Canadian Capability:

Space-Based Observations

Kimberly Strong

Department of Physics
University of Toronto

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Outline

- Atmospheric Environment Themes
- Space-Based Missions
  → An Overview of Current, Planned, & Proposed Missions
- Current & Future Technical Capabilities
- Current & Future Measurement Capabilities
- Future Considerations

Atmospheric Environment Themes

Earth System Science

- coupled processes (chemical, dynamical, microphysical)
- coupled regions (surface to thermosphere)

Climate Change

- radiation (solar input, clouds, aerosols, greenhouse gases)
- coupled regions (land surface, ocean, atmosphere)
- natural vs. anthropogenic processes
- indicators of global change (monitoring, early warning)

Northern High Latitudes

- troposphere and climate (feedbacks, interactions, water cycle)
- middle atmosphere (ozone, polar dynamics, noctilucent clouds)
- anthropogenic effects (trends, physical climate)

Environmental Monitoring and Prediction

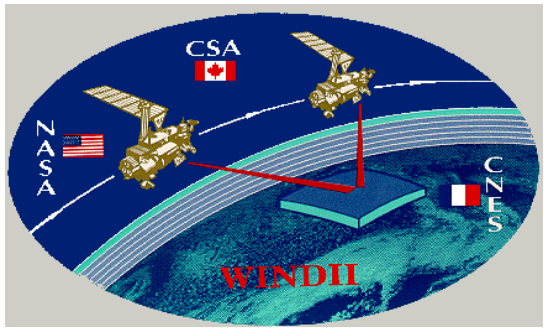
- air quality (tracking pollutants, forecasts)
- weather and climate (data volumes, clouds, surface effects)
- data assimilation and modelling

Space-Based Missions (selected & proposed)

In (approximately) chronological order

- WINDII – Wind Imaging Interferometer
- MANTRA – Middle Atmosphere Nitrogen TRend Assessment
- MOPITT – Measurements Of Pollution In The Troposphere
- OSIRIS – Optical Spectrograph and InfraRed Imaging System
- ACE – Atmospheric Chemistry Experiment
- MAESTRO – Measurement of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation
- SALI – Spectral Absorption Line Imager
- SWIFT – Stratospheric Wind Interferometer for Transport Studies
- MIMI – Mesospheric Imaging Michelson Interferometer
- MOXI – Mesopause Oxygen Imager
- MESO – Microsat Experiment for Sounding Oxygen atom densities
- ORACLE – Ozone Research by Advanced Cooperative Lidar Experiment
- CloudSat – includes Cloud Profiing Radar (CPR) and Profiling A-Band Spectrometer/Visible Imager (PABSI)
- MOPITT-2 – Measurements Of Pollution In The Troposphere 2

WINDII
Wind Imaging Interferometer



Scientific Objectives

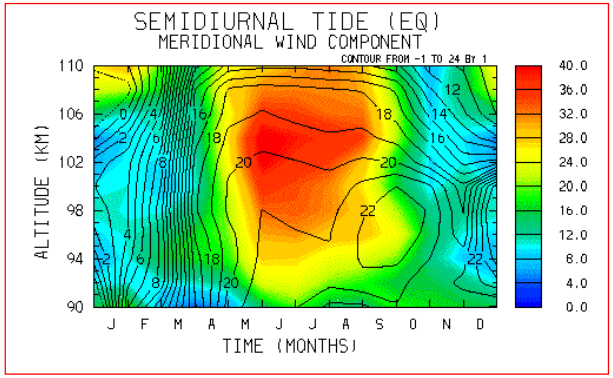
- to measure the global wind fields and atmospheric composition at the top of the altitude range covered by the UARS spacecraft (80-300 km)
- to characterize large scale atmospheric wave phenomena
- to measure seasonal and long term variations in atmospheric composition, particularly atomic oxygen
- to measure polar mesospheric cloud phenomena
- to model the global upper atmosphere weather

Relevant Atmospheric Environment Themes

- Earth System Science
  e.g., mesosphere-thermosphere coupling, chemical-dynamical coupling
- Northern High Latitudes
  e.g., PMCs, noctilucent clouds, polar mesospheric dynamics

WINDII

Wind Imaging Interferometer



Overview

Measurements	winds to < 10 m/s, temperature, atomic oxygen, aerosols, and emission rate from 80 to 300 km
Instrument Design	all-glass field-widened achromatically and thermally compensated phase-stepping Michelson interferometer, using a CCD detector to image visible airglow emission
Viewing Geometry	images limb in two orthogonal view directions
Spectral Region	500-900 nm: 557.7 (O^1S), 730 (OH), 762 (O_2)
Launch Date	September 12, 1991
Lifetime	continues to operate (>22 million images)
Platform	Upper Atmosphere Research Satellite (NASA)
Principal Investigator	G.G. Shepherd, York University
Industry Participation	CAL Corporation, AIT Corporation

