--> **Inflation** the theory which hopes to resolve these and other remaining puzzles

--> Epoch of **Inflation;** a period of exponential expansion at the earliest times

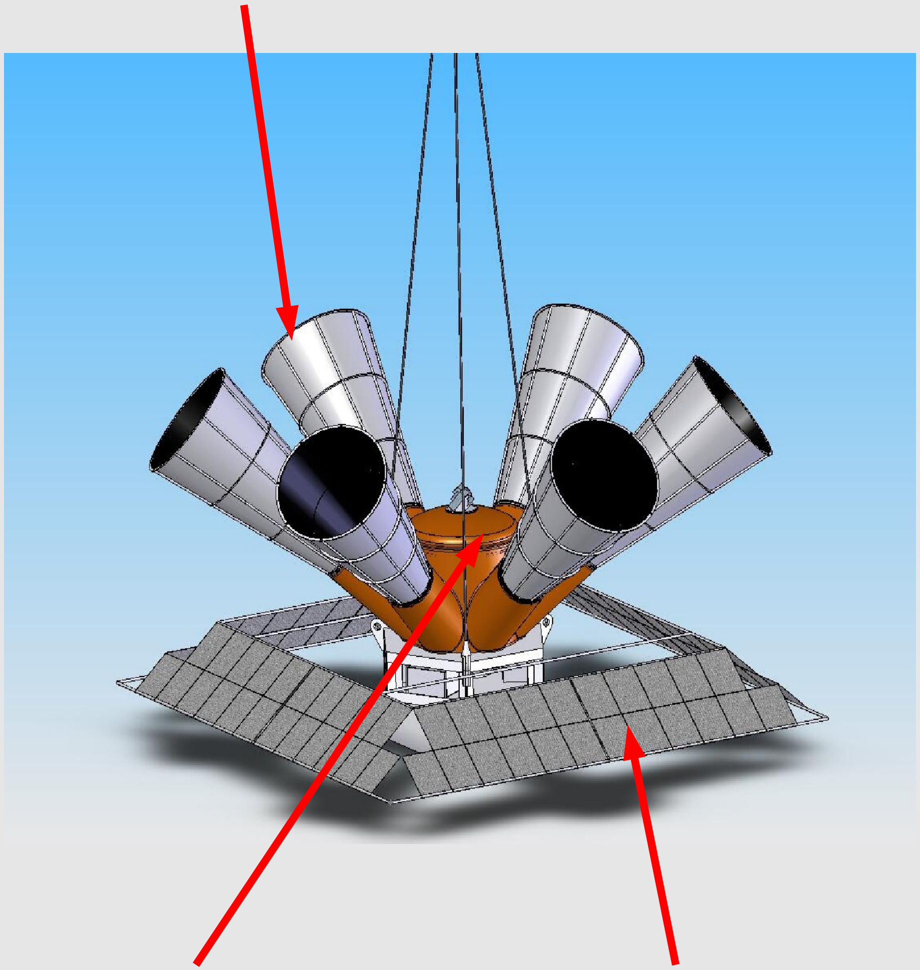
--> CMB **B-mode polarization** a probe of Inflation

--> These large scale B-modes sourced by background of primordial gravity waves





SPIDER Instrument Overview



--> Balloon-borne instrument

--> Spins in azimuth, fixed elevation (45º)

--> Six telescopes, five different frequencies from 70 to 300 GHz

--> ~1º resolution at 100GHz

--> 6 instrument inserts cooled to 4K in 1000 litre LHe cryostat

--> 2312 detectors cooled to ~250 mK

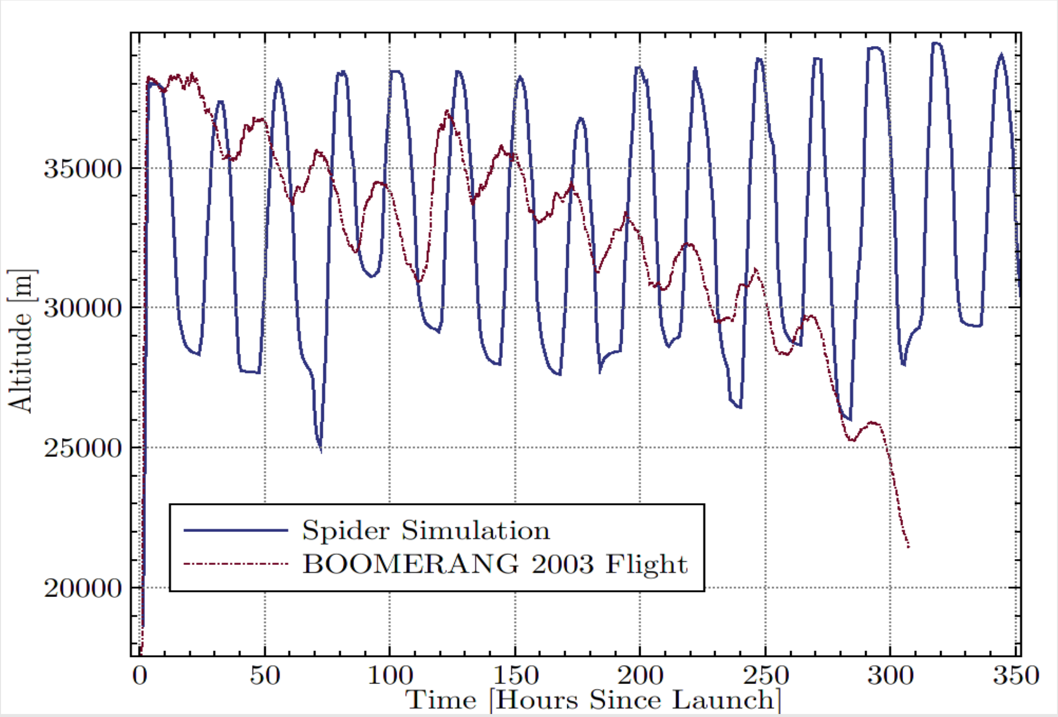
How will SPIDER measure B-modes?

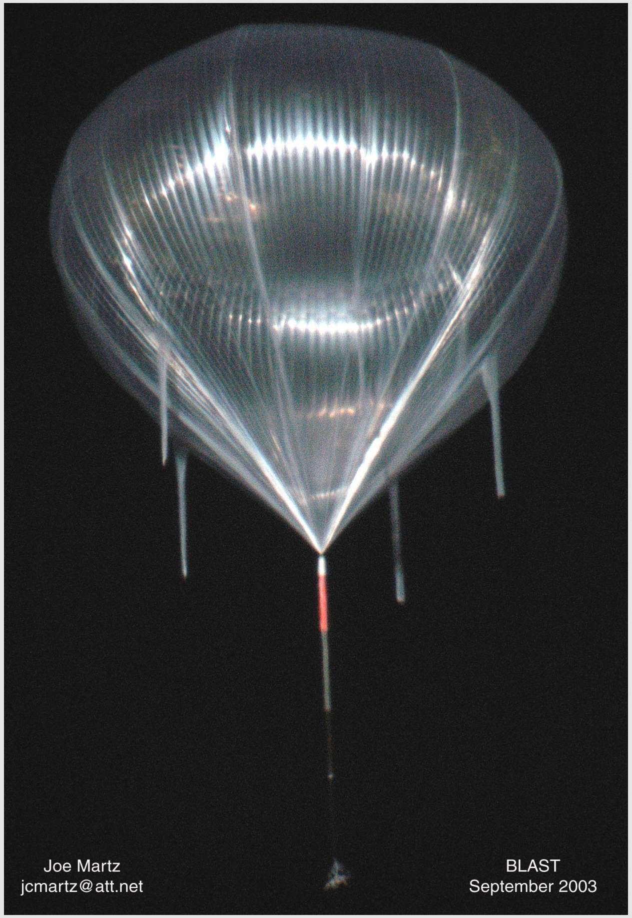
--> 25 day conventional balloon flight

--> Altitude range 27-39 km

--> Similar altitude as BOOMERANG03

--> Atmospheric loading in SPIDER bands below 0.1%





BLAST at float. cool.

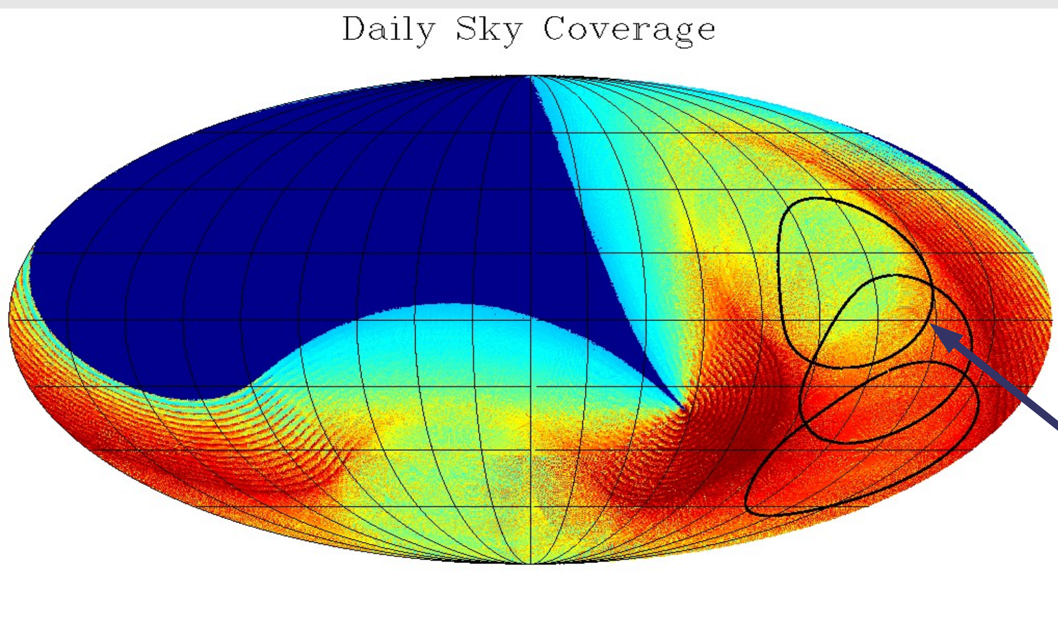
SPIDER Will Go Around the World

--> Launch from Alice Springs, Australia

--> Around the world, mid-latitude (-23º S) flight

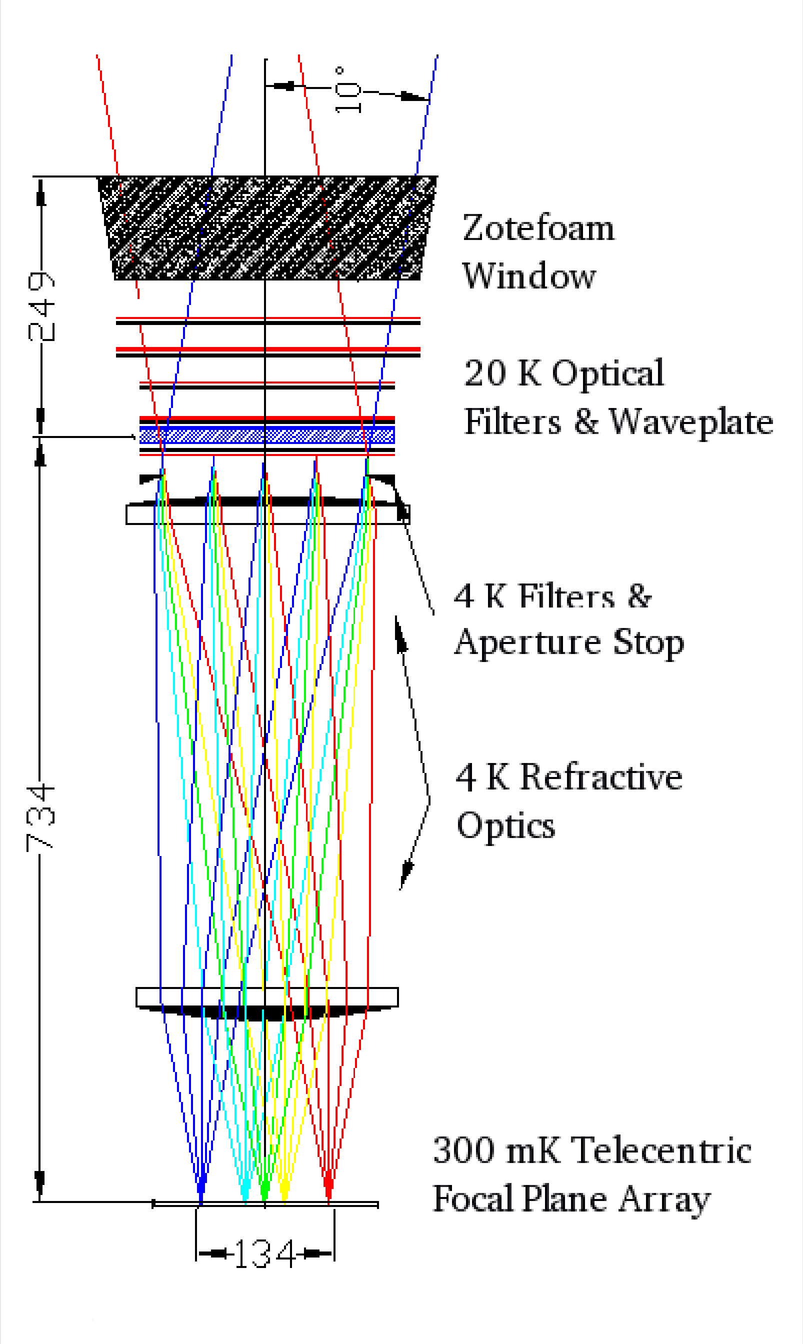
--> Instrument spins in azimuth, observing only at night

--> Observe >50% of the sky with good cross-linking



path of a pixel for single gondola rotation

Spider Optical Train



--> Optics compact and cooled
= good pre-flight instrument
characterization +
stability in-flight

--> External baffle provides
excellent control of far side
lobes

--> Rotating half-wave plate
modulates incoming
polarization above detector
1/f noise into white noise

--> Minimize systematics

New Detector Technology

--> New antenna-coupled bolometer array technology

--> Each pixel has orthogonally polarized antenna

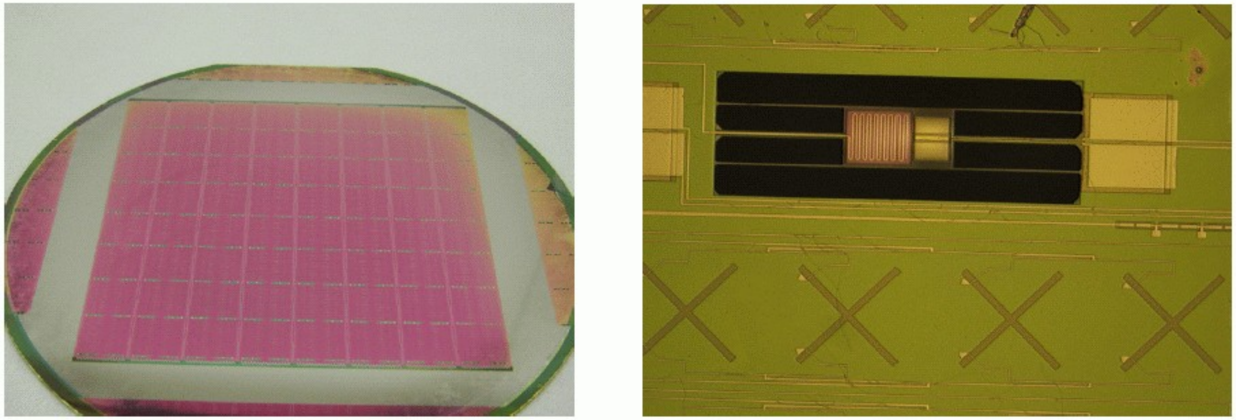


Figure 12: 4-inch-diameter wafer with 8 × 8 spatial pixels (left) and a closeup on a released TES and four antenna pairs at 50× magnification (right).

--> Single 145 GHz detector sensitivity 100 $\mu K_{CMB} s^{1/2}$

--> No feeds, low mass, close-packed = lots of detectors

Observing Band (GHz)	Bandwidth (GHz)	Beam FWHM (arcmin)	Number of Spatial Pixels	Number of Detectors	Single-Detector Sensitivity ($\mu K_{CMB}\sqrt{s}$)	Instrument Sensitivity ($\mu K_{CMB}\sqrt{s}$)
80	19	72	100	200	110	7.8
100	24	58	(2×)144	(2×)288	100	4.2
145	35	40	256	512	100	4.4
225	54	26	256	512	204	9.0
275	66	21	256	512	351	15.5

SPIDER Canada

CITA ICAT
Canadian Institute for Theoretical Astrophysics
L'institut canadien d'astrophysique theorique

SpiCam

SCUBA2 DAS

--> Payload **attitude control** based on proven BLAST & BOOMERANG designs

--> Pair of **CCD cameras** on rotating platform above payload, fixed on sky

--> Gondola

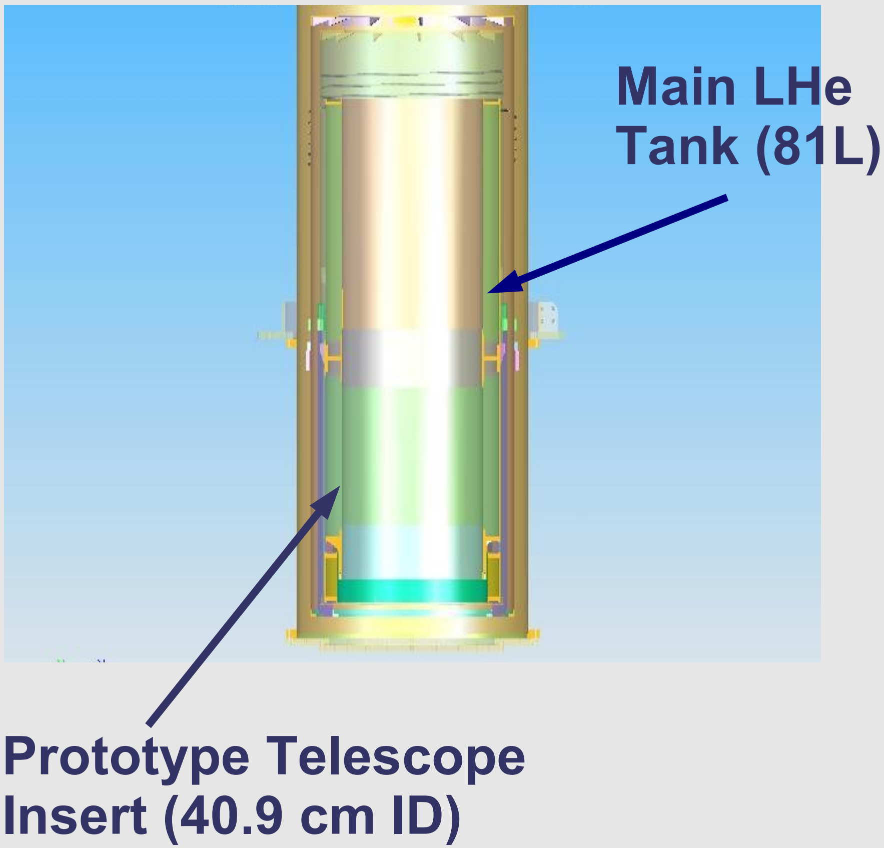
--> **Warm electronics**; time domain multiplexing DAS based on SCUBA2 & ACT

--> **Power system**; solar arrays charging batteries

--> **Analysis** on 512-processor (and growing) Beowulf cluster at CITA

What's the the plan?

Test Flight Cryostat (150 Kg)



--> CSBF Test flight spring 2008 from Palestine, Texas

--> Fly one insert only in test cryostat on (balanced) full LDB gondola

--> Allow testing of detectors, receiver, DAS, and attitude control/pointing

--> 25 day LDB Flight Nov. 2010 from Australia

SPIDER People

Caltech:
Andrew Lange
Sunil Golwala
Bill Jones
Pete Mason
Victor Hristov
Chao-Lin Kuo
Amy Trangsrud
Justus Brevik
A. Crites

Cardiff U:
Peter Ade
Carole Tucker

CWRU:
John Ruhl
Tom Montroy
Rick Bihary

CEA:
L. Duband

CITA:
Dick Bond
Carrie MacTavish
Olivier Dore

Imperial College:
Carlo Contaldi

IPAC:
Brendan Crill

JPL:
Jamie Bock
Jerry Mulder
Anthony Turner
Warren Holmes

UBC:
Mark Halpern
Elia Batastelli
Bryce Burger

NIST:
Kent Irwin
G. Hilton

U. Toronto:
Barth Netterfield
Enzo Pascale
Marco Viero

If I had a million dollars: In search of cold ionospheric currents

Johnathan Burchill
Natural Resources Canada, Geomagnetic Lab

Abstract:

A great success story in space physics was the prediction and confirmation of electric currents in the auroral upper atmosphere. These currents play a key role in the electrodynamic coupling between the ionosphere and the magnetosphere. The role of sub-eV ionospheric electrons in this electrodynamic coupling remains poorly understood, however, and direct detection of their spectra remains elusive. I will review the science behind these cold ionospheric currents, and discuss a sounding rocket mission to investigate them directly.

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Organization:	Natural Resources Canada, Geomagnetic Lab
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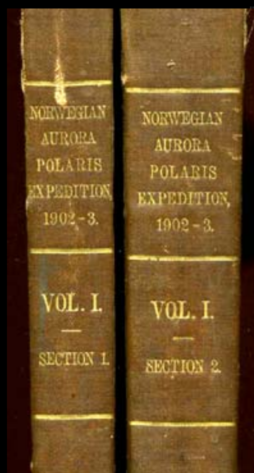
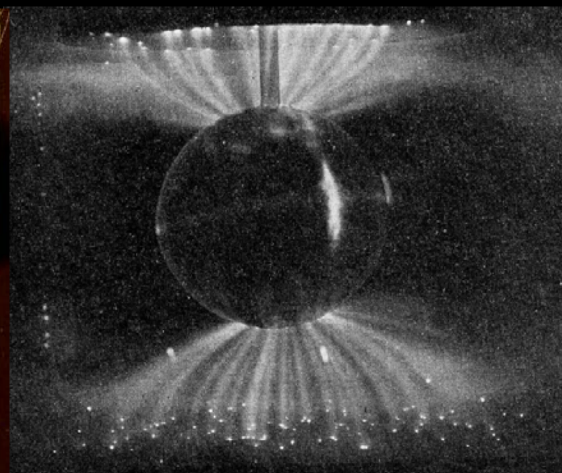
Presenting Author Telephone:	613-837-5137
Preferred Session:	Proposals for future projects by graduate students and postdocs
Presentation Method:	Talk
Presenting Author Title:	Postdoc

If I had a million dollars: in search of cold ionospheric currents



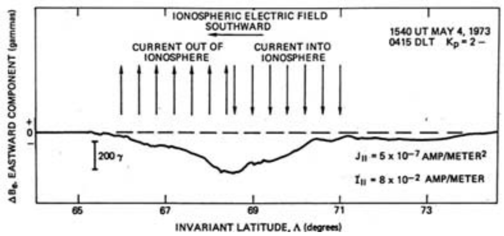


Johnathan Burchill
Visiting Scientist, NRCan Geomagnetic Lab
Email: jburchil@nrcan.gc.ca

Northern Lights over Canada, seen from the International Space Station

Photo credit: NASA
(public domain)

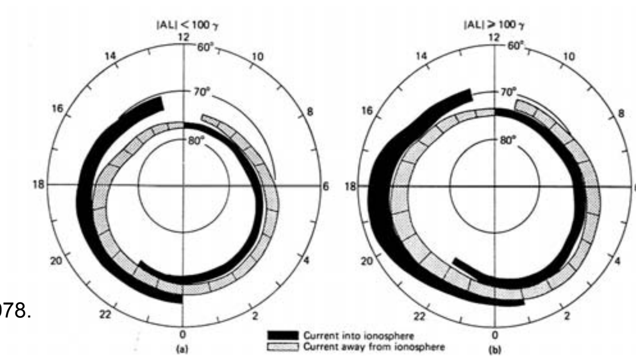
Field-Aligned Currents from the Triad satellite



Zmuda and Armstrong, 1974.
JGR Vol. 79, No. 31

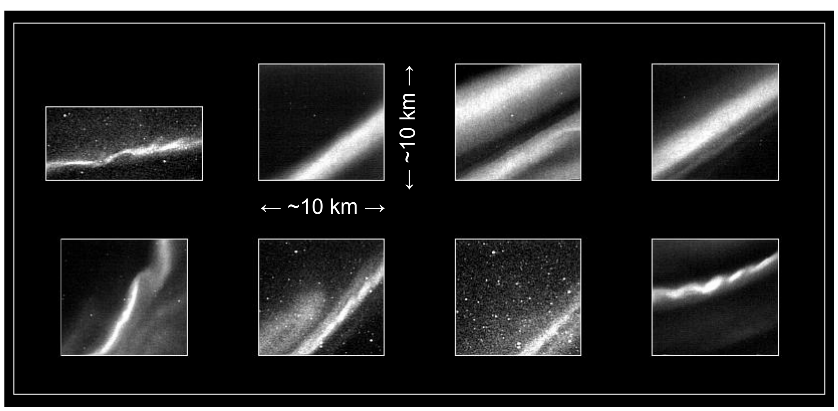
$$\nabla \times \boldsymbol{B} = \mu_0 \boldsymbol{J} + \frac{1}{c^2}\frac{\partial \boldsymbol{E}}{\partial t}$$

$$J_{\parallel} \approx \frac{1}{\mu_0}\frac{\partial(\Delta B_e)}{\partial x}$$



Iijima and Potemra, 1978.
JGR Vol. 83, No. A2

Thin Auroral Forms obtained by the Portable Auroral Imager



From Trondsen, 1998.

Theoretical Physics at the arc's edge

Thermal electrons

St.-Maurice et al., 1996
JGR 101, A1, 335

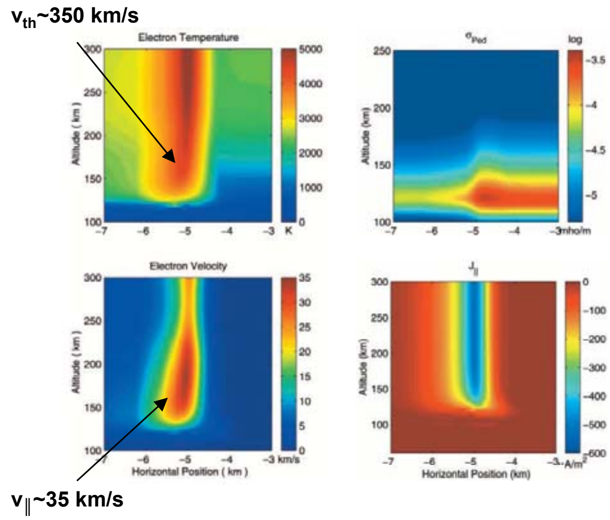
Noel et al., 2000
Ann. Geophys., 18, 1128-1144

Noel et al., 2005
Ann. Geophys., 23, 2081-2094

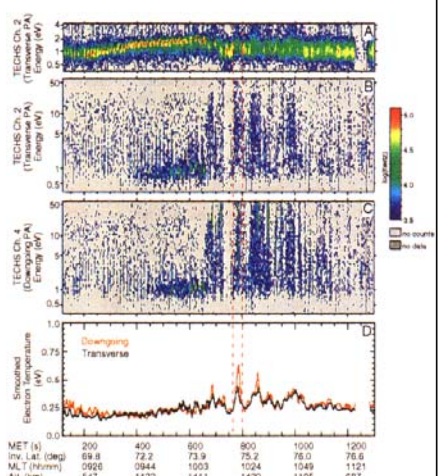
Incoherent Scatter Radar/ Ion acoustic waves

Rietveld et al., 1991
JGR 96, 19291

Villain et al., 1987, 1990
JGR 92, 12327 & JGR 95, 7833

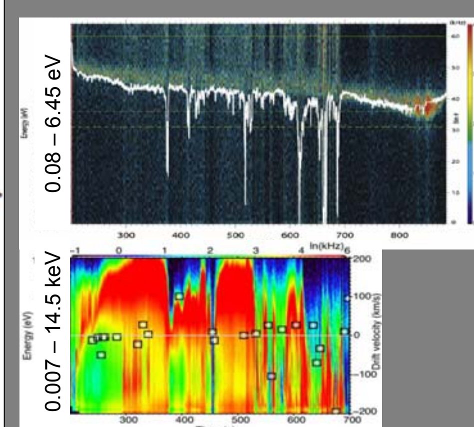


Day-time observations
from SCIFER (TECHS)
25 Jan 1995



Pollock et al., 1996

Night-time observations
from SIERRA (TED)
14 Jan 2002

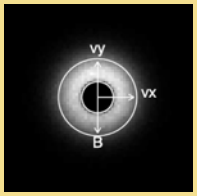


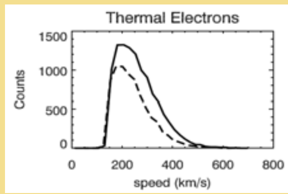
MacDonald et al., 2006: attempt thermal electron flow estimate

If I had a million dollars: go after the thermal electron currents

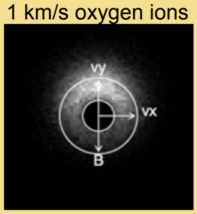
Are there techniques sensitive enough to detect thermal electron currents?

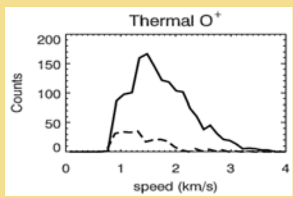
35 km/s electrons





1 km/s oxygen ions





Strategy:

- Build on experience from Freja CPA, GEODESIC, Cusp-2002, and ePOP electron instruments, other groups
- Collaborate on low-energy characterization facilities
- Develop techniques to deal with spacecraft charging and finite gyro-radius effects
- Fly instrument on suborbital rocket through the current closure region

DETECT sounding rocket

Detection of Elusive Thermal Electron Currents Today

•Thermal Electron Spectrometer
•Impedance probe
•Langmuir probe
•Suprathermal/Energetic particles
•Magnetic fields
•Electric fields
•Attitude control
•Ground-based optics, mags

Launch into fine-structured auroral arc system, 300 km apogee

GEODESIC launch into aurora.
(© Paul Nicklen Photography)

Science Issues and Associated Platforms

1. UTLS chemical composition and processes
- NRC Falcon with remote sensing (12.5 km)
- NRC T-33 with in situ (12.5 km)
- ARA Egrett witjh in situ (15 km)
- Retired Military: C-F 5 (17 km)
- UAVs (17 km)

2. Tropospheric Pollution and Transport
- NRC Convair, NRC Twin Otter

3. Clouds and Climate
- NRC Convair

4. Meteorology and Forcasting
- NRC Convair

5. Validation of Satellite Instruments
- NRC Convair

Collaboration Issue

Within Canada

Expand access to NRC facilities for Universities

Links between Universities

Stronger link between CSA and NRC

One Year Plan

CFI proposal with CSA contribution

York U, U of T, EC, NRC, CSA

NRC: T33, Falcon, (Egrett)

Investigate z > 50 kft (CF-5)

Ten Year Plan: Continuity

Investment in the infrastructure

Build University interest

Deployment pool for universities

Long term funding support

Industry involvement

Space Instrument Testing

SHOW
ARGO
ARGUS
EC (McElroy)

LIDARS

Darwin or Costa Rica:
- **Convection and transport in the tropopause region**
- **Tropopause dynamics and generation of gravity waves**
- **UTLS Water vapour**

Ontario:
- **Cirrus clouds and effects of aircraft exhaust**
- **jetstream turbulence and mixing**
- **tropospheric ozone (lidar downward)**
- **convection, transport of pollutants and strat/trop exchange**
- **Testing of space instruments**

Rockies:
- **gravity wave breaking**
- **Strat Trop exchange**
- **Cloud Physics and water vapour**

North/Arctic:
- **Forest Fires**
- **Strat/trop exchange**
- **tropospheric ozone (lidar downward)**

COMMUNITY WORKSHOP ON SCIENCE FROM SUBORBITAL VEHICLES (BALLOONS, AIRCRAFT, ROCKETS)

BREAK-OUT SESSION: BALLOONS

Discussion Lead: Ben Quine
Reporter: Kaley Walker

New Science & Missions: Topics

- **What are the major issues and new science questions that can be addressed with each platform?**

Atmospheric

- How can we probe the atmosphere at better resolution than we do now?
- Investigating the high level aerosols in outflow layers – combining observations with models, investigating the impacts for chemistry
- Radiation budget – upward and downlooking
- Improving our understanding of the sources and sinks of greenhouse gases – using balloons to sample of different scenes, use results for validation of upcoming satellite missions, getting accurate vertical structure information, feeding this into improving models
- What is the impact of forest fires on the global atmosphere?
- Radiative impact of aerosols

New Science & Missions: Topics

- **What are the major issues and new science questions that can be addressed with each platform?**

Atmospheric (cont.)

- Better vertical resolution – ascent, improved occultation, limb scanning – implies higher temporal resolution, more frequent flights
- Combining biomass observations/modeling: dta leading to development and improvement of vegetation canopy lidar scattering models
- Improving our understanding of global stratospheric winds –SWIFT
- Water vapor distribution

Astrophysics

- Are there other planets that could support life?
- Is our solar system and our planetary system unique?
- What is the physics that describes the earliest hottest densest time of the universe?
- When did the first stars form?
- Where did the initial matter density fluctuations come from?
- Why is the universe so smooth?

New Science & Missions: Topics

- **What new approaches, techniques, and technologies are being developed for each platform ?**

POINTING SYSTEM ACCURACY!!!!!!!!!!!!

COMMUNICATIONS - High speed data link

Autonomy – improvements in system operation

Duration

Control – overpressure, controlled in height, zeppelin, aerobots (steerable)

Power systems

On-board storage

Detector technologies – continuous improvement

Modular payload – structure, systems

Differential GPS – depends strongly on satellite orientation,

Being able to access know how!

New Science & Missions: Topics

- **How important is each platform for the development and testing of new instruments?**

INVALUABLE 11/10

Feeds into space missions – science, technology, expertise

Cal/val – synergy between balloons and satellite missions

- **Discuss activities, opportunities, and goals for the next ten years for each platform.**

Answer science questions – need balloons to do this best

Sustainable ballooning program – yearly opportunities

Building and maintaining student experience – with responsibility (as much as possible)

Usefulness to Space program – spin off for space science and space technology

Test most future sat. instruments

Canadian long duration capability

Canadian-led large projects (encourage international collaboration)

Arctic launch capability (circumpolar)

Deployable launch capability – access to both hemispheres

New Science & Missions: Topics

- **What are the challenges?**

People – HQP – stability for people, facilities

Absence of program

Reliability – launch failures, system failures, quicker reflight

Frequency of opportunities

Managing funding for large and small projects

Multi-agency coordination

Data archiving – astro has this, atmos working on this

Funding of development of new instruments

Present Activities: Topics

- **What is the level of interest in flight opportunities for each platform in Canada?**

High 22/10

- **What are the opportunities for international collaboration?**

Huge - collaboration as equal partners, pull our weight more so than we have, timely funding mechanism for these collaborations

CSBF – talk about possibilities also with CNES

As piggyback instruments – flexible+capable to fit this category, technical challenge dedicated flights ~$100s

- **How can collaborations between Canadian universities, government agencies, and industry, and with international partners be created and enhanced?**

Get together, make a plan as a "community", takes effort, tapping all available funding sources – save outselves

Infrastructure: Topics

- **What infrastructure is needed to enable new missions?**

Astron. – LDB 40 MCF, basically need CSBF equivalent

Develop new instruments needs infrastructure

Atmos. – range of payload launches available – 600-700kg for MANTRA – 2+pointing = 200 kg -> 500 kg max. total payload mass

- Power, telemetry, pointing system
- Hand launch 45 kg max. for gondola system

But depends on size of payloads we want to support

- **What are the relative merits of building and/or maintaining the Canadian capacity for balloon and rocket launches vs. contracting launches or piggy-backing on international missions?**

Financial – what's cheaper? By magnitude of payload

Intangible – availability, supporting Canadian industry, interaction between hqp and industry, reliability (number of launches strongly influences this)

Infrastructure: Discussion

- **Recommendations for what is needed to maintain continuity.**

Stably funded program with relatively quick turnaround

CFI to rebuild balloon base – hand-in-hand with CSA - EC – industry participation

Way of funding international opportunities that helps facilitates this in a timely manner

Break-out Session: Balloons *Slide 9*

Vision: Topics

- **What should be done in the next year to begin to realise that vision?**

Kaley will organize planning meeting for balloon community

Leveraging of CFI or other funding should be given consideration in small payloads AO

Break-out Session: Balloons *Slide 10*

COMMUNITY WORKSHOP ON SCIENCE FROM SUBORBITAL VEHICLES (BALLOONS, AIRCRAFT, ROCKETS)

BREAK-OUT SESSION: ROCKETS

February 2, 2007

Discussion Lead: David Knudsen, U of C
Reporter: Johnathan Burchill, NRCan/U of C
Johnny Aase, U of C
Rebecca Batchelor, U of T
Gordon James, CRC
Denis Laurin, CSA
Laureline Sangalli, U of C
Andrew Yau, U of C

New Rocket Science Possibilities

- First direct detection of thermal electron currents
- Direct detection of parallel electric fields
- Field-aligned plasma flow in the ionosphere
- Resolve sub-decameter structure of wave-particle interaction in time and space
- In-situ observation of auroral wave generation and propagation
- Vertical and horizontal structure of ion-neutral coupling and Joule heating in the lower ionosphere/thermosphere
- Mesosphere/PMSE/NLC?
- Astronomy?
- Material science, zero-G?

Unique Capabilities

- access to lower ionosphere
- high-resolution microphysics
- multiple payloads; multi-point measurements
- fast turnaround

- microgravity

New Rocket Technologies

- reusable rocket vehicles
- high altitude (>3000 km), long-range (>1000 km) vehicles
- standardized interfaces
- trajectory shaping
- miniaturized multiple sub-payloads

Infrastructure: Topics

- What infrastructure is needed to enable new missions?
  - Maintain industrial capability (Bristol vehicle and payload expertise)
- Recommendations for what is needed to maintain continuity:
  - **Stability and predictability**

Break-out Session: Rockets *Slide 5*

10-year Vision

- Describe a ten-year vision for the Small Payloads Program.
  - Remain science-driven
  - Enhance student involvement and outreach.
  - Increase number of Canadian groups involved in rocket research.

