Investigating Middle Atmospheric Chemistry at the Polar Environment Atmospheric