MANTRA

Middle Atmosphere Nitrogen TRend Assessment

Scientific Objectives

- to measure the primary reactive trace gases that control stratospheric ozone concentrations.
- to compare these measurements with those obtained from similar balloon campaigns over the past 20 years.
- to determine if there have been long-term trends in the amount or partitioning of odd-nitrogen compounds, and if so, whether they are contributing to ozone depletion at northern mid-latitudes.

Relevant Atmospheric Environment Themes

- Climate Change
  e.g., trends as indicators of global change, mid-latitude ozone chemistry
- Environmental Monitoring and Prediction
  e.g., monitoring of changes in nitrogen and chlorine compounds

MANTRA

Middle Atmosphere Nitrogen TRend Assessment

Measurements	Profiles of ozone, NO_2, HNO_3, HCl, N_2O, CH_4, CO_2, H_2O, CFC-11, CFC-12, winds, humidity, P, T; g-b columns of ozone, NO_2, SO_2; upper limits on BrO, OClO; aerosol optical depth; J-values
Instruments	**Main Balloon:** NO_2 Spectrophotometer, Radiometers (2), OH Spectrometer, Photodiode Array Spectrometers (2), AOTF Spectrometer, FTIR; **Sondes:** Ozone (14), Radio (15), Aerosol (3); **Ground-based:** Brewer, Zenith-Sky Grating Spectrometer, Photodiode Array Spectrometer
Viewing Geometry	**Balloon:** emission, solar occultation, limb scanning; **Ground:** direct Sun & Moon, zenith-sky
Launch Date	August 24, 1998; tentative reflight in 2000
Launch Location	Vanscoy, SK (52°N, 107°W)
Lifetime	Intended – 18 hour flight; Actual – 9 days
Platform	11.6 mcf balloon, float altitude of 35 km
Principal Investigator	K. Strong, University of Toronto
Industry Participation	Scientific Instrumentation Ltd.

MOPITT

Measurements Of Pollution In The Troposphere

Scientific Objectives

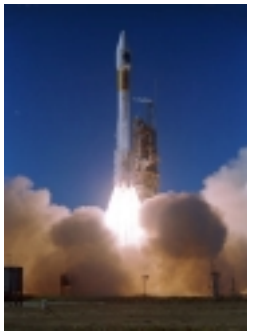
- to provide the first long-term global measurements of CO and CH_4 concentrations in the troposphere
- focus on distribution, transport, sources, and sinks
- CO: → to identify natural and anthropogenic surface sources
  → to investigate transport of CO from surface to tropopause
  → to improve understanding of tropospheric OH chemistry
- CH_4: → to identify natural and anthropogenic surface sources
  → to improve quantitative understanding of biogeochemical cycles

Relevant Atmospheric Environment Themes

- Earth System Science
  e.g., chemical-dynamical coupling, surface-troposphere coupling
- Climate Change
  e.g., indicators of global change, natural vs. anthropogenic forcing
- Environmental Monitoring and Prediction
  e.g., tropospheric air quality, tracking pollutants

MOPITT

Measurements Of Pollution In The Troposphere



Overview

Measurements	CH_4 columns to 1%; CO columns and profiles to 10%
Instrument Design	8-channel infrared correlation spectrometer; 8 IR detectors cooled to 100 K; on-board calibration sources and cold space view calibration
Viewing Geometry	nadir sounding; cross-track scanning
Spectral Region	2.26 μm (CH_4), 2.33 μm (CO), 4.6 μm (CO)
Spatial Resolution	horizontal: 22 x 22 km vertical: surface to 15 km in 3 km layers (CO)
Launch Date	December 18, 1999
Lifetime	five years
Platform	Terra, formerly EOS AM-1 (NASA)
Principal Investigator	J.R. Drummond, University of Toronto
Industry Participation	COM DEV International