Break-out Session: Rockets *Slide 6*

Vision: Discussion

- Describe a ten-year vision for the Small Payloads Program.
  - Re-vitalize the program through:
    - regular and **predictable** opportunities
    - involvement of multiple groups/organizations in Canada and elsewhere.

- What should be done in the next year to begin to realise that vision?
  - Follow through with SPP AO. Assess proposals and initiate funding in a timely manner.

Vision: Plan

- One Canadian-led rocket every 3-4 years
- Canadian instruments on foreign-led missions
- C$500k/year baseline
- Supplement with international partnerships (US, Norway, Japan)
- What should be done in the next year to begin to realise that vision?
- Raise profile of student recruiting program

Posters

1 and 2 February 2007

POSTERS			
Industrial capabilities/interests	Grandmont	Balloons/ Aircraft	Suborbital instrument projects at ABB Bomem
Industrial capabilities/interests	Hahn	Balloons	High-altitude Balloon Flights as a Test and Operations Platform for Lidar Systems
Past / Case Studies	Lytkine	Balloons	PROSPECTS OF DEVELOPING BALLOON-BORNE GAS SENSORS BASED ON LONG-WAVELENGTH VCSELS FOR IN SITU CHEMICAL ANALYSIS OF THE ATMOSPHERE
Past / Case Studies	Melo	Balloons	BrO and NO2 measurements during the MANTRA 2004 campaign: comparisons with co-located ACE and ENVISAT satellite measurement.
Industrial capabilities/interests	Sommerfeldt	Balloons	Science using balloons
Industrial capabilities/interests	Sommerfeldt	Balloons	Space Science Engineering
Past / Case Studies	Toohey	Balloons	Observing nitrogen in the stratosphere: connecting present and past
Past / Case Studies	Wunch	Balloons	MANTRA, Turnaround, and the University of Toronto's Balloon-Borne Fourier Transform Spectrometer

Suborbital instrument projects at ABB Bomem

Frederic Grandmont*, Marc-Andre Soucy, Jacques Giroux, Henry Buijs
ABB Bomem

Abstract:

ABB Bomem was founded in 1973 in the foot step of Dr. Henry Buijs thesis work on Fourier Transform Spectroscopy measurement in the infrared (FTIR) from balloon. Even though the company growth came primarily from the commercial applications of FTIR, the company always remained dedicated to support research projects and experiments that could benefit from FTIR technology. In the nineties, the company expanded its R&D based activities to include space applications such that the ABB Bomem name is now known as a world leader in FTS space instrumentation. Its most well known instruments are the SciSat payload launched in 2003 primarily to measure tropospheric ozone. Another important achievement is NOAA's next generation of polar-orbiting weather satellite which payload will include an FTS-based sounder built by ABB Bomem and ITT Industries. Also of interest is Japan GOSAT mission which aims at measuring Greehouse gas concentration to support the Kyoto protocol.

Such important space missions are always preceded by a series of demonstration and research instruments taken to sub-orbital elevation to help build a science case, validate or calibrate the satellite data output. A list of airborne/balloon borne instruments projects conducted at ABB will be presented.

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Presenting Author Email:	frederic.j.grandmont@ca.abb.com
Presenting Author Telephone:	418-877-2944x318
Preferred Session:	Industrial capabilities and interests
Presentation Method:	Poster
Presenting Author Title:	Industry

Community Workshop on Science from Suborbital Vehicles
Environment Canada, Toronto, 1-2 February 2007

Heritage and Recent Developments on Fourier Transform Spectrometry at ABB

Frédéric Grandmont, Marc-André Soucy, Jacques Giroux, Henry Buijs, ABB
frederic.j.grandmont@ca.abb.com **http://www.abb.com/analytical**

Abstract

ABB Bomem was founded in 1973 in the foot steps of Dr. Henry Buijs thesis work on Fourier Transform Spectroscopy measurement in the infrared (FTIR) some of which were made from balloon. Even though the company growth came primarily from the commercial applications of FTIR, the company always remained dedicated to support research projects and experiments that could benefit from FTIR technology. In the nineties, the company expanded its R&D based activities to include space applications such that the ABB Bomem name is now known as a world leader in FTS space instrumentation. Its most well known instruments are the SciSat payload launched in 2003 primarily to measure tropospheric ozone. Another important achievement is NOAA's next generation of polar-orbiting weather satellite which payload will include an FTS-based sounder built by ABB Bomem and ITT Industries. Also of interest is Japan GOSAT mission which aims at measuring Greenhouse gas concentration to support the Kyoto protocol. Such important space missions are always preceded by a series of demonstration and research instruments taken to sub-orbital elevation to help build a science case, validate or calibrate the satellite data output. A list of airborne/balloon borne instruments projects conducted at ABB is presented.

ARIES

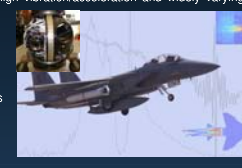
The ARIES instrument is a fast scanning interferometer mounted in the instrumentation pod of a MRF C-130 for the UK Meteorological Office. Based on the Bomem MR series, the system is used for remote sensing of the earth and the atmosphere (0 – 10 km range). This instrument has successfully flown in various missions. The system has been rejuvenated at ABB in 2006 to extend lifetime.

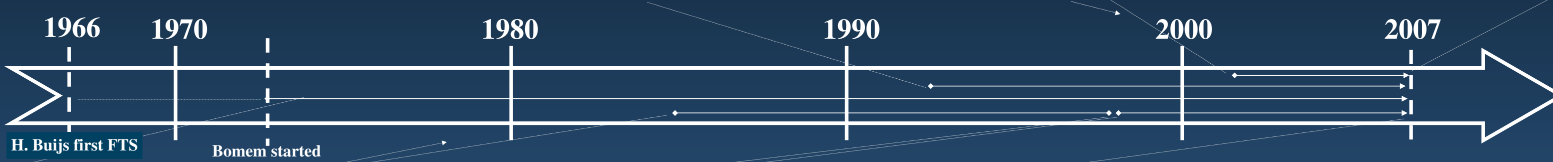
SARIS

SARIS is an airborne imaging spectrometer flown on-board an F-15 fighter. ABB designed and built SARIS for the US Air Force. This system is designed to acquire infrared signatures from targets, missiles, flares, etc. Datacube are acquired simultaneous to a co-registered high definition IR Camera. One of the challenges of SARIS was to design an instrument that would be able to perform in an environment of high vibration/acceleration and widely varying temperature.

Data sheet summary:

- Spectral range 2 – 5 mm
- 16X16 pixels imagery
- 3000 to 375 spectral bands
- Up to 150 datacubes sec
- (212 Mbits/sec data rate)

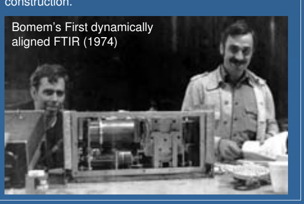




Balloon Borne Instrument

The first instruments built by ABB Bomem in the 70's were balloon-borne Fourier transform spectrometers for atmospheric measurements by solar occultation. A series of these instruments were built, in particular for Atmospheric Environment Services of Canada, University of Denver and the French CNRS.

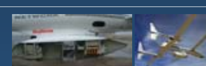
Also, a special cryogenically cooled FT system was built for NASA Goddard for atmospheric absorption measurements. These instruments featured high throughput with 2" aperture, and high resolution to 0.01 cm-1. They also offered numerical filtering for data reduction and used dynamic alignment of one of the interferometer mirrors to maintain the required accuracy on the recombining beams. Most of these systems are still in use more than 15 years after their construction.


Bomem's First dynamically aligned FTIR (1974)

HIS (High-resolution Interferometer Sounder)

The HIS instrument is based on the Bomem balloon-borne instruments and has been developed for the University of Wisconsin. It has been used to demonstrate the possibility of replacing filter radiometers for temperature and humidity profiling of the atmosphere. The system is owned and operated by the University of Wisconsin. The HIS and NAST-I are flown on a NASA ER-2 high altitude aircraft (modified research-version of an U2 airplane).
http://cimss.ssec.wisc.edu/his/his.html

NASTI



The NAST-I (NPOESS Airborne Sounding Testbed Interferometer) is a high resolution Michelson interferometer, developed in collaboration with MIT Lincoln Laboratory. Its objectives are to to define optimal spectral characteristics like spatial resolution and scan geometry characteristics of the NPOESS IR sounder. The unapodized spectral resolution of NAST-I is 0.25 cm-1 within a 590 - 2810 cm-1 (3.6 - 17 microns) spectral range. The infrared radiance measurements obtained from the NAST-I instrument provide detailed spectral characteristics of the atmosphere and land surface along with detailed atmospheric temperature and water vapor profiles. ABB provided the heart of this Fourier Transform Spectrometer, i.e. the interferometer including the metrology source and the control electronics for the moving mirror and the dynamic alignment.

And many others…

Tokyo Tokyo was a demonstration instrument in preparation for the TANSO interferometer to be flown on the GOSAT satellite which ABB is also responsible of delivering. The Tokyo instrument flew onboard various platforms: Zeppelin, Cessna type, jet aircraft.

Safegard Safeguard is an airborne version of the state-of-the-art fast scanning interferometer MR254. This system is used to detect chemical agents from an aircraft. It is rugged and had successful test flights mounted in a modified DC-3. It is a compact, low-weight design using two-band detector an a down-looking telescope.

Chips The CPS Spectroradiometer is an infrared interferometer designed to operate in the instrumentation pod of a high performance jet aircraft. The system consists of the sensor head module containing optical components as well as a dual-range detector, the computer electronics module as well as the power supply.

MINT

The Miniature INTerferometer (MINT) is an ABB initiative funded by the CSA through the STDP program to develop a very compact size interferometer module. MINT will find several field or space applications, like the monitoring atmospheric constituent concentration, or the measurement of geological samples in planetary exploration. Our company will also benefit from an improved portability that the new technology will bring to its commercial and industrial applications. A new commercial instrument based on that architecture is about to be released in February 2007

Interferometer Features

- Power Consumption: 4 watts (motor drive, thermal stabilization and metrology detection)
- Mass: 0.6 Kg
- Dimension: Within 10 cm x 10 cm x 5 cm
- Modulation Efficiency: > 85 %
- Spectral Sampling: < 2 cm-1
- Optical Throughput: Beam size larger than 15 mm
- Spectral Range 500 - 3000 cm-1
- Spectral Accuracy < 10 ppm
- Spectral Instability < 2 ppm (single sweep)
- Radiometric Instability < 0.02% (1 min)
- OPD Rate: From step-scan up to 10 cm/s
- Operational Temp. Range: 0 to +40 C
- Survival Temp. Range: -55 to +71 C

Compared to a traditional interferometer, MINT features a major reduction in size, weight and power consumption while preserving a good spectral resolution. It will also show good spectral and radiometric stability and it will be compatible with harsh environment. As part of the present STDP project, a prototype will be built and tested.

Conclusion

- Existing designs and technologies cover a wide range of applications :
  - Atmospheric Sounding (Atmospheric Research, Climatology, Weather Forecasting)
  - IR Signature and Target Characterization (Defense and Research)
  - Gas Detection for Environmental Protection & Homeland Security (Fugitive Emission, Chemical Agents,…)
- Strong heritage and experience is available at ABB

High-altitude Balloon Flights as a Test and Operations Platform for Lidar Systems

John F. Hahn, Optech Incoporated

Abstract:

High-altitude balloon flights offer potential benefits to lidar instrument development and operation. This paper is intended to promote discussion of these benefits and possible applications. High altitude balloon flights can deliver to the user a space-like environment, prolonged flight duration and payload retrievability, all of which are valuable in the test of lidar instrumentation. Space lidar instruments, beyond the breadboard but not yet at the engineering model stage of development, can be tested and demonstrated for extended periods of time. This would constitute the advancement of the instrument's technology readiness level (TRL) to TRL-6: System/subsystem model or prototype demonstration in a relevant environment (ground or space). TRL-6 is considered the threshold level of preparedness acceptable for spaceflight.

More commonly, an engineering model is built and tested on the ground, including thermal-vacuum tests that can last up to several days. While ground-based T-vac testing has the clear advantage of offering accessibility to monitoring instrumentation, prolonged operation of lidar systems in such circumstances may prove problematic. Operator eye-safety and safety within the laboratory must be considered. Demonstrating the capability to retrieve useful science information requires coupling the lidar to the outside world through multiple windows. And the laser, as the most problematic element in the lidar system, is tested in the relevant environment for a period of time substantially less than typical mission lifetimes. Flying lidar instrumentation on a balloon, however, can offset these limitations. Once aloft, there are few operator safety issues and no difficulties in coupling the instrument to the outside world for demonstration / intercomparison purposes. Since balloon payloads are retrievable and since ample data could be collected in this test case, instrument development could be accelerated, given the availability of room on balloon flights.

Operationally, the slow-drift / prolonged dwell potential of balloon flights makes it possible for high density data to be collected over geographically remote regions. These capabilities, it would seem, could do much to improve the quality of the topographical models in remote regions, in terms of both vertical accuracy and horizontal resolution. The density of data provides attendant advantages to the measurement statistics. Moreover, full waveform signal collection from lidar systems flying over forested areas can be used to estimate the biomass of the area, an important step towards establishing the planetary carbon budget. The experimental data can further be used to develop more accurate vegetation scattering models, for instrument modeling or interpretation purposes. Balloon-borne data of this type would be a useful high-spatial resolution complement to orbital vegetation canopy mapping, providing tie points to data collected from space, making for robust interpretation of all collected data.

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Presenting Author Title:	Industry

Optech

High-altitude Balloon Flights as a Test and Operations Platform for Lidar Systems

John F. Hahn / Optech Incorporated
Community Workshop on Science from Suborbital Vehicles
McTaggart Auditorium, Environment Canada
4905 Dufferin Street, Toronto, Ontario
February 1-2, 2007

Fig. 2

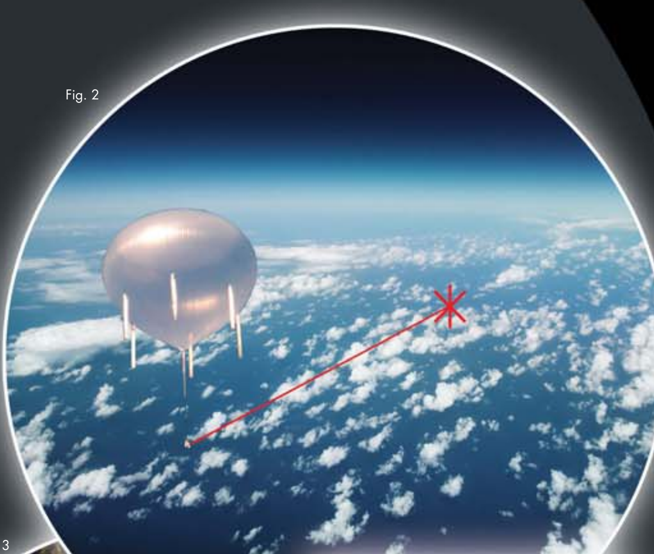

Fig. 3

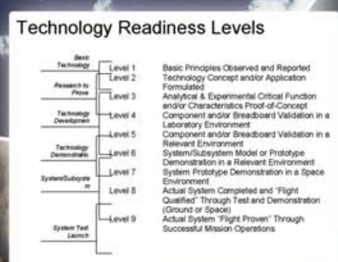

Fig. 1

Scientific balloons images courtesy of Aerostar International Inc

Introduction

High-altitude balloon flights offer potential benefits to lidar instrument development and operation. This paper is intended to promote discussion of these benefits and possible applications.

High-altitude balloon flights can deliver to the user a space-like environment, prolonged flight duration and payload retrievability, all of which are valuable in the test of lidar instrumentation. Space lidar instruments, beyond the breadboard but not yet at the engineering model stage of development, can be tested and demonstrated for extended periods of time. This would constitute the advancement of the instrument's technology readiness level (TRL) to TRL-6: System/subsystem model or prototype demonstration in a relevant environment (ground or space). TRL-6 is considered the threshold level of preparedness acceptable for spaceflight.

"Technology Readiness Levels" are graded steps in assessing the preparedness of instrumentation for space flight (see Figure 1)*.

More commonly, an engineering model is built and tested on the ground, including thermal-vacuum tests that can last up to several days. While ground-based T-vac testing has the clear advantage of offering accessibility to monitoring instrumentation, prolonged operation of lidar systems in such circumstances may prove problematic. Operator eye-safety and safety within the laboratory must be considered. Demonstrating the capability to retrieve useful science information requires coupling the lidar to the outside world through multiple windows. And the laser, as the most problematic element in the lidar system, is tested in the relevant environment for a period of time substantially less than typical mission lifetimes. Flying lidar instrumentation on a balloon, however, can offset these limitations. Once aloft, there are few operator safety issues and no difficulties in coupling the instrument to the outside world for demonstration / intercomparison purposes. Since balloon payloads are retrievable and since ample data could be collected in this test case, instrument development could be accelerated, given the availability of room on balloon flights.

Operationally, the slow-drift / prolonged dwell potential of balloon flights makes it possible for high density data to be collected over geographically remote regions. These capabilities, it would seem, could do much to improve the quality of the topographical models in remote regions, in terms of both vertical accuracy and horizontal resolution. The density of data provides attendant advantages to the measurement statistics. Moreover, full waveform signal collection from lidar systems flying over forested areas can be used to estimate the biomass of the area, an important step towards establishing the planetary carbon budget.
The experimental data can further be used to develop more accurate vegetation scattering models, for instrument modeling or interpretation purposes. Balloon-borne data of this type would be a useful high-spatial resolution complement to orbital vegetation canopy mapping, providing tie points to data collected from space, making for robust interpretation of all collected data.

Space Lidar Characterization

High-altitude balloon flights can approximate some of the environmental conditions expected on extra-terrestrial planetary environments, particularly Mars. For lidar instrument concepts that have been demonstrated as laboratory breadboards but that require further test of critical issues, high-altitude flights can provide a effective way to simultaneously advance the technology readiness level of the concept and to characterize its operation, i.e. measure the typical behavior of instrument properties which may affect the accuracy or quality of the derived data products** or demonstrate its ability to get the right answers when tested against known scientific standards and materials***.

The Rayleigh environment at high-altitudes would:

– Provide a well-defined lower scattering limit
– Consequently provide a robust test of instrument performance
– Permit the Rayleigh volume backscatter coefficient corresponding to the Martian atmosphere to be simulated (~15 km altitude at mid-latitudes) as well as the Martian scale height by canting the lidar at ~45 degrees, assuming an isothermal profile (reasonable for this altitude) (see Figure 2)

Balloon flights are particularly useful for these tests because :

– Long flight duration, e.g. 20 days, is possible
– Temperatures at 15 km altitude are also Mars-like (~210K)
– Rayleigh scattering at this altitude is very small, suggesting reduction of data from multiple waveforms. Deployment of a test lidar in a stabilized, high-altitude balloon could help ensure that the same air column is sounded during collection of multiple wavelengths

Vegetation Canopy & Topographical Mapping

The measurement, mapping and monitoring of terrestrial biomass (i.e., carbon sources and sinks) remains imperative for many programs concerned with understanding changes in the Earth's climate. Full waveform lidar retrieval has been used for the purpose of biomass estimation in forested regions, since the return signal provides accurate range data for both the top of forest canopy and the ground return, from which vegetative height can be estimated. In addition, scattering from the vegetative understory varies according to the type and density of the vegetation so that estimates of important parameters such as the lead area index can be estimated with the use of lidar data. However, improved scattering models can do much to improve the interpretation of lidar data. One method of improving the vegetation scattering models is long term collection of scattering data by balloon.

High-altitude balloon flights offer an operational platform for further test. In Figure 3, a high-altitude balloon appears over a forested region. A lidar system with a full-waveform digitizer is carried by the gondola. The balloon slowly drifts over the test region, allowing ground personnel to carefully characterize the test area independently for intercomparison with the lidar data. This permits:

– The collection of large volume, full lidar waveform vegetation canopy data sets
– The comparison of lidar vegetative data with ground-based vegetative sensor and measurement data
– The collection of high density topographical data, which is of interest in watershed assessment and mineralogical exploitation

Lidar data collected from a flight altitude of 15 km would have a 1.5 m diameter footprint, with vertical resolution of 10 cm. With a slow drift speed, the measurements could be made nearly contiguous. This type of data density would be difficult to obtain with heavier-than-air aircraft.

Summary

High-altitude balloons offer a number of benefits to lidar system development and applications:

– Space-like conditions, very similar to extra-terrestrial planetary conditions, are available permitting characterization of lidar performance
– Long residence periods within these conditions are possible
– High-altitude balloons are easily capable of carrying aloft lidar systems, with attendant power supplies
– High-altitude balloons with their linger time offer the possibility of collecting high-density vegetation canopy data, with accompanying high-density topographical data

* Mankins, John C. *Technology Readiness Levels: A White Paper*, Advanced Concepts Office, Office of Space Access and Technology, NASA, April 6, 1995 <http://www.hq.nasa.gov/office/codeq/trl/index.htm>

** *Multi-angle Imaging Spectro-Radiometer (MISR) In-Flight Radiometric Calibration and Characterization Plan*, Jet Propulsion Document No. JPL D-1331, April 29, 1996 <http://eospso.gsfc.nasa.gov/ftp_ATBD/REVIEW/MISR/RADCAL-MISR.pdf>

*** Calibration, Characterization, Cataloging Definitions for Phoenix Draft 3 Contributions from: J. Marshall, R. Romero, M. Gross, L. Tamppari, Jan. 16, 2004

PROSPECTS OF DEVELOPING BALLOON-BORNE GAS SENSORS BASED ON LONG-WAVELENGTH VCSELS FOR IN SITU CHEMICAL ANALYSIS OF THE ATMOSPHERE

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Abstract:

Long-wavelength vertical-cavity surface-emitting lasers (VCSELs) with a buried tunnel junction which are currently commercially available from VERTILAS (Germany) possess a unique combination of properties valuable for the development of novel instrumentation for in situ chemical analysis of the atmosphere using unmanned vehicles. Some of these properties are: 1) almost continuous coverage of the spectral range between 1.3 and 2.0 um with a narrow-linewidth laser emission; 2) continuous tuning of individual VCSELs over intervals up to 20 nm; 3) the capability of producing single-mode emission with predictable parameters (such as frequency, linewidth, power) in a wide range of operation parameters; 4) circular output beam facilitating a compact fiber-optical architecture of gas sensors; 5) capability of being modulated by injection current at frequencies up to few GHz allowing for the application of ultra-sensitive gas detection techniques; 6) ultra-low power consumption. We will present the results of our studies of the VCSELs operating near 1512 nm, 1577 nm, and 1564 nm and suitable for ultra-sensitive detection of NH3, CO2, CO, CH4, H2S, and H2O. To simulate a wide range of measurement conditions we have developed an absorption cell allowing to control gas temperature and pressure in the ranges of 100 - 300 K and 10-3 - 1 bar, respectively. The design of the cryogenic absorption cell and the results of preliminary experiments on gas sensing with long-wavelength VCSELs at low temperatures and low pressures will be presented. Measurement strategies and a concept design of compact VCSEL-based balloon-borne gas sensors for in situ chemical analysis of the atmosphere will be discussed.

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Presentation Method:	Poster
Presenting Author Title:	Research Associate

Prospects of developing balloon-borne gas sensors based on long-wavelength VCSELs for *in situ* chemical analysis of the atmosphere

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ABSTRACT

Long-wavelength vertical-cavity surface-emitting lasers (VCSELs) with a buried tunnel junction (BTJ) [1] which are currently commercially available from VERTILAS (Germany) possess a unique combination of properties valuable for the development of novel instrumentation for *in situ* chemical analysis of the atmosphere using unmanned vehicles. Some of these properties are: 1) almost continuous coverage of the spectral range between 1.3 and 2.0 µm with a narrow-linewidth laser emission; 2) continuous tuning of individual VCSELs over intervals up to 20 nm; 3) the capability of producing single-mode emission with predictable parameters (such as frequency, linewidth, power) in a wide range of operation parameters; 4) circular output beam facilitating a compact fiber-optical architecture of gas sensors; 5) capability of being modulated by injection current at frequencies up to a few GHz allowing for the application of ultra-sensitive gas detection techniques; 6) ultra-low power consumption. These properties can be employed for the development of compact and robust VCSEL-based gas sensors for *in situ* chemical analysis of the atmosphere from balloon platforms.

1. Structure and packaging of BTJ-VCSELs

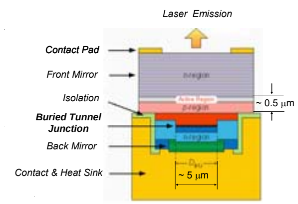

Fig. 1. The structure of BTJ-VCSELs (VERTILAS, Germany) [1]

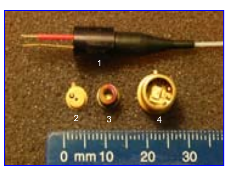

Fig. 2. Packaging VCSELs (VERTILAS, Germany):
1) laser is coupled with an optical fiber;
2) laser chip is mounted on a heat sink;
3) TO-46 package with AR coated optical window;
4) laser chip is mounted on a Peltier cooler.

2.BTJ-VCSELs at low temperatures

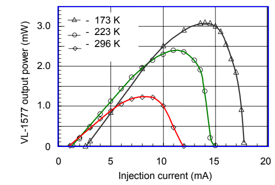

Fig. 3. Output power of laser VL-1577 versus injection current with substrate temperature as a parameter [2].

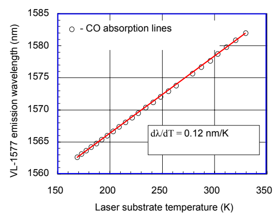

Fig. 4. Tuning laser VL-1577 by substrate temperature with injection current is set to 4.5 mA [2].

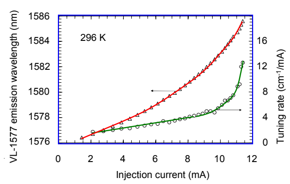

Fig. 5. Tuning laser VL-1577 by injection current at substrate temperature set to 296 K [3].

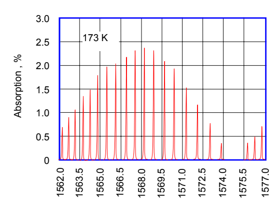

Fig. 6. The CO spectrum of 3ν absorption band acquired by tuning laser VL-1577 with injection current at the substrate temperature set to 173 K. Absorption path is 1.8 m

3. Low gas pressures and temperatures

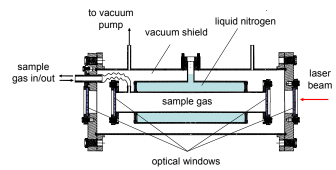

Fig. 6. Cryogenic gas cell with a 50-cm absorption path.

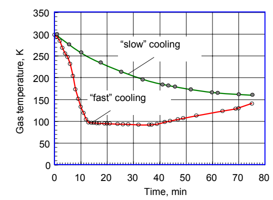

Fig. 7. "Fast" and "slow" cooling regimes of the cryogenic gas cell.

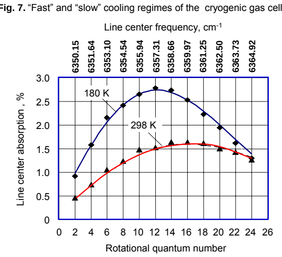

Fig. 8. Measured with a VCSEL (symbols) and calculated (solid lines) thermal distribution of rotational levels of the $2\nu_1+2\nu_2^0+\nu_3$ CO_2 R branch at 298 and 180 K. Absorption path is 50 cm. CO_2 concentration is $3.18\cdot10^{17}$ cm^{-3} (6 Torr at 180 K).

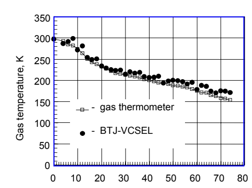

Fig. 9. Comparison of the gas temperature measured by a gas thermometer (blank symbols and solid line) and with a VCSEL (filled symbols) using CO_2 absorption lines R10 and R22 of the $2\nu_1+2\nu_2^0+\nu_3$ branch. The gas cell filled with CO_2 at a pressure of 10 Torr at 298 K was cooled to 150 K in a "slow" regime.

4. Balloon-borne gas analyzer

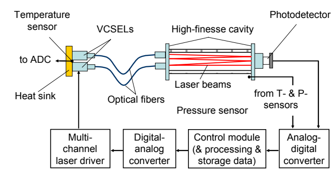

Fig. 10. Block-diagram of a scanning VCSEL-based gas analyzer.

VCSELs are mounted on a heat sink which can be kept at an ambient temperature. Both the output power and frequency of the VCSELs increase with decreasing ambient temperature (Fig. 3, Fig. 4). A control module provides a modulation current superimposed on a variable DC bias to acquire absorption spectra (Fig. 5, Fig. 6). The spectra averaged over ~ 1-s time intervals are stored as binary files along with the VCSEL substrate temperature and injection current needed to calibrate laser scans [4]. A high-finesse cavity increases an absorption path up to several km. A real-time gas analysis is possible with a remote access to the control module during the measurements.

Table. Summary of the VCSEL-based gas analyzer characteristics.

Parameter	Value
VCSELs	
Emission wavelength:	*1.3 µm - 2.0 µm*
Tuning range:	*9 nm at 300 K; 15 nm at 170 K*
Output power:	*~ 1 mW at 300 K; ~ 3 mW at 170 K*
High-finesse cavity	
Length:	*from 0.3 m to 1 m*
Mirror reflectivity:	*from 99.0 % to 99.97 %*
Effective absorption path:	*from 30 m to 3.3 km*
Detection limit:	*sub-ppm; a few ppb for some gases*
Number of VCSELs coupled:	*from 1 to 10 with one cavity*
Rate of spectrum acquisition:	*~ $3\cdot10^3$ spectra per hour*
Data storage requirements:	*5 Gb (for a 3-day campaign)*
Compounds to be analyzed:	*H_2O, CO_2, CO, CH_4, NH_3, H_2S …*
Maximum volume requirements:	*10^3 cm^3 (cavity); 500 cm^3 (electron.)*
Weight & power requirements:	*< 1 kg; 1 -10 W (depending on task)*

5. CONCLUSIONS

VCSELization of tunable diode laser spectroscopy (TDLS) promises a good perspective especially for the development of portable gas sensors for many applications including chemical analysis of the atmosphere from unmanned vehicles. Scanning VCSEL-based instruments can combine a panoramic view of FTIR spectroscopes with the resolution, sensitivity and robustness of TDLS sensors.

ACKNOWLEDGEMENTS

The work has been supported by the Canada Foundation for Innovation (CFI) and by the Natural Sciences and Engineering Research Council of Canada (NSERC).

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5. ALLSAS web-site: http://www.ualberta.ca/~alytkine/ALLSAS/.

BrO and NO2 measurements during the MANTRA 2004 campaign: comparisons with co-located ACE and ENVISAT satellite measurement

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Abstract:

Validation of satellite measurements is an important and challenging exercise. In the case of NO2 and BrO, this activity is particularly difficult given that both species have a significant diurnal variability and that the independent measurements to be used for the validation activity are often not co-located in time with the satellite measurements. Models can be used to reconcile the timing of the measurements, but the small number of available measurements remains a major problem for many validation activities. Most frequently, information about the vertical distribution of the species in question is required and although this information can be obtained from balloon measurements, balloon flights are rather rare and normally do not span all the desired seasons and locations. Ground-based measurements are more regular but although they may contain information about the vertical distribution of the species in question, this is usually at low vertical resolution. Therefore, opportunities when co-located ground-based and balloon measurements are available become particularly useful for validation activities: the balloon-based profile can be used to assess the ground-based retrieval at the same time as the satellite profiles. In addition, the ground-based measurements may span many days, thereby enhancing the likelihood of co-locations with the satellite observations. In this paper we present comparisons of NO2 and BrO vertical distributions measured from a balloon-borne SAOZ instrument, from ground-based zenith-sky spectrometers, and from two satellites: ACE and ENVISAT. The balloon and ground-based measurements were taken from mid-latitude during summer as part of the MANTRA 2004 campaign.

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Presentation Method:	Poster
Presenting Author Title:	Government

BrO and NO_2 measurements during the MANTRA 2004 campaign: comparisons with co-located ACE and ENVISAT satellite measurement

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** Currently at the Canadian Space Agency, St-Hubert, PC, Canada*

Community Suborbital Workshop – February 1-2, 2007, Canada

Abstract

- **Validation of satellite measurements is an as important as challenging activity**.
  - NO_2 and BrO have significant diurnal variability and correlative measurements are often not co-located in time with the satellite measurements.
  - Models can be used to reconcile the timing of the measurements: have restrictions,
  - The small number of available measurements remains as a major problem.
- **Information about the vertical distribution may be required**
  - balloon flights are rare and do not span all the desired seasons and locations.
  - Ground-based measurements: more regular in time, low vertical resolution (after retrievals).

•Opportunities when co-located ground-based and balloon measurements are available are particularly useful for validation activities: the balloon-based profile can be used to assess the ground-based retrieval at the same time as the satellite profiles.

•In this paper we present comparisons of NO_2 and BrO vertical distributions measured from a balloon-borne SAOZ instrument, from ground-based zenith-sky spectrometers, and from two satellites: ACE and ENVISAT. The balloon and ground-based measurements were taken from mid-latitude during summer as part of the MANTRA 2004 campaign.

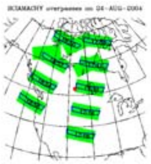
MANTRA Measurements

- MANTRA (Middle Atmospheric Nitrogen Trend Assessment): set of balloon campaigns to investigate the chemical balance of the northern hemispheric mid-latitude stratosphere. Particular focus on the budget of mid-latitude ozone. A detail description of the MANTRA campaign is given in [*Strong, et al.*, 2005]).
- 2004 Campaign conducted in Vanscoy, Saskatoon (52N, 107W).

http://www.atmosp.physics.utoronto.ca/MANTRA/index.html

SCIAMACHY Measurements:

The SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY (SCIAMACHY) - instrument on board the European Space Agency Envisat satellite launched on 1 March 2002. The SCIAMACHY primary mission objective: global measurements of trace gases in the troposphere and in the stratosphere.



ACE Measurements:

- SCISAT is a Canadian satellite mission composed of two instruments: ACE-FTS and MAESTRO. It was launched on 12 August 2003 into a low-Earth circular orbit (altitude 650 km, inclination 74º). The SCISAT mission, as well as the ACE-FTS instrument, are described in detail in [*Bernath, et al.*, 2005]. The ACE-FTS field of view is 1.25 mrad, about 4 km, and a vertical sampling is also about 4 km.
- Atmospheric T, P, and altitude profiles of chemical constituents are retrieved using a global fit approach. ACE-FTS measurements are made with a vertical resolution of about 4 km but the Level 2 data are interpolated on to a 1 km vertical.

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9 - Rodgers, C. D. (2000), Inverse methods for atmospheric sounding: Theory and practice, World Sci., River Edge, N.J.
10 - Strong, K., et al. (2005), Atmos Ocean, 43, 283-29 9.

Objectives:

To use measurements MANTRA 2004) for:

1) To **assess the performance of two independently developed retrieval codes** for determination of the vertical distribution of NO_2 from ground-based measurements by comparing the results with the balloon measurements,

2) **To use the MANTRA measurements to evaluate the capabilities of a box model** to describe the NO_2 diurnal variation, and

3) **To compare the MANTRA** campaign measurements complemented by the box model with **SCISAT (ACE-FTS instrument) and ENVISAT (SCIAMACHY instrument)** BrO and NO_2 measurements.

MANTRA - an ideal scenario for those studies since the campaign was conducted in late summer mid-latitudes when the stratospheric zonal wind changes from easterly to westerly leaving the stratosphere close to photochemical control.

Ground-based instruments:

•MANTRA 2004 involved a set of ground-based instruments among then:

- The Système d'analyse par observations zénithales ground-based instrument (hereafter referred as SAOZ-GB)
- A spectrometer, designed and built at the University of Toronto (hereafter referred as UT-GB).
- The ground-based measurements spanned from August 15 to September 12, 2004 and included measurements of ozone and NO_2 slant column densities (SCD) as a function of solar zenith angle (SZA).

•NO_2 slant column densities (SCD) measured as a function of the solar zenith angle (SZA) are extracted from the solar spectra measurements by the two instruments (SAOZ-GB and UT-GB) using the DOAS technique ([*Platt*, 1994]). Although there are some differences between the analysis done by the SAOZ team and by the UT-GB team, inter-comparisons involving exchange of codes show a generally good agreement between the results (described by Fraser et al., *in preparation*).

•More details on UT-GB in [*Bassford, et al.*, 2005] and for the SAOZ-GB in [*Pommereau and Goutail*, 1988].

Balloon Measurements:

•MANTRA 2004: a balloon flight carrying the Système d'analyse par observations zénithales balloon instrument (hereafter referred as SAOZ-BrO) was conducted on August 24 during sunset.

•This flight provided vertical profiles of BrO and NO_2 during the ascent of the balloon and during sunset (here defined as solar zenith angle=90°).

Box Model

We use here a photochemical box model to simulate the NO_2 diurnal variation. Details of the model can be found at McLinden et al, 2000.

The box model is run in three configurations:

-All the fields imputed from a CTM model;

-Constrained by Temperature and ozone measurements (ACE);

-Constrained by Temperature, Ozone, and NOy measurements (ACE);

-Constrained by Temperature, Ozone, NOy, and Cly measurements (ACE).

Model capability in reproduce the NO_2 measurements during MANTRA is significantly improved with the model is constrained by ACE measurements.

The model is used then to reconcile MANTRA and SCIAMACHY measurements (time).