OSIRIS

Optical Spectrograph and InfraRed Imaging System

Scientific Objectives

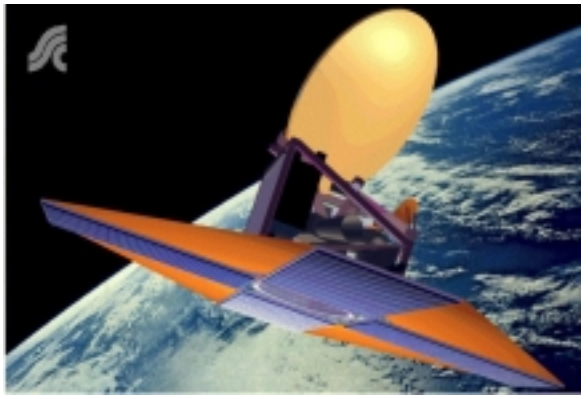
- to elucidate the geographical extent of and mechanisms for polar ozone depletion, and to study dilution effects and heterogeneous chemistry due to sulphate aerosols outside the polar regions
- to establish the relative role of odd hydrogen chemistry and the effects of transport and corpuscular radiation in the mesosphere
- to establish the variability of water vapour in the summer mesosphere
- to study mechanisms that couple the upper and lower atmosphere, e.g., downward transport of aurorally enhanced NO, and the vertical exchange of minor species such as odd oxygen, CO and H_2O

Relevant Atmospheric Environment Themes

- Earth System Science
  e.g., coupling processes, stratosphere-mesosphere coupling
- Northern High Latitudes
  e.g., polar ozone depletion
- Environmental Monitoring and Prediction
  e.g., data assimilation

OSIRIS

Optical Spectrograph and InfraRed Imaging System

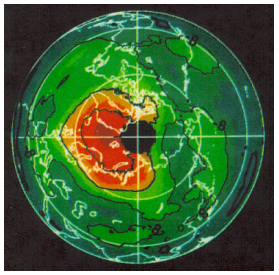


Overview

Measurements	OS: profiles of ozone, NO_2, OClO, BrO, O_2, T, and aerosol from ~15 to 60 km; IRI: profiles of O and ozone
Instrument Design	OS: UV-visible grating spectrometer with CCD detector for scattered sunlight; IRI: simultaneous imaging of IR emission features onto InGaAs array
Viewing Geometry	limb-viewing, scans through tangent heights
Spectral Region	280-800 nm at 1-2 nm resolution; 1.27μm
Launch Date	mid-2000
Lifetime	two years
Platform	Odin (Swedish Space Corporation)
Principal Investigator	E.J. Llewellyn, University of Saskatchewan
Industry Participation	Routes Inc.

ACE

Atmospheric Chemistry Experiment



Scientific Objectives

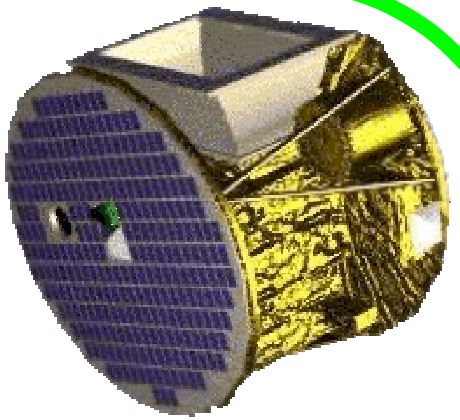
- to investigate Arctic ozone loss and, by means of modelling and measurements, attempt to quantify the contributions from dynamics and chemistry, and the role of aerosols and PSCs
- to assess the mid-latitude ozone budget
- to study descent in the winter vortex
- to investigate retrieval of wind speeds to a precision of 5 m/s using Doppler shifts of the line positions
- to assess the potential impacts of biomass burning and the rapid transport of burning products by convective activity in the troposphere
- to monitor CFCs during the lifetime of the mission

Relevant Atmospheric Environment Themes

- Earth System Science
  e.g., chemical-dynamical-microphysical coupling
- Climate Change
- Northern High Latitudes
  e.g., Arctic ozone loss, vortex descent, heterogeneous chemistry

ACE

Atmospheric Chemistry Experiment



Overview

Measurements	a suite of ~30 gases at 5-20%, pressure, temperature, clouds, aerosol effective radius
Instrument Design	infrared Fourier transform spectrometer with InSb/MCT sandwich detectors, and an auxiliary two-channel visible/near infrared imager
Viewing Geometry	solar occultation
Spectral Region	700-4100 cm^{-1} at 0.025 cm^{-1}; 1.02 & 0.525 μm
Spatial Resolution	3-4 km from surface to as high as ~100 km
Launch Date	early 2002
Lifetime	two years
Platform	SCISAT-1 (Canadian Space Agency)
Mission Scientist	P. Bernath, University of Waterloo
Industry Participation	Bomem