Results:

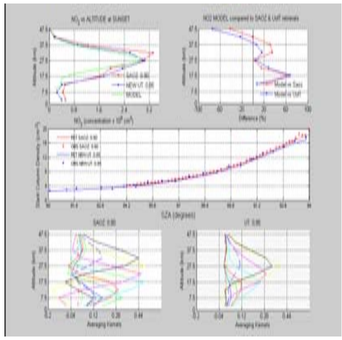
Retrieval of Vertical Distribution of NO_2 from Ground-based Measurements:

•Since the scattering geometry changes with SZA, **a time series of slant column measurements contains information on the vertical distribution of NO_2** throughout the atmosphere.

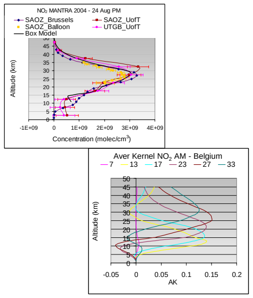
•The NO_2 vertical distribution is retrieved using the optimal estimation method based on the algorithms for solving atmospheric inversion problems developed by Rodgers (1976, 1990, 2000).

•Details of the retrieval method used at UofT can be found in [*Melo et al*. 2005].

•Details of the retrieval algorithm developed at Brussels (IASB-BIRA) can be found at [*Hendrick et al.* 2004].

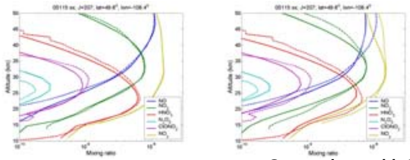


Results using the retrieval algorithm from UofT and the UT-GB and SAOZ-GB instruments data:
-Upper panel: NO_2 vertical distribution (right) and difference between retrieval and box model.
-Mid panel: comparison of the SCDs
-Lower panel: averaging kernels of the retrievals using the two different datasets.

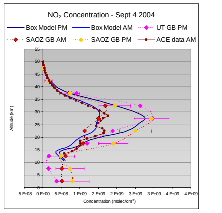


Results using independent retrieval algorithms:
-Upper panel: retrieved NO_2 vertical profile using SAOZ-GB measurements and the two independently developed retrieval algorithms. Also shown is the vertical profile using the co-located UT-GB measurement and the UofT algorithm and the results of the box model.
- Lower panel: averaging kernels from the Brussels retrieval algorithm.

Box Model – ACE Measurements:

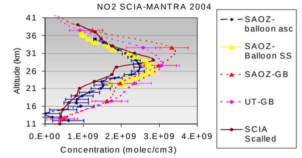


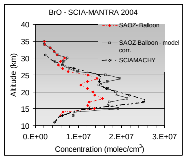
Results using the box model:
Right panel: only model
Left panel: constraining the model with T, O_3, NO_y and Cl_y from ACE.



NO_2 diurnal variation as in the box model. Comparison with ground-based retrievals and ACE

Comparison with SCIAMACHY





Science using balloons

Dale Sommerfeldt*
Werner Ostwald
Scientific Instrumentation Ltd

Abstract:

Science studies using balloons have many advantages over other types of vehicles. This poster will highlight these advantages including cost, scheduling and measurement time. It will also provide the launch experience Scientific Instrumentation Ltd has had over the past 25 years. These will include successes, failures, weather delays, launch locations and brief information on each project.

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Preferred Session:	Industrial capabilities and interests
Presentation Method:	Poster
Presenting Author Title:	Industry

Space Science Engineering

Dale Sommerfeldt*
Jeremy Gates
Kevin Nordstom
Werner Ostwald
Chinqiao Tong
Yan Feng
Scientific Instrumentation Ltd

Abstract:

Scientific Instrumentation Ltd (SIL) has provided engineering design, manufacture and flight support of many space science projects over the past 26 years. These include space, near space and ground based instrumentation. The poster will display some of the projects and outline SIL's support expertise and products available to the science community.

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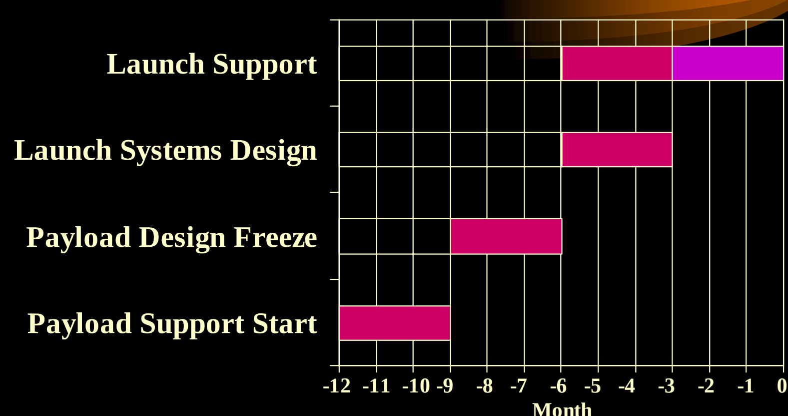
Presentation Method: Poster
Presenting Author Title: Industry

Science using Balloons

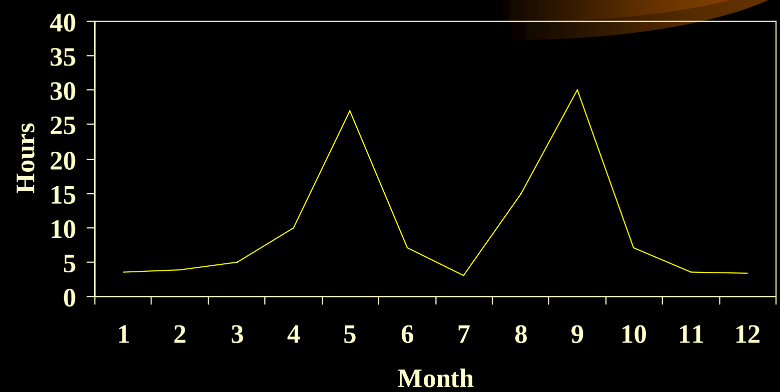
- *Atmospheric <40Km*
- *Low cost*
- *Long measurement time*
- *Instrument quality requirements minimal*
- *Reflight short turnaround*
- *Training base for science students*

Balloon Payload Launch Schedule



Float Time

ALT: 35-37Km   LAT: 53N   Range: 300Km



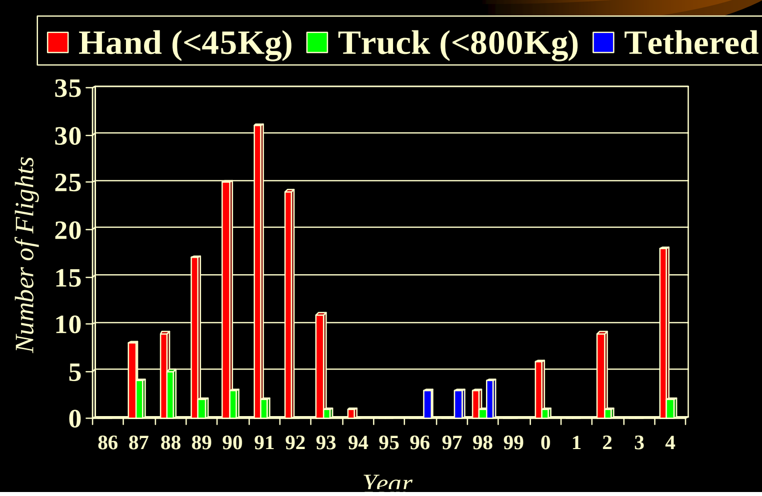
Launch Cost Comparisons

	SMALL		MEDIUM	
	1	2	3	4
Altitude (Km)	37	37	37	38
Balloon (tcm)	8.5	20	120	335
Science (Kg)	10	35	200	400
COST ($1000's)				
Balloon and Gas	4	6	60	115
Launch and Recovery	18	36	67	67
Insurance	?	?	?	?
Total Cost	22	42	127	182
2nd Flight	13	17	88	143

Scientific Instrumentation Ltd

- Incorporated 1980
- Payload engineering
- Payload flight support
- Instrument design and manufacture
- Space, Near Space, Terrestrial applications
- Balloon launch capability since 1987
- ISO 9001-2000 Registered

SIL Balloon Launch Activity



Vanscoy, Sk. Launch Site

Remote launches

- Alert, NWT- 76
- Churchill, Mb- 2
- North Bay,On-1
- Eureka, NWT- 1
- Roleau, SK- 4

Tethered balloons

MANTRA payload

- 12 scientific instruments
- Weight: 650Kg
- Flown four times
- 14Kw power system
- 16ch - 90Kb data down link
- Video link
- 300Kb downlink
- 1 uplink(300 baud)

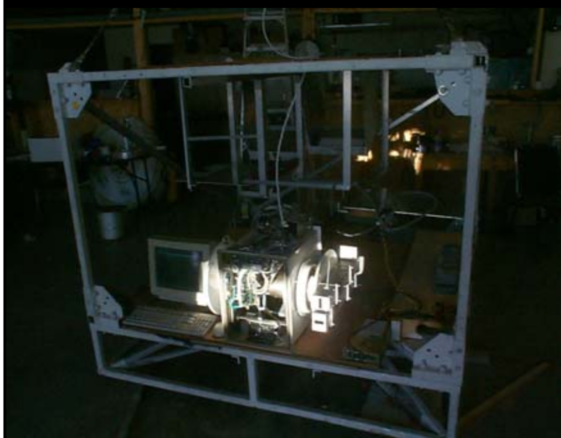
WMO payload

- Ozonesonde intercomparison
- 6 country participation
- 8-10 sondes/flight
- 10 flights-8 days

Mini-Radiometer

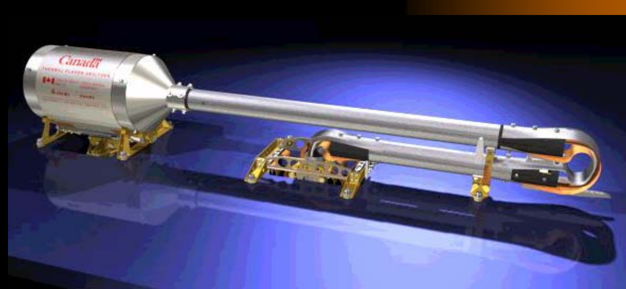
- Developed by MSC
- Scans 4-14 microns
- Measures Nitric Acid
- Manufactured 30+
- Flown in the Arctic
- 2 instruments have been flown several times

Pointing System



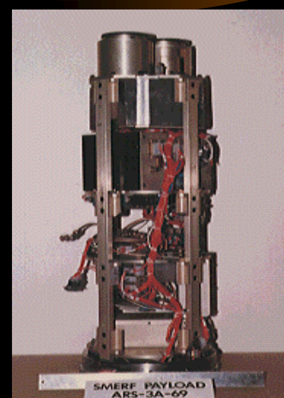
- Solar- Balloon borne
- 2 axis-accuracy 0.1deg
- Azimuth cap. 1300Kg
- Elevation cap. 50Kg
- Under development for limb scanning

Thermal Plasma Analyzer



- Japanese Planet-B Mars probe boom assembly
- Mechanical and Electrical Design and Fabrication

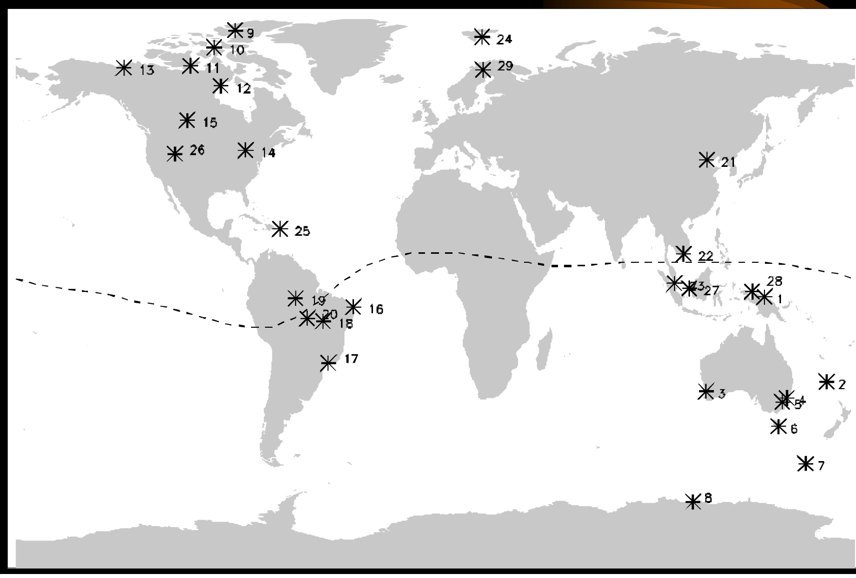
SMERF- BBIII payload



CADI- Digital Ionosonde

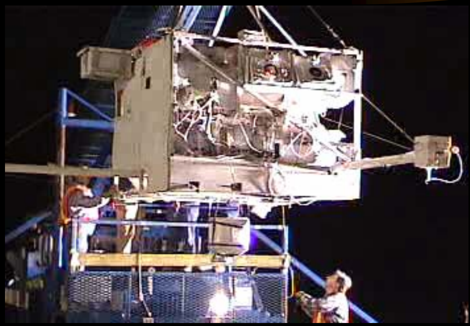
- Type of RADAR
- Operates 1-20MHz
- Height to 1000Km
- Ionization density
- Gravity waves

CADI -sites



Super Dual Auroral Radar Network
SuperDARN

MANTRA Launch



India

Remote launches

Churchill

Alert

Payload design and build

Sounding Rocket payloads

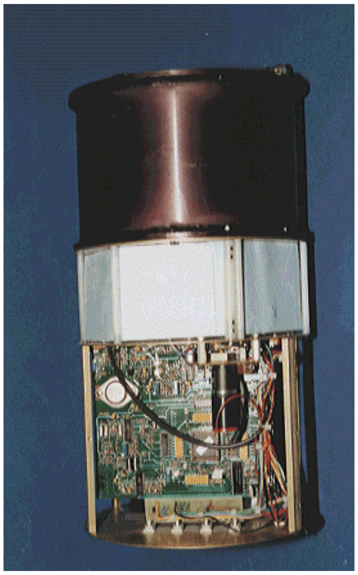
Science using balloons

Indonesia

SuperDARN

CADI-Digital Ionosonde

Mini Radiometer



Observing nitrogen in the stratosphere: connecting present and past

M.Toohey* (1), B. M. Quine (2), K. Strong (1), D. Wunch (1), James R. Drummond (1), C. Midwinter (3), C. T. McElroy (1), and the MANTRA Science Team

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(3) Meteorological Service of Canada, Downsview, ON, Canada

Abstract:

MANTRA was directly linked to the storied history of Canadian balloon-based stratospheric observation through the participation of two emission radiometer instruments. These specific instruments were fabricated as part of a set of virtually identical models in the 1970's, and were designed to measure atmospheric thermal emission in the 715-1250 cm-1 range, from which the vertical mixing ratio profile of HNO3 could be retrieved. The emission radiometer was an integral component of the Stratoprobe missions of the 1970's and 1980's, and a number of independent Arctic and midlatitude missions. The instruments were resurrected with the idea that data collected during MANTRA campaigns, as well as available data collected during flights of the 1980's and early 1990's could be analyzed consistently with an improved profile retrieval technique. Successful completion of this goal should result in a long-term data set of trace gas profiles, spanning a time period of significant changes to the chemistry of the stratosphere. Such a data set could prove valuable in testing current understanding of the chemical balances involving ozone and nitrogen species, and how the relationships have changed with time. We present a description of the improved retrieval technique developed and some retrieved profile results. We also include discussion of the strengths and weaknesses of the emission radiometer technique, and a discussion of issues related to the detection of long term trends with balloon-based observations.

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Preferred Session:	Past projects and case studies
Presentation Method:	Poster
Presenting Author Title:	Grad Student

Observing nitrogen in the stratosphere: connecting present and past

M. Toohey* (1), B. M. Quine (2), K. Strong (1), D. Wunch (1), James R. Drummond (1), C. Midwinter (3), C. T. McElroy (1), and the MANTRA Science Team

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1. MANTRA – Science goals

MANTRA was a stratospheric balloon mission with campaigns in 1998, 2000, 2002, 2004 launched from Vanscoy SK, (52°N, 107°W) in late summer.

MANTRA Science Goals

- To fly a comprehensive suite of instruments in order to measure the vertical profiles of the key stratospheric species that control the mid-latitude ozone budget.
- To combine these measurements with those obtained from similar northern mid-latitude campaigns of the past 20 years, in order to quantify changes in the chemical balance of the stratosphere.
- To compare multiple measurements of the same trace species made by different instruments, in order to resolve previously observed discrepancies and to assess the instruments' performance.
- To use the balloon-borne measurements for validation and ground-truthing of satellite missions.

Emission radiometers play a significant role in MANTRA science goals, since they have a substantial flight heritage, and have been used to compile a temporal nitric acid (HNO_3) dataset spanning almost 30 years.

2. Nitric acid chemistry

As a relatively long lived reservoir species of reactive nitrogen (NO_y), HNO_3 plays an important role in the chemistry of the atmosphere. In the stratosphere, ozone is destroyed through reactions catalyzed by NO_x (NO_x = NO + NO_2). Such catalytic cycles are interrupted by the conversion of NO_x into the relatively stable reservoir species HNO_3

$$NO_2 + OH + M \rightarrow HNO_3 + M.$$

NO_x can be released from HNO_3 through photolysis and oxidation:

$$HNO_3 + h\nu \rightarrow NO_2 + OH$$

$$HNO_3 + OH \rightarrow NO_3 + H_2O.$$

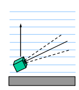
While polar winter ozone loss is due largely to chlorine catalytic cycles, HNO_3 plays a key role in the extent and degree of ozone loss. HNO_3 is a key component of Polar Stratospheric Clouds (PSCs), that act as surfaces for the heterogeneous reactions that release active chlorine radicals from reservoir species. Furthermore, as PSC particles grow sufficiently large, sedimentation can occur, leading to stratospheric denitrification. PSC induced denitrification leads to a reduction in active nitrogen available to tie up chlorine radicals into reservoirs and acts to prolong the period of catalytic ozone loss in the polar spring.

The source of all stratospheric NO_y is the transport of N_2O from the troposphere. Since N_2O is increasing at 3% per decade due to anthropogenic activity, the NOy burden is likely increasing also. Whether or not this potential trend is present in HNO_3 timeseries is complicated by the competing effect of increased chlorine loading, which increases the importance of $ClONO_2$ as a lower stratospheric NO_y reservoir. Rinsland et al. [1991] report an observed trend of $-(0.16 \pm 0.50)\%\ yr^{-1}$ in HNO_3 total columns between 1951 and 1990. The large uncertainty of this estimate is due to the uncertainty in historical measurements.

3. The emission radiometer instrument

Key facts:

- Developed in early 1970's. Made observations of HNO_3 critical to early understanding of nitrogen budget of stratosphere (e.g. Evans et al., 1982).
- Measures atmospheric thermal infrared emission during balloon ascent until liquid nitrogen cryogen is exhausted.
- Continuously variable filter wheel allows scanning from 8-14mm (715-1250cm^{-1}) at low spectral resolution (20cm^{-1}).
- In-flight radiance calibrations performed using blackbody calibration flap, with embedded platinum resistance thermometer.
- Primary measurement goal: HNO_3, also measures emission from O_3, CFC-12, CFC-11, N_2O, CH_4, CO_2, H_2O.

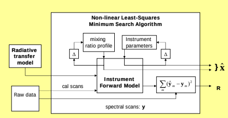


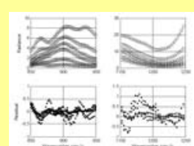
4. Data analysis

Data is collected during the ascent of the balloon, from the ground to float altitude. An "onion-peeling" method of analysis used in the past has been replaced with a forward estimation technique using detailed atmosphere and instrument models and a least-mean-squares simplex estimator to find the best-fit state vector ($\hat{\mathbf{x}}$), comprised of volume mixing ratios for several gas species and instrument parameters. Key components of the analysis include (see flow chart to right):

- HITRAN line data used to create absorption coefficient spectrum for region of interest, using pressure and temperature data from a radiosonde onboard the balloon gondola. A model atmosphere is composed of thirteen layers between 5 and 40 km altitude.
- In-flight black-body calibration used to measure instrument response function under varying pressure and temperature regime of measurements.
- Non-linear simplex estimator used to solve for best fit mixing ratios of six trace species: HNO_3, O_3, N_2O, CFC-11, CFC-12, and CH_4. VMR profiles of CO_2 and H_2O are used to calculate emission radiance, but are held to climatological standards. Estimation algorithm iterates all atmospheric levels simultaneously to find a global solution.
- Measurement residuals calculated to indicate how well the mixing ratio matches the instrument measurements.

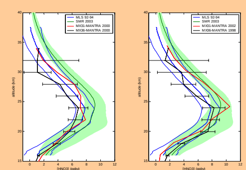
Sample fit spectra and fit residuals are shown in figure to right. HNO_3, CFC-11 and CFC-12 are retrieved in the 850-950cm^{-1} region. O_3 is retrieved from the 1150-1250 cm^{-1} region.





5. Results

- Retrieved HNO_3 profiles from two emission radiometer instruments from MANTRA campaigns in 1998, 2000 and 2002 are shown in figure below.
- Results are generally consistent between the two instruments and between the different years, except for 2002, in which the peak HNO_3 mixing ratio measured is significantly larger than previous years.
- The figure also contains July-August-September mean HNO_3 profiles as measured by the Microwave Limb Sounder (MLS) onboard UARS (calculated over the years 1992-1994, see Santee et al. for description of MLS HNO_3 measurements) and by the Sub-Millimeter Radiometer (SMR) onboard Odin (for 2003). Unfortunately, MANTRA campaigns didn't coincide with observations made by either of these satellite based instruments. Nevertheless, the mean satellite observations can be compared to the MANTRA measurements as a rough check.
- MANTRA HNO_3 measurements generally fall within the 1-sigma variability of MLS measurements. Only the MANTRA 2002 measurement falls outside of this range, showing closer agreement with the SMR measured mean from 2003.



- The difference between the two instruments may be due to systematic bias between the two retrieval systems, or due to a trend on HNO_3 over the time span between the measurements. The MANTRA measurements can not rule out the possibility of a trend in HNO_3.

6. Ongoing work: Trend analysis

- Raw data collected during emission radiometer flights of the 1980's and early 1990's is being reprocessed using the retrieval technique developed for the MANTRA results. This work should result in a long-term data set of HNO_3 profiles, which will be used to test the hypothesis that HNO_3 profiles are changing with time in response to changing source and sink strengths.
- Related work with the Canadian Middle Atmosphere Model and satellite observations such as those from the Atmospheric Chemistry Experiment (ACE) and the Microwave Limb Sounder (MLS) (e.g. Toohey and Strong, submitted) is leading to an understanding of the level of natural variability of HNO_3 in the summer season when MANTRA measurements are taken. This is important in order to estimate the noise in the measured timeseries. This natural variability, along with the measurement uncertainty, will lead to uncertainties in the calculated trend.

Acknowledgements

The authors would like to acknowledge the Canadian Space Agency, the Meteorological Service of Canada, the National Science and Engineering Research Council of Canada, and CRESTech for their support of MANTRA.

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MANTRA, Turnaround, and the University of Toronto's Balloon-Borne Fourier Transform Spectrometer

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(5) Environment Canada

Abstract:

The Middle Atmosphere Nitrogen TRend Assessment (MANTRA) high-altitude balloon campaigns have provided a forum for dynamical research and instrument development. Campaigns were held in Vanscoy, SK, at a scientifically and practically advantageous time of year called turnaround, when stratospheric zonal winds change from easterly to westerly. A climatology of zonal winds provided us with a launch window, containing August 26 through September 5, wherein stratospheric zonal wind speeds are low enough in Vanscoy to facilitate a launch. These campaigns also allowed for the development of the first Canadian balloon-borne Fourier transform spectrometer in 30 years, which we call the University of Toronto's Fourier transform spectrometer (U of T FTS). The electronics and software development of the U of T FTS will be described, and the first spectrum from the MANTRA 2004 balloon flight will be shown. The U of T FTS also participated in a ground-based intercomparison campaign in Toronto with the Toronto Atmospheric Observatory Fourier transform spectrometer (TAO-FTS) and the Portable Atmospheric Research Interferometric Spectrometer for the Infrared (PARIS-IR). The resolutions of these three instruments are significantly different, allowing us to investigate the effect of resolution on the retrieval of total columns of O3, HCl, N2O and CH4, and determine what parameters most affect the retrievals. The two lower-resolution instruments (PARIS-IR and the U of T FTS) were found to measure 4-day average total columns of O3, HCl, N2O and CH4 to within 3.5% of the TAO-FTS total columns. The largest errors were produced by the total column retrievals of the stratospheric species (O3 and HCl). In order to achieve this 3.5% agreement for the stratospheric species, the instrument line shape of the U of T FTS and PARIS-IR instruments had to be taken into account.

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Presentation Method:	Poster
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Environment Canada / Environnement Canada

MANTRA, Turnaround, and the University of Toronto's Balloon-Borne Fourier Transform Spectrometer

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The Middle Atmosphere Nitrogen TRend Assessment (MANTRA) high-altitude balloon campaigns have provided a forum for dynamical research and instrument development. Campaigns were held in Vanscoy, SK, at a scientifically and practically advantageous time of year called turnaround, when stratospheric zonal winds change from easterly to westerly. A climatology of zonal winds provided us with a launch window, containing August 26 through September 5, wherein stratospheric zonal wind speeds are low enough in Vanscoy to facilitate a launch. These campaigns also allowed for the development of the first Canadian balloon-borne Fourier transform spectrometer in 30 years, which we call the University of Toronto's Fourier transform spectrometer (U of T FTS). The electronics and software development of the U of T FTS will be described, and the first spectrum from the MANTRA 2004 balloon flight will be shown. The U of T FTS also participated in a ground-based intercomparison campaign in Toronto with the Toronto Atmospheric Observatory Fourier transform spectrometer (TAO-FTS) and the Portable Atmospheric Research Interferometric Spectrometer for the Infrared (PARIS-IR). The resolutions of these three instruments are significantly different, allowing us to investigate the effect of resolution on the retrieval of total columns of O_3, HCl, N_2O and CH_4, and determine what parameters most affect the retrievals. The two lower-resolution instruments (PARIS-IR and the U of T FTS) were found to measure 4-day average total columns of O_3, HCl, N_2O and CH_4 to within 3.5% of the TAO-FTS total columns. The largest errors were produced by the total column retrievals of the stratospheric species (O_3 and HCl). In order to achieve this 3.5% agreement for the stratospheric species, the instrument line shape of the U of T FTS and PARIS-IR instruments had to be taken into account.

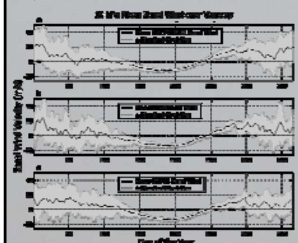

Figure 1. The 10-hPa mean zonal winds over Vanscoy, SK (52°N, 107°W). The solid black curve is the mean zonal wind speed and the grey shaded region is the standard deviation. Negative values are easterlies, positive values are westerlies.

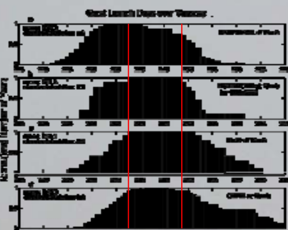

Figure 2. The normalized number of years for which good launch days are likely over Vanscoy, SK. The vertical red lines indicate the launch window: good launch days in every year between 1993-2002.

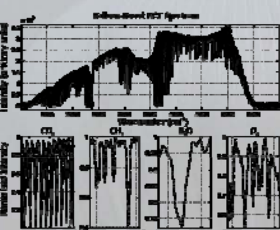

Figure 3. The first balloon-based spectrum recorded by the U of T FTS. Detail in the spectrum is shown in the lower panels.

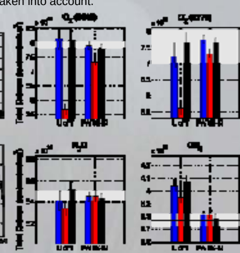

Figure 4. Mean column amounts with different methods of including ILS information. The black horizontal line is the TAO-FTS mean and the grey shading is the standard deviation. The error bars show the standard deviation of the retrieved values.

% difference	O_3 3040	O_3 2775	HCl	N_2O	CH_4
U of T: TAO	**3.3**	0.7	1.7	0.4	**2.3**
PARIS: TAO	0.8	**2.6**	**3.2**	0.4	0.5
U of T: PARIS	**2.5**	**3.2**	1.5	0.8	**1.7**

Table 1. Percent difference between the four-day total column averages for the three FTSs. Blue bold numbers are statistically significant to within 95%.

Turnaround

The MANTRA mission, as described in [1], aims to investigate the chemical interactions that affect ozone, focussing on the specific role of nitrogen compounds. These objectives are met by a launch during late summer, which is dynamically quiescent and closer to photochemical control. Practically, the balloons should be launched when the stratospheric wind speeds are at a minimum in order to ensure that the payload remains within the telemetry range (approximately 500 km) for the duration of mission science (typically 18 hours). Low stratospheric wind speeds occur in mid-latitudes in late summer, during a time of year called "turnaround."

Figure 1 shows the time series of zonal winds at 10 hPa over Vanscoy, SK (52°N, 107°W) from three different data sources: from NCEP/NCAR reanalysis for 1979-2003, the MetO analysis for 1993-2002 and a CMAM model run for 24 years at current conditions. The shaded regions about the solid black curves show the standard deviation of the winds. The late summer turnaround event occurs when the black curve crosses from negative (easterly) zonal wind velocities to positive (westerly) zonal wind velocities. Note the low variability of the zonal winds throughout the summer.

To develop a climatology of turnaround, we chose to limit our definition of turnaround to periods of time during which the stratospheric zonal wind speeds were in the process of changing from easterly to westerly, and fell between ±4m/s. These days represent appropriate launch days for the MANTRA balloon. Figure 2 shows the statistical distribution of these launch days–saturated days indicate that in every year, that day was an appropriate launch day. This defines a launch window (between the vertical red lines) that includes August 26 – September 5. The launch dates for the MANTRA balloons have all fallen within or very close to the window as well: in 1998, the balloon was launched on August 24; in 2000, August 29; in 2002, September 3; and in 2004, September 1.

Details of this study can be found in [2,5].

The University of Toronto's Balloon-Borne Fourier Transform Spectrometer

The U of T FTS was developed from a research-grade, ground-based ABB-Bomem DA5 Fourier transform spectrometer with a 50-cm maximum path difference and a spectral range covering 1200-5000 cm^{-1} across two detectors (InSb and MCT). The instrument measures many atmospheric trace-gas species of interest to the MANTRA science goals with high vertical and spectral resolution.

The original software, designed for ground-based measurements, was embedded in the control computer for the instrument, and in order to update the software, the control computer and nearly all of the original electronics had to be replaced. This was done using off-the-shelf components, which resulted in a significantly smaller instrument that was reduced in mass from around 90kg to 55kg, with reduced power consumption from around 140W to 65W.

The software was replaced by LabVIEW control software, creating a robust and easily-controlled instrument, adaptable to either balloon-based or lab-based work, containing accessible housekeeping information (voltages, temperatures and instrument status information), downlink capability and an embedded scheduler.

The MCT spectrum, seen in Figure 3, was recorded while looking through the atmosphere from a float altitude of approximately 35 km at a 89° solar zenith angle. A selection of microwindows are displayed in the lower panels, showing the absorption features used to retrieve atmospheric concentrations of the trace gases CO_2, CH_4, N_2O, and O_3.

Details of this work are described in [3,5].

Determining the Effect of Spectral Resolution on Total Column Trace Gas Retrievals

The U of T FTS recorded ground-based measurements for four days in late summer of 2005 alongside two other FTS instruments: the Toronto Atmospheric Observatory FTS (TAO-FTS) with a maximum path difference of 250 cm, and the Portable Atmospheric Research Interferometric Spectrometer for the Infrared (PARIS-IR) with a maximum path difference of 25 cm. The goals of the intercomparison were to determine what effect resolution has on retrieved total column amounts of O_3, HCl, N_2O, and CH_4, and what retrieval parameters allow for the best comparison results.

The observation strategy for the campaign was constructed to focus on the effects of the instrument resolution on the retrieved column amounts. This was achieved by measuring simultaneously from the same location, in the same spectral range and using similar retrieval methods with identical a priori information, line parameters and forward model. Retrievals for all three instruments were executed using SFIT2.

Figure 4 shows that including instrument line shape (ILS) information in SFIT2 retrievals, either by retrieving ILS parameters with SFIT2 (blue bars) or by inputting a priori information about the ILS from a gas cell measurement (black bars) is very important for the retrievals of stratospheric species, such as O_3 and HCl, and less so for tropospheric species like N_2O and CH_4. The red bars are total columns retrieved when the ILS for the instrument is assumed to be perfect. The horizontal bars with grey shading are the total column amounts and standard deviation retrieved by the TAO-FTS, which, for the purposes of this intercomparison, are considered to be closest to the "truth."

The results of this intercomparison are shown in Table 1. Mean total column amounts over the four days of measurements were compared, and the lower-resolution instruments can retrieve total column amounts to within 3.5%. The largest errors are seen for the stratospheric species. Values in blue bold are statistically significant differences.

Details of this work are described in [4-6].

References and further information:
1. K. Strong, et al. MANTRA — A balloon mission to study the odd-nitrogen budget of the stratosphere. Atmos. Ocean, 43(4):283–299, December 2005.
2. D. Wunch, M. P. Tingley, T. G. Shepherd, J. R. Drummond, G. W. K. Moore, and K. Strong. Climatology and Predictability of the Late Summer Stratospheric Zonal Wind Turnaround over Vanscoy, Saskatchewan. Atmos. Ocean, 43(4):301–313, December 2005.
3. D. Wunch, C. Midwinter, J. R. Drummond, C. T. McElroy, and A.-F. Bagès. The University of Toronto's Balloon-Borne Fourier Transform Spectrometer. Rev. Sci. Inst., 77(9):093104, September 2006.
4. D. Wunch, J. R. Taylor, D. Fu, P. Bernath, J. R. Drummond, C. Midwinter, K. Strong, and K. A. Walker. Simultaneous ground-based observations of O_3, HCl, N_2O and CH_4 over Toronto by three FTIRs with different resolutions. Atmospheric Chemistry and Physics Discussions, 6:10883–10928, October 2006.
5. D. Wunch. Measurements and Data Analysis from a Balloon-Borne Fourier Transform Spectrometer. PhD thesis, University of Toronto, 2007.
6. J. R. Taylor, D. Wunch, C. Midwinter, A. Wiacek, J. R. Drummond and K. Strong. An extended intercomparison of simultaneous ground-based Fourier Transform Spectrometer measurements at the Toronto Atmospheric Observatory. In preparation for JQSRT.

The background picture is of the partially-inflated MANTRA balloon just before launch on September 1, 2004.

This document presents a scientific and technical approach to using the Global Hawk UAV in a scientific demonstration project. The document is the original NASA proposal modified by the removal of cost and proprietary information and certain appendices. (D. Fahey and A. Tuck, January 2007)

A Revised Proposal to:

Office of Earth Science (OES)
National Aeronautics and Space Administration
Washington, DC 20024

In response to:

A Letter of Invitation
January 8, 2001

NRA-00-OES-02
UAV-Based Science Demonstration Program

TITLE:	The Global Hawk Tropical Tropopause Experiment (GHATTEX): Exploring the tropical tropopause region of the Pacific Ocean with the Global Hawk UAV platform
AWARDEE:	Aeronomy Laboratory National Oceanic and Atmospheric Administration 325 Broadway R/AL6 Boulder, CO 80305-3328
PRINCIPAL INVESTIGATOR:	Dr. Adrian F. Tuck 303/497-5485 303/497-5373 (fax) tuck@al.noaa.gov
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DATE OF REQUEST:	1 March 2001

The following is the original Table of Contents. An asterisk (*) following the page number indicates removed or modified content. (D. Fahey and A. Tuck, January 2007). Asterisks in the text indicate removed cost numbers.

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The Global Hawk Tropical Tropopause Experiment (GHATTEX)

National Oceanic and Atmospheric Administration Aeronomy Laboratory
Boulder, Colorado

Fact Sheet

Mission Purposes

- Demonstrate the utility of the large payload capacity, high cruise altitude, and long endurance of the Global Hawk for atmospheric research.
- Observe the distribution of radiatively and chemically important species on large spatial scales in the tropical Pacific region.
- Study radiative transfer, atmospheric chemistry, and dynamics in the tropical upper troposphere and lower stratosphere and their relation to global climate processes.

Instrument Payload

- Methane (CH_4), ozone (O_3), water vapor (H_2O), carbon dioxide (CO_2), aircraft-level temperature and pressure, temperature profiles, background particles (4 nm to 1 μm), Ice Particles (0.5 to 60 μm)

Global Hawk UAV

- Demonstrated capability to take a 680-kg (1500-lb) payload to 20 km (65000 ft) for 32 hours, cruising at 350 knots; to date (17 January 2001) the aircraft has flown 759 hours in 65 flights.

Project Team

- ***Management***

Dr. A. F. Tuck	Project PI	NOAA AL
Dr. D. W. Fahey	Project Co-PI	NOAA AL
Dr. G. Hübler	Project Coordinator	NOAA AL
lLt. A. Wehner	Global Hawk Programs	U.S. Air Force ASC/RAV
Mr. G. Loegering	Global Hawk Manufacturer	Northrop Grumman Ryan Aero. Ctr.
Dr. S. Buhr	Education/Public Outreach Coordinator	CIRES, U of Colorado

- ***Instrument Team***

Dr. B. W. Gandrud	PMI, Inc.	Ice particles (MASP)
Dr. R. S. Gao	NOAA AL	Carbon dioxide
Mr. K. K. Kelly	NOAA AL	Water vapor
Dr. M. J. Mahoney	NASA JPL	Temperature profiles (MTP)
Dr. E. C. Richard	NOAA AL	Ozone and methane
Mr. T. L. Thompson	NOAA AL	Temperature and pressure
Dr. J. C. Wilson	U of Denver	Small particles (FCAS III/NMASS)

- ***Theory Team***

Dr. M. J. Alexander	NWRA/CORA	gravity wave studies
Prof. R. A. Plumb	MIT	modeling studies of chemistry and transport
Dr. K. H. Rosenlof	NOAA AL	meteorological support
Prof. M. H. Hitchman	U of Wisconsin	atmospheric transport modeling
Prof. R. E. Newell	MIT	modeling of atmospheric processes
Prof. D. W. Waugh	Johns Hopkins U	modeling of atmospheric processes

- ***Technical Support***

Ms. S. J. Hovde	NOAA AL	data archive and Internet support
Mr. R. H. Winkler	NOAA AL	instrument control and data acquisition

Flight Plans

- Two types of flights in both a summer and winter deployment, with flight levels between 45,000 and 65,000 ft.:
  - *Meridional TransEquatorial flight* **25 hours, Edwards AFB (34ºN) to 35ºS and return.**
  - *Triangular TransPacific flight* **32 hours, Edwards AFB (34ºN) to (7ºN, 135ºW) to (7ºN, 155ºE) and return.**

Data Analysis Topics

- Radiative balance near the tropical tropopause.
- Mixing and recirculation between and within the upper troposphere and lower stratosphere.
- Particle production near the tropical tropopause.
- Tropical dynamics, i.e., gravity wave studies, large-scale stratospheric reverse Walker circulation.
- Scale invariance and its relation to mixing and transport processes.

GHATTEX Executive Summary

(Excerpted January 2007)

GHATTEX will make well-calibrated, high-accuracy observations of water vapor, ice particles, aerosols, ozone, methane, carbon dioxide, temperature profiles, and meteorological variables near the tropical tropopause on the scale of the Pacific Basin. The measurements will be made with long-heritage instruments onboard the proven, long-endurance high-altitude Global Hawk UAV. Global Hawk is provided by the U. S. Air Force and built and operated by Northrop Grumman Ryan Aeronautical Center. The aircraft has demonstrated capability to take a 680 kg (1500 lb) payload to 20 km (65000 ft) for 32 hours cruising at 350 knots; to date (17 January 2001) it has flown 759 hours in 65 flights.

GHATTEX mission flights in the upper troposphere and lower stratosphere will originate from California and will occur in pairs in winter and summer deployments. The Triangular TransPacific flight will reach the longitude of Australia with a large transect along the equator. The Meridional TransEquatorial flight will cross the equator deep into the Southern Hemisphere. The scientific return from the flight data interpretation will include (i) quantifying terms in the radiative balance of the upper troposphere and lower stratosphere to better define the response of the atmospheric circulation to climate change; (ii) examining particle production near the tropopause to quantify terms in the stratospheric aerosol budget; (iii) providing evidence on scales from those of local gravity waves to that of the Walker Cell to better define the role of gravity waves in climate, and (iv) examining the scale invariance of trace species and meteorological variables in the upper troposphere and lower stratosphere over an unprecedented wide range of horizontal scales, as a way of improving the numerical modeling of the atmosphere.

GHATTEX is made possible by the cooperation and support of the U. S. Air Force (USAF) Reconnaissance Systems Program Office (ASC/RAV) at Wright Patterson Air Force Base and Northrop Grumman Ryan Aeronautical Center (NG-RAC), the provider and the manufacturer of the Global Hawk UAV, respectively. The GHATTEX Project Team is led by Dr. A. F. Tuck, Principal Investigator, from the NOAA Aeronomy Laboratory. He is supported at NOAA by Dr. D. W. Fahey, Co-Principal Investigator. The Team includes highly experienced individuals from NOAA; Particle Metrics, Inc.; the Jet Propulsion Laboratory/Caltech; the University of Denver; the University of Colorado's Cooperative Institute for Research in Environmental Science; Colorado Research Associates Inc.; the Massachusetts Institute of Technology; the University of Wisconsin at Madison; and The Johns Hopkins University. The aeronautical engineering and flight operations will be managed cooperatively by ASC/RAV and NG-RAC. The total cost and financial risk to NASA in the GHATTEX project is lowered by the substantial *in-kind* contribution from the NOAA Aeronomy Laboratory totaling approximately 27% of that requested from NASA.

1.0 Introduction

The design and construction of uninhabited aerial vehicles (UAVs) has grown substantially in the last decade. The use of UAVs for environmental research and monitoring is often cited in describing the value of these new platforms. The performance goals of UAVs, as with all aircraft, include a varied combination of payload, range, and cruise altitudes. The upper troposphere and lower stratosphere (UT/LS) have long been considered central regions for the maintenance of the radiative balance and hence of climate, particularly in the Pacific [*Doherty and Newell,* 1984; *Holton et al.,* 1995]. This location is also believed to be the site where much of the air which enters the stratosphere crosses the tropopause, although this view has been questioned recently; the subject is controversial [*Jackson et al*., 1998; *Dessler*, 1998]. This near-tropopause region in the tropics between 150 hPa and 50 hPa is a central one for radiative transfer, for dynamics and for chemistry. Although data are limited in this region, notable data sets are available from profiles of the NASA ER-2 aircraft and about 15 flights of the NASA WB-57F aircraft into the Central American tropical area during the recent WAM (1998) and ACCENT (1999) projects. These flights have provided enough observations of water, cirrus, aerosol, ozone, methane and carbon dioxide content to hint at the variety and complexity of the processes likely to be involved, and to raise important questions. They do not however provide a clear picture of how the composition of the region is maintained.

GHATTEX will use the Global Hawk UAV to fly an established, proven payload of chemical, microphysical and meteorological instruments near the tropical tropopause on the scale of the Pacific Basin. The tropical Pacific is the “firebox of the circulation,” a key element of the world weather system. Our goal is to provide the atmospheric sciences community with new observations of gases and particles made over a wide range of longitudes and latitudes in the upper troposphere and lower stratosphere (UT/LS) and use these data to address key processes related to atmospheric circulation and climate. Using the proven capabilities of the Global Hawk and its chosen payload is the most economical way to acquire these data from a highly remote region.

GHATTEX observations include methane, ozone, water vapor, carbon dioxide, ice particles, small particles, and temperature profiles. The interpretation of the flight data will include (i) quantifying terms in the radiative balance of the UT/LS to better define the response of the atmospheric circulation to climate change; (ii) examining particle production near the tropical tropopause to quantify terms in the budget of stratospheric aerosols; (iii) providing evidence of gravity waves and large-scale circulation in the UT/LS to better define their role in climate; and (iv) examining the scale invariance of trace species and meteorological variables in the UT/LS as way of evaluating and improving the numerical modeling of the atmosphere.

The Global Hawk is the only UAV with performance specifications suitable to meet GHATTEX objectives. The Global Hawk is the recipient of the 2001 Collier Award from the National Aeronautics Association. It has demonstrated capability to take a 680-kg (1500-lb) payload to 20 km (65,000 ft) for 32 hours cruising at 350 knots and, as such, represents a major step forward in the platform resources available for atmospheric research. This new aircraft has been proven in 65 test and mission flights totaling over 759 airborne hours. The capacities of Global Hawk provide GHATTEX with substantial margins for the payload mass, volume, and power. Most of the proposed payload instruments have a long heritage, evident in the data acquired by them in NASA ER-2 and WB-57F high-altitude missions since 1987.

The use of the aircraft – payload combination of the Global Hawk UAV offers an exciting future for atmospheric science research. The highly experienced project managers, science team, and engineering and flight operations personnel assembled for GHATTEX are confidently poised to take the first steps into this future.

1.1 Revised Proposal Structure

This Revised Proposal follows NASA guidelines for describing Science and Technical Approach, Management and Cost, and Education and Outreach Plan. The GHATTEX Implementation Plan was submitted to NASA’s Office of Earth Science on January 31, 2001. This Proposal incorporates substantial material from the **Implementation Plan**, which is attached here as **Appendix I**. The Proposal references further material from the Plan throughout the text using the prefix ‘**IP-**’ for references to figures, tables, and sections.

The scientific aspects of GHATTEX are described in Sections II and III of the original proposal submitted to NASA's Office of Earth Science on 27 April and 8 May 2000. Subsections from the original proposal include Scientific Background (II.A), Science Objectives (II.B), Scientific Capability of the Payload (II.C), Relation to Office of Earth Science Themes (II.D), Scientific Flight Planning (III.F), and Data Analysis and Interpretation (III.H). These sections are reproduced here in their entirety in **Sections 2.0 - 2.4**. No changes have been made to the text except to modify figure numbers and section headings to be consistent with the format used here in the Revised Proposal.

2.0 Scientific Perspective

2.1 Scientific Background

A variety of science studies will be possible with data collected during GHATTEX. Here we give a sampling of the scientific issues of interest.

• **Radiative balance.** In the tropics, the troposphere above the Earth's surface becomes optically thin to infrared radiation above about 14 km. This means that the radiative behavior of the scale height above this altitude will be sensitive to those entities (trace gases, aerosols and temperature) which affect the absorption, emission and scattering of radiation in the layer. The system is highly interactive, particularly through the coupling of water abundance and its phase changes with the vertical temperature structure and deep convection. The quantities needed for an accurate simulation of the system will be measured with high accuracy over long spatial scales for the first time during GHATTEX.

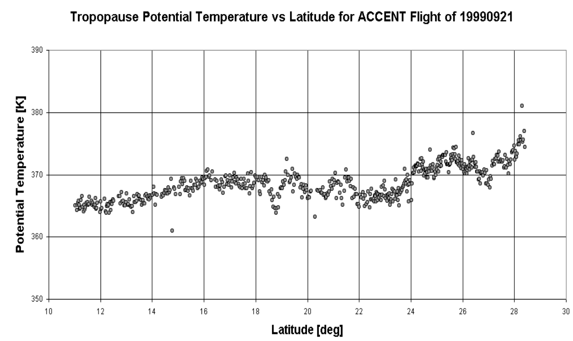

Figure 2.1-1. The potential temperature of the tropopause, obtained by MTP during a WB-57F flight from San Jose, Costa Rica to Houston, TX on September 21, 1999, during ACCENT.

Convection, radiation and large-scale upwelling all likely play a role in maintaining the height of the tropical tropopause [*Thuburn and Craig,* 1997]. In spite of numerous studies over several decades (see *Highwood and Hoskins* [1998] and references therein), a thorough understanding of the basic physics associated with the tropopause is lacking [*Thuburn and Craig,* 2000]. Detailed high-resolution measurements of radiatively active trace species (H_2O, O_3) and the vertical temperature structure coupled with cloud and aerosol information surrounding the tropopause are needed to further untangle questions regarding tropopause maintenance. The proposed GHATTEX flights would allow acquisition of such data over a large spatial scale that could be incorporated into models examining tropopause physics.

Some of the WAM and ACCENT flights by the WB-57F between 30°N and 5°N near 95°W have provided informative observations at, above and below the tropical tropopause in spring and fall. One of these was the potential temperature of the tropical tropopause, θ_{TROP}, made by the MTP and plotted as a function of latitude in **Figure 2.1-1**. Not only does the value of θ_{TROP} for the flight of September 21, 1999, show a slope from low values at inner tropical latitudes to values 10 to 20 K higher at latitudes near the subtropical jet stream (25º N to 30º N), but the inner tropical values are greater than the largest equivalent potential temperatures found at the tropical surface. Therefore, some processes not accounted for by equilibrium thermodynamics must be operating. We will investigate the hypothesis of horizontal transport of higher potential temperature air from the mid-latitude lower stratosphere to the lower-latitude troposphere. Ozone and methane measurements should provide indicators of this transport. With the long-range capability of the Global Hawk, we will be able establish them twice over the entire width of the tropics in a single flight. Such transport would tend to destabilize the tropical UT/LS to vertical air parcel motion, and so allow underlying convection to rise to higher altitudes than in the surrounding air. In addition, we will use total water and cirrus observations from the Global Hawk in conjunction with satellite cloud top data and Lagrangian analysis to examine whether this constitutes a "pumping" mechanism by which near surface air is transported to and through the tropical tropopause.

• **Mixing and recirculation.** There is evidence from the NASA ER-2 transit flights between Hawaii and Fiji in 1994 that species with higher abundances in the Northern Hemisphere troposphere (relative to the Southern Hemisphere) were also more abundant in the Northern hemisphere lower stratosphere. This implies that either the deep convection in the ITCZ does not mix Northern Hemisphere and Southern Hemisphere air in equal proportions, or that upward transport across the tropopause north and/or south of the ITCZ is a significant mechanism [*Tuck et al.*, 1997]. The Global Hawk meridional transect flights will be able to test these ideas.

In addition to questions regarding the mixing of Northern Hemisphere and Southern Hemisphere air within tropical convection, questions also remain as to the degree of mixing between tropical and mid latitude air contained in the lower stratosphere. Several studies [*Volk et al*., 1996; *Minschwaner et al*., 1996; *Herman et al*., 1998 and others] have attempted to quantify the amount of lower stratospheric isentropic mixing. Data from GHATTEX would contribute to such estimates by providing first time measurements spanning the width of the ITCZ.

Recirculation of air between the upper troposphere and lower stratosphere has been suggested on the basis of localized vertical profiles by the NASA ER-2. This has implications both for particle production and the exact chemical composition of air which enters the stratosphere. It is known that maintaining mass continuity in the lower stratosphere requires that the majority of mass flux upwards in the inner tropics through 100 hPa (16.5 km) actually flows poleward, with only a small amount continuing upward through the 60-hPa (19.5-km) surface. Calculations [*Rosenlof et al*., 1997] put the ratio of fluxes at 6, implying that 1/7 of the air ascending through the 100 hPa surface between 10˚N and 10˚S in the annual zonal mean continues upwards through 60 hPa. The remaining 6/7 must move poleward and eventually downward. Some portion of that which moves downward likely mixes back into the upper tropical troposphere. Evidence from tropical ER-2 tracer data exists for recently tropospheric air in the lower stratosphere, and recently stratospheric air in the upper troposphere. Mid-latitude air from the lower stratosphere is found in both the outer and inner tropics above, at and below the tropical tropopause. It follows that some air recirculates between the upper troposphere and lower stratosphere. Our proposed flights will allow an examination of the implications of recirculation for such concepts as the age of the air [*Hall and Plumb,* 1994], the tropical pipe [*Plumb,* 1996], and the tropical tape recorder [*Mote et al.,* 1996], with many observations over a very wide range of scales.

• **"Mirror-image" Walker circulation.** Based upon vertical wind measurements from profiling radars it has been suggested that a "mirror image" of the long-established tropospheric Walker circulation exists in the lower stratosphere over the tropical Pacific, spanning the entire basin [*Gage et al*., 1991]. The case is reinforced by maps of outgoing longwave radiation (OLR) from satellites; namely, OLR is a minimum above the high, cold, thick cirrus shields situated above the convective upwelling in the western tropical Pacific, which comprises the upward branch of the tropospheric Walker circulation. These cirrus shields will protect the lower stratosphere above from the upward flux of infrared radiation emitted by the warm atmosphere and ocean beneath. This is not true in the eastern tropical Pacific, where the air is generally much clearer. The pattern in the lower stratosphere of heating in the east and cooling in the west is hypothesized to lead to a "mirror-image" Walker circulation, as implied by the radar observations of vertical velocities. The

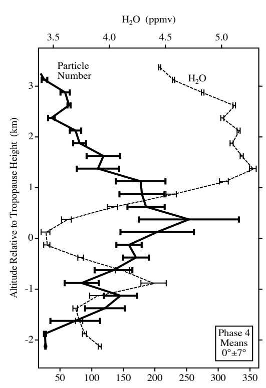

Figure 2.1-2. The abundances of condensation nuclei and total water plotted as a function of altitude from the tropical tropopause within 7º latitude of the equator by the ER-2 during ASHOE-MAESA. October 1994 average.

measurements of methane, ozone and water we propose from the Global Hawk will allow this concept to be tested during a single flight. The presence of longitudinally varying gradients on the scale of the Pacific basin would have important implications for models of the general circulation, and for how injection of air into the stratosphere is viewed.

• **Particle production.** It has been shown [*Brock et al.*, 1995] that particle production occurs at the tropical tropopause, based upon a limited number of ER-2 profiles taken during the ASHOE-MAESA project (**Figure 2.1-2**). The details of the mechanism, however, and its possible relationship to cloud processes remain unclear. The effect of recirculation on particle formation may be important, and we expect the correlations we will obtain along the long flight tracks of the Global Hawk over regions of ascent and descent on many scales in the Pacific basin to be informative in this respect.

• **Tropical dynamics.** The Quasi-Biennial Oscillation (QBO) of the equatorial lower stratosphere, first noted by *Reed et al.* [1961] and *Veryard and Ebdon* [1961] is a much studied phenomenon, but historically poorly modeled in free running general circulation models. However, recent attempts at resolutions that allow generation of equatorial gravity waves are making progress [*Horinouchi and Yoden*, 1998; *Takahashi*, 1999]. Gravity waves were found to be an important component of the forcing required for a realistic simulation. *Dunkerton* [1997] noted that as model resolutions improve, eventually all scales of motion relevant to the QBO may be explicitly simulated. However, at the present, parameterizations are still required. *Pfister et al.* [1993a,b] have shown it possible to infer gravity wave momentum fluxes with aircraft measurements of temperature, pressure and winds, similar to those proposed with the Global Hawk. Although presently radiosonde estimates of gravity wave properties [*Sato and Dunkerton,* 1997] are used to characterize convectively generated waves, measurements across the entire Pacific basin will be quite valuable in producing characterizations valid on global scales.

• **Scale invariance.** Recently, it has been discovered that total water, ozone, methane, wind and temperature were scale invariant in the upper troposphere, at the tropopause, and in the lower stratosphere during WB-57F flight tracks south from Houston (30˚N, 95˚W) to inner tropical latitudes in the range 5˚N to 12˚N [*Hovde et al.,* 2000]. **Figure 2.1-3** provides an example for water, ozone, wind speed, and temperature. This result is consistent with the fractal behavior (power law scaling) demonstrated earlier during NASA ER-2 flights in the extratropical lower stratosphere, extending from scales as long as one Earth radius down to a few hundred meters. The physical significance of scale invariance lies in the accompanying long-

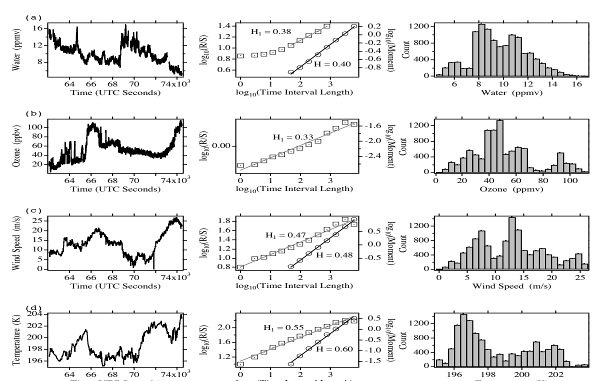

Figure 2.1-3. Scaling behavior for total water, ozone, wind speed and temperature, taken from the WB-57F on the same flight as **Figure 2.1-1**. The traces are in the left hand column, the corresponding log-log plot is in the middle column, and the frequency distribution is in the right hand column. Linearity in the log-log plot indicates scale invariance, with an associated asymmetric histogram. The departure from linearity at about 6 s in the top row indicates that instrument noise and atmospheric variability have become equal for total water on that time scale.

tailed probability distributions of variables along horizontal flight tracks; there is an implication that all scales are involved in the maintenance of the mean state, with substantial contributions from relatively infrequent, high amplitude events. The unique capability of the Global Hawk as regards long flight tracks should enable the examination of the scale invariant behavior towards the longest scales on which it might occur - it cannot be longer than half an Earth circumference, or 180 great circle degrees. We anticipate continuous flight segments as long as 100 great circle degrees (11,000 km). The scale of these segments will also overlap with larger scales that are resolvable by both satellite observations and by global numerical models. The benefits from this natural complementarity should be significant to all three approaches in that the *in situ* results from the Global Hawk will be set in a larger context, the global approaches will know "what they are averaging over." The tests [*Hicke et al.*, 2000] of a mesoscale model made using fractal methods during a WB-57F flight through mountain waves from the Rockies (**Figure 2.1-4**) could thus be extended to much larger scales at low latitudes, and may offer valuable clues as to how to approach the representation of small scales in global models.

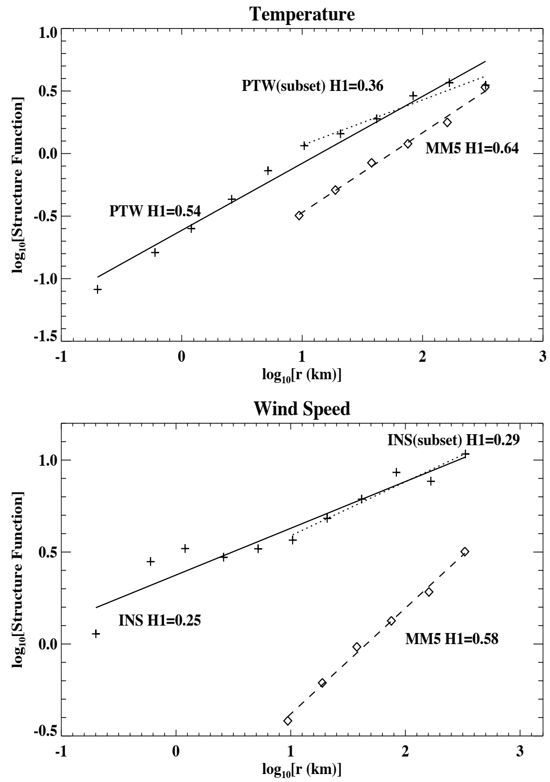

Figure 2.1-4. Comparison of flight data with the MM5 model. Data are from the 11 April 1998, WB-57F flight of WAM over northern Wyoming, U.S.A. Log-log plot of interval distance versus structure function used in calculation of *H*1, a measure of persistence (0 indicates antipersistence or noisy data, 1 indicates persistence or smooth data). (a) Observed temperatures (plusses; solid line) and interpolated MM5 modeled (diamonds; dashed line) temperatures. (b) Wind observations (plusses) and interpolated MM5 modeled (diamonds) horizontal wind speeds. Least squares fits also plotted. Dotted line indicates fit to observation structure functions using only MM5 scales. Note that the MM5 modeled data are smoother than the observations. From *Hicke et al.,* 2000.

2.2 Science Objectives

The GHATTEX data set and its interpretation will contribute to the following science objectives:

- Establish the distribution of water, cirrus, aerosols, ozone, carbon dioxide and methane in the tropical UT/LS on the scale of the Pacific basin.
- Understand, through analysis, modeling, and use of satellite data, the maintenance of these distributions from dynamical and radiative standpoints.
- Test the hypothesis that the interplay between deep convection and adiabatic transport from mid-latitudes is a major mechanism in the maintenance of the tropical tropopause.
- Examine the extent to which interhemispheric asymmetries in chemical composition are linked to the ITCZ.
- Observe evidence for recirculation of air between the tropical troposphere and stratosphere.
- Test the hypothesis that there is a "mirror-image" Walker Circulation in the lower stratosphere over the tropical Pacific.
- Make observations to further explore particle production at the tropical tropopause.
- Extend the horizontal scales upon which fractal behavior (power law scaling, scale invariance long-tailed probability distribution functions) in the tropical UT/LS was observed by the NASA ER-2 and

WB-57F aircraft by a factor of four and combine the overlapping spatial scales with satellite data to understand the processes at work.

- Observe convectively generated, tropical gravity waves with long, horizontal wavelengths and attempt to estimate their contribution to the momentum budget of the tropical lower stratosphere.
- Use tracer observations coupled with transport models to examine mixing processes and bulk transport into and within the tropical lower stratosphere.

2.3 Scientific Capability of the Payload

The methane observations reveal significant atmospheric structure in level flight on the WB-57F at 50,000 ft in the upper tropical troposphere. This structure can be correlated in a consistent manner with structure in ozone and with the chemical composition of individual aerosol particles. High methane appears to be a marker for near surface air. Correlation with water near the tropical tropopause provides powerful insight into how processes there affect the total hydrogen budget in the stratosphere above, an important issue for both chemistry and circulation there.

Ozone is an essential measurement near the tropopause, because it is a tracer there and because it is radiatively important. It also initiates much of the photochemistry via its photodissociation to produce reactive, excited oxygen atoms.

Carbon dioxide is an important molecule in the radiation balance of the atmosphere, and has also been demonstrated to be a useful tracer in the UT/LS [*Boering et al.*, 1996]. The interhemispheric gradient in the troposphere can be transported to the stratosphere, for example, and there is also a seasonal variation in the troposphere, particularly in the Northern Hemisphere.

Total water corresponds to water vapor in the absence of cirrus clouds, and to the sum of water vapor and vapor from evaporated ice crystals in their presence. Its measurement is central to any computation of the radiative balance, and in the interpretation not only of the effects of deep convection but also in the interpretation of the data from the particle sizing instruments. The degree of dryness of the lower stratosphere is also an important observation, and by extension its correlation with methane. Methane is lost photochemically in the middle and upper stratosphere, leading to less than tropospheric abundances in the lower stratosphere.

Aerosol particles are important because they may affect radiative transfer directly, and indirectly if they are capable of acting as condensation nuclei to form ice crystals (cirrus) which can have large effects upon both solar and terrestrial radiation. The discovery that they are produced at the tropical tropopause [*Brock et al.,* 1995] adds interest, particularly in view of evidence from NASA ER-2 flights that recirculation of air between the upper troposphere and lower stratosphere occurs, and from NASA WB-57F flights that the aerosol content of mercury and organics near the tropical tropopause is unexpectedly high.

Cirrus ice particles may range from a few to many tens of microns in size, and may have very complex effects on both UV/visible and upon infrared radiation. When they grow large enough, their gravitational sedimentation leaves behind dehydrated air masses, a mechanism which is certainly important in the entry of air to the stratosphere in the inner tropics. The maintenance of cirrus sheets in the upper tropical troposphere poses some important questions [*Boehm et al.,* 1999]. Subvisible cirrus is important in the 1 to 2 km below the tropical tropopause, both radiatively and as a possible player in the dehydration of air entering the stratosphere. Microphysical modeling suggests that the maintenance of subvisible sheets for long times and on long scales may entail upwelling on those scales [*Boehm et al.,* 1999; *Sherwood*, 1999]. Our payload will be able to examine this phenomenon using MASP cirrus observations and tracer correlations.

The temperature profiles above and below the aircraft are of vital importance to the mission science. The tropopause is accurately located while in horizontal flight, and structures from gravity waves on scales of hundred meters to scales on the length of the flight track are revealed, with vertical resolution of typically 100 m near the aircraft and 700 m a scale height away. An example, filtered to highlight gravity waves, is shown in **Figure 2.3-1**.

Temperature and pressure measurements are fundamental both to the science and to the operation and data analysis of the other instruments. The temperature will be recorded at 50 Hz, and in conjunction with horizontal winds from the aircraft's GPS navigation system at the same frequency, will allow these variables to be recorded at length scales as short as 3.5m, easily short enough for the scale invariance

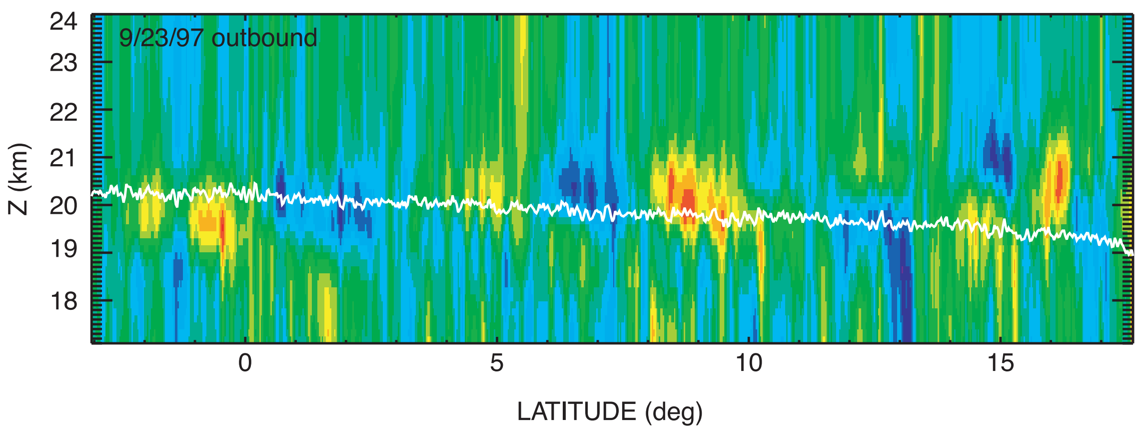

Figure 2.3-1. Temperature perturbations as a function of flight path latitude and altitude as measured by the MTP instrument flying on the NASA ER-2 aircraft in the stratosphere. The flight occurred on September 23, 1997, originating in Barbers Point, HI. Color indicates the temperature deviation from a 500-km running mean computed separately at each height. Peak perturbations are 5K. The white line shows the aircraft flight path.

analysis to be extended to those at which three-dimensional Kolmogorov turbulence theory should apply. The scale invariance software has been used to distinguish noise from atmospheric variability in time series of the NASA ER-2 and WB-57F data records.

Collectively, the GHATTEX payload is more than the sum of its parts. It will measure all categories of physical properties - gaseous, aerosol and solid – which affect radiative transfer. The water, tracers, ozone and aerosols will allow much dynamical inference on a very wide range of scales, and will be revealing about how variations in chemicals correlate as a function of scale.

2.4 Relation to Office of Earth Science Research Themes

• ***Theme 2, Global Water and Energy Cycle***

Is the cycling of water through the atmosphere accelerating? There is a recently reported trend in tropical tropopause cold point temperatures [*Simmons et al*., 1999], and a longer-standing and recently extended trend in the water vapor content of the lower stratosphere at northern mid-latitudes [*Harries*, 1976; *Oltmans and Hofmann*, 1995].

Satellite data also suggest "trends" over the last nine years in the total hydrogen content of the middle and upper troposphere [*Evans et al.,* 1998]. Our flights will investigate the mechanisms that might cause such behavior, on scales ranging from 200 m to 11000 km.

How can the integrated effects of fast atmospheric, land and ocean surface processes be accurately included in large scale climate models? The scale invariance in water and meteorological variables, which also exists for ozone and methane, extends over NASA ER-2 and WB-57F tracks from 200 m up to the longest observed scales of 2800 km. The Global Hawk will extend this scale to 11,000 km over the Pacific basin, and for winds and temperature will yield observations on a scale of 3.5 m. This will permit a test of Kolmogorov turbulence theory, and allow examination of the atmosphere for a scale break marking a transition between 2D and 3D turbulence. Scale invariance implies fractal geometry and long-tailed probability distributions. Because fractal geometry employs a complicated building block (as observed) with a simple algorithm (power law scaling) to describe the morphology of a convoluted object, it may have important implications for the representation of processes as a function of scale in large-scale climate models. Hicke *et al.* [2000] have shown that the MM5 mesoscale model, for example, does not produce the power law scaling observed from the WB-57F (**Figure 2.1-4**). The Global Hawk will extend such a test to the scales simulated by GCMs. Scale invariance may imply that parameterization by diffusive formulations at scales below the grid size has fundamental limitations.

• ***Theme 3, Climate Variability and Prediction***

Can the observed climate trends be attributed to a specific factor? This is of course a very complicated, multivariate problem. Nevertheless, as noted in Theme 2 above, it is possible that we may find mechanisms to explain the increase in stratospheric water vapor. The water vapor content of the lower stratosphere has been shown to be radiatively important [*Forster and Shine*, 1999], and hence may play a role in climate trends. Climate trends may also be affected by ozone decreases related to subtropical jet stream dynamics [*Reid et al.*, 2000].

Can current global climate variations be understood and predicted? Climate variability is believed, on the basis of numerical modeling and some limited observations, to be affected both by trace gases (particularly those which absorb in the 7- to 14-μm window) and by aerosols. The proposed Global Hawk payload will make direct observations of water vapor, ozone, carbon dioxide, methane, aerosols and cirrus in a crucial region, the UT/LS in the Pacific basin. We expect to investigate this on a very wide range of scales by interpreting and comparing model results.

• ***Theme 4, Atmospheric Chemistry***

How will stratospheric ozone respond to the reductions in atmospheric abundance of ozone-destroying industrial chemicals? It has been established that only ~10 to 15% of the air rising in the inner tropics at ~100 hPa continues through ~50 hPa to populate the "overworld" [*Rosenlof et al.,* 1997]. Our results will help address the consequence of this for short-lived industrial compounds and aerosols in the stratosphere. It has also been established that there has been an increase over the last 30 years in the frequency of transport from the upper tropical troposphere across the subtropical jet stream into the lower stratosphere of northern mid-latitudes, accounting for up to 30% of the observed ozone loss there by the direct effect of the associated dilution [*Reid et al.,* 2000]. Our flights will throw further light on this mechanism.

How does the chemistry of atmospheric trace constituents respond to and affect climate? If the suggestion that the maintenance of the tropopause is importantly influenced by the adiabatic exchange of air between the tropics and mid-latitudes is correct [*Hovde et al.,* 2000], the way is open for the operation of an interactive coupling between chemistry and climate. Ozone heating is an important element in the radiative balance at the tropopause; a rise in tropopause height of only 5 to 10 m a year could make a very significant contribution to the observed mid-latitude ozone loss [*Hoinka*, 1998]. The examination of the chemical composition of the UT/LS in the subtropics and tropics on very long scales will address the mechanisms at work in the Pacific basin, where much of the ascent is believed to occur.

3.0 Science Plan

GHATTEX seeks to demonstrate how measurements from a long endurance, high-altitude UAV such as the Global Hawk can be used to examine a remote region of the upper troposphere and lower stratosphere (UT/LS) over the tropical Pacific basin. GHATTEX will examine the composition of this region with detailed, high-frequency observations of meteorological, radiative and chemical importance. The observations will be made with a payload of established, well-calibrated sampling instruments linked with satellite data and atmospheric model results to place them in a broader scientific context. GHATTEX specific science objectives are listed above in **Section 2.2** and the proposed payload instruments are listed in **Section 2.3**.

3.1 Project Requirements IP-Section 2.1

The GHATTEX science objectives place a number of critical requirements on the instruments used, the makeup of the assembled team, and the aircraft performance. In addition, project cost effectiveness must be taken into account. A summary of the specific requirements for GHATTEX are as listed below. This proposal and the attached Implementation Plan confirm how these project requirements are being or will be met.

- *Scientific Instrument Requirements.* The collective requirements imposed on the instruments include the following:
  - must address one or more of the GHATTEX science objectives;
  - must be certified safe for flight in the expected environments;
  - must be configured to operate in an autonomous mode;
  - must have sufficient reliability to ensure data are acquired throughout the long flights;
  - must have sufficient accuracy and precision to ensure that the data are of scientific quality;

- must fit within the volume, weight and power available on the aircraft;
- must output sufficient status information for the aircraft to ascertain the health of the instruments; and
- must allow the aircraft control system to power the instruments on and off during flight.

• *Project Team Requirements*. The most critical requirement for project success is the demonstrated ability of the key personnel associated with the project to provide and operate the payload instruments and to scientifically interpret the acquired data set. This requirement implies that the principal investigators must have experience with high-altitude aircraft missions, that the instrument PIs have flown the selected or similar instruments, and that the theory team be well-versed in the theoretical and modeling aspects related to flight planning and in the interpretation of the expected data sets.

• *Aircraft Performance Requirements*. The minimum performance requirements of the aircraft are defined by the particular project objectives. For GHATTEX, these include:
- service ceiling in excess of 60,000 ft. (18 km);
- minimum unrefueled radius-of-action of 5000 nautical miles (9260 km);
- payload capacity in excess of 1000 lbs (450 kg) and volume of 17 cu. ft (0.48 m^3);
- minimum of 5 kW of electrical power;
- sufficient reliability to ensure project success; and
- a well-defined process for conducting safe flight operations.

• *Operational Requirements*
- mission safety verified by reviews;
- schedule certainty provided by well-defined procedures for integration and operation of the instruments on board the UAV;
- laboratory facilities to support the deployment team; and
- demonstrated performance by the aircraft in areas similar to the GHATTEX deployment areas.

• *Education and Public Outreach Activities*. The EPO activities chosen to provide access to GHATTEX activities are:
- Internet website;
- teacher-scientist partnerships;
- media relations; and
- EAFB Open House.

3.2 Project Concept IP-Section 2.1.2

The GHATTEX Project consists of four major components: the Project Team, the Instrument Payload, the Global Hawk UAV Platform, and Education and Public Outreach activities. Each of these components is briefly described below.

• *Project Team*. The GHATTEX Project Team includes technical support and scientific members (see **Table 3.2-1**). Dr. Adrian Tuck will act as the project leader and, along with Dr. David Fahey, will be involved in all aspects of the project. In addition, Dr. Gerhard Hübler will perform project coordination and technical support in order to assist Dr. Tuck and Dr. Fahey in the project management. Each instrument has a science and support team based at the instrument home institution and lead by an Instrument PI as listed in **Table 3.2-1**. The Science Team includes the Instrument PIs and their associated teams, and several other investigators leading theoretical and modeling aspects related to flight planning and the interpretation of the expected data sets. The NG-RAC point-of-contact is Mr. Greg Loegering, a senior staff engineer associated with the Global Hawk program from its inception. In addition to Mr. Loegering, the GHATTEX support team from NG-RAC includes design engineers, project leads, and flight test personnel as required. The point-of-contact for the USAF, the provider of the Global Hawk UAV, will be 1st Lt Adam Wehner of the Global Hawk Special Projects Office at Wright Patterson AFB. A short curriculum vita is attached in **Appendix D** for each participant listed in **Table 3.2-1**.