MAESTRO

Measurement of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation

MAESTRO
Measurement of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation

Scientific Objectives

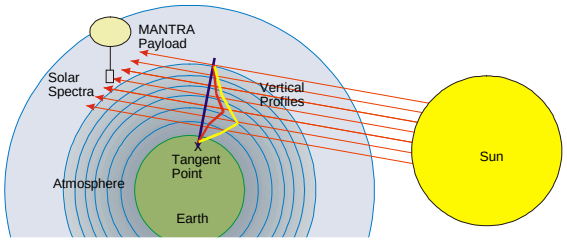
- to provide wavelength-dependent atmospheric extinction data from 300-1000 nm in order to quantify aerosol properties (size distribution, particle densities, surface area)
- to measure ozone profiles at high precision, high vertical resolution, and over a wide altitude range in order
- to measure profiles of other trace gases in the UV-visible region
- to address issues of northern latitude ozone distribution, influence of aerosols and PSCs, recovery from chlorine loading, and stratosphere-troposphere exchange

Relevant Atmospheric Environment Themes

- Earth System Science
  e.g., role of aerosols, stratosphere-troposphere exchange
- Northern High Latitudes
  e.g., Arctic ozone loss, vortex descent, heterogeneous chemistry

MAESTRO

Measurement of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation



Overview (proposed)

Measurements	aerosols, ozone profiles, NO_2, SO_2, OClO, BrO, H_2O, O_2, O_4, temperature, pressure
Instrument Design	grating spectrometer with diode array detector
Viewing Geometry	solar occultation and nadir backscatter mode
Spectral Region	300-1000 nm at 0.5-1.0 nm spectral resolution
Spatial Resolution	goal: <1.5 km in vertical
Launch Date	2002 – tentative
Lifetime	two years
Platform	SCISAT-1 (Canadian Space Agency) – tentative
Principal Investigator	C.T. McElroy, Meteorological Service of Canada
Industry Participation	EMS Technologies Canada Ltd.

SALI

Spectral Absorption Line Imager

Scientific Objectives

- to measure the water vapour content in the upper mesosphere, in conjunction with a density and temperature experiment during a mesospheric cloud occurrence in summer
- to study the atmospheric environment of mesospheric clouds in relation to their possible role as an indicator of global change in the middle atmosphere
- to develop a five-year collaborative programme to explore new science and technology in the development of small instrumented rockets for the observation and study of trace gases in the MLT region

Relevant Atmospheric Environment Themes

- Climate Change
  Mesospheric clouds (polar and noctilucent) may be a product of human activity. If this is so, monitoring their equatorial boundary will provide a sensitive measure of atmospheric change. However, it is important to distinguish between the contributions to this change from trends in water vapour and temperature.

SALI

Spectral Absorption Line Imager

Overview (proposed)

Measurements	mesospheric H_2O profiles to 0.1 ppmv
Instrument Design	Fabry-Perot interferometer with elevation tracking mirror, filters, etalon, and CCD camera
Viewing Geometry	solar occultation from rocket: Sun at limb is imaged from behind the tangent point; apogee is near max. measurement altitude (~100 km)
Spectral Region	936 nm
Spatial Resolution	vertical: better than 2 km from 50-90 km
Launch Date	prototype flight - expected October 2000; SALI experiment - July 2001 / July 2003
Launch Location	Andoya Rocket Range, Norway (69°N,16°E)
Lifetime	SALI experiment - July 2001 / July 2003
Platform	Viper 5 motor (Orbital Sciences) with 15X-type payload (Andoya RR, Norwegian Space Centre)
Principal Investigator	M.G. Shepherd, CRESS, York University
Industry Participation	Mayes Mullins Enterprises Ltd.

SWIFT

Stratospheric Wind Interferometer for Transport Studies

Scientific Objectives

- to provide high resolution global measurements of horizontal winds in the stratosphere for both day and night
- to study tropical stratospheric winds, including climatologies and characterization of zonal mean oscillations and planetary waves
- to address several issues regarding constituent transport in the stratosphere: e.g., the isolation of the tropical stratosphere, and global budgets of ozone transport
- to use the wind data in data assimilation efforts, and to combine it with contemporaneous measurements in a dynamically consistent manner

Relevant Atmospheric Environment Themes

- Earth System Science
  e.g., dynamics, spatio-temporal coupling
- Environmental Monitoring and Prediction
  e.g., data assimilation of winds

SWIFT

Stratospheric Wind Interferometer for Transport Studies

Overview (proposed)

Measurements	winds to 5 m/s and ozone to 5%, from 20-45 km
Instrument Design	field-widened Michelson interferometer with Fabry-Perot filters and MCT array detector, designed to observe thermal IR emission
Viewing Geometry	limb imaging in two orthogonal directions
Spectral Region	8-9 μm (ozone emission)
Spatial Resolution	vertical: 2.25 km; horizontal: 50 km
Launch Date	TBD
Lifetime	two years
Platform	TBD: 600 km orbit, inclination of 60-70° or 20°
Principal Investigators	G.G. Shepherd, I.C. McDade, W.A. Gault
Industry Participation	EMS Technologies Canada Ltd.