Table 3.2-1 GHATTEX Project Team **IP-Table 2.1-1**

Participant or PI	Institution	Activity
Project PI		
Dr. A. F. Tuck	NOAA Aeronomy Laboratory, Boulder, CO	Project PI
Dr. D. W. Fahey	NOAA Aeronomy Laboratory, Boulder, CO	Project Co-PI
Instrument PI		
Dr. B. W. Gandrud	Particle Metrics, Inc., Boulder, CO	Ice particles (MASP)
Dr. R. S. Gao	NOAA Aeronomy Laboratory, Boulder, CO	Carbon dioxide
Mr. K. K. Kelly	NOAA Aeronomy Laboratory, Boulder, CO	Water vapor
Dr. M. J. Mahoney	NASA Jet Propulsion Laboratory, Pasadena, CA	Temperature (MTP)
Dr. E. C. Richard	NOAA Aeronomy Laboratory, Boulder, CO	Ozone and methane
Mr. T. L. Thompson	NOAA Aeronomy Laboratory, Boulder, CO	Temperature and pressure, and GPCC computer
Prof. J. C. Wilson	University of Denver, Denver, CO	Small particles (FCAS/NMASS)
Theory PI		
Dr. M. J. Alexander*	NorthWest Research Associates, Colorado Research Associates Division, Boulder, CO	Data interpretation
Prof. R. A. Plumb	Massachusetts Institute of Technology, Boston, MA	Data interpretation
Dr. K. H. Rosenlof	NOAA Aeronomy Laboratory, Boulder, CO	Meteorological support
Prof. M. H. Hitchman**	University of Wisconsin-Madison, Madison, WI	Data interpretation
Prof. R. E. Newell**	Massachusetts Institute of Technology, Cambridge, MA	Data interpretation
Prof. D. W. Waugh**	Johns Hopkins University, Baltimore, MD	Data interpretation
Project Support		
Ms. S. J. Hovde	NOAA Aeronomy Laboratory, Boulder CO	Data archive support
Mr. G. Loegering	Northrop Grumman Ryan Aeronautical Center, San Diego, CA	Global Hawk integration and operations
Mr. R. H. Winkler	NOAA Aeronomy Laboratory, Boulder CO	Instrument control and payload data acquisition
Dr. G. Hübler	NOAA Aeronomy Laboratory, Boulder CO	Mission coordination and technical support
1st Lt A. Wehner	USAF ASC/RAV, Wright Paterson AFB, OH	Global Hawk provider representative
Education outreach		
Dr. S. Buhr	Cooperative Institute for Research in Environmental Sciences, Univ. of Colorado, Boulder, CO	Coordinate student and teacher outreach activities

* Funded separately by the National Science Foundation
** Funded separately by NASA's Atmospheric Chemistry Modeling and Analysis Program (ACMAP)

• *Instrument Payload*. The GHATTEX payload consists of eight instruments and the GHATTEX Payload Control Computer (GPCC) (see **IP-Table 2.1-2** and **Figures 3.2-1**, **3.2-2**, and **3.2-3**). Descriptions of each instrument are included in **IP-Section 2.1.2.1**. All instruments have participated in airborne sampling except the CO_2 instrument being constructed as part of this project. The CO_2 instrument design will be based on a proven NOAA Aeronomy Laboratory CO_2 instrument in use on the NOAA WP-3D aircraft. Seven of the eight instruments comprising the GHATTEX payload have been operated in unpressurized spaces at altitudes up to 68,000 ft on the NASA ER-2 and WB-57F subsonic research aircraft, for flight durations of up to 8 hours. Thus, these seven instruments have already been flight qualified to operate in the environments expected in the UAV. The eighth, the CO_2 instrument, will be built during the GHATTEX pre-deployment phase by NOAA/AL. An existing NOAA/AL CO_2 instrument operates on the

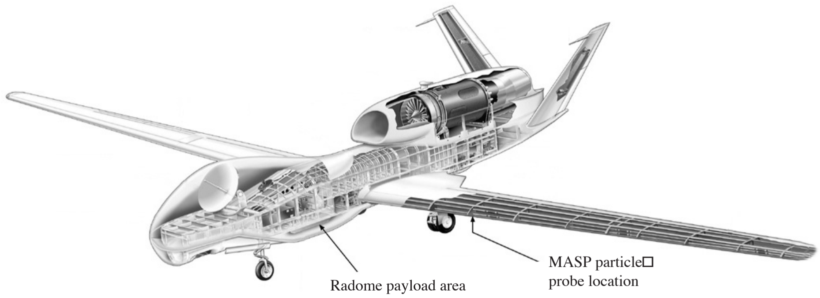

Figure 3.2-1 Schematic of the Global Hawk UAV showing the GHATTEX payload areas. All instruments except MASP aerosol probe will be located in the SAR radome below the forward fuselage. MASP will be mounted under a wing.

NOAA WP-3D aircraft in flights reaching up to 24,000 ft for up to 10 hours. This instrument has participated in a regular series of NOAA research flights addressing air quality in the troposphere.

All instruments in GHATTEX will operate completely autonomously and record data with on board digital storage media. Power and communication to the instruments will be handled by the GPCC. The GPCC will also record instrument status and some instrument data in order to provide redundancy for the instrument data recording systems.

• *Global Hawk UAV Platform Description*. The Global Hawk UAV is the only currently available UAV that can be used to meet GHATTEX flight and payload objectives. The Global Hawk has been developed for the U.S. Air Force by the Ryan Aeronautical Center of the Northrop Grumman Corporation (NG-RAC).

Global Hawk, which first flew in February 1998, is a jet-powered aircraft with a conventional aluminum fuselage and graphite composite wings and appendages (see **Figure 2.1-2**). The aircraft is 44.4 ft. long, 15.2 ft. high, and has a wingspan of 116.2 ft. Fully loaded with fuel, the aircraft has a maximum take-off gross weight of 25,800 pounds. The maximum estimated range of the aircraft is 11,040 nautical miles (20,500 km or 0.5 of the Earth's circumference) at Mach 0.6 with an endurance of 32.6 hours to start of landing descent.

The maximum operating altitude is 65,000 ft. The current payload capacity is near 1500 pounds, and currently consists of an integrated synthetic aperture radar (SAR) and electro-optic/infrared reconnaissance payload. In addition, the aircraft can provide up to 6.2 kVA of AC power, up to 2.95 kW of DC power, and has been certified for operation at temperatures down to -77ºC. GHATTEX will use only about 50% of the payload mass, volume, and power capacities of Global Hawk.

The Global Hawk has been designed to fit seamlessly into the national airspace system. It has standard mode 3/A and mode C transponders, and a satellite communication relay that allows the command and control operator (CCO) to talk to ATC over VHF and UHF radio even though the CCO is hundreds of

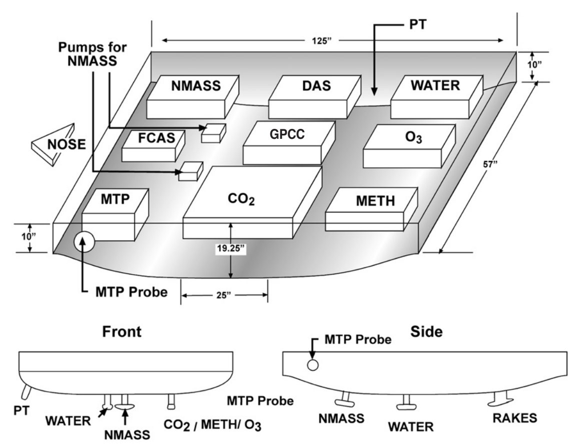

Figure 3.2-2 Schematic of the location of the GHATTEX instruments in the SAR radome payload area. The direction of the Global Hawk nose and dimensions are indicated in the figure. The instruments correspond to the payload list in Table 2.1-2 where METH indicates methane, and DAS indicates the MASP (ice particles) data acquisition system. Small particles are measured with the combination of FCAS-III and NMASS instruments. The FFS is shown in front and side views in the lower part of the figure. Schematic inlet and exhaust probe locations are indicated on the FFS. The Pressure and Temperature probe instrument is represented by the 'PT' designation on the FFS.

miles away in the command and control shelter. It currently operates out of Edwards Air Force Base (EAFB) (co-located with NASA Dryden Flight Research Center) for the U.S. Air Force by Ryan Aeronautical under an FAA issued certificate of authorization.

• *Education and Public Outreach Activities*. The GHATTEX project provides an opportunity for students, teachers, and the public to learn about scientists' efforts to understand Earth's atmosphere in remote regions and to learn about a unique airborne platform that facilitates access to the atmosphere. Education and Public Outreach (EPO) activities will include several components. A website will be set up and maintained to provide access to GHATTEX information, images, schedules, and input from GHATTEX scientists and interested teachers. Partnerships between teachers and GHATTEX scientists will allow teachers improve their knowledge of the atmosphere and contemporary research efforts. Media contact will be made to distribute press releases regarding GHATTEX activities and announce the availability of educational material. An Open House will be conducted at EAFB for the public to view the aircraft and some GHATTEX instrumentation and to contact scientists. The GHATTEX EPO plan includes rigorous and complete formative and summative evaluation. The EPO team has extensive experience in designing and implementing evaluation of similar programs.

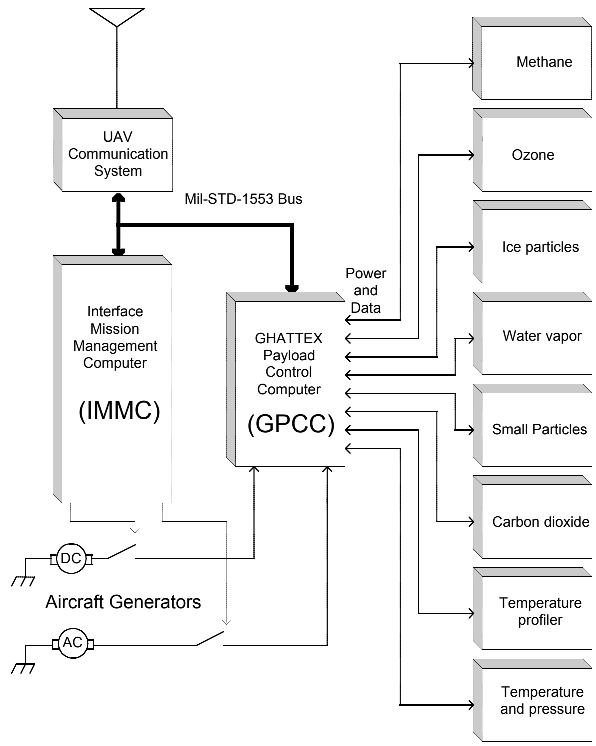

Figure 3.2-3 GHATTEX Payload Control Computer (GPCC) configuration. The IMMC and UAV Communication System are part of the Global Hawk aircraft system. The GPCC will control power and communication connections to the GHATTEX payload instrument suite with commands sent by the IMMC.

3.2.1 GHATTEX Alternatives Considered — *IP-Section 2.2.1*

Alternative scientific goals, flight plans and payloads were considered in developing GHATTEX. Among them were deployments to a Southern Hemisphere location to study the Antarctic ozone hole, a deployment to EAFB to study Arctic ozone loss at high northern latitudes, and a deployment from EAFB to circumnavigate the Earth at the equator at altitudes near the tropical tropopause.

The polar missions would have necessitated payloads involving larger and heavier instruments. These would have added more expense to deploy, and in some cases would have conflicted with the USAF condition that any modifications to the aircraft must be rapidly reversible. For example, we would like to have included the Particle Analysis by Laser Mass Spectrometry (PALMS) instrument to investigate both polar stratospheric clouds and tropical aerosol and cirrus, but it is designed to fit the WB-57F nose; redesign of the instrument to fit the Global Hawk would have cost $1 to 2M and taken 1 to 2 years, thus eliminating it as an option. Therefore, since the PALMS would require a substantial re-design, and the deployment costs to Argentina or Chile would have been prohibitive at about $3M, the polar missions were no longer attractive. Additionally, the deep and extensive regions of very cold temperatures (less than -77ºC) in the polar vortices would have necessitated certification of the Global Hawk for operation in lower temperatures, with a probable cost that would have been prohibitive in the context of the NRA. Finally, a circumnavigation experiment would require a deployment to an equatorial site about 180º longitude away from that of EAFB (120ºW). The costs of such a deployment would have been approximately $3M, a cost that eliminated this experiment from consideration.

The GHATTEX payload of chemical, microphysical and meteorological instruments form a comprehensive, synergistic suite for this UAV demonstration project. A number of other instruments could substantially enhance the scientific return from the GHATTEX flights. Four examples are cited here; namely, an airborne gas chromatograph, a whole air sampler, an interferometric, high-spectral resolution radiometer covering the spectral range from the near to the far infrared, and a water vapor and aerosol lidar system. A two-channel airborne gas chromatograph measuring several long-lived gases has been successfully flown on a balloon and the WB-57F aircraft by Dr. J. Elkins of NOAA Climate Monitoring and Diagnostics Laboratory. A water vapor and aerosol lidar system has been designed and built for the Perseus UAV in cooperation with Dr. E. Browell of NASA Langley Research Center. One or more of these instruments could be accommodated easily in the forward fuselage payload area of the Global Hawk with additional instrument and science team costs of about $**** per instrument.

3.3 Global Hawk Advantages

The overriding advantage of the Global Hawk platform is its ability to carry a substantial payload of autonomous instruments on flight tracks spanning the Pacific tropical basin. It is the *only* aircraft that is capable of doing this at the requisite altitudes near the tropical tropopause, and that also meets the NASA NRA requirement of no substantial development. Accordingly, this aircraft was chosen as the project platform. No other aircraft, inhabited or uninhabited, meets or exceeds the Global Hawk's combined specifications of altitude, range, and payload capacities. In addition, the Global Hawk is compatible with the national and international airspace infrastructure and is a reliable and well-supported UAV platform.

• *Altitude, range, and payload*. The maximum operating altitude of the Global Hawk is 65,000 ft., the maximum estimated range is 11,040 nautical miles with an endurance of 32.6 hours to start of landing descent, and the current payload capacity is near 1500 lbs. The aircraft can provide up to 6.2 kVA of AC power, up to 2.95 kW of DC power, and has been certified for operation at temperatures down to -77ºC. (See **Section 3.2, IP-Section 2.0, IP-Table 2.3-1**). Although both the ER-2 and the WB-57F aircraft can meet the GHATTEX payload and altitude requirements, the operational, unrefueled radius-of-action of these aircraft is only 1500 nautical miles.

• *Airspace management*. The Global Hawk has been designed to operate in both national and international airspace. Global Hawk flights (see next paragraph) include those over the U.S.A., the Pacific Ocean, and the Atlantic Ocean. Airspace management issues are discussed further in **Section 4.5** and **IP-Section 2.7**.

• *Flight-proven capabilities*. Global Hawk has undergone an extensive series of taxi and flight tests to establish its flight envelope, as well as successfully completing its military-utility assessment test phase. As of January 2001, the Global Hawk fleet has accumulated a total of 759.1 flight hours in 65 flights. These include flights from EAFB to Alaska and back, a deployment to Eglin AFB in Florida, and one flight to Portugal and back (see **IP-Appendix D**). Flight duration exceeded 20 hours in 14 flights, while the maximum flight duration was 31.5 hours. (Global Hawk now holds the official world record for endurance of a jet-powered aircraft.) Maximum flight altitude exceeded 60,000 ft on 40 flights with an overall maximum altitude of 66,400 ft. Most flights carried full USAF sensor payloads (1500 lbs), and many operated outside the restricted airspace of EAFB. The duration, altitude, and location of the Global Hawk flights have demonstrated the aircraft performance and operations necessary to achieve GHATTEX objectives. Furthermore, these test and mission flights demonstrate that issues of flight safety (see **IP-Section 2.6**) and airspace management (see **IP-Section 2.7**) have been handled successfully.

Future USAF flights are planned to the equator at longitudes of 95° to 125°W during northern winter 2000/2001 and to Australia during the spring of 2001. These proposed flight tracks are very similar in part to the proposed GHATTEX flight tracks (see **Section 4.3**) and consequently will add relevant Global Hawk experience for meeting GHATTEX flight objectives.

• *Support*. The Global Hawk UAV was developed and is supported by its provider, the U.S. Air Force (USAF), and the manufacturer, Northrop Grumman Ryan Aeronautical Center (NG-RAC). GHATTEX will take advantage of this extensive infrastructure and experience already in place for the Global Hawk. The USAF at WPAFB will work directly with NOAA/AL and NG-RAC to achieve the GHATTEX payload integration and flight objectives. In addition, Colonel Wayne M. Johnson, of the Global Hawk Systems Program Office at WPAFB has formally supported the use of the Global Hawk in GHATTEX in a letter to the Project PI received 28 February 2001 (see **Appendix C**). This letter is an update of the commitment received from Colonel Robert E. Dehnert, Jr., dated 3 May 2000. GHATTEX is the only external Global Hawk project to be approved by the USAF from many requests. Mr. Norm Sakamoto of NG-RAC (Vice

President, New Business Development, Global Hawk) has also written an updated letter of support (see **Appendix C**), thus providing the requisite contractor support required by the NRA. Funding for Global Hawk activities will be transferred to USAF WPAFB and managed along with other tasks within their Global Hawk Systems Program Office. GHATTEX funding will also be provided to the USAF 452[nd] FLTS through WPAFB to support Global Hawk flight operations at EAFB.

3.3.1 Collier Award

The Global Hawk has received the 2001 Collier Award from the National Aeronautic Association. The award is presented annually for 'the greatest achievement in aeronautics or astronautics in America, with respect to improving the performance, efficiency, and safety of air or space vehicles, the value of which has been thoroughly demonstrated by actual use during the preceding year' (see http://naa-usa.org/website/html/newsset.html.). Northrop Grumman will accept the award at a meeting of the National Aeronautical Association in May 2001.

3.3.2 Milestone II Approval

In addition to being selected as this year's winner of the Collier Award, the Global Hawk program successfully obtained Defense Acquisition Board (DAB) milestone II approval for full engineering and manufacturing development (EMD), as well as approval for low-rate initial production (LRIP). This approval further ensures that the Global Hawk will be available to support the GHATTEX objectives.

3.4 Changes from Original Proposal

The science objectives and project strategy for obtaining those objectives have remained unchanged from the original proposal. The scientific aspects of the original proposal are reproduced in **Section 2.0**. The proposed scientific outcomes of GHATTEX are unchanged from the original proposal. In the GHATTEX schedule, the winter mission flights now occur before the summer mission flights as a result of the delay in start date from the original proposal.

3.5 Scope and Risk Mitigation

3.5.1 Scope Options — *IP-Section 2.2.2*

Scope options will facilitate changing the project objectives during GHATTEX in the event of difficulty with meeting cost and schedule requirements. Because both the aircraft and the payload are well proven, many of the costs are associated with the salaries of the people who will perform the three main tasks: (i) instrument preparation and payload integration; (ii) test flights and science flights; (iii) data analysis and scientific research. Two principal scope options are:

• *Cancellation of the summer flight deployment*. The summer flight window begins 3.5 months after the winter flights in a separate deployment. Costs for the summer flights are primarily associated with aircraft operations and instrument and theory team participation. Because the cancellation would occur well in advance of the deployment, full costs for the deployment would likely be saved. If the winter flights were successful, then mission data would be available for scientific interpretation. Thus, a substantial fraction of the scientific objectives of GHATTEX would still be met without summer flights.

• *Reduction of the data analysis period*. The reduction of the data analysis period or the number of funded participants could be used to reduce costs in the final phase of GHATTEX. The costs of the theory and data analysis activities in year three are a significant fraction of the total proposal cost. The costs are spread over 10 investigator groups in 5 institutions. However, without the data analysis activities, there would be no scientific return from the mission flights. A substantial amount of data analysis will be done by NOAA/AL investigators who are funded directly from NOAA/AL's *in-kind* contribution to GHATTEX. Thus, some data analysis will occur without NASA funds in year three. Some data analysis costs are being supported indirectly from ACMAP funds as directed by Dr. P. DeCola (per discussion in November 2000). ACMAP activity would involve Prof. M. Hitchman, Prof. R. Newell, and Prof. D. Waugh (see **Table 3.2-1**). Other sources within NASA could also be asked to support data analysis if GHATTEX support were not made available.

Cancellation of the summer science flights would truncate the schedule by 2 months, if this scope option were decided upon at the end of the winter flights. Exercising the option of canceling the last 6 months of the project (half the theory and data analysis) would shorten the entire project from 36 to 30 months.

The entire cost of the summer deployment would be saved if the scope decision were taken promptly after the winter flights. Cutting the last 6 months of the project would save approximately half the money budgeted for theory and data analysis, depending on exactly when the option was decided upon.

The total GHATTEX cost can be reduced to $**** by exercising the scope option to reduce the data analysis period. In the event that airframe #5 remains available for GHATTEX flights, the $**** cost reserve would then be used to restore the data analysis budget as presented in this proposal. The decision regarding the use of airframe #5 would be made early enough in the schedule to allow theory investigators to plan for the extended data analysis activity.

3.5.2 Risk Mitigation

Risk mitigation is discussed in **Section 5.5**.

3.6 Data Analysis, Archival, and Distribution Plan — IP-Section 2.8

The basic data analysis, archival, and distribution plan for GHATTEX has not changed from the original proposal. The science team's theoretical capability however has been considerably enhanced by the addition of new team members. Prof. M. Hitchman (Univ. of Wisconsin), Prof. R. Newell (MIT), and Prof. D. Waugh (Johns Hopkins) will reprioritize current funding from NASA's Atmospheric Chemistry Modeling and Analysis Project (ACMAP) to analyze the GHATTEX data set. A letter of support for the reprioritization from Dr. Phil DeCola, ACMAP Program Manager is included in **Appendix C**. Travel funds for these investigators are included in the GHATTEX budget.

3.6.1 Data Analysis — IP-Section 2.8.1

Data analysis with the archived GHATTEX data set will follow procedures and methods that have been used successfully in previous high-altitude aircraft missions. Most of the GHATTEX Instrument PI and Theory PI teams have substantial experience interpreting aircraft data sets of gases, particles, and meteorological parameters. Other interested theoretical investigators have been invited to collaborate with the GHATTEX Science Team in the interpretation process. These studies can be performed without the acquisition of new hardware or software. All investigators have adequate facilities for analysis activities.

Science objectives as delineated in the original proposal for GHATTEX are listed below, followed by a) key measurements needed, b) analysis methods, and c) responsible Science Team members. For successful analysis activities, it is imperative that the majority of the instruments function adequately for at least one of the two flights planned in each deployment.

- Establish the distribution of H_2O, cirrus, aerosols, O_3, CO_2 and CH_4 in the tropical UT/LS over the Pacific basin.
  a) All proposed measurements needed.
  b) Meteorological, statistical and visual analyses.
  c) D. W. Fahey will lead this activity, which will involve many Science Team members.
- Understand through analysis, modeling, and use of satellite data the maintenance of these distributions from dynamical and radiative standpoints.
  a) O_3, H_2O, temperature, pressure critical; other aircraft measurements useful. Satellite cloud (GOES, GMS, Aqua) and tracer (UARS, Terra, POES) measurements also useful.
  b) Radiative transfer, trajectory, and chemical modeling.
  c) R. A. Plumb and A. F. Tuck will lead this analysis activity, in collaboration with all other Science Team members.
- Test the hypothesis that the interplay between deep convection and adiabatic transport from mid-latitudes is a major mechanism in the maintenance of the tropical tropopause.
  a) Temperature, H_2O, O_3, aerosol distribution, cloud information from satellite.
  b) Radiative transfer modeling, trajectory modeling, tracer modeling.
  c) A. F. Tuck, R. A. Plumb, and M. Hitchman will lead this activity, with input from other investigators.

- Examine the extent to which interhemispheric asymmetries in chemical composition are linked to the ITCZ.
  a) Measurements crossing the ITCZ required, O_3 and CH_4 are critical, other measurements useful, satellite observations of cloud cover required.
  b) Statistical analyses.
  c) A. F. Tuck and R. E. Newell will lead this activity, with input from other investigators.
- Observe evidence for recirculation of air between the tropical troposphere and stratosphere.
  a) Need vertical profiles in the deep tropics of long-lived tracers (O_3, CH_4) and aerosols.
  b) Statistical analyses.
  c) A. F. Tuck and D. W. Fahey will lead the activity, with input from other investigators and guided by R. A. Plumb.
- Test the hypothesis that there is a "mirror-image" Walker Circulation in the lower stratosphere over the tropical Pacific.
  a) Temperature, pressure, H_2O, and O_3 required; CH_4 useful. Flight track crossing the equatorial Pacific needs be oriented in an E-W direction in the lower stratosphere. One such flight in each deployment is needed to assess seasonal differences.
  b) Examination of horizontal gradients of relevant species and temperature, radiative and transport modeling also will be performed.
  c) A. F. Tuck and D. W. Waugh will lead this activity with input from other investigators.
- Make observations to further explore particle production at the tropical tropopause.
  a) Aerosol, temperature, pressure, and H_2O critical. Upper troposphere and lower stratosphere measurements on or near the Equator required.
  b) Statistical analyses and aerosol production modeling.
  c) J. C. Wilson will lead this activity.
- Extend the horizontal scales in the tropical UT/LS upon which fractal behavior has been observed by a factor of four and combine the overlapping spatial scales with satellite data to understand the processes at work.
  a) O_3, temperature, CH_4, H_2O critical, other aircraft measurements useful.
  b) Compute probability distribution functions (PDFs) and fractal indices for individual flights, and examine statistics over all flights.
  c) A. F. Tuck, E. C. Richard, and S. J. Hovde will lead this activity, aided by R. E. Newell.
- Observe convectively generated, tropical gravity waves with long, horizontal wavelengths and estimate their contribution to the momentum budget of the tropical lower stratosphere.
  a) MTP measurements taken over long flight tracks at a single level in the lower stratosphere, flight level temperature and navigational horizontal winds needed.
  b) Spectral analysis and gravity wave modeling
  c) M. J. Alexander and M.J. Mahoney will lead this activity.
- Use tracer observations coupled with transport models to examine mixing processes and bulk transport into and within the tropical lower stratosphere.
  a) Pressure, temperature, O_3, and CH_4 critical, meteorological analyses also required.
  b) Statistical analyses, trajectory modeling, tracer-tracer mixing modeling and chemical modeling.
  c) R. A. Plumb, K. H. Rosenlof, and D. W. Fahey will lead this activity.

3.6.2 Quality Assurance Approach — *IP-Section 2.8.2*

Data used in the GHATTEX interpretive studies need to be highly accurate and precise. Individual instrument investigators will be responsible for ensuring the quality of their data via in-flight or ground-based calibrations. All instruments except CO_2 have flown autonomously before, and have established calibration procedures. The GHATTEX CO_2 instrument design and calibration procedures will follow that of a NOAA/AL instrument which has flown autonomously on the NOAA WP-3D aircraft. Instrument PIs will be responsible for submitting flight data to the archive after a careful evaluation for quality factors specific to their instrument.

3.6.3 Data Protocol — *IP-Section 2.8.3*

All GHATTEX Project Team members subscribe to the following eight points of the data-sharing agreement as implemented in previous high-altitude airborne projects:

1) Preliminary data in graphical form should be available to all Science Team members within 24 hours after a flight.
2) Data that have undergone quality assurance checking by the respective Instrument PIs should be submitted to a common archive available to all Science Team members within 30 days after a flight.
3) Final data will be due 6 months after completion of the final GHATTEX flight. Submission of test flight data, although encouraged, will be up to the instrument investigators' discretion.
4) One year after the final flight, data will be made publicly available. This will be within 6 months after the formal end of the GHATTEX Project.
5) Each investigator's data are considered proprietary until the data are published in the refereed literature, or are published and released via the GHATTEX archives to the science community.
6) Individual GHATTEX members may release their proprietary data to whomever they wish. They may not release data of other GHATTEX members without consent.
7) An investigator whose proprietary data are to be used in an investigation has the right to be included among the authors of any resulting publication, but must work with the authors to determine such need.
8) GHATTEX members publishing results must always provide appropriate acknowledgement and citation of those who collected and provided the data, regardless of contribution to the publication.

3.6.4 Archival Plan — *IP-Section 2.8.4*

A common password protected ftp archive will be established at the NOAA Aeronomy Laboratory. Data files following the NASA/Ames file format used for previous NASA ER-2 aircraft experiments will be submitted to that archive.

One year after the final GHATTEX flight (within 6 months after project completion), the archive will be moved to an anonymous ftp site on a NOAA/AL computer. The archive will also be made available to any requesting NASA data center and a CD-ROM produced. NOAA/AL has already hosted a password-protected data archive for two NASA WB-57F aircraft experiments, so no software development is required. Software currently in place automatically checks the files for format errors upon submission, and notifies the file creator as to any problems with the file. One computer to handle the GHATTEX data will need to be acquired prior to the first GHATTEX flights. S. J. Hovde and K. H. Rosenlof will be responsible for establishing and maintaining the data archive.

3.6.5 Roles and Responsibilities — *IP-Section 2.8.5*

Instrument investigators will be responsible for checking the quality of their data and submitting data to the project archive in a timely manner as detailed in the GHATTEX data protocol given in **Section 3.6.3**. Instrument investigators will work on data analysis activities both independently and in conjunction with theory members of the GHATTEX Science Team. Specific analysis investigations and responsible Science Team members are listed in **Section 3.6.1**. Additional analysis will be the responsibility of the individual investigators. Data archive maintenance and CD-ROM preparation will be the responsibility of NOAA/AL.

4.0 Technical Plan — IP-Section 3.0

4.1 Payload Integration Plan — IP-Section 2.3

The approach to payload integration is conservative and driven by USAF constraints, by schedule and by cost. The primary consideration was to reach a payload installation design that would satisfy the scientific requirement for instrument inlet access to aerodynamically clean air (representative of the atmosphere), and also the USAF requirement that modifications to the airframe be minimal and rapidly (hours to one day) reversible. In addition, existing Global Hawk payload electrical and signal interfaces must be used.

The integration concept for the GHATTEX payload is for it to take the place of the SAR antenna and radome underneath the aircraft just below the wing attach points. The existing SAR radome will be replaced by a custom-built fiberglass fairing structure (FFS) with a similar aerodynamic envelope as the current SAR radome, but with the instrument air intakes and exhaust included. The instruments will be bolted to the easily attachable and detachable Airborne Payload Mounting Plate (APMP), and covered by the FFS. The location of the instruments within the FFS will be aided by the large payload volume margin. The enclosures of the new and existing payload components will mount in the payload area without interference from other payload components.

The Global Hawk's Integrated Mission Management Computer (IMMC) will control the GHATTEX AC and DC payload power using the same two output discrete commands now used to control the sensor payload power, and will use its avionics MIL-STD-1553 bus to communicate with the GPCC. The GPCC will be tested with a simulator during the integration preparation process.

Payload integration begins upon delivery of the instruments to the NOAA Aeronomy Laboratory with the electrical signal checkout of the interconnect cable between the GPCC and each of the instruments. This is followed by integration of the instrument control software running in the GPCC, and the verification that it functions as expected. In parallel, the mechanical design work required to mount the instruments on the APMP is completed, so that upon delivery of the bare APMP plate from NG-RAC, the instruments can be mounted on it and fit checked with all of the other instruments. Lastly, a final checkout of the APMP is completed at the Aeronomy Lab prior to its delivery to the NG-RAC Global Hawk Systems Center.

Upon receipt of the APMP at the NG-RAC Global Hawk Systems Center, aircraft integration testing will be performed in order to verify that:

- the interface with the IMMC works as expected;
- the instrument status information is correct;
- the payload APMP is compatible with the aircraft's electrical system; and
- there are no issues that would affect the safety of flight.

Upon completion of the final safety-of-flight checks in the Global Hawk Systems Center, the APMP will be delivered to the Birk Flight Test Facility located at EAFB Southbase where the Global Hawk UAVs are located. Once the APMP is delivered to Birk, the mechanical installation of the mounting adapters, electrical signal cables and the APMP is completed. After completion of the mechanical installation work on the UAV, the GHATTEX payload will undergo a series of tests including:

- an EMI compatibility check;
- a systems functional check;
- an engine run check;
- a pre-flight check run-through; and
- several taxi tests.

Once all of the aircraft integration work is completed, a flight readiness review (FRR) is held to show that sufficient testing has been successfully completed prior to first flight, and that the aircraft along with the payload is ready to perform its mission. The FRR will be conducted by the Global Hawk Chief Engineer's Office, WPAFB.

Once payload integration has been physically achieved and approval for flight has been obtained, there is provision for 24 hours of test flight(s) within the EAFB R-2508 flight test complex (see **IP-Figure 2.3-1** for a map of the R-2508 restricted airspace complex). The first flight will be a short one of 4 to 6 hours duration, and will primarily be used to verify that the instruments function as expected, that the in-flight operating procedures associated with the payload are checked out, and that the GHATTEX Project Team become familiar with the standard Global Hawk flight test routine. The last of these local test flights will be planned to include long flight segments near the high tropopause in order to expose instruments to low temperatures.

4.1.1 Payload Characteristics and Margins — *IP-Section 2.3.1*

The GHATTEX payload instruments are specified in **IP-Table 2.1-2**, and their operational history in terms of research flights and hours by aircraft platform are shown in **IP-Table 2.3-1**. The total GHATTEX mass and power budgets, together with the capacity remaining on the Global Hawk, are shown in **IP-Table**

2.3-2. The payload volume occupies less than 50% of that available in the SAR payload area (see **Figure 3.2-2**).

Since the instruments were designed for and have operated in unpressurized, unheated space at up to FL680 at temperatures as low as -89ºC on the ER-2 and WB-57F aircraft, adequate environmental controls are already in place, as an integral part of each instrument. The operational histories for the ER-2 and WB-57F instruments were obtained under certification by the NASA authorities at Ames Research Center, Dryden Flight Research Center and Johnson Space Center. The CO_2 instrument was certified by NOAA for flight on the WP-3D at the agency's Air Operations Center, MacDill AFB, FL, and the new CO_2 instrument will be qualified through similarity and test.

4.1.2 Payload Integration Issues and Concerns ***IP-Section 2.3.2***

As can be seen from **IP-Table 2.3-2**, there are generous margins for aircraft power and weight capacity. Therefore, the aircraft's performance and its ability to support the GHATTEX requirements are a low risk. This assessment will be further examined after the planned USAF flights of the Global Hawk to the equator and back, and to Australia and back prior to the performance of the GHATTEX mission flights. The payload installation was designed to be simple, and to use the existing aircraft infrastructure that currently supports the surveillance payload. There are no concerns in regard to the ability to rapidly convert the aircraft back to its surveillance configuration due to the modularity of the GHATTEX payload, and the fact that the aircraft modifications specific to GHATTEX are minor and do not interfere with the normal operation of the aircraft.

There are two areas to which the payload team will pay particular attention as GHATTEX unfolds. One is the payload integration; but the concern here is no greater or less than when the integration is on to a manned platform being used for the first time. An example is the WAM and ACCENT integration on the WB-57F of several instruments designed for the ER-2. The engineering team from NG-RAC and from the NOAA Aeronomy Laboratory (T. L. Thompson, R. H. Winkler) and the Instrument PI teams have long experience in the electrical, electronic and mechanical installation of sophisticated instruments on to high altitude aircraft.

A second area to which extra attention will be paid is in the implications of 25 and 32 hour flights for the instruments. All the instruments have successfully completed typical ER-2 and WB-57F flights of 8 and 6+ hours respectively, with the water, ozone, and MTP instruments having completed a 10.3-hour flight from Stavanger (59ºN, 6ºE) to Wallops Island (38ºN, 75ºW). All have been exposed for at least 6 hours at temperatures colder than -77ºC in unpressurized and unheated spaces, and have been run continuously in the laboratory for periods of days. As part of the instrument payload evaluation at the NOAA/AL in the integration phase, the payload instrument suite will be run for periods in excess of 32 hours, the planned duration of mission flights. Test flights will operate the instruments for extended periods and expose the payload to low temperatures. None of the instruments use cryogens, so payload preparation times and flight duration will not be constrained by cryogen hold times. The instrumental data are not being telemetered to the ground in real time, because of the cost to modify the UAV communications system for that purpose and because Ku SATCOM coverage is not available in the regions that GHATTEX will be flying in. However, the "health of the instruments" will be available in real time, and a rotation of scientists will be provided for consultation with the CCO in real time during each flight, particularly as regards the application of go/no-go criteria.

4.1.3 Instrument Modifications and Payload Integration Planning ***IP-Section 2.3.3***

For the GHATTEX science payload, a suite of seasoned instruments was chosen that have a demonstrated successful flight history on the NASA ER-2 and WB-57F aircraft. In addition several of the instruments were also deployed on other platforms. Only two items will be new in the suite: a newly constructed CO_2 instrument and the GHATTEX payload control computer (GPCC). The CO_2 instrument is based on a commercial instrument. Two prototypes have already been extensively operated (> 200 hrs) by the Aeronomy Lab on the NOAA WP-3D and the NSF/NCAR Electra aircraft while conducting air quality research. On other platforms like the ER-2 and WB-57F, either the pilot or the scientific observer have command over the operation of the scientific payload via on/off switches. On the Global Hawk, the GPCC will take over this function. It will control the power distribution to the science payload and communicate with the separate instruments to monitor their health. The GPCC will use an off the shelf processor (PC104) and will be designed with the knowledge gained from the development of NOAA/AL computer-controlled instruments. These well-seasoned instruments are operated by Instrument PIs who are well-versed in adapting their instruments on to various platforms.

The integration process for the individual instruments can be broken down into three major task groups: mechanical, electrical and communications integration. All the instruments need to be mounted on the APMP, all need sampling inlets (except MTP and MASP), and some also need exhaust ports. The GPCC will provide power and communication connections to all instruments. Software needs to be written and tested that allows the individual instruments to communicate their health to the GPCC. Discussions with NG-RAC about the integration and all the pertinent issues are well underway. The specific modifications to individual payload instruments are documented in **IP-Sections 2.3.3.2** through **2.3.3.8**. Onboard communications and interface control document (ICD) development are described in **IP-Sections 2.3.4** and **2.3.5**, respectively.

The choice of the platform will make the mechanical and electrical integration straightforward and consequently low risk. All instruments aside from the MASP - which will be mounted to the wing structure - will be located in the SAR bay. Individual instruments are contained in one or more metal boxes that will be mounted to a common structure, the APMP. This concept allows integration and subsequent testing of the science payload separately before it is installed on the airframe. The mechanical integration will entail the design and fabrication of clips and brackets that tie the various boxes to the APMP. The design will be done in contact with NG-RAC which in turn is responsible for certification of structural integrity. The inlets and exhaust will be integrated and mounted to a new fairing (FFS) that NG-RAC will provide. The MTP instrument uses a microwave transparent window. This window will be integrated into a sub-fairing which then mounts to the FFS.

For the electrical integration we will tap into the science power bus in the SAR bay. The power distribution to the individual instruments will be controlled via individual sets of GPCC activated relays. Separate power harnesses for each instrument will be manufactured.

Communication between GPCC and the each instrument's internal computer will proceed via RS-232 communication protocol. The communication protocol will be developed in close contact with the Instrument PIs by Mr. T. L. Thompson of NOAA/AL who will build the GPCC. Since there is only limited bandwidth available on the standard communication and control links from the mission control center to the Global Hawk, only limited data regarding instrument status and observations will be sent to the operations center.

The communication between GPCC and the Global Hawk control and communications components is accomplished via a MIL-STD-1553 interface. NG-RAC will define the communication protocol with the GPCC.

The payload integration will take place in several steps at several locations. It will start with the preparation of the instruments at their home institutions while NG-RAC designs and fabricates the APMP. After the APMP is delivered to NOAA/AL ten months after kickoff, the mechanical installation of the individual instruments and the GPCC will proceed. Also the power harnesses and communication harnesses from GPCC/power distribution to the separate instruments will be fabricated. Once this is accomplished, the operation of the science payload integrated on the APMP will be tested and verified (see **Figure 5.4-1**, Project Schedule**).**

The completed scientific payload will be shipped to NG-RAC 16 months after Program kick-off. At NG-RAC the payload and the power and communication interfaces will be tested on a simulator. After successful demonstration of performance and confirmation of no interference, the payload will be send to EAFB for integration on the airframe.

4.1.4 Payload Certification and Test Flights — *IP-Section 2.3.6*

The majority of the instruments that comprise the GHATTEX payload have already been certified for flight in the expected UAV environment, and will require no further instrument level certification testing. The two subsystems requiring additional testing are the GPCC and the CO_2 instrument. These two subsystems will undergo a series of environmental tests in order to ensure that they will function in the expected environments. These environmental tests will include at a minimum, a vibration test per MIL-STD-810 using the defined UAV vibration levels (4.12 g rms for a minimum of 15 minutes in each of the three axes), and a temperature–altitude test per MIL-STD-810 in which the subsystems will be subjected to the equivalent altitude and temperature environment expected at 65,000 ft.

Certification of the payload for flight on the Global Hawk entails more than verifying that the instruments will operate properly in the expected environments. Certification also requires a sufficient level of system level testing to verify the function of the flight-critical systems necessary to accomplish mission objectives. (The expected verification testing has already been defined above in the introduction to **Section 4.1**) The culmination of this testing results in a FRR, where the Chief Engineer of the Global Hawk Special Program Office has an opportunity along with his staff and support organizations to examine the test data. The result of the FRR is then the approval for flight of the GHATTEX mission.

After the FRR, one additional test will be performed, the "takeoff-abort" test. This test is usually performed a few days prior to the first flight after a major change in the aircraft configuration, and requires the entire mission crew, including the GHATTEX support personnel, to go through the mission launch procedures just as if the aircraft was going to fly. The aircraft is prepared for flight and towed out to the mission start waypoint, powered up normally, commanded to taxi to the runway, and then commanded to takeoff. The rotation speed (V_R) during pre-flight is set very low, so that the aircraft will automatically abort the takeoff.

A few days later, the first test flight of the GHATTEX mission will be flown entirely within the R-2508 restricted range complex. As stated above, the first test flight will be a short one of 4 to 6 hours duration, and will primarily be used to verify that the instruments function as expected, that the in-flight operating procedures associated with the payload are checked out, and that the GHATTEX Project Team is familiar with the standard Global Hawk flight test routine. There is provision in our proposed budget for a total of 24 hours of "test" flights, and for planning purposes we expect to need only one additional test flight in which the aircraft will fly a 16- to 20-hour mission. This second test flight will include long flight segments near the high tropopause in order to expose instruments to low temperatures.

The performance of the interface between the aircraft and the payload during test flights will be monitored by NG-RAC and NOAA/AL engineers. The performance of the instruments will be monitored, and selected housekeeping and science data recorded by the GPCC **(IP-Section 2.3.4)**, in addition to the storage of such data which is built into each instrument. The long performance heritage of the instruments will serve as a benchmark against which fully satisfactory performance during the test flights can be established. The Project PI, in close consultation with the Instrument PIs, will decide when the payload is science ready (see Science Readiness Review, Project Schedule, **Figure 5.4-1**).

4.2 Deployment Plan — IP-Section 2.4

The deployment plan will consist of a test flight period of 4 weeks and 2 mission deployments of 3 weeks each during which the instrument teams and the science team deploy to EAFB. The test flights and mission deployments each include a one-week contingency period to allow flexibility in meeting objectives. All flights will launch and recover from EAFB. The test flight period will begin 16 months after receipt of funding, and use the 24 hours budgeted for test flights. The first mission deployment in winter 2002/2003 will include one 'meridional' transect flight and one 'triangular' Pacific Basin flight (see **Section 4.3**). The second mission deployment will include the same pair of flights in the period July – September 2003. This pattern of flights will meet the requirements for long surveys of the tropical Pacific, both well into the Southern Hemisphere, and of the equator to Australia, in the seasons that offer maximal contrast in the temperatures near the tropical tropopause. The GHATTEX Project Schedule has large flight windows for each of the summer and winter flights and a backup winter flight window to provide substantial flexibility in achieving the planned number of flights. The Project Schedule is shown in **Figure 5.4-1**.

4.2.1 Deployment Concept — IP-Section 2.4.1

The Birk Facility at EAFB will provide the space used during deployments. With the exception of the MTP instrument, the payload instruments and their support equipment will be shipped from Colorado three days before the beginning of each three-week deployment. The MTP instrument will travel from JPL (Pasadena) to EAFB by a method selected by the instrument PI. The shipment from Colorado will be made with a single air-conditioned, air-ride moving van. This shipping method has proven successful in previous deployment activities involving the NASA ER-2 and WB-57F aircraft. Other shipments of instruments and support equipment to NOAA/AL, to the NG-RAC facilities in California, and to the Birk Facility will be handled separately by individual investigators as needed.

The laboratory space will be in the Birk Facility in close proximity to the Global Hawk hangar space. The payload will be bolted to the APMP at the NG-RAC Global Hawk Systems Center, delivered to the Birk Facility, and electrically connected to the IMMC via the GPCC. It will then be tested for electrical, mechanical and scientific functionality with the FFS attached in place with the air inlets embedded.

The next stage will be to perform taxi tests with the payload and its fairing in place, according to the procedures established by NG-RAC/USAF for Global Hawk operations. Two such trials are planned. Following successful completion of taxi trials, the first test flight will be under taken. If the instruments function normally, as revealed by the "health of the instruments" data stream, the flight will be continued to six hours duration and the Global Hawk recovered. The instrument teams will then analyze the scientific data for quality and completeness. Instrument adjustments will be undertaken as needed based on the data analysis. Further test flights will be scheduled as deemed necessary by the Instrument-PI group and aircraft operations personnel until test flight requirements are satisfied. After instruments are performing satisfactorily, the time remaining in the total of 24 test-flight hours will be used in a last test flight to expose the payload to low ambient temperatures near the subtropical tropopause over EAFB. After the test flights, the first mission deployment will include the two winter flights, starting with the 25-hour Meridional TransEquatorial flight ((34ºN, 118ºW) → (35ºS, 111ºW) → (34ºN, 118ºW)). After this flight, the 32-hour Triangular TransPacific flight will be undertaken (see **Section 4.3**). During the next six months, the data will be analyzed so as to provide maximum feedback and insight for the repeat of the flight pair during the following summer. After the summer pair of flights, the remaining months will be used for scientific data analysis.

4.2.2 Facility Needs — *IP-Section 2.4.2*

The needs for the deployment of the GHATTEX payload and Science Team to EAFB are as follows:

- Space for the payload and Science Team at the Birk Facility where the Global Hawk is based.
- Minimum 1500 sq. ft. of space, enclosed by walls and roof, air conditioned, with clean, sealed floor.
- 27 standard tables, approximately 60" L x 36" W x 30" H with one chair for each table.
- Access door to permit entry of ground carts up to 48" width.
- The following power supplies must be readily distributable among the tables:
  - 60A, 60Hz, 115 VAC; 7kVA, 400Hz, 115 VAC; 3kW, 28 V DC
- Two computer drops, easily connectable to hubs
  - NOAA/AL will supply each 16-port hub connectable to the table locations.
- 32 addresses for connectivity to the Internet via the hubs.
- Access to GHATTEX home institutions through any firewall is required.
- Access for GHATTEX Project Team to the facility through any security checks that apply. There are 7 non-U.S. citizens involved, 3 Canadians, 1 German, 2 Britons, and 1 New Zealander. Of these, 2 Canadians and 1 German are part of the Instrument PI teams for whom access to the Global Hawk in the Birk Facility is essential. All non-U.S. citizens are permanent residents or possess a work visa.

The hangar, range, communications and support needs are to be supplied by USAF through EAFB, and are in regular use by the Global Hawk. Facilities costs have been provided by EAFB and are included in the GHATTEX budget (see also commitment letter from EAFB in **Appendix C**). Deployment activities will be scheduled when support can be provided by 452nd Flight Test Squadron (FLTS) at EAFB.

4.2.3 Expendables — *IP-Section 2.4.3*

Expendables will be carried on board the aircraft by three instruments and used on the ground during deployments. The materials all have established handling procedures and do not pose a hazard to personnel. No cryogens are used on board the aircraft. Further details are provided in **IP-Section 2.4.3**.

4.2.4 Scope — *IP-Section 2.4.4*

The plan is for three deployments to EAFB:

(1)	Test flights	September 2002	3 wks plus 1 wk contingency	
(2)	Winter flights	November 2002 - March 2003	2 wks plus 1 wk contingency	2 science flights
(3)	Summer flights	July - September 2003	2 wks plus 1 wk contingency	2 science flights

Each deployment period includes a one-week contingency to extend the deployment if instrument, platform, weather, or other difficulties arise. The planned order of flights within the winter and summer deployments is the Meridional TransEquatorial flight followed by the Triangular TransPacific flight (see **Section 4.3**).

4.2.5 Deployment Readiness Review — *IP-Section 2.4.5*

A Deployment Readiness Review (DRR) will be held at monthly intervals during GHATTEX using email inquiries to the Science Team, with issues structured according to the WBS (**Figure 5.2-1**) and Project Schedule (**Figure 5.4-1**). In this way, every activity important for the deployments will be under periodic review.

Reviews will be held as teleconferences conducted by the GHATTEX Project PIs from Boulder during which all activities critical to success will be reviewed. Dr. Tuck and Dr. Fahey will be responsible for determining review objectives and conducting the review. Deployments will be scheduled only after a successful Flight Readiness Review **(Section 4.1.4)** that will address payload integration status. When the payload is deemed ‘flight ready,’ the Test Flight Readiness Review will be conducted to address issues and scheduling of the Test Flight Deployment **(Section 4.1.4)**. Two further DRRs will precede the Winter and Summer Deployments, respectively. The Science Readiness Review will signal the successful completion of the test flight phase. The timing of these reviews is available in the Project Schedule **(Figure 5.4-1)**.

4.2.6 Schedule — *IP-Section 2.4.6*

The GHATTEX Project Schedule is specified in **Figure 5.4-1**. Test flights are planned in September 2002, followed by winter flights in the period November 2002 to March 2003 and summer flights in the period July to September 2003. The project flight windows provide flexibility to schedule the three-week deployment period and with consideration of other USAF commitments of Global Hawk personnel and resources.

4.2.7 Roles and Responsibilities — *IP-Section 2.4.7*

We view it as essential to have key roles performed by individuals who are not only fully qualified, but who have shared participation in GHATTEX from its inception. **IP-Table 2.4-1** lists the roles and responsibilities of the principal participants of GHATTEX. In several cases, more than one name is listed against the role. In each case, the responsibility is that of managing the execution of the duties associated with the role, which will often involve a sub-team of others.

4.3 Flight Plan — IP-Section 2.5

This section will define the GHATTEX project flight concept, and all of the relevant parameters associated with planning and actually carrying out the proposed flights. Mission planning will be performed by NG-RAC, with input from the Project PIs and the Project Coordinator, using the standard mission planning procedures already established for the operation of the Global Hawk UAV. The actual mission plan is generated using an Air Force Standard mission-planning tool known as AFMSS (Air Force Mission Support System) that has been adapted for use on Global Hawk. In addition, there are several documents that have been used in the Global Hawk mission planning process and will be used in GHATTEX. These documents include “AFFTC Instruction 11-1, Edwards AFB Range Procedures” (**IP-Appendix H**), and NG-RAC Document Number 367-5000-891, “Global Hawk Mission Planning Guide.” The mission flight concept and flow are described in **IP-Section 2.1.1** and **IP-Figure 2.1-1**.

4.3.1 Mission Flight Concept — *IP-Section 2.5.1*

GHATTEX proposes two pairs of flights, one pair occurring during northern winter, and one pair of flights during northern summer. Each pair of flights consists of a Meridional TransEquatorial flight in the Eastern Pacific region, and a Triangular TransPacific flight in the Central Pacific region (see **Figure 4.3-1**).

The Meridional TransEquatorial flight will originate out of EAFB located in California’s Mojave Desert, and stay within the R-2508 restricted airspace complex (**IP-Figure 2.3-1**) until the aircraft is above FL450 (45,000 ft). The aircraft will then proceed along its programmed route over sparsely populated areas to the coast, fly south-southeast along the coast in international airspace to intercept the 111° meridian, proceed due south along the 111° meridian to 35° south latitude in international airspace, then return along the same route. The outbound leg will be flown using the aircraft’s normal cruise climb mode at an altitude no higher than FL650, and thus will be in the lower stratosphere. During the return leg, the aircraft will be

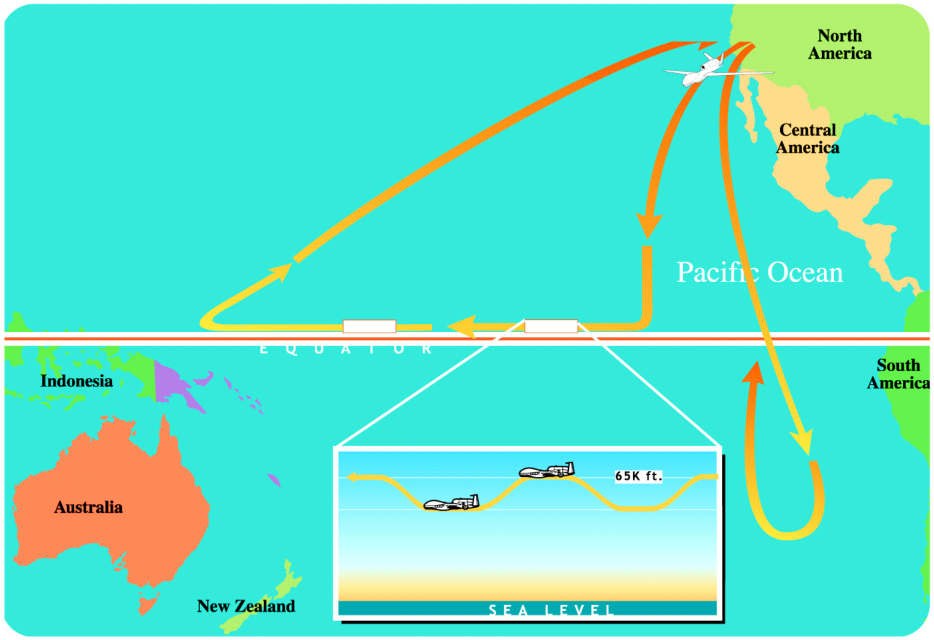

Figure 4.3-1 Schematic of proposed flight plans for the Global Hawk UAV. The two mission flights in each science deployment will be the Meridional, TransEquatorial flight followed by the triangular, TransPacific flight. Both flights will take off and land at EAFB, CA.

commanded to descend to and fly at three discrete altitudes for sampling purposes. These three discrete altitudes are currently planned to be FL450, FL500 and FL550. After the discrete altitude sampling is completed, the aircraft will be commanded to climb back to nominal cruise altitude taking samples along the route back to EAFB.

The Triangular TransPacific flight will also originate out of EAFB, and will again stay within the R-2508 restricted airspace complex until the aircraft is above FL450. The aircraft will then proceed along its programmed route over sparsely populated areas to the coast, proceed south along a great circle route to (7°N, 135°W) in international airspace. Once the aircraft reaches 7°N latitude, the aircraft will proceed along the 7°N parallel until reaching approximately 155°E longitude. At (7°N, 155°E), the aircraft will fly a great circle route back to EAFB. During the portion of flight along the equator, the aircraft will be commanded to descend down to FL450 several times in order to take samples at these lower altitudes.

4.3.2 Flight Planning Criteria — *IP-Section 2.5.2*

Each mission flight will have specific flight plan criteria. During the test flights, aircraft systems and the instrument payload will be the dominant considerations (see **Section 4.3.3**). Flights will be planned to demonstrate the performance of each with flights of increasing length. Flight tracks will remain over the EAFB range where air space management issues are routine for the Global Hawk Test Team (see **Section 4.5**). For the mission flights, scientific flight planning criteria will be added in addition to the aircraft and instrument criteria.

4.3.2.1 Scientific flight planning criteria — *IP-Section 2.5.2.1*

Meteorological flight planning tools for high altitude aircraft have been developed at the NOAA/AL. These computer programs have been used most recently during the WAM (1998) and ACCENT (1999) missions with the WB-57F aircraft. Input data to the programs consist of NCEP aviation forecasts and NOAA satellite images. Wind, temperature, estimates of cloud top temperature and other derived fields such as potential vorticity were used to plan flight tracks through scientifically interesting regions that were also deemed safe by the WB-57F pilots. Forecast files were downloaded as soon as they become available from the NOAA Information Center and satellite data was obtained from both Unidata and NASA data feeds. For this experiment, safe operation of the UAV around regions of convection is of great concern.

Because of this, more timely satellite information than available through standard Unidata sources is required. During 2001, the USAF will fly the Global Hawk to Australia for an extended deployment. During that time the Global Hawk's operators will undoubtedly gain significant knowledge and experience in flying the aircraft in the vicinity of severe tropical convection. This added knowledge will be incorporated into our flight planning procedures. The required satellite information will be available through USAF channels. However, if needed, CIRA at the Colorado State University can provide GOES cloud top temperatures information on a contract basis. For coverage in the Far Western Pacific, data from GMS or polar orbiting satellites will be required. The U.S. Navy runs a receiving station that can obtain GMS data real time, and initial contacts indicate that they could provide the required information on a contract basis.

Statistically, the highest clouds in the tropical Pacific occur between 100ºE and 140ºE (based on OLR averages). For this reason, the first science flight will transect the equator in the eastern Pacific. This will only require GOES-W data, and avoid regions of statistically most active convection. The coldest cloud top temperatures within range of the planned flights occur in January and south of the equator. Therefore, a longitudinal transect at 7ºN in Northern Hemisphere winter will be quite possible. A mid-summer longitudinal transect will be possible, but will require careful monitoring of conditions via satellite. The location of the Pacific warm pool also impacts where severe convection is likely to occur, and pre-flight-day planning will also take that into account also using current information from satellite.

4.3.3 Go/Go-No Criteria — *IP-Section 2.5.3*

The mission go/no-go criteria can be considered in two parts: the aircraft specific go/no-go criteria and the payload go/no-go criteria. The basic flight planning criteria for the aircraft include taking into account safety of flight issues, contingency and alternative landing fields, and programming in communications frequencies for the long over water flight. These issues are addressed in part in **IP-Appendices E** through **I** and have been taken into account in USAF extended mission flights of the Global Hawk to Alaska and Portugal. The specific aircraft go/no-go criteria include weather related criteria, aircraft system related criteria, and FAA/AFFTC specific criteria. **IP-Table 2.5-1** is a summary of the aircraft specific go/no-go criteria. Implicit in the payload criteria evaluation is that the GPCC must be fully operational.

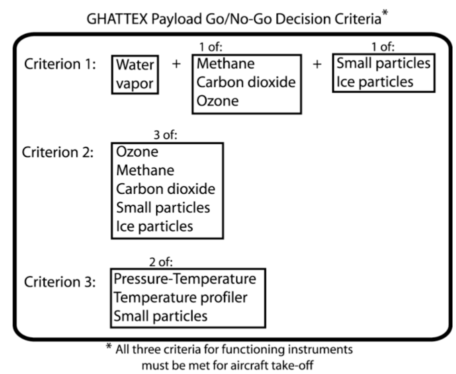

Figure 4.3-2 Go/no-go criteria for Global Hawk UAV payload on mission flights.

The payload specific go/no-go criteria are illustrated in **Figure 4.3-2**. As can be seen from the figure there are three go/no-go criteria associated with the payload, and these can be summarized as follows:

- The water instrument must be functioning and must be accompanied by a measurement instrument which can be used as a tracer near the tropical tropopause, and by some information about the behavior of the particulate matter;
- There must be either two particle measurements or two tracer measurements to accompany at least one in the other category;
- There must be adequate information available post-flight about the prevailing meteorological conditions.

4.3.4 Roles and Responsibilities — *IP-Section 2.5.4*

The USAF 452nd Flight Test Squadron (FLTS) has responsibility for Global Hawk UAV operations at EAFB. The Project PI has responsibility for making the flight plan request, which embodies the Science Team's requirements, to the 452nd FLTS. The flight planning procedure used by the 452nd FLTS has been thoroughly developed and exercised over the 65 flights of the Global Hawk to date (see **IP-Appendix D** and **Sections 4.4** and **4.5**). The Instrument-PI teams have responsibility for preparing their instruments for flight at the deployment site, integrating them on board the aircraft before flight, participating in pre-flight tests and checks, and downloading their instrument after a flight.

4.4 Non-NASA Aircraft Safety Plan IP-Section 2.6

The Global Hawk UAV is a non-NASA aircraft owned by the U.S. Air Force and operated at EAFB. Flight test safety at EAFB (also known as the Air Force Flight Test Center or AFFTC) is governed by a number of U.S. Air Force instructions and guidelines. These guidelines and instructions were followed during the initial developmental flight testing of the Global Hawk UAV, as well as during its operational utility assessment flights. These guidelines will continue to be utilized and followed for GHATTEX, and form the basis for our compliance with NASA's aircraft safety policy. These documents include the following and are provided as addenda to the Implementation Plan (**Appendix I**):

- **IP-Appendix E: Flight Safety and Technical Considerations Guide for Flight Testing, AFMC Pamphlet 91-1, 18 March 1997.** This appendix, written by the Air Force Materiel Command as a guide for U.S. Air Force sponsored flight tests, established the framework in which the Global Hawk flight test process was developed. It essentially provides a "checklist" for what questions need to be raised when performing and conducting flight tests out of the EAFB Flight Test Center, with the specific goal of leading flight test participants to consider all the risk factors that may be encountered during the flight test process.
- **IP-Appendix F: AFFTC Test Safety Review Process, AFFTC Instruction 91-5, 12 July 1999.** This appendix, written by the U.S. Air Force Flight Test Center staff contains specific instructions on how to reduce the risk of mishaps during flight test activities. This instruction pamphlet has been utilized throughout the Global Hawk UAV flight test program as the basis for the preparation and presentation of safety related data to the applicable safety review boards.
- **IP-Appendix G: Range Safety Criteria for Unmanned Air Vehicles, RCC Document No. 323-99, December 1999.** (http://afmc.wpafb.af.mil). This appendix, written by the Range Commanders Council's Range Safety Group, provides guidance on how to answer the question: "Is this unmanned air vehicle safe to fly on my range?" This document was also utilized during the Global Hawk flight test program to further ensure flight safety.
- **IP-Appendix H: Remotely Operated Aircraft Tests (ROA), R-2515, AFFTC Instruction 11-1, Attachment 1, April 1998.** This instruction pamphlet provides specific procedures for the conduct of flight tests of unmanned air vehicles, and is followed for all flights of the Global Hawk. The worksheet at the end of this document is filled out for each Global Hawk flight in order to obtain the appropriate approvals for that particular flight.
- **IP-Appendix I: Preliminary Safety Analysis for the Tier II+ HAE UAV, TRA Report No. 367-4100-159.** This safety analysis was prepared by the NG-RAC system engineering staff prior to the Global Hawk's first flight in order to systematically identify and provide mitigation plans for the specific hazards associated with flight of the UAV. It is important to note that this systematic review of the applicable safety hazards of the aircraft identified no unacceptable system safety hazards. This review is provided here in order to further satisfy NASA's safety policy, and substantiate our assertion that the Global Hawk UAV is safe to fly.

The flight safety review and decision process described in these appendices is currently used by the USAF and NG-RAC in Global Hawk operations and will satisfy NASA requirements for the operation of non-NASA, Department of Defense-owned, aircraft in NASA funded projects. This conclusion was reached in teleconference discussion with Mr. Warren Hall of NASA Ames Research Center in November 2000 who is a NASA-designated safety representative for aircraft operations. GHATTEX reviews are included in the Project Schedule (**Figure 5.4-1**) and listed in **IP-Section 3.2.1**.

The flight testing and safety analysis already carried out for the Global Hawk UAV is the basis of aircraft safety and mission assurance for GHATTEX and the assertion that the Global Hawk UAV is 'safe to fly.' GHATTEX mission flight parameters are within or comparable to those demonstrated to date (see **Sections 3.1-3.3**) and show that the Global Hawk has the capability to meet the flight requirements. The 65 flights of the Global Hawk demonstrate its airworthiness (**IP-Appendix D**). The background and experience of the operators, as developed over the course of the Global Hawk program within the USAF, are adequate to operate the Global Hawk in GHATTEX. The requirements of GHATTEX will not expose the service provider, the USAF, or the manufacturer, NG-RAC, to risks beyond their capabilities. The GHATTEX payload is a suite of customized sampling instruments developed for airborne platforms and, hence, is unique and of high value. The value of the payload and the aircraft warrant operation under strict safety rules.

Also, in compliance with NASA's aircraft safety policy, the Memorandum of Agreement (MOA) executed between NOAA and the U.S. Air Force includes a definition of the roles and responsibilities for conducting flight operations for GHATTEX (see the draft MOA in **IP-Appendix J**). The Air Force will specify that their contractor, NG-RAC, be responsible for conducting the actual flights, with operational oversight by the responsible test organization located at AFFTC. All flights conducted for GHATTEX will continue to follow the standard procedures already established for conducting Global Hawk flights. Also included in our project plan is a formal flight readiness review in which readiness and safety will be assessed prior to the first flight of GHATTEX in accordance with Global Hawk standard operating procedure.

4.4.1 Flight Test Safety of the Global Hawk — *IP-Section 2.6.1*

The process used to approve the Global Hawk UAV for its maiden flight at EAFB began with the preparation, by the Global Hawk development contractor, of the 'Preliminary Safety Analysis for the Tier II+ HAE UAV' (**IP-Appendix I**). This analysis systematically identified safety critical hardware and software areas, provided an assessment of hazards, and documented requisite hazard controls and follow-on actions. The Global Hawk UAV was specifically evaluated for hazard severity, hazard probability, and operational constraints based on the best available data, including mishap data from similar systems and other lessons learned. Safety provisions and alternatives needed to eliminate hazards or reduce their associated risk to an acceptable level were also included in the analysis. A preliminary assessment made for this Implementation Plan identified no hazards unique to GHATTEX that have not already been identified in either **IP-Appendix I** or in the numerous safety review boards held during the flight testing of the Global Hawk UAV.

The Preliminary Safety Assessment (**IP-Appendix I**) was used as source material for preparation of a series of "Safety Review Board (SRB)" briefings as required by the documents cited above. It was the approval of the SRB package that authorized the Global Hawk flight test team to proceed onto the next series of tests in the flight test program. At each major juncture in the test program, an SRB was convened to review the test plans for the upcoming series of tests and any safety risks associated with those tests.

In preparation for an SRB, a detailed flight test plan document was generated that defined test objectives, outlined tests to be performed, addressed special procedures to be followed, and delineated safety and security requirements. In addition, "Test Hazard Analysis" (THA) sheets were also prepared. **IP-Table 2.6-1** provides a list of the SRBs and other applicable flight readiness reviews held. It illustrates that the process used to approve the aircraft for flight was very systematic. Based on the extensive and systematic flight-safety assessments already completed for the Global Hawk, it is judged fully acceptable to undertake GHATTEX flight objectives.

4.4.2 Weather Risk during Science Flights — *IP-Section 2.6.2*

The primary weather conditions that could be relevant for Global Hawk safety in the tropics are deep thunderstorms and temperatures below the -77°C to which the aircraft is certified. These conditions will be known and monitored in real time through the satellite link relaying the aircraft flight data back to the CCO at EAFB, and from the weather satellite data links available there from existing USAF sources, which will also be available from the GHATTEX flight planning suite. The real-time data from the Global Hawk can be used to take avoidance action if the temperature approaches the certification limit, and the satellite data can be used to plan avoidance action from deep thunderstorms. Thunderstorms above 50,000 ft over the continental U.S. in summer have been avoided by these means. By the time of GHATTEX, the USAF will have done flights in the tropical eastern Pacific and out of Australia, including the transit flights to and from EAFB that necessarily transect the region of the GHATTEX triangular TransPacific flights. These operations are underpinned by the considerations in **Sections 4.1** and **4.3.2**, **IP-Appendices E-I** and **K**.

4.5 Airspace Management Plan — IP-Section 2.7

The Global Hawk UAV will be operated only from EAFB during GHATTEX project flights. Global Hawk has been approved for operations over EAFB, in FAA-controlled air space, in international air space, and over the Pacific and Atlantic Oceans (see **Section 3.3**). Operations in all of these areas have been successful. Access to airspace in GHATTEX will follow procedures already established within the Global Hawk flight test program.

The GHATTEX mission flights in FAA-controlled airspace will be conducted in accordance with FAA Order 7610.4J, Chapter 12, Section 9, since the aircraft is a military owned and remotely operated aircraft (ROA). Order 7610.4J, Chapter 12, Section 9 requires that, for the operation of the Global Hawk:

- an FAA approved Certificate of Authorization (COA) be acquired;
- the aircraft be equipped with standard aircraft position lights and high intensity strobe lights in accordance with criteria stipulated in 14 CFR, Section 23.140;
- the aircraft be equipped with an altitude encoding transponder that meets the specifications of 14 CFR, Section 91.215;
- the aircraft lights be operated during all phases of flight;
- the transponder shall be set to operate on a code that is assigned by air traffic control, and that the ROA pilot-in-command have the capability to reset the transponder code while the ROA is airborne;
- the ROA shall be equipped with instantaneous two-way radio communication with all affected ATC facilities;
- the ROA pilot-in-command complies with all ATC clearances; and
- the proponent and/or its representatives, shall be noted as responsible at all times for collision avoidance maneuvers with nonparticipating aircraft and the safety of persons or property on the surface.

The aircraft is currently operated under the auspices of COAs issued by the manager of the Western Pacific Region Airspace Branch (see **IP-Appendix K** for an example of a Global Hawk COA). As shown in **IP-Table 2.7-1**, the aircraft is in full compliance with the requirements of Order 7610.4J, Chapter 12, Section 9, and will be flown in accordance with the provisions of the COA issued for the aircraft during the period of the GHATTEX flights. As a condition of the COA, specific requirements exist for coordination procedures, communications procedures, traffic avoidance procedures, and Lost Link/Mission Abort procedures. These are described in **IP-Section 2.7.1**.

4.5.1 International Air Space — *IP-Section 2.7.2*

The conditions for operating in international air space have been fulfilled by the Global Hawk during its mission to Portugal, and will be fulfilled by USAF flights in a way relevant to both GHATTEX profiles when operating in the eastern Pacific and en route to Australia during 2001. If these missions involve overflight of small islands belonging to other nations, the USAF will handle obtaining overflight permission. The GHATTEX flights could be planned to detour around these nations, if necessary.

5.0 Management Plan — IP-Section 3.0

The GHATTEX management structure shown in Figure 5.0-1 is based on existing relationships between the participants. The Project PI (Dr. A. F. Tuck) will have the primary responsibility for management of the GHATTEX. He will establish adequate information channels to continually monitor all and any part of the project, and instructional channels to implement project decisions. He will preside over an electronic (Internet) forum by means of which discussion of problems and decisions can be effected on a timely and continuing basis. Physical meetings will be held involving project staff as the need arises. Monthly and quarterly reviews of the project will be incorporated as milestones. The lines of communication will go from the Project PI to the following individuals: the Project Co-P.I. (Dr. D. W. Fahey), the Project Coordinator (Dr. G. Hübler), the USAF ASC/RAV representative (1st Lt A. Wehner) (a program manager is to be appointed by ASC/RAV upon award of funds by NASA), the NG-RAC representative (Mr. G. Loegering) (a program manager will be appointed by NG-RAC upon award of funds by NASA), and the Education and Public Outreach coordinator (Dr. S. Buhr). These individuals will have lines of communication into the five task areas (**Figure 5.0-1**), as necessary. The USAF and NG-RAC representatives and managers have responsibilities primarily within their own institutions, while the Project Coordinator will communicate with the Project PIs, the PIs of the Instrument and Theory Teams, and as necessary with USAF and NG-RAC.

The data and information tools by which the Project PI will monitor the project will be the Project Schedule **(Figure 5.4-1)**, the GHATTEX Work Breakdown Structure **(Figure 5.2-1)**, and the Risk

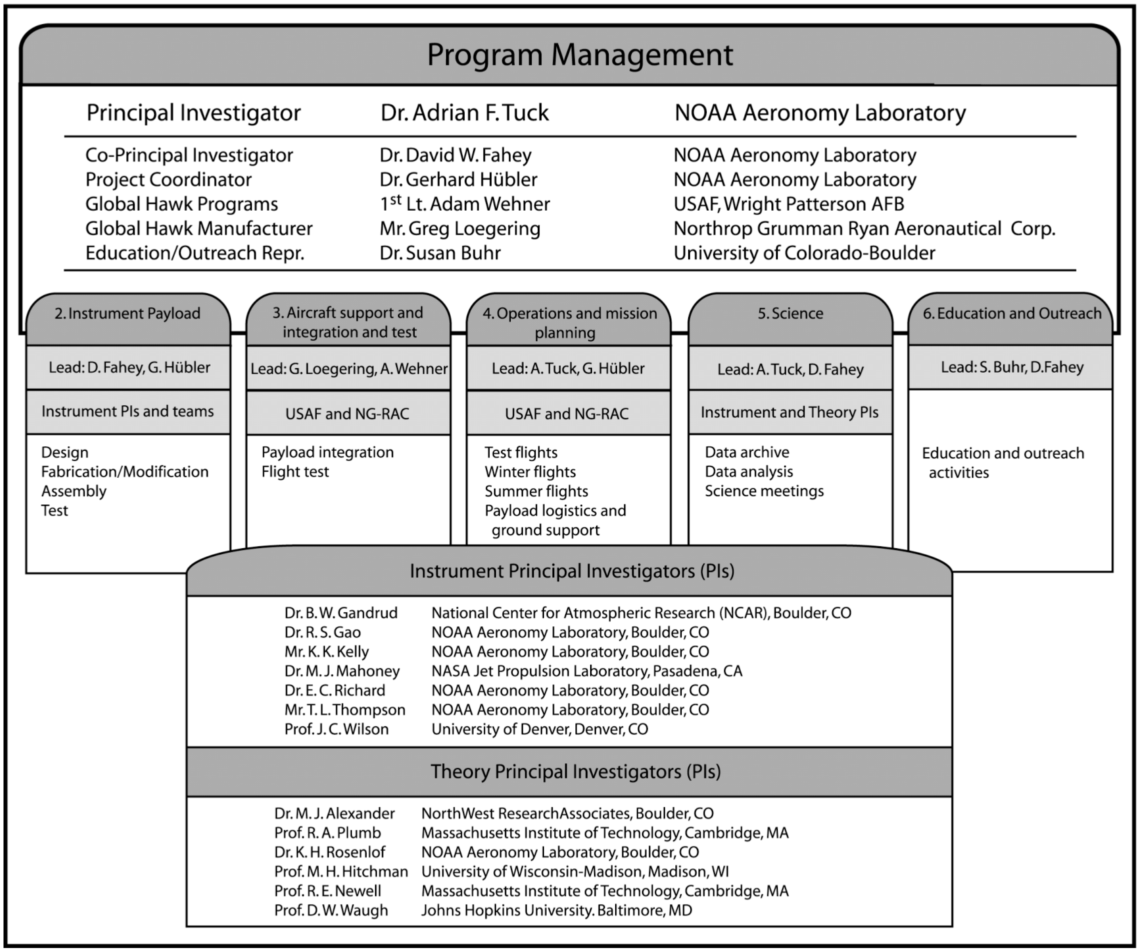

Figure 5.0-1 GHATTEX management structure

Assessment matrix (**IP-Table 3.6-3**) associated with the WBS. Each person identified as having cost and schedule responsibility will be tasked with providing a monthly status report to the Project Coordinator via email. Roles and responsibilities of project personnel are listed in **IP-Table 2.4-1**, GHATTEX Personnel Responsibilities. Management of tasks during the pre-deployment, deployment, and post-deployment phases are described in **IP-Sections 3.1.1, 3.1.2,** and **3.1.3**, respectively.

The primary managerial link from the PI institution (NOAA/AL) is to ASC/RAV, defined in an MOA between NOAA and USAF (**IP-Appendix J**). This arrangement allows GHATTEX to join smoothly to and leverage off the existing management structure for the Global Hawk UAV. This structure has evolved over more than five years and has been shaped by and incorporates system engineering approaches and project control tools. Upon award of funding by NASA, ASC/RAV and NG-RAC will appoint Program Managers for full-time support of the GHATTEX effort. This will facilitate both management of key GHATTEX tasks and avoid conflicts with the baseline USAF program with the Global Hawk.

The management approach for GHATTEX is Integrated Project Management (IPM) as depicted **Figure 5.0-1**. The GHATTEX Project PI has overall responsibility for GHATTEX. The Project PI is supported by the Project Co-PI, Project Coordinator, program representatives from the USAF and NG-RAC, and a Education and Public Outreach Coordinator. These key personnel provide lead the management of all Level 2 tasks of the WBS with direct communication to the Project PI. This management team provides guidance, instruction, and oversight to the larger group comprised of Instrument PIs and Theory PIs. Personnel within USAF and NG-RAC will be managed by their respective institutions. There is communication both vertically and horizontally within the IPM structure in **Figure 5.0-1**, as the project situation demands. Because the GHATTEX requirements were frozen at an early stage, which was in large part possible because of the maturity of the payload instruments and of the platform, the IPM and the WBS were defined in a clear manner early in the genesis of GHATTEX.