MIMI

Mesospheric Imaging Michelson Interferometer

Scientific Objectives

- to observe dynamical quantities and ozone in upper stratosphere and mesosphere in order to characterize dynamical signatures and transport
- to complement constituent measurements by providing information on large tidal and planetary wave motions
- to characterize the energetics in the mesopause region
- unique ability to diagnose dynamics and transport in the upper stratosphere and mesosphere

Relevant Atmospheric Environment Themes

- Earth System Science
  e.g., transport and feedbacks between mesosphere and stratosphere
- Environmental Monitoring and Prediction
  e.g., response of circulation and thermal structure of the middle atmosphere to changing profiles of radiative constituents
- Northern High Latitudes
  e.g., mesospheric dynamical structure and transport over the pole, noctilucent clouds, stratosphere-mesosphere coupling

MIMI

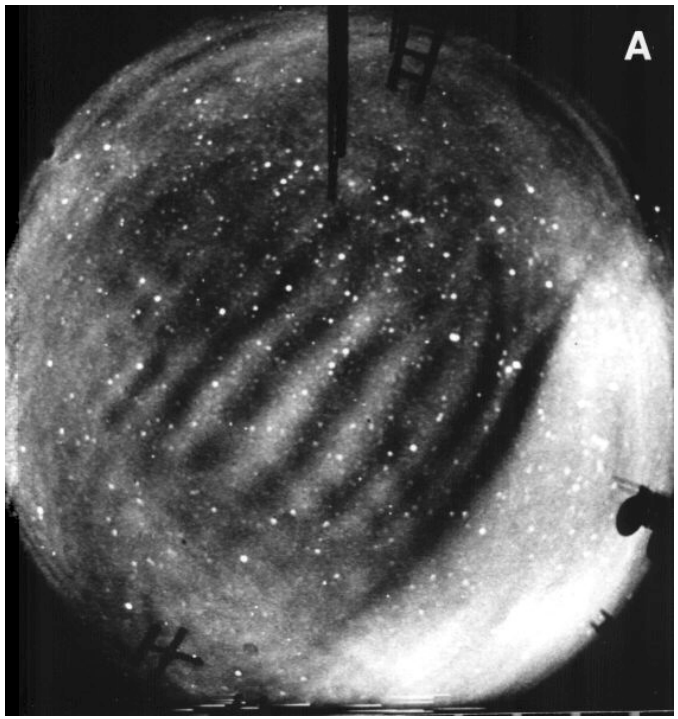
Mesospheric Imaging Michelson Interferometer

Overview (proposed)

Measurements	horizontal wind, temperature, density, pressure, ozone and atomic oxygen
Instrument Design	wide-angle Michelson interferometer designed primarily to observe emission lines of O_2
Viewing Geometry	limb-viewing with 6 fields of view (45, 135, 225, 315, 0, 180 to satellite track)
Spectral Region	IR-atmospheric band at 1.27 microns (O_2, OH)
Spatial Resolution	vertical: 2 km from ~45-100 km; horizontal: 400 km
Launch Date	TBD
Lifetime	at least 1 year
Platform	orbiter at 400-700 km, inclination of 40-70°
Principal Investigator	W.E. Ward, CRESS/CRESTech, York University
Industry Participation	EMS Technologies Canada Ltd.

MOXI

Mesopause Oxygen Imager



Scientific Objectives

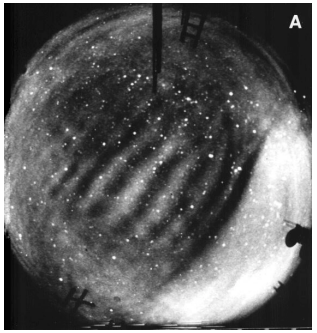
- to measure wavelengths and amplitudes of the horizontal component of airglow intensity fluctuations
- to study small-scale structures and gravity waves in the mesosphere

Relevant Atmospheric Environment Themes

- Earth System Science
  e.g., mesospheric dynamics, spatio-temporal coupling

MOXI

Mesopause Oxygen Imager



Overview (proposed)

Measurements	small-scale structures from 85-100 km, derived from images of the O_2 A-band nightglow
Instrument Design	imaging system with collecting telescope, narrow-band filter, and cooled CCD array detector
Viewing Geometry	nadir-viewing
Spectral Region	762 nm (O_2 emission)
Spatial Resolution	2.5 km with ~150 km across-track field-of-view
Launch Date	TBD: flight opportunity sought
Lifetime	two years
Platform	TBD: need 0.25° pointing stability (pitch and roll) during a ~6.5 s measurement
Principal Investigator	K. Gilbert, University of Western Ontario
Industry Participation	EMS Technologies Canada Ltd.

MESO

Microsat Experiment for Sounding Oxygen atom densities

Scientific Objectives

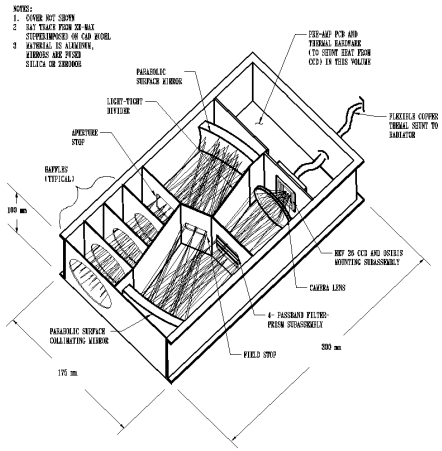
- to measure global distributions of atomic oxygen in the upper mesosphere and lower thermosphere, *i.e*. the 80 to 110 km region
- to measure oxygen atom densities with the spatial, local time, and seasonal resolution required to study issues related to atmospheric dynamics, chemical heating and the control of MLT atomic oxygen
- to provide colour-indexed measurements of artificial nightlights generated by urban lighting, biomass burning, oil flares, *etc*.
- to measure small-scale spatial fluctuations in airglow caused by atmospheric gravity waves and provide global information on their amplitudes and frequency of occurrence
- to provide global distributions of mesopause region temperatures and planetary albedo

Relevant Atmospheric Environment Themes

- Earth System Science
  e.g., mesosphere-thermosphere coupling, dynamical-chemical-radiative coupling

MESO

Microsat Experiment for Sounding Oxygen atom densities



Overview (proposed)

Measurements	vertically resolved atomic oxygen density profiles in the mesosphere from column integrated nighttime airglow emission rates of O_2 and OH
Instrument Design	three multi-channel imaging photometers
Viewing Geometry	nadir viewing
Spectral Region	UV, visible, and near-IR regions
Spatial Resolution	high horizontal resolution from 80 to 110 km
Launch Date	TBD
Lifetime	TBD
Platform	TBD
Principal Investigator	I.C. McDade, York University
Industry Participation	Bristol Aerospace, Routes Inc., CRESTech

ORACLE

Ozone Research by Advanced Cooperative Lidar Experiment

Scientific Objectives

- to measure global tropospheric and stratospheric profiles of ozone at high spatial and temporal resolution, during both day and night (including polar night)
- to detect aerosol and PSC distributions to investigate heterogeneous chemistry

Relevant Atmospheric Environment Themes

- Earth System Science
  e.g., chemical-microphysical coupling, stratosphere-troposphere coupling
- Northern High Latitudes
  e.g., ozone measurements during polar night and day, PSCs
- Environmental Monitoring and Prediction
  e.g., tropospheric ozone

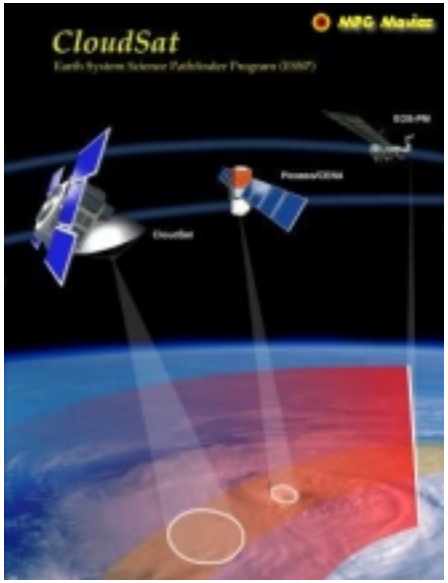
ORACLE

Ozone Research by Advanced Cooperative Lidar Experiment

Overview (proposed)