The Instrument PIs and the Theory PIs are central to the project; they have the responsibility for managing their individual activities, using the established internal procedures at their respective institutions. The Project Control Plan, described in **Section 5.3**, delineates how the IPM will work coherently in the overall GHATTEX project.

5.1 Roles and Responsibilities IP-Section 3.3

The GHATTEX Project Team and Personnel Responsibilities are listed in **Table 3.2-1** and **IP-Table 2.4-1**, respectively. Changes to personnel from the original proposal are: the addition of Prof. M. Hitchman, Prof. R. Newell, and Prof. D. Waugh as theory investigators; and the selection of Dr. G. Hübler as Project Coordinator. All Team members have qualifications and experience (**Appendix D**) that are highly relevant to their role in GHATTEX, as outlined in the attached curriculum vitae.

The Project PI has overall responsibility for GHATTEX. Specific duties include:

- cost and schedule performance;
- defining the science goals of GHATTEX;
- recommendations to change scope based on the science objectives and available resources in the event of operational difficulties;
- maintaining communication between all participants;
- preparing for and participating in design, safety, and flight readiness reviews;
- distributing funding resources to all participating institutions and monitoring contractual arrangements with non-government institutions;
- assigning the Project Coordinator with essential tasks related to the instruments, aircraft, and field activities;
- flight planning activities related to meeting the science objectives within operational constraints;
- arranging for and leading discussions of the interpretation of flight data; and
- preparing the Science Report from GHATTEX.

The dedicated GHATTEX Project Co-PI has significant advantages for mission planning, mission execution, and scientific data evaluation. The Project Co-PI will support the Project PI in all phases of the project. While the Project PI has overall responsibility for GHATTEX, the Project Co-PI will share responsibility for many aspects of the planning and execution, thereby making the management process more effective and efficient. Sharing responsibility will be particularly important during the deployment phase when many issues need attention and decisions must be made promptly. The Project PI and Co-PI will keep each other fully informed of matters as they evolve so that either could take a decision or action if circumstances dictate.

We note that the Project PI was the Project Scientist for the AAOE and AASE ER-2 and DC-8 missions, which pioneered the airborne investigation of polar ozone loss from the Straits of Magellan and Norway, in 1987 and 1989 respectively. He was also Project Scientist for the ASHOE/MAESA mission from New Zealand and Hawaii in 1994, and for the WB-57F Aerosol Mission (WAM) from Houston in 1998, which was a successful PI-mode project. The Project Co-PI was the Project Scientist for the POLARIS ER-2 mission from Alaska in 1997, and was the Instrument PI for the NO/NO_y instrument on nine ER-2 missions between 1987 and 2000, in addition to being Instrument PI for the new CIMS instrument for HNO_3 during the ACCENT mission in 1999. The Project Coordinator has fulfilled this role on the NOAA WP-3D missions that have used a comprehensive suite of chemical instruments to investigate air quality in the troposphere over the U.S. and the North Atlantic.

The Project Coordinator will work closely with the Project PI and Co-PI to coordinate all aspects of the project. The Project Coordinator will:

- monitor cost and schedule compliance;
- interface between the Science Team and the flight organization;
- handle communication among participants regarding instruments, payload configuration, data handling, and field deployments; and

- act as coordinator for the instrument groups during field deployments.

The GHATTEX management structure (IPM) is shown in **Figure 5.0-1**. The Project PIs, USAF, and NG-RAC will maintain close collaboration and communication regarding the preparation and use of Global Hawk in GHATTEX. Relationships between the Project PI and members of USAF (1st Lt A. Wehner) and members of NG-RAC (Mr. G. Loegering) are already established and will be expanded as needed to address Global Hawk issues as they arise.

The Project Coordinator will act as a liaison between NOAA, USAF, and NG-RAC to coordinate matters pertaining to the aircraft, and project teams during the preparation and deployment phases of GHATTEX. The Project PI will also directly interact with the project teams as needed to help guide the activities related to meeting the science objectives. The Project Coordinator will focus on the technical objectives of establishing payload performance and details of the field activities and the deployment participants. Each team member will have a responsibility to provide a timely response to management requests and timely input concerning matters that affect the ability of the team to meet the science and performance goals of GHATTEX.

The Instrument PIs are listed in **Table 3.2-1**. Each Instrument PI is broadly experienced in acquiring science-quality data in a team approach using aircraft platforms in the upper troposphere and lower stratosphere. Each Instrument PI has unique skills and experience related to their respective instrument. Each Instrument PI has the following responsibilities:

- prepare their respective instrument to be flight-ready to acquire science-quality data using a support team of their choice;
- work within the IPM to design, construct, and integrate their respective instrument and sampling inlet (if needed) on board Global Hawk;
- participate in reviews as requested;
- support their respective instrument during the field deployments for test and mission flights;
- prepare a final data set from each flight and make it available to the data archive and other investigators;
- analyze and interpret their instrument data in the context of other acquired data sets to address the science goals of GHATTEX; and
- cost and schedule control and reporting.

The Theory Team has been chosen to support the interpretation of the acquired data set and participate in predicting the conditions along proposed flight tracks as part of mission flight planning. Theory Team members responsibilities are:

- participate in the interpretation of the aircraft data sets as outlined by GHATTEX science objectives and as described in **Section 3.6.1**;
- participate in predicting the meteorological and chemical context of planned test and science flights; and
- cost and schedule monitoring and reporting.

The Education and Public Outreach Coordinator will be responsible for supervising all aspects of the proposed EPO activities. The Coordinator has extensive experience in planning, designing, implementing, and evaluating similar activities. Other EPO team members will include NOAA/AL, NOAA ERL, and EAFB staff with extensive experience in public outreach, and CIRES Outreach Program staff with extensive and specialized experience. The Coordinator's responsibilities are:

- to coordinate, plan, and carry out all aspects of the proposed outreach activities; and
- cost and schedule monitoring and reporting.

Members of NOAA/AL will provide technical support for the GPCC and for flight data archiving. The individuals providing this support have unique and considerable experience related to these particular tasks.

Other technical support be will provided by members of the USAF at Wright-Patterson AFB and of NG-RAC. The USAF will support and coordinate the use of the Global Hawk in GHATTEX on an as needed/as available basis. Similarly, one or more members of NG-RAC will support and help manage the modification, preparation, and use of the Global Hawk at NG-RAC. Mr. Greg Loegering is the principal NG-RAC contact. The management structure within NG-RAC and the USAF will be responsible for tasking its respective personnel to meet the accepted tasks. The joint NOAA/USAF/NG-RAC management structure will do periodic updates and assessments of progress and make any recommendations to maintain progress. The NG-RAC Statement of Work identifies and assigns all of the tasks associated with preparing and flying the Global Hawk in GHATTEX.

5.2 Work Breakdown Structure IP-Section 3.4

The Work Breakdown Structure (WBS) (**Figure 5.2-1**) shows the principal components of GHATTEX. The Level 2 components of the WBS are Project Management, Instrument Payload, Aircraft Support and Integration and Test, Operations and Mission Planning, Science, and Education and Public Outreach. The WBS components are described in the WBS Dictionary in **IP-Table 3.4-1**. The WBS tasks are nominally divided into pre-deployment, deployment, and post-deployment phases in **Figure 5.2-1**. NOAA, NG-RAC, USAF, and CIRES will share the IPM components (see **Figure 5.0-1**). The Instrument Payload components include all of the measurements and the payload computer (see **IP-Table 2.1-2**). The Aircraft Support component is subdivided into Payload Integration and Flight Test. The Level 3 categories include all principal aspects of the respective components. The Science component includes sublevel categories of data archiving, data analysis, and Science Team meetings. These encompass all aspects of the data analysis process.

The GHATTEX Project Schedule (**Figure 5.4-1**) shows the timeframes of the Level 2 and 3 components and sublevel categories through the three project phases. Some of the components range over more than one project phase. The project reviews and milestones: Kick-off, Critical Design Review, Flight Readiness Review, Deployment Readiness Review, Mission Flights, Science Report Delivery, are also shown in **Figure 5.4-1**.

GHATTEX Work Breakdown Structure (WBS)

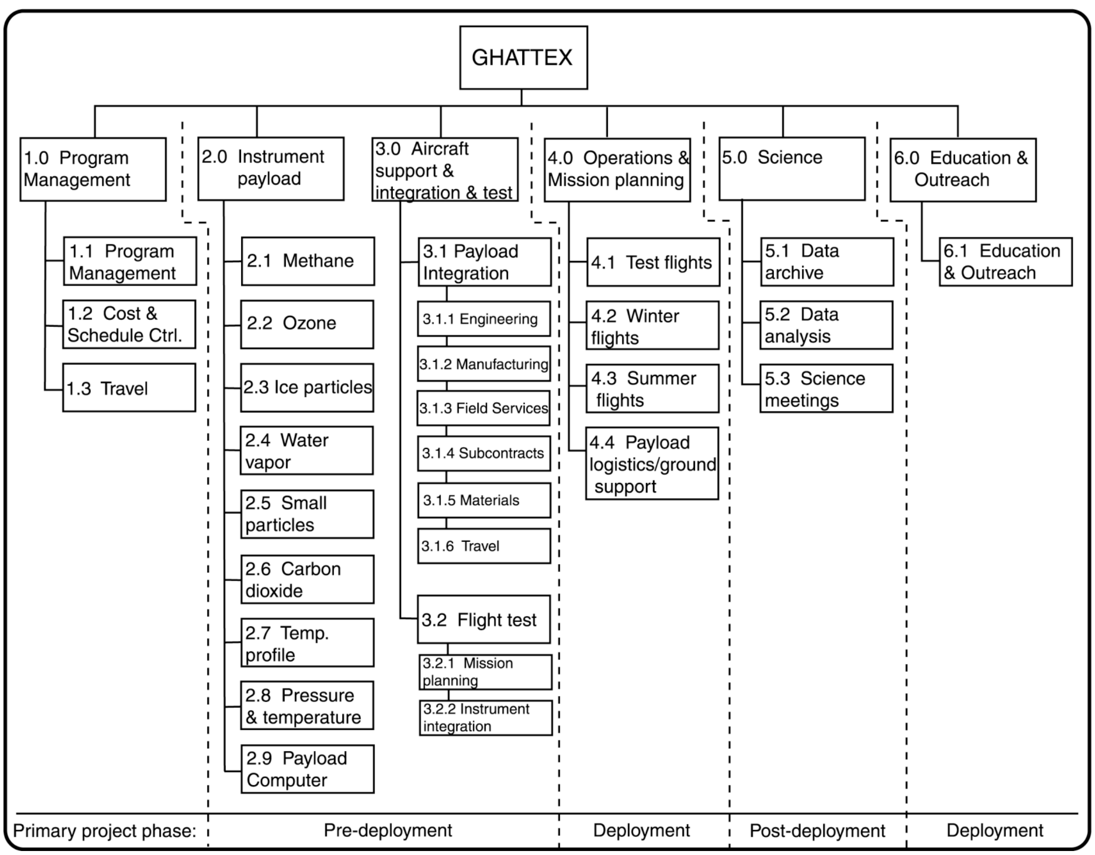

Figure 5.2-1 GHATTEX Work Breakdown Structure (WBS)

5.3 Project Control Plan IP-Section 3.5

The Project Control Plan embodies and administers the plans and processes that are used to define and execute GHATTEX. It includes managements of costs, contracts and configuration, and control of the schedule.

5.3.1 Plans and Requirements *IP-Section 3.5.1*

A well-structured series of management plans developed early in the project control all phases of the GHATTEX project. Documented processes support the plan with an emphasis on preventing rather than reacting to programmatic concerns.

The Project Plan (PP) describes the plans and processes used on GHATTEX. The PP describes how the GHATTEX project is carried out and serves as the controlling document for implementing the GHATTEX project throughout its life cycle. The PP will be prepared at the beginning of the project and is used as the primary guide for executing the project. The PP includes the following elements:

Project Plan Elements
Contracts and SOW
Work Authorization
Work Breakdown Structure
WBS Dictionary
Integrated Project Schedule
Project Reviews and Milestones
Project Organization and Management
System Engineering
Project Budgets and Earned Value Monitoring
Receivable/Deliverable List
Subcontracting
Resource Management and Control

The key to controlling cost and schedule is early definition, documentation, and freezing of top-level requirements, while retaining design flexibility at the subsystem level. At the beginning of the project, the project requirements are formally frozen to establish a technical baseline. GHATTEX has progressively traded technical performance against cost to provide a maximum value. Substantial margins in the Global Hawk capacities prevent mass, power, and volume from being cost and design drivers. Specification of requirements will continue in the design phase of the project. Subsystem requirements are adopted to meet optimized cost and schedule goals for a specified (fixed) performance level rather than to optimize each subsystem. This requires retaining subsystem-requirements flexibility throughout the design phase. With a high percentage of the hardware already existing, changes to technical requirements during the GHATTEX project will be minimal.

5.3.2 Cost Management *IP-Section 3.5.2*

Cost management control requires the maintenance of a baseline plan that remains fixed unless scope changes are approved. This enables a meaningful tracking of cost and schedule variances.

Accumulation of actual costs occurs monthly at Level 3 of the WBS. GHATTEX uses an integrated set of charts, graphs and tables to display the current, past, and predicted future cost and schedule variances using standard earned value system (EVS) techniques. The EVS compares task completion against milestones associated with selected WBS elements. WBS elements are selected for EVS monitoring based on current activity and budget thresholds. Level of effort tasks such as payload integration are compared to the time-phased budget plan. Each element has an earned value attached to its completion status; actual expense is compared to planned expense at any time. The value of incomplete (slipped) work can be readily determined. Slipped work represents unplanned expense to complete, and must be mitigated through recalculation of the planned expense profile or the schedule. The Project PI does this on recommendation from the technical staff and contracting officers in NOAA/AL and can involve allocation of budget or schedule reserves.

Responsible task leaders will analyze cost status and trends for their respective elements. As a minimum, the IPM members convey cost concerns to the Project PI during monthly management reviews and more frequently, if appropriate. Independent project level cost analysis is performed by the Project Coordinator who reports any issues and concerns to the Project PI and IPM team leaders. The variance information is utilized by the IPM team leaders to evaluate programmatic status, and take corrective actions if warranted.

As part of its reserve management program, GHATTEX compares the monthly EVS cost and schedule reports to the budget plan in order to produce estimates of cost at completion. These figures are compared to the project baseline to validate the team's assessment of current project status, remaining efforts, and appropriate use of reserves.

5.3.3 Schedule Control — *IP-Section 3.5.3*

The GHATTEX Project Schedule is shown in **Figure 5.4-1**. Schedule management uses proven tools such as Microsoft Project, providing the project managers with sufficient insight into scheduling issues to detect and mitigate problems early. The Project PI has overall schedule responsibility and will be supported by the top-level IPM managers.

This schedule is updated at the beginning of the project upon completion of the detailed project network. Each individual within the IPM has his or her own schedule that, while consistent with this overall schedule, lays out events and activities in the most convenient and efficient format for his or her particular effort.

Microsoft Project software is used to generate the networks. It has been successfully used on other programs within NOAA/AL. The integrated network, to be completed after project start, identifies the timing for the highest level receivables/deliverables. It readily allows project assessment of any accomplishment deficiency and evaluation of alternative recovery scenarios for IMP consideration and action.

The complete Microsoft Project schedule network defines the work dependencies, the critical path, and the amount of slack in non-critical paths based on inputs of task duration and key anchor dates. The network also defines all of the schedule margin periods in the total project flow and facilitates proactive management of the margin. Schedule output is displayed as a network or Gantt-type charts.

Detailed subsystem schedules have been developed for all hardware, software, and integration elements. Detailed subassembly and program network schedules are developed for the GHATTEX project. Microsoft Project, along with a standard suite of software products, will be used throughout on the project. Subsystem schedules will be rolled-up into one master project schedule, which will then be coordinated and transmitted electronically. The detailed schedule is also the foundation of the GHATTEX performance measurement system.

Schedule reserves are budgeted for each subsystem in addition to the project-wide slack. Potential scope changes identified in the project plan provide additional schedule margin and recovery options for IMP consideration and action.

5.3.4 Contract Management — *IP-Section 3.5.4*

The NOAA contract manager allocates funding to its research partners and is funded by NASA directly (see **Appendix E**). The Project PI acts as the GHATTEX project manager and is responsible for the performance of the contract, and any and all changes that may occur.

5.3.5 Configuration Management — *IP-Section 3.5.5*

The Project PI, in conjunction with the IPM team leaders, defines the configuration program for GHATTEX and documents the policy and procedures. The plan addresses our simple method for controlling changes across systems and organizational boundaries. Configuration management is carried out using the existing practices within the performing organizations.

5.3.6 Project Assessment — *IP-Section 3.5.6*

The assessment of the GHATTEX Project has two aspects. The first is the continuing process by which the Project PI monitors the project as it evolves, using the techniques described above. The scientific assessment of the GHATTEX project at completion will be embodied in the GHATTEX Science Report **(Figure 5.4-1)**. Its production will be a joint activity of the Science Team led by the Project PI.

5.4 Schedule IP-Section 3.2

The GHATTEX Project Schedule is shown in **Figure 5.4-1**. The major scheduled tasks map to the WBS Level 2 tasks (**Figure 5.2-1**). Important reviews, milestones and project phases (pre-deployment, deployment, and post-deployment) are included (see listing in **IP-Section 3.2.1**). Linkages between tasks show the critical path. Start and end dates for tasks are shown along with duration in business days.

Our schedule management process implements:

- planning in early stages to define and understand the work;
- inserting slack and risk mitigation into the baseline plan;
- monitoring performance and updating predictions based on historical performance; and
- reacting immediately to recover delays.

Initial planning for GHATTEX has been accomplished and is captured in our integrated project schedule (**Figure 5.4-1**). This baseline includes funded slack and risk mitigation plans and key decision dates before proceeding to the next phase. During the program, performance against this baseline is continually monitored across all program elements through weekly and monthly meetings. The tools used for schedule management are Microsoft Project and a variety of other software programs.

The team's resources are available to quickly address and resolve problems. Techniques for recovering schedule slips include replanning and rearranging tasks to work around obstacles, applying additional resources (e.g., personnel, facilities, cost reserves), and modifying individual tasks to maintain system schedule. Resources from throughout the team are shared wherever necessary to maintain schedule progress.

A compelling majority of the GHATTEX schedule time frames are highly certain and predictable by virtue of being anchored in the teams' actual performance history. This allows for flexibility in the development of cost and schedule reserves.

Specific margins and reserves will be built into the baseline plan and allocated according to the perceived risk of a problem, whether cost, schedule, or technical. This management approach builds resiliency into our baseline plan.

We are planning a phased release of schedule reserve when required during the project life cycle. The Project Coordinator maintains schedule metrics to provide a constant assessment of the health of the project to the Project PI. Our schedule reserve will be funded, so that use of the schedule reserve to solve unforeseen development problems does not directly impact cost or technical performance.

5.5 Project Risk Assessment and Management Plan IP-Section 3.6

Risk management is a disciplined, well-defined and continuous system engineering process that identifies risks, analyzes their impact, prioritizes them according to their impact, and then develops and carries out plans for mitigation of those risks that have a critical impact on the success of the project. Our risk management approach uses three major categories or levels of risk, and these three are summarized in **IP-Table 3.6-1**.

Our specific approach to risk management for GHATTEX consists of four primary steps:

1) Risk identification: A survey of all areas of the project is performed and potential areas of risk are defined; this process is repeated as necessary to ensure that all risks are systematically identified.
2) Risk assessment: Once the risk identification survey has been completed, each risk is assessed as to its impact on the scope, schedule and budget available, on its probability of occurrence, and on the consequence of occurrence. A summary of the initial risk identification survey is shown in **IP-Table 3.6-3**.
3) Risk Mitigation Plan Generation: A mitigation plan is then developed for those items with a risk level of medium or higher. The plan consists of a number of "Risk Mitigation Waterfall Charts" showing the time history of the assessed risk at each critical milestone of the project. The charts also depict the specific actions taken in order to get to a lower level of risk.
4) Risk Management: Management of risk periodically tracks the progress of the risk mitigation tasks identified on the waterfall charts and provides management control in order to ensure that the risks are reduced to acceptable levels.

ID	Task Name	Duration	Start	Finish
1	**Major Program Milestones**	**804 day**	**Tue 5/1/**	**Mon 5/31/**
2	Contract Award	0 day	Tue 5/1/0	Tue 5/1/0
3	Contract Start	0 day	Fri 6/1/0	Fri 6/1/0
4	Critical Design Review	0 day	Fri 11/30/0	Fri 11/30/0
5	APMP Delivery to NOAA	0 day	Fri 3/1/0	Fri 3/1/0
6	Instrumented APMP Returns to NG-RAC	0 day	Mon 6/3/0	Mon 6/3/0
7	Flight Readiness Review	0 day	Tue 8/20/0	Tue 8/20/0
8	Test Flight Readiness Review	0 day	Mon 9/2/0	Mon 9/2/0
9	NASA Safety Review	0 day	Mon 9/2/0	Mon 9/2/0
10	Deployment Readiness Review (DRR)	0 day	Mon 9/2/0	Mon 9/2/0
11	Local Test Flights Begin	0 day	Tue 9/3/0	Tue 9/3/0
12	Science Readiness Review	0 day	Fri 11/1/0	Fri 11/1/0
13	First Flight DRR	0 day	Fri 11/8/0	Fri 11/8/0
14	Second Flight DRR	0 day	Tue 6/24/0	Tue 6/24/0
15	Third Flight DRR	0 day	Mon 11/3/0	Mon 11/3/0
16	Science Report	0 day	Mon 5/31/0	Mon 5/31/0
17	Project Completion	0 day	Mon 5/31/0	Mon 5/31/0
18	**Project Phases**	**782 day**	**Fri 6/1/**	**Mon 5/31/**
19	Pre-deployment	326 day	Fri 6/1/0	Fri 8/30/0
20	Deployment	274 day	Mon 9/2/0	Thu 9/18/0
21	Post-deployment	182 day	Fri 9/19/0	Mon 5/31/0
22	**Instrument Integration**	**262 day**	**Fri 6/1/**	**Mon 6/3/**
23	Methane	241 day	Fri 6/1/0	Fri 5/3/0
24	Ozone	241 day	Fri 6/1/0	Fri 5/3/0
25	Ice Particles	241 day	Fri 6/1/0	Fri 5/3/0
26	Water Vapor	241 day	Fri 6/1/0	Fri 5/3/0
27	Small Particles	241 day	Fri 6/1/0	Fri 5/3/0
28	**Carbon Dioxide**	**241 day**	**Fri 6/1/**	**Fri 5/3/**
29	Design	125 day	Fri 6/1/0	Thu 11/22/0
30	Fabrication & Assembly	84 day	Fri 11/23/0	Wed 3/20/0
31	Test	32 day	Thu 3/21/0	Fri 5/3/0
32	Temperature Profiler	241 day	Fri 6/1/0	Fri 5/3/0
33	Pressure & Temperature	241 day	Fri 6/1/0	Fri 5/3/0
34	**Payload Computer**	**241 day**	**Fri 6/1/**	**Fri 5/3/**
35	Design	125 day	Fri 6/1/0	Thu 11/22/0
36	Fabrication & Assembly	84 day	Fri 11/23/0	Wed 3/20/0
37	Test	32 day	Thu 3/21/0	Fri 5/3/0
38	Schedule Reserve	20 day	Mon 5/6/0	Fri 5/31/0
39	Instruments Complete	0 day	Fri 5/31/0	Fri 5/31/0
40	Integration to APMP	66 day	Fri 3/1/0	Fri 5/31/0
41	APMP Delivery to NG-RAC	1 day	Mon 6/3/0	Mon 6/3/0
42	**Aircraft Support**	**306 day**	**Mon 7/2/**	**Mon 9/2/**
43	Requirements Development	33 day	Mon 7/2/0	Wed 8/15/0
44	Release Preliminary ICD	0 day	Wed 8/15/0	Wed 8/15/0
45	**Integration**	**228 day**	**Thu 8/16/**	**Mon 7/1/**
46	Analysis & Flight Control	87 day	Thu 8/16/0	Fri 12/14/0
47	Mechanical	141 day	Thu 8/16/0	Thu 2/28/0
48	Software	207 day	Thu 8/16/0	Fri 5/31/0
49	Electrical	121 day	Thu 8/16/0	Thu 1/31/0
50	Fabrication & Assembly	64 day	Mon 12/3/0	Thu 2/28/0
51	Test	208 day	Thu 8/16/0	Mon 6/3/0
52	Simulator Test @ NG-RAC	20 day	Tue 6/4/0	Mon 7/1/0
53	Schedule Reserve	10 day	Tue 7/2/0	Mon 7/15/0
54	Test & Checks @ EAFB	35 day	Tue 7/16/0	Mon 9/2/0
55	**Operations**	**710 day**	**Fri 6/1/**	**Thu 2/19/**
56	**Mission Planning**	**710 day**	**Fri 6/1/**	**Thu 2/19/**
57	Preliminary Planning	327 day	Fri 6/1/0	Mon 9/2/0
58	Test Flights	15 day	Tue 9/3/0	Mon 9/23/0
59	Reserve	5 day	Tue 9/24/0	Mon 9/30/0
60	Primary Winter Flight Window	90 day	Fri 11/15/0	Thu 3/20/0
61	Primary Summer Flight Window	58 day	Tue 7/1/0	Thu 9/18/0
62	Backup Winter Flight Window	69 day	Mon 11/17/0	Thu 2/19/0
63	Payload Logistics/Ground Support	449 day	Mon 6/3/0	Thu 2/19/0
64	Science Data/Analysis/Archive	455 day	Tue 9/3/0	Mon 5/31/0
65	Education/Public Outreach	782 day	Fri 6/1/0	Mon 5/31/0

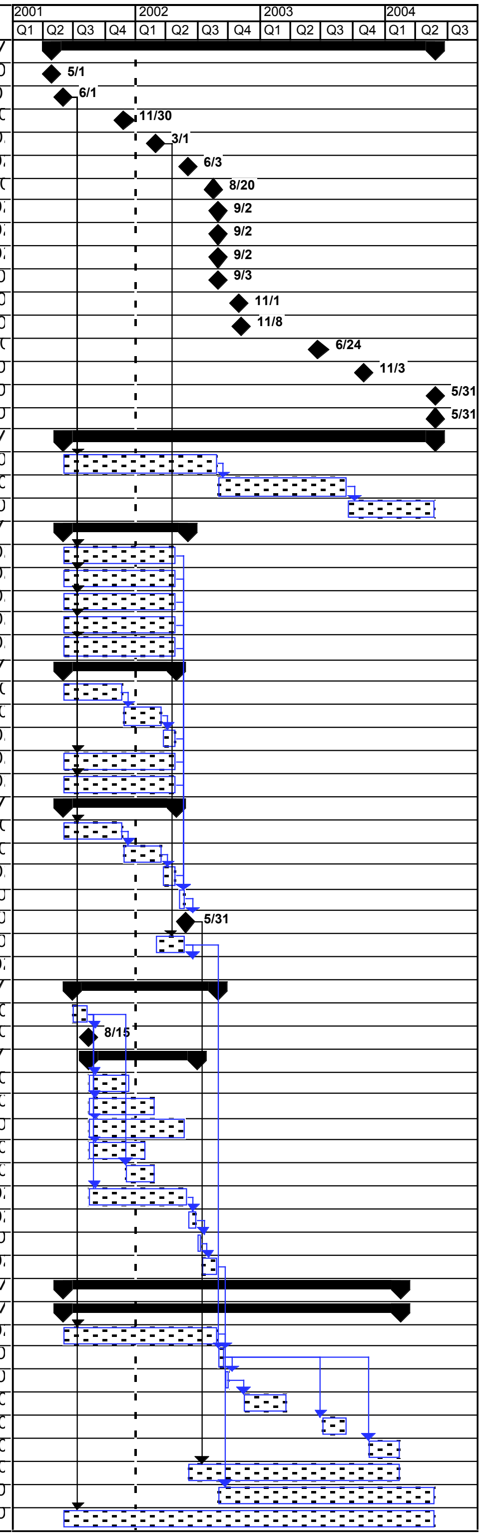

Figure 5.4-1 GHATTEX Project Schedule

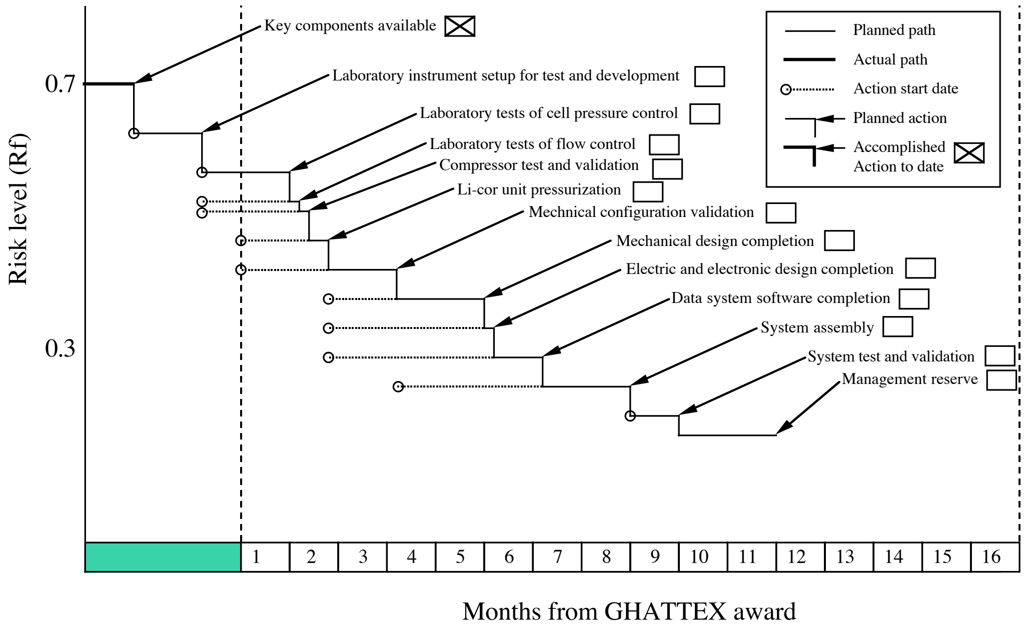

Figure 5.5-1 Risk mitigation plan (waterfall chart) for the CO_2 instrument

The worksheet shown in **IP-Table 3.6-2** was used by the Project Team to aid in the assessment of the risk of the individual items contained in the WBS, and **IP-Table 3.6-3** contains a summary of the assessment made using the worksheet. **IP-Appendix M** contains all of the individual worksheets filled out by the team for the GHATTEX risk assessment including the documentation of the guidelines used in assigning the numerical values of the worksheet itself.

The integration of the existing payload instruments onto the Global Hawk is considered low risk because the payload margins of weight, volume, and power are large (**IP-Table 2.3-2**) and the technical and Instrument-PI teams have considerable experience with the associated tasks. According to our analysis the new CO_2 instrument and the GPCC are medium risk items and require the generation of a waterfall chart for risk mitigation (see **Figure 5.5-1** and **IP-Figure 3.6-2**). The following sections summarize the plans to mitigate risk for both of these medium-risk items before payload integration completion. All other tasks are low risk.

5.5.1 Carbon Dioxide Instrument Risk Mitigation Plan — *IP-Section 3.6.1*

The detailed waterfall chart is shown in **Figure 5.5-1** to mitigate the risk associated with building the CO_2 instrument. The waterfall chart shows how risk from software and hardware maturity will be reduced over the integration period to provide an overall low risk (see **IP-Appendix M**). There is a two-month management reserve in the schedule with a further five months before the first test flight. The cardinal points are (i) the instrument design closely resembles an existing NOAA CO_2 instrument which is mission-proven on the WP-3D aircraft and (ii) that there is substantial schedule reserve. The GHATTEX Project Schedule (**Figure 5.4-1**) shows the tasks associated with the instrument building.

5.5.2 GHATTEX Payload Control Computer (GPCC) Risk Mitigation Plan — *IP-Section 3.6.2*

The detailed waterfall chart is shown in **IP-Figure 3.6-2** to mitigate the risk associated with building the GPCC computer. The GHATTEX Project Schedule (**Figure 5.4-1**) shows the tasks associated with the computer building. The waterfall chart shows how risk from software and hardware maturity will be reduced over the integration period to provide an overall low risk (see **IP-Appendix M**). It is important to note that the GPCC is to function as the electrical and electronic interface between the established, and proven payload instruments and an established and proven airframe. Standard buses and protocols are to be used; there will be eight months of time available to test and operate the interface with the payload before the test flights. The engineer responsible for this item, Mr. T. L. Thompson, has over 20 years experience in interfacing these and similar instruments with the U-2, ER-2 and WB-57F aircraft, and indeed designed the electronics and coded the software for several of them.

5.5.3 Mitigation of Risk Arising from Global Hawk Availability *IP-Section 3.6.3*

There is risk in the availability of the Global Hawk should the USAF have a high priority call for it in the event of a world crisis. In the absence of a crisis, GHATTEX has the full support of the USAF as the only external Global Hawk project that has received approval out of many requests. If there were a crisis during which Global Hawk was unavailable, the response would be a slippage of the entire remaining GHATTEX schedule from the date of the priority call. There is scope for such mitigating slippage, depending upon when the priority call removed availability of the Global Hawk. The schedule calls for completion of the flights on 18 September 2003 whereas the project finishes on 31 May 2004, allowing up to 8.5 months of slippage. Because such an event is an overarching risk, it is discussed separately here rather than in the detailed sections below. The precise impact of such an event would depend on when it occurred. The scope risk is obvious; however, it could lead to a complete loss of all GHATTEX flights only if the aircraft was unavailable from the test flights, which begin 3 September 2002, to the end of the project, 31 May 2004, a period of 21 months. If there were no flights, there would be a budgetary impact, basically a saving of all the flight and deployment costs. As a consequence of our schedule flexibility and the close cooperation with the USAF that is inherent in GHATTEX, we consider the risk associated with Global Hawk availability to be low.

A conservative approach by the USAF to Global Hawk flights across large ocean tracks has led to airframe #5 being fitted with International Maritime Satellite (INMARSAT) capability as a second independent satellite communication link. In order to mitigate risk to GHATTEX, provision has been made for reserve funding to install INMARSAT capability on a second airframe. This reserve would be used only in the event that airframe #5 becomes unavailable for GHATTEX.

The calculated Global Hawk Critical Reliability is 1 aircraft loss in 541 flights (thereby defining Mean Flight to Loss (MFTL)), where a flight is assumed to be 42 hours long. This yields a reliability of 0.99815 and corresponds to 22682 hours of mean time to critical failure (MTTCF; a failure rate of 4.40E-05). The flight critical reliability analysis followed a standard methodology for predicting the air vehicle probability of survival, and the details of the analysis can be found in the NG-RAC Document Number 367-4100-058.

5.5.4 Risk in the Pre-Deployment Phase *IP-Section 3.6.4*

Risk to scope. The scope risk in this phase lies essentially in whether the proposed payload can be integrated on to the Global Hawk. Because the margins in mass, volume and power are large (see **IP-Table 2.3-2** and **Section 4.1.1)** we see no risk that any of these factors will prove limiting.

Risk to schedule. The schedule risk in this phase comes from preparation of the payload. It is largely in the production, testing and integration of the two medium risk items, the CO_2 instrument and the GPCC; the mitigation of these is discussed above in **Sections 5.5.2** and **5.5.3** respectively. Schedule and cost reserves will be used to mitigate risk as needed.

Risk to budget. The budgetary risk in the pre-deployment phase is largely that connected with the payload integration, which includes the design, manufacture and test for form, fit and function of the mechanical and electrical interfaces between the Global Hawk and the payload. The tasks outlined in the NG-RAC SOW (**IP-Appendix N)** are to be fulfilled by NG-RAC under contract. The NG-RAC cost proposal is based on very detailed WBS and Task ID analysis, and the tasks do not involve any major innovations or impacts on the structure and shape of either the Global Hawk or the payload. NOAA/AL's proposed budget does have provision of reserves in connection with the NG-RAC contract, as shown in the cost summary (see **Appendix E**). With regard to the medium-risk payload items, CO_2 and GPCC, adequate cost reserves are included in the budget. Should this not be the case, NOAA/AL will assume responsibility for completing the design and construction of the CO_2 instrument and GPCC.

5.5.5 Risk in the Deployment Phase *IP-Section 3.6.5*

Risk to scope. The scope risk during deployment can arise from malfunctioning of the Global Hawk or malfunctioning of the payload, or conceivably from weather conditions outside limits for landing and take-off. The existing track record of the Global Hawk operating from EAFB indicates that both malfunction and local weather conditions are in the low risk category as regards scope, since such delays will be short enough that while flights might be delayed, they would not be cancelled. Payload function affects the aircraft take-off decision as described by the go/no-go criteria (see **Figure 4.3-2** and **Section 4.3.3**), and manages the scope risk. It would apply during the 25- and 32- hour flights as well as before take-off. The risk is in the low category.

The scope risk arising from the Global Hawk's altitude and time-at-altitude capabilities is very small. The performance of the Global Hawk as measured by the combination of duration, range, altitude, and payload (see **Section 3.3**) is to our knowledge unrivalled. The performance has been demonstrated in 759.1 hours of flight time (**IP-Appendix D**). The range of 11,000 nautical miles means that the radius of action from EAFB is one quarter of the Earth's circumference. The turnaround time between flights is 1 to 2 days. This, together with the issues of availability, payload mass, volume and power, and weather capability in the context of conditions at EAFB which are dealt with elsewhere in this section, mean that the risk to mission accomplishment arising from the Global Hawk's characteristics is small. By the time of the GHATTEX deployment phase, USAF flight operations will have demonstrated performance in the GHATTEX regions in the tropical Pacific.

There is scope risk in the deployment phase, arising from the scope option of omitting the summer flights, leaving only the test flights and winter flights (see **Section 3.5.1**).