Measurements	ozone profiles from the PBL to 50 km to ≤10%; Intermittent ozone retrievals below 2.5 km; aerosols and PSCs
Instrument Design	differential absorption lidar (DIAL) with Ti:Sapphire laser and deployable telescope
Viewing Geometry	both day and night operation
Spectral Region	308, 320, 524, 747nm
Spatial Resolution	ozone: 2.5 km × 200 km vertical by horizontal from PBL to 35 km; lower resolution from 35 to 50 km and <2.5 km; PSC 1a: 0.5 km × 2.3 km; PSC 1b: 0.4 km × 50 km; PSC 2: 50 m × 4 km
Launch Date	TBD, TBD + 3 years, TBD + 6 years
Lifetime	10 days (demo), one year, two years +
Platform	Space Shuttle (demo), free flyer
Partners	NASA, CSA, MSC, 7 universities, Optech (Canada examining feasibility of receiver system)

CloudSat



Scientific Objectives

- to profile the vertical structure of clouds, cloud liquid water and ice water content, and cloud optical properties
- to quantitatively evaluate the representation of clouds and cloud processes in global atmospheric circulation models
- to quantitatively evaluate the relationship between liquid water and ice content and radiative heating by clouds
- to investigate the effects of aerosols on cloud formation and processes

Relevant Atmospheric Environment Themes

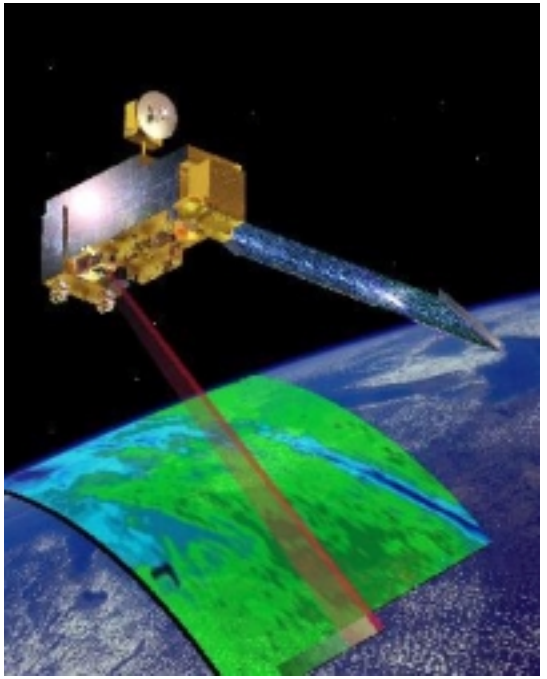
- Earth System Science
  e.g., microphysical-radiative coupling
- Climate Change
  e.g., role of clouds, incorporation into GCMs and climate models
- Environmental Monitoring and Prediction
  e.g., weather and climate

CloudSat

Overview

Measurements	cloud properties: thickness, height, water and ice content, optical depth, precipitation, particle sizes, emissivity, albedo, radiative heating
Instrument Design	combined passive and active: Cloud Profiling Radar (CPR), Profiling A-Band Spectrometer/ Visible Imager (PABSI) for O_2
Viewing Geometry	nadir-looking radar and nadir-reflected sunlight
Spectral Region	94 GHz; 760-770 nm at 0.5 cm^{-1} resolution
Spatial Resolution	radar: horizontal = 1.4 km $\times$ 4 km; vertical = 500 m from 0-20 km, 250 m from 5-20 km
Launch Date	2003
Lifetime	two years (four + expected)
Platform	CloudSat platform, flying in formation with PICASSO-CENA and EOS-PM
Partners	NASA/JPL, Colorado State Univ., US Air Force, US DOE, Ball Aerospace, CSA, MSC, CPI

MOPITT-2



Scientific Objectives

- to fly a second, upgraded version of MOPITT for global measurements of CO and CH_4
- to enable the establishment of a long-term data set for these gases
- to use these measurements to provide long-term forecasting of the effects of industrialization on society

Relevant Atmospheric Environment Themes

- Earth System Science
  e.g., chemical-dynamical coupling, surface-troposphere coupling
- Climate Change
  e.g., indicators of global change, natural vs. anthropogenic forcing
- Environmental Monitoring and Prediction
  e.g., tropospheric air quality, tracking pollutants

MOPITT-2

Overview (proposed)

Measurements	CH_4 columns to 1%; CO columns and profiles to 10%
Instrument Design	infrared correlation spectrometer; IR detectors cooled to 100 K; on-board calibration sources and cold space view calibration
Viewing Geometry	nadir sounding; cross-track scanning
Spectral Region	TBD
Spatial Resolution	TBD
Launch Date	2005 timeframe
Lifetime	five years
Platform	TBD: International Space Station? free flyer?
Principal Investigator	J.R. Drummond, University of Toronto

CSA Concept Studies
Related to the Atmospheric Environment

- **Design Study for MIMI**
  B. Gault, G. Shepherd, W. Ward, D.W. Tarasick, T. Raab, G. Buttner
- **MIMI Forward Model**
  D.W. Tarasick, W. Ward, P. Gauthier
- **Mesopause Temperature Limb Sounder (MTLS)**
  R.P. Lowe, D. Turnbull, K. Gilbert, G. Buttner, N. Rowlands
- **ALIVE - A Limb Imaging Vertical spectrograph Experiment**
  I.C. McDade (PI), K. Strong, B.H. Solheim, D. Degenstein, E.J. Llewellyn
- **Water Vapour, Polar Mesospheric Clouds and Climate Change**
  M.G. Shepherd (PI)
- **Gravity Waves in the Mesosphere**
  R.P. Lowe (PI)
- **SWIFT – Stratospheric Wind Interferometer for Transport Studies**
  B. Gault (PI)
- **OHMS – OH Measurements from Space**
  K. Strong (PI), J.R. Drummond, B.T. Tolton, and M.R. Bassford

Current & Future Technical Capabilities

Michelson Interferometer (for winds)

- WINDII
- SWIFT
- MIMI

Infrared Spectroscopy

- MOPITT[-2]
- ACE
- SALI

UV-Visible Spectroscopy

- OSIRIS (OS)
- MAESTRO
- MESO

Imaging

- OSIRIS (IRI)
- ACE (visible)
- MOXI

Active Sounding

- ORACLE
- CloudSat

Current & Future Measurement Capabilities - 1

Earth System Science

SCIENTIFIC ISSUES	CAPABILITIES
chemical-dynamical coupling	WINDII, MOPITT[-2], ACE, SWIFT, MESO, MIMI
chemical-microphysical coupling	OSIRIS, ACE, MAESTRO, ORACLE
microphysical-dynamical coupling	ACE
microphysical-radiative coupling	CloudSat
surface-troposphere coupling	MOPITT[-2]
stratosphere-troposphere coupling	ACE, MAESTRO, ORACLE
stratosphere-mesosphere coupling	OSIRIS, MIMI
mesosphere-thermosphere coupling	WINDII, MESO, MIMI
spatio-temporal coupling	WINDII, SWIFT, MIMI, MESO

Current & Future Measurement Capabilities - 2

Climate Change

SCIENTIFIC ISSUES	CAPABILITIES
changes in solar input	
changes in oceanic coupling (heat)	
changes in surface-atmosphere coupling	MOPITT[-2]
natural vs. anthropogenic processes	MOPITT[-2], ACE, MAESTRO
indicators of global change (monitoring, early warning)	MANTRA, MOPITT[-2], ACE, MAESTRO, SALI, MIMI
clouds, aerosols, greenhouse gases	MOPITT[-2], ACE, CloudSat, ORACLE
climate simulation models	CloudSat

Current & Future Measurement Capabilities - 3

Northern High Latitudes

SCIENTIFIC ISSUES	CAPABILITIES
Arctic climate feedbacks and interactions	ACE
Arctic atmospheric water cycle	
Arctic troposphere	ORACLE
ozone depletion: chemistry, dynamics, and aerosols/PSCs	OSIRIS, ACE, MAESTRO, ORACLE
polar dynamics	ACE, MIMI, ORACLE
noctilucent clouds	WINDII, MIMI, SALI
anthropogenic effects (trends, climate)	ACE, MAESTRO

Current & Future Measurement Capabilities - 4

Monitoring and Prediction

SCIENTIFIC ISSUES	CAPABILITIES
air quality (tropospheric ozone, other gases, UV radiation)	MOPITT[-2], ORACLE
tracking pollutants and trends	MANTRA, MOPITT[-2]
impact of changing profiles of radiative constituents	MIMI, SALI
spatially and temporally dense measurements for weather and climate	CloudSat
cloud characterization in NWP	CloudSat
effects of Earth's surface (transfer from ocean, lakes, ground to atmosphere)	
data assimilation and/or chemical/dynamical atmospheric modelling	MANTRA,MOPITT[-2], OSIRIS, ACE, MAESTRO, SWIFT, MIMI, ORACLE

Future Considerations

- recruitment and development of personnel and teams
- long-term funding to build and maintain teams and projects
- collaborations
  - → university, industry, government
  - → national
  - → international
- instrument development
- integrated measurement programs
  - → ground-based, balloon, aircraft, rocket, satellite
- support for related studies
  - → modelling (dynamics, chemistry, radiative transfer, data inversion), data assimilation, laboratory spectroscopy