Risk to schedule. During the deployment phase, the schedule risk arises from functionality of platform and payload, and from weather conditions at EAFB for take-off and landing. Because there is one-week contingency for each window (test flights and science flights (see **Figure 5.4-1**), and because there are 90 and 58 day windows for the pairs of winter and summer flights, we see little schedule risk associated with the science flights. This situation is further mitigated by a 69-day backup window for winter flights. The schedule risk arising from the possible occurrence of unforeseen problems during the test flights is accommodated by having a 3-week period with a 1-week contingency reserve to accommodate 24 hours of test flights. Since the platform and payload are proven, this too is a low risk item.

Risk to budget. The budget risk in the deployment phase consists largely of the travel and subsistence costs of the GHATTEX Project Team at EAFB, and is readily quantifiable (item 1.3, GHATTEX WBS, **Section 5.2**, **Figure 5.2-1**). Should the test flights and science flights be successfully executed early in their respective windows, savings will accrue.

5.5.6 Risk in the Post-Deployment Phase *IP-Section 3.6.6*

In the absence of the second scope option (see **Section 3.5.1**), the entire activity in the post-deployment phase is low risk, because of the quality of the Science Team and because of the existence of much pre-tested and successfully used analytical and scientific software. If the second scope option is adopted, half the Science Data/Analysis/Archive activity GHATTEX Project Schedule (**Figure 5.4-1**) would be omitted. There would be a substantial loss of scientific return arising from such an action, but the risk to the production and archival of the science quality data would be low, since all the mechanisms by which it is to be achieved have been exercised many times during ER-2 and WB-57F missions. This scope option would truncate the project schedule by 6 months, and in so doing would result in substantial cost reduction, as intended.

5.5.7 Margins and Reserves *IP-Section 3.6.7*

The allowances made for margins and reserves were determined by considering the results of the risk analysis described in the preceding parts of **Section 5.5**. The considerations reflect up to 17 years of experience with the payload instruments and three years of flight experience with the Global Hawk. The allowances use the risk assessment worksheets shown in **IP-Tables 3.6-1** and **3.6-2** and **IP-Appendix M**.

The margins and reserves in the schedule are conservative. This was made possible by the proven performance of the platform and of the payload, and is enhanced by the six-month separation between the winter and summer deployments. NOAA/AL's acceptance of the cost liability for the design and construction of the new CO_2 instrument and GPCC substantially reduces the cost risk of completing the GHATTEX payload. Finally, there is an eight-month period at the end of the project in which a backup winter flight window is scheduled.

The GHATTEX budget will include reserves for the payload integration phase. Reserves will be available for completing and integrating the two medium risk items on to the Global Hawk. Budgetary allowance has also been made to accommodate the one-week reserve that is included in each of the three deployments. Management of these reserves will be on the basis of the earned value system reporting.

Because the payload integration phase occurs early in the GHATTEX Project, there will be time to consider scope options if necessary, such as cutting the later stages of the project activity: the summer flights and the data analysis. If the margins and reserves are not consumed during payload integration, it will be possible to expand the margins and reserves for the later flight phases, even though these are low risk activities.

5.6 Liability Assessment and Management Plan IP-Section 3.7

Liability, per the NASA safety policy for the use of military operated and owned aircraft has been handled per a memorandum of agreement between the Global Hawk Systems Program Office, U.S. Department of Defense, and the NOAA Aeronomy Laboratory, U.S. Department of Commerce. See **IP-Appendix J** for a copy of the applicable MOA.

The liability management will be within the rules set for the Federal Government, which insures itself. The Global Hawk will be operated under the assumptions that govern the USAF fleet, i.e., that the USAF deals with liability. The payload instruments will be operated under the same assumptions that have governed their operation on NASA, NOAA, and NSF aircraft during their extensive past history; namely, that the owners of the instruments will not seek recompense from the owners of the aircraft in the event of loss. Each institution will be responsible for its own instrument(s).

NOAA/AL does not accept liability for the cost and schedule performance of GHATTEX participants outside NOAA/AL. NOAA/AL does accept liability for the tasks related to NOAA/AL payload instruments and data archiving. This applies to the design and construction of the new CO_2 instrument and GPCC by NOAA/AL staff. The Project PI and Co-PI, however, do accept responsibility for monitoring the cost and schedule performance of all aspects of the project, for providing feedback to the participants concerning cost and schedule performance, for identifying strategies to mitigate cost and schedule problems, and for allocating cost reserves to assist in the mitigation.

6.0 Cost Plan and Supporting Documentation

The GHATTEX cost plan is based on detailed cost information from NOAA/AL and other participating institutions. Project total costs and separate institutional costs are summarized in **Table ES-1** in the Executive Summary. The breakdown of project costs is shown in **Appendix E** in **Table 1**, Total Mission Cost Funding Profile; **Table 2**, Phase Cost Breakdown by WBS and Major Cost Category Template; and **Table 3**, Phase Cost Breakdown by WBS. Short Work Package Agreement (SWPA) forms are also included for each institution along with a statement of indirect cost schedules. Other issues related to the cost plan are discussed in the following sections.

As presented in **Tables 1, 2, and 3**, the total GHATTEX cost to NASA is $**** (RY$). With the addition of $****, the sum of *in-kind* contributions from NOAA/AL and CIRES, the total program cost is $****. Costs were developed by NOAA/AL; University of Denver; University of Colorado; MIT; Particle Metrics, Inc.; Northrop Grumman-RAC; Department of the Air Force; and JPL personnel familiar with other recent program cost histories. We understand the costs at a detailed level and use proven, effective control methods, such as the Earned Value System and Critical Path Scheduling, to ensure that the as-delivered cost meets the proposed cost.

During the final stages of budget definition, the USAF decided that it was necessary to mitigate risk to GHATTEX by having the provision of cost reserves to equip a second Global Hawk airframe with INMARSAT capability (see **Section 5.5.3**). This led to an increase of $**** in the NG-RAC cost, all of it reserve. Similarly, the increase of the total USAF cost to $**** is attributable largely to the provision of very conservative cost reserves for risk mitigation. In the case that Global Hawk Airframe #5 is not available and the $**** NG-RAC cost reserve is used to install INMARSAT on a second airframe, the total NASA proposed cost can be contained to $**** by reducing the data analysis period as discussed in the scope options (see **Section 3.5.1**).

6.0.1 Cost Estimating Methodology

General Cost Estimating Methodology. Upon receipt of the proposal instructions the Project PI reviewed the scope of work, analyzed the requirements, and evaluated how the work would be performed by NOAA/AL. After this was accomplished, the Project PI contacted the IPM team leaders (estimators) and knowledgeable individuals to develop a task concept and strategy, complete the analyses, and provide technical and cost inputs to the proposal. **IP-Figure 4.1.2-1** illustrates the process NOAA will use to provide a thorough review of the GHATTEX project and ensure a detailed, accurate, and complete technical and cost proposal.

Both technical and cost inputs are based on the GHATTEX Project Schedule, hardware specifications, data requirements, statement of work, and other governing documents contained or referenced in the proposal instructions. These dictate the WBS, WBS task descriptions, and task schedules that are the starting point for the detailed cost estimates. The estimators are responsible for evaluating the level of detail of work, the required subtasks, the similarity to previous efforts with which they are familiar, selecting the basis of estimate, and generating the baseline estimate for their work effort.

All applicable elements of cost have been identified, (i.e. labor, materials, travel, other direct costs), and estimated by element for the lowest WBS level where the tasks could be defined in detail. Data from the detailed cost estimates have been entered into the appropriate spreadsheets for analysis and submittal. Special parts and subcontract estimates have been solicited from vendors. From these direct cost estimates, a time-phased budget has been prepared.

The Project PI reviewed these estimates for accuracy and completeness as they were received from the IPM team leaders. The Project PI has conducted further review for consistency with the task concept and strategy. A final review has been conducted with the NOAA/AL Laboratory Director to approve the above and to ensure compliance with the GHATTEX proposal directives.

Northrop Grumman Ryan Aeronautical Center. Pricing provided by NG-RAC for all direct charges is based on estimates, some of which were supported by historical actual costs. NG-RAC's estimates reflect judgments by the various performing organizations (and/or the Pricing Department) as reviewed and adjusted by Management. Among the factors taken into account in NG-RAC's estimating process are the risk and uncertainties associated with the type of effort requested by NOAA's Statement of Work (SOW) to NG-RAC in such areas as material (e.g., configuration changes), schedule, labor productivity, etc (see **IP-Appendix N** for a copy of the SOW from NOAA to Northrop Grumman for performing GHATTEX). The cost proposal provided to NOAA by NG-RAC was not the company's most optimistic estimate of the cost of performing the work under the most favorable of circumstances, but represents an amount within which NG-RAC's management believes that the company has a reasonable likelihood of completing the work in view of the schedule, technical requirements, business situation and other circumstances.

Labor estimates were based on grass roots estimates developed by the functional groups responsible for the various tasks defined in the SOW. These cost estimates are entered onto a NG-RAC standard form, and includes all labor costs, material costs and travel costs per department per task. The project lead at NG-RAC collects the filled out forms, reviews them, makes changes as necessary and often in consultation with the functional engineering lead, and then submits them to pricing. Pricing then uses a standard methodology for applying labor rates, overhead rates, capital costs of money and profit, and produces a cost proposal. The generated cost proposal is then reviewed by NG-RAC's management including the Global Hawk Program Director, the Global Hawk Business Manager and the project lead to ensure that the appropriate assumptions were used, that all specified tasks were adequately covered by the functional engineering leads and that the cost estimates are reasonable.

6.0.2 Cost Methodology Basis and Heritage

All GHATTEX subsystems have a strong basis and substantial heritage for cost methodology. GHATTEX subsystems include the eight instruments and the GPCC of the science payload, the Global Hawk modifications and operations, data analysis, and Education and Public Outreach activities.

Seven of the eight payload instruments have flown extensively on other high-altitude aircraft in other airborne projects. All instrument PIs have participated extensively in similar airborne projects with the GHATTEX or related instruments. The instrument techniques and flight heritage are briefly described in **IP-Section 2.1.2.1.** The eighth instrument, CO_2, will be designed and constructed following the successful approach for another CO_2 instrument on another NOAA aircraft (see **IP-Section 2.1.2.1**). The integration tasks for the GHATTEX Global Hawk configuration and flight plans are described in **Section 2.3.3**. The GHATTEX tasks are similar to those undertaken during the design, construction, and use of these working instruments. The identification of integration costs are therefore based on experience with working instruments on the ground and on board other airborne platforms.

The GHATTEX Project PI and Co-PI have extensive experience with airborne projects involving the NASA ER-2 and WB-57F aircraft. Responsibilities include the Project PI and instrument PI roles. NOAA/AL original estimates for their participation in the STEP, AAOE, AASE, AASE II, SPADE, ASHOE/MAESA, STRAT, POLARIS, and SOLVE missions with the NASA ER-2 were within the actual outturns to within a few percent. No funds for cost overruns were requested from NASA. The GHATTEX Project PI was also PI for the WB-57F Aerosol Mission (WAM). WAM was a PI-mode project that was highly successful and completed within the budget requested from NASA's UARP and AEAP. The GPCC design and construction follows the general approach guidelines used for other computers used in autonomous aircraft and balloon instruments in NOAA/AL over the last two decades. The GPCC is described in **Section 2.3.3.8**. The experience with control and date acquisition for the NOAA/AL aircraft instruments on the NASA ER-2 is particularly relevant. The GPCC cost estimates are based on this substantial heritage of previous instrument computers.

Northrop Grumman Ryan Aeronautical Center (NG-RAC) is the original and sole manufacturer and operator of the Global Hawk UAV. GHATTEX requires modifications to the SAR antenna payload bay, mechanical and electrical integration of the science payload instruments, and integration of payload command and control features into the aircraft electronic systems. The NG-RAC cost estimates are based on the engineering experience of manufacturing the aircraft and conducting flight tests which have accumulated 760 airframe flight hours.

Analysis of GHATTEX data and data archive activities will be carried out by the science and support team, which includes Instrument PIs and theory investigators. All have extensive experience analyzing aircraft data sets in a meteorological context using various atmospheric models. The cost estimates will be based on this extensive prior experience.

Education and Public Outreach (EPO) activities will be coordinated in GHATTEX by personnel with extensive experience in EPO activities. Cost estimates are derived from this experience and from estimates provided by EPO professionals at cooperating institutions.

Management of the GHATTEX project will be the responsibility of the GHATTEX PI with the support of the Project Co-PI, Project Coordinator, and other team members. The PIs and Project Coordinator have extensive experience in the management of aircraft field activities during the integration, deployment, and post-deployment phases. Cost estimates for management activities are based on this substantial collective experience.

6.0.3 Reserves

Reserves are allocated to cost, and schedule. These are released in each of the three phases of the project. Our cost reserve is sufficient to accommodate underestimates historically encountered (**Table 6.0-1**). This reserve is 16.3% and is commensurate with our assessment of the program risk. Since the NG-RAC and USAF tasks are both related to the modification and operation of the Global Hawk UAV, the cost reserves will be effectively combined for the overall task. Thus, an 22% cost reserve ($****) is available for the combined cost of $**** of the USAF and NG-RAC tasks. Note that a substantial sum of the NG-RAC reserve, $****, will be used only if it is necessary to equip a second airframe with INMARSAT capability.

6.0.4 Funding Profile

The GHATTEX funding profile fits within the funding profile as outlined in the proposal instructions. Over the life of the program, the cost profile of GHATTEX requires 53.7% of the available program funding, allowing a high value of return for the funding spent. This fraction reduces to 49.6% if the INMARSAT reserve is unused.

6.0.5 Cost Reporting

In addition to the extensive Project Control Plan of GHATTEX (see **Section 5.3**), a formal cost report will be provided to NASA on a monthly basis. A 533M form will be generated on a monthly basis and forwarded to NASA for review. The cost inputs will be provided by each of the GHATTEX partners and compared against the cost and schedule baseline as a formal presentation of our programmatic controls. The budget includes provision for a professional cost accountant to spend four hours per month to prepare GHATTEX reports required by the Project PI and NASA.

Table 6.0-1. GHATTEX budget reserves (Numbers removed for distribution (Jan. 2007))

Institution	**NASA budget request (K$)**	**Reserve (%)**	**Reserve (K$)**
NOAA Aeronomy Laboratory	****	****	****
University of Denver	****	****	****
NASA Jet Propulsion Laboratory	****	****	****
Particle Metrics, Inc.	****	****	****
Massachusetts Institute of Technology	****	****	****
Education and Public Outreach	****	****	****
Northrop Grumman-Ryan Aeronautical Center	****	****	****
]U.S. Air Force ASC/RAV	****	****	****
Theory team travel	****	****	****
Total	****	****	****

6.0.6 Contractual and Financial Relationships

The contractual and financial relationships within GHATTEX are the following:

- NOAA/AL will be the sole recipient of funds from NASA ESE for GHATTEX;
- Program funding will be distributed as outlined in the formal GHATTEX budget proposal as accepted by NASA ESE;
- NOAA/AL will distribute and allocate a certain fraction of received funds for instrument teams, data archiving, project coordinator, and other support;
- NOAA/AL will let subcontracts through NOAA's Mountain States Administrative Support Center (MASC) to the following institutions:
  - USAF for costs associated with Global Hawk modifications and operations (use existing funding mechanism with NG-RAC);
  - University of Denver, NASA JPL, and Particle Metrics, Inc. for instrument teams;
  - MIT for Theory Team support; and
  - CIRES for Education and Public Outreach.
- The Project PI, Project Co-PI, and Project Coordinator will participate in the oversight of the subcontracts;
- Each subcontract will be defined with a Statement of Work;
- Subcontracts to non-government agencies will be monitored during the contract performance period by members of the MASC contracting unit and the Project PI and Co-PI.

The USAF, as the Global Hawk provider, has an existing subcontract with NG-RAC as the Global Hawk manufacturer and operator. No other contractual or financial relationships exist among the GHATTEX participating institutions. The relationship with the flight range will be handled by the existing arrangement between ASC/RAV and EAFB.

The subcontract to support the NG-RAC SOW will be handled by a transfer of funds from NOAA/AL to the USAF WPAFB. The relationship between USAF WPAFB and NOAA/AL regarding the transfer of funds for GHATTEX activities will be defined with an MOA (see **IP-Appendix J**). Both parties will sign the MOA before receipt of GHATTEX funds by NOAA/AL. WPAFB will transfer GHATTEX funds to NG-RAC based on the NG-RAC cost proposal and SOW (see **IP-Appendi**x **N)** and provide management of those funds during GHATTEX. As per 1st Lt Adam Wehner, the management approach for the NG-RAC SOW at WPAFB will include:

- Program Management
- Cost and Schedule Reporting
- Integrated project schedule

- Program reviews

The GHATTEX management team will make use of the management and reporting functions at WPAFB to monitor GHATTEX progress concerning cost and schedule issues.

The transfer of funds to USAF from NOAA/AL will be done under the U.S. Economy Act that facilitates interagency funding transfers. The NOAA/AL MOA with USAF will specify details of this transfer (see **IP-Appendix J**). This method was used successfully in November 2000 to transfer funds to NG-RAC for production of the GHATTEX Implementation Plan.

6.0.7 Workforce Staffing Plan

The GHATTEX workforce is distributed throughout several organizations and institutions (see **Table 3.2-1**). The work force staffing plan by WBS element and fiscal year is included in **Appendix E**. All participating teams that will receive GHATTEX funds have submitted budgets for their activities which are included in this proposal. These budgets include the costs of workforce staffing and, hence, indicate that sufficient staffing is available or will be acquired by each group to complete their respective GHATTEX tasks. The GHATTEX tasks to be undertaken by each group as outlined in the WBS are familiar to the respective group and, hence, each is highly experienced in planning the workforce staffing to accomplish the designated tasks. Thus, the risk to GHATTEX from workforce staffing issues is low.

7.0 Education and Public Outreach Plan

7.1. Project Overview

The GHATTEX UAV project is an engaging "hook" to promote learning about the processes of science, such as the interplay between scientific progress and technology. The goals of the mission, including testing for the presence of a "mirror-image" of the Walker cell in the lower stratosphere, and understanding more about global climate processes, provide a good opportunity for teaching fundamental concepts in scientific inquiry and Earth systems science. The project is well aligned with NASA's strategic goals and objectives, particularly those of the ESE Education program. We will "educate the educators" through in-service and pre-service teacher education, develop and disseminate effective supplemental curriculum materials, inform new community audiences and the media, and involve scientists in science communication and education efforts.

Our specific goals include:

- to share the value of cutting-edge NASA-sponsored Earth systems research with a large, diverse, national audience;
- to increase public understanding of global climate and innovative UAV aeronautics;
- to increase public understanding of the relationship between science and technology; and
- to facilitate effective interaction between the science and education communities.

The well-established CIRES Outreach Program, University of Colorado, will have overall responsibility for providing GHATTEX EPO. Partnerships with Dryden Flight Research Center and Edwards Air Force Base Public Affairs Offices (PAOs), local schools, NASA's national information dissemination infrastructure and others will provide a variety of informal and formal science education opportunities. We estimate that ~150 teachers, 1000 students, and more than 500 members of the general public could be reached by this program through direct contacts, teachers' workshops, and the proposed Open House. A much wider audience will be reached via the proposed web site and public media (TV/radio).

7.2 Education and Public Outreach Statement of Work

Elements of the GHATTEX EPO project include formal education, informal education and media relations, diversity impacts, and leverage of existing systemic reform efforts. Front-end, formative and summative evaluation is included throughout the project, enhancing the usefulness of this project as a model for future Global Hawk and UAV EPO providers.

7.2.1 Formal Education

The GHATTEX project provides plenty of interest for students through the exciting aeronautics and cutting-edge scientific questions. That interest will in turn motivate cognitive learning gains. GHATTEX teacher-partners will be responsible for developing curriculum materials, which reflect inquiry-based best practices and are aligned with National Science Education Standards, and Colorado state and local district standards. An example of a standards-aligned activity would be to generate an experimental design to answer a specific climate question with a choice of UAV and other platforms and instrumentation. Students could then compare their solutions, discuss the trade-offs involved, and critique real study designs. In order to do this, students would need to understand how scientists know about global climate, the range and extent over which different processes occur, and the capabilities and uses of available technology, including UAVs and the Global Hawk. This activity would meet standards in inquiry, Earth and space science and technology. Other possible activities could include students gathering local data, such as sampling and analyzing local aerosol sources or observing weather patterns, then scaling up their understanding of local processes to the global scale addressed in GHATTEX objectives.

Teacher/Scientist partnerships: Teacher/scientist partnerships are the backbone of the project. Through these partnerships, the educational expertise of the teachers will be used to develop, test and disseminate GHATTEX educational materials, with contributions by GHATTEX scientists and outreach staff. GHATTEX Outreach personnel understand the important components of facilitating such partnerships, as demonstrated through our workshops (http:/cires.colorado.edu/˜k12/earthworks) and our successful brokering of partnerships for the Teachers Experiencing the Arctic (TEA) Program (The field journal of a CIRES-brokered TEA teacher, Ms. Cathi Koehler, is online at http://glacier.rice.edu/tea/). In particular, we pay attention to strong facilitation of the partnership, explicit communication with all parties, and good organization ("Science Education Partnerships," A. Sussman, Ed., University of California, San Francisco, 1993).

We will recruit two teachers for partnership with GHATTEX scientists. The teachers will be chosen by the following criteria:

- Grade level: one who teaches at grades 5 through 8 level and one who teaches at grades 9 through12 level.
- Experience: one mid- to late-career master teacher and a promising early career teacher.
- Proximity: the teachers should live close enough to NOAA to participate.
- Expertise: demonstrated ability in inquiry- and field-based classroom implementation.
- Diversity: we will pay special attention to recruiting excellent teachers who serve under-represented or disadvantaged groups.

In this way, we will mitigate the risk to the project from teacher attrition, provide a peer community and establish a mentoring relationship between the two educators

Teachers will be provided with stipends, substitute teacher costs, materials costs, and travel funds. Teachers will work with GHATTEX scientists for one day a month in the pre-deployment period, travel to Edwards AFB for both flight deployment periods, and spend six weeks in implementation and dissemination to other teachers (in-service and NSTA). Teachers will pilot-test materials with their own students, and provide access for evaluating the project. Scientists will aid in ensuring scientific accuracy and access to data for curriculum development, and will visit the teacher's classrooms with hands-on interactive presentations.

Supplemental Curriculum Materials: GHATTEX-related curriculum products include:

- Educational component of the project web site.
- Mission posters with standards-aligned activities.
- Preparation of GHATTEX curriculum teacher guide and Scout badge materials.

Each supplemental educational product will be developed in adherence to NASA ESE Product review criteria, and will go through NASA ESE product review. We will disseminate the materials electronically, through teacher workshops (local, NSTA, Dryden FRC), to prospective teachers, and through our systemic reform venues.

For the education component on the project web site, the teachers will guide the development of the web site, establish appropriate content and activities, and pilot-test the prototype web site in their classrooms. This component will be implemented and maintained by Ms. S. Hovde, the CIRES GHATTEX scientist responsible for the overall project web site. The web site will contain the following elements:

- Teacher-designed investigations using a subset of GHATTEX data. A suitable student interface will allow data manipulation and exploration.
- Curriculum guide to web site and other GHATTEX curriculum materials.
- Photos and the teachers' field journals.
- Links to other sites of interest, such as NASA climate resources and UAV information.
- Press materials such as broadcast quality video and still photos of the GHATTEX mission with the Global Hawk, provided by the Dryden FRC public affairs office.
- Dissemination through other web sites and publications, such as the National Science Teachers Association web site and the NASA ESE newsletter.

For the mission posters, teachers will design a supplemental educational poster to be put through NASA ESE product review. A possible poster topic would be the types and uses of UAVs, with strong connections to mission and learning objectives. The poster will include activities on the bottom as a cut-off supplement and which will be available in portable document format on the project web site.

For the curriculum and teacher guides, the teachers will develop curriculum and teacher guides connected with the GHATTEX web site and the mission poster. These materials will also be disseminated and included in portable document format on the GHATTEX web site.

7.2.2 Informal Education and Media Relations

An Open House will be held at Edwards Air Force Base immediately following the winter deployment period. Public affairs personnel at Edwards AFB and Dryden FRC are very experienced at providing Open House events of this type, and have agreed to provide logistics, advertising and materials support.

Elements of the Open House include:

- advertising to school groups, aeronautics groups, Girl and Boy Scout groups, and senior groups;
- tours of the Global Hawk and hands-on presentations by the scientists;
- demonstrations of remote-controlled model aircraft by enthusiasts;
- teacher workshop with classroom materials in advance of the event;
- development of local Scout badge materials in aeronautics and/or climate to be disseminated beforehand and during the event;
- press releases and materials prepared by NOAA outreach personnel and the Dryden FRC public affairs office and distributed nationally; and
- estimated 500-plus attendees.

Press releases will be prepared and distributed several times during the project, prior to each deployment and to the Open House. NOAA personnel and the Dryden PAO will prepare the releases, press materials and disseminate them.

7.2.3 Diversity Impacts: Post-Secondary

In addition to using diversity as criteria in selecting GHATTEX teacher partners, we will make involvement in GHATTEX available to a participant in each of two diversity programs:

- The SOARS Program (Student Opportunities in Atmospheric and Related Sciences) is an effective program designed to retain talented minority-group undergraduates in geosciences. Information on the SOARS program may be found at http://www.ucar.edu/soars/. CIRES currently provides $*** per year to sponsor a SOARS protégé position, and travel funds have been included in the EPO budget to enable the protégé to take part in deployment flights at EAFB.
- NOAA's Boulder Environmental Technology Lab (ETL) partnership program with three Historically Black Colleges and Universities (HBUC) (Spelman, Clarke-Atlanta, and Morehouse), which bring faculty to Boulder for summer programs.

7.2.4 Leverage of Existing Efforts

Pre-service teacher education: The GHATTEX EPO coordinator is instructor of a NASA Opportunities for Visionary Academics (NOVA) course for pre-service teachers at the University of Colorado, Boulder (GEOL 2110 Physical Science in Earth Systems). The course is highly recommended for all University of Colorado, Boulder elementary certificate students, about 100 students per year. Our target impact over the project period is 2 to 3 sections per year with 25 students each. GHATTEX curriculum products will be included in the course, with the possibility of securing Phase III NOVA funding to develop and disseminate an on-line module for the other 76 NOVA institutions.

District systemic reform: GHATTEX curriculum products will be included in a resource book, which CIRES has developed for a local school district to support their Earth systems curriculum implementation. This effort is being disseminated as a model for similar implementation efforts.

7.2.5 Project Evaluation

An evaluation doctoral student in the School of Education will conduct formative and summative evaluation, a model that has been successful in the CIRES Outreach program. We are dedicating 7% of the total direct costs of the project to evaluation, with administrative and project coordinator time also available. This is in line with NSF evaluation guidelines (5 to 10%). In particular, we will evaluate the utility of the teacher/scientist partnerships from the perspective of all participants, the effectiveness of the curriculum materials, and the extent of increased public awareness due to the Open House. We intend the results of this evaluation to provide decision-making information for future providers of Global Hawk and UAV EPO. To this end, results of the evaluation will be included on the project web site.

Both qualitative and quantitative evaluation methods will be used to provide in-depth data and a basis of comparison between methods. Methods will include semi-structured interviews, participant journals, surveys, participant and student observation, and pre- and post-assessment of student learning. Prior to the start of the project, interviews will be conducted with all stakeholders (teachers, scientists, outreach staff) in order to assess the important objectives of all parties. The evaluation design particulars (such as interview questions) will be driven initially by education research on scientist/teacher partnerships and scientists involvement in outreach. However, we will remain open to unanticipated outcomes as we respond to the formative evaluation results.

Table 7.2-1 describes which assessment methods are connected to which project objective. Also included is a description of which participant groups are included and when during the project the assessment will occur. Each project element to be evaluated (partnerships, materials, and open house) is followed by a set of objectives for that element (i.e., the measurable goals for that element). For example, in order to assess the impact of the partnership on the GHATTEX teachers' practices, we will use interviews with the teachers, the teachers' journals, a survey instrument on teaching practices and observation in the teachers' classrooms as a basis for evaluation.

7.3 Education and Public Outreach Personnel and Qualifications

Dr. Susan Buhr (CIRES Outreach program Associate Director) will have overall responsibility for implementing the GHATTEX EPO project. Dr. Buhr is an educator and scientist able to carry out these responsibilities, as described in her CV. Other CIRES outreach staff expertise in traditional and on-line curriculum development, evaluation, and classroom teaching will also be available.

Ms. Jenny Baer-Riedhart (Dryden FRC) will provide advertising, logistics, and press materials support for the Open House.

Mr. Gary Martins (Edwards AFB) will provide support for the Open House.

Dr. Christine Ennis (Aeronomy Laboratory) will provide a point of contact with the NOAA public affairs office.

Ms. Susan Hovde (CIRES/AL) will provide technology expertise for the project web site, and will implement the EPO web site. See her CV in the personnel section.

Table 7.2-1. Education and Public Outreach Project Evaluation

Project Element and Associated Objectives	Methods Used to Assess Objective			
Element 1. Teacher/Scientist partnerships	Interview pre-,mid-, and post partnership	Teacher Journals	Survey inventory of teaching practices	Observation: students and partners in action
Objective 1a. Assess effectiveness of partnership from all participants' perspectives.	Teachers, scientists and staff	Qualitative analysis of themes	---	At NOAA, in field and in classroom
Objective 1b. Assess impact on teachers' practices.	Teachers	Qualitative analysis of themes	Pre- and post-	Classroom
Objective 1c. Increase understanding of factors important in scientist education outreach.	Scientists	---	---	---
Element 2. Curriculum materials	Interviews	Surveys	Observation	Other methods
Objective 2a. Assess usability of web site by students during classroom pilot-test	Teachers/ Students	---	Teachers/ Students	Student talk-aloud
Objective 2b. Assess utility to teachers of web site/poster/curriculum guide.	Workshop attendees	Workshop attendees, web site visitors	Workshop attendees	Site counters, trackers
Objective 2c. Assess student learning gains	Teachers-GHATTEX and workshop attendees	GHATTEX Teachers and workshop attendees	Class visits	Pre- and post-assessment
Element 3. GHATTEX Open House	Interviews	Surveys	Short-answer survey	
Objective 3a. Increase public awareness of Earth Systems phenomenon	Attendee exit interviews	Attendee exit surveys	Feedback from Scout and community group leaders	
Objective 3b. Increase public awareness of NASA's enabling role	Attendee exit interviews	Attendee exit surveys	Feedback from Scout and community group leaders	

7.4 Education and Public Outreach Costs

GHATTEX EPO direct costs are approximately 1% of the project total, plus University of Colorado indirect costs. CIRES will contribute two months of Dr. Susan Buhr's salary to the project, and will contribute $*** per year to the National Center for Atmospheric Research to support a SOARS protégé.

7.5 Education and Public Outreach Work Schedule

A schedule for EPO activities is shown in **Figure 7.5-1**. See the detailed evaluation plan for the evaluation work schedule.

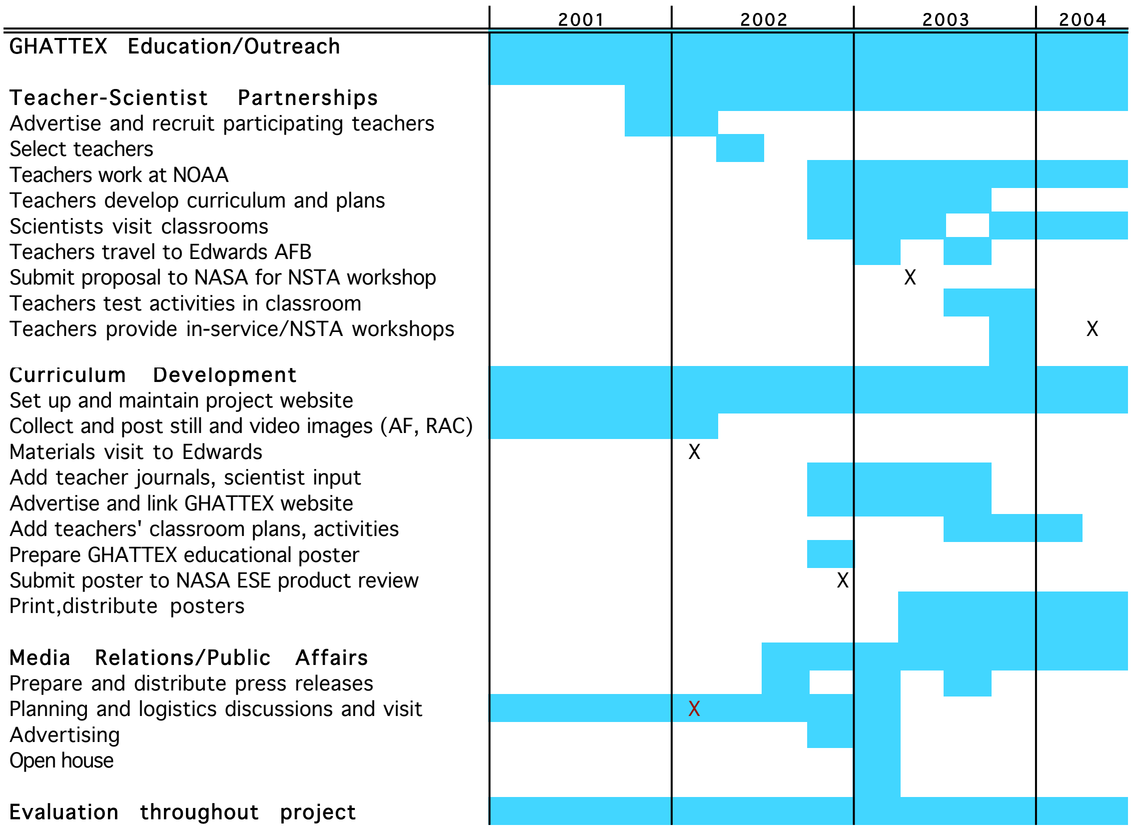

Figure 7.5-1. Education and Public Outreach Activity Schedule

Appendix A: Acronyms

Acronym	Definition
AAOE	Airborne Antarctic Ozone Experiment
AASE	Airborne Arctic Stratospheric Expedition
AASE II	Airborne Arctic Stratospheric Expedition II
ACCENT	Atmospheric Chemistry of Combustion Emissions Near the Troposphere
ACMAP	Atmospheric Chemistry Modeling and Analysis Program
AEAP	Atmospheric Effects of Aviation Project
AFB	Air Force Base
AFFTC	Air Force Flight Test Center
AFMC	Air Force Materiel Command
AFMSS	Air Force Mission Support System
AL	Aeronomy Laboratory
APMP	Airborne Payload Mounting Plate
ASC/RAV	Aeronautical Systems Center/ Reconnaissance Systems Program Office
ASHOE/MAESA	Airborne Southern Hemisphere Ozone Experiment/Measurements for Assessing the Effects of Stratospheric Aircraft
ATC	Air Traffic Control
CIRA	Cooperative Institute for Research in the Atmosphere
CIRES	Cooperative Institute for Research in Environmental Sciences
CCO	Command and Control Operator
CFR	Code of Federal Regulations
COA	Certificate of Authorization
DRR	Deployment Readiness Review
EAFB	Edwards Air Force Base, CA
EMI	Electromagnetic Interference
EPO	Education and Public Outreach
ERL	Environmental Research Laboratories
ESE	Earth Science Enterprise
ETL	Environmental Technology Laboratory
EVS	Earned Value System
FAA	Federal Aviation Administration
FCAS	Focused Cavity Aerosol Spectrometer
FFS	Fiberglass Fairing Structure
FL	Flight Level
FLTS	Flight Test Squadron
FRR	Flight Readiness Review
GCM	General Circulation Model
GHATTEX	Global Hawk Tropical Tropopause Experiment
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
GPCC	GHATTEX Payload Control Computer
GPS	Global Positioning System
HAE	High Altitude Endurance

HBUC	Historically Black Universities and Colleges
ICD	Interface Control Document
ID	Identifier
IMMC	Integrated Mission Management Computer
INMARSAT	International Maritime Satellite
IPM	Integrated Project Management
ITCZ	Inter Tropical Convergence Zone
JPL	Jet Propulsion Laboratory
MASC	Mountain Administrative Support Center
MASP	Multiple-Angle Aerosol Spectrometer Probe
MFTL	Mean Flight to Loss
MIT	Massachusetts Institute of Technology
MM5	NCAR/PSU Mesoscale Model 5
MOA	Memorandum of Agreement
MTP	Microwave Temperature Profiler
MTTCF	Mean Time to Critical Failure
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NG-RAC	Northrop Grumman, Ryan Aeronautical Center
NMASS	Nucleation-Mode Aerosol Size Spectrometer
NOAA	National Oceanic and Atmospheric Administration
NOVA	NASA Opportunities for Visionary Academics
NRA	NASA Research Announcement
NSF	National Science Foundation
OES	Office of Earth Science
OLR	Outgoing Longwave Radiation
PALMS	Particle Analysis by Laser Mass Spectrometry
PAO	Public Affairs Office
PDF	Probability Distribution Function
PI	Principal Investigator
PIC	Pilot-In-Command
POES	Polar-Orbiting Operational Environmental Satellite
POLARIS	Photochemistry of Ozone Loss in the Arctic Region In Summer
PP	Project Plan
PSU	Pennsylvania State University
PT	Pressure-Temperature Instrument
QBO	Quasi-Biennial Oscillation
RCC	Range Commanders Council
ROA	Remotely Operated Aircraft
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communication
SOLVE	SAGE III Ozone Loss and Validation Experiment
SOW	Statement of Work

SPADE	Stratospheric Photochemistry Aerosols and Dynamics Experiment
SRB	Safety Review Board
STEP	Stratosphere-Troposphere Exchange Project
STRAT	Stratospheric Tracers of Atmospheric Transport
SWPA	Short Work Package Agreement
THA	Test Hazard Analysis
TRA	Teledyne Ryan Aeronautical
UARP	Upper Atmosphere Research Program
UARS	Upper Atmosphere Research Satellite
UAV	Uninhabited Aerial Vehicle
USAF	United States Air Force
UT/LS	Upper Troposphere/Lower Stratosphere
WAM	WB-57F Aerosol Mission
WBS	Work Breakdown Structure
WPAFB	Wright Patterson Air Force Base

Appendix B: References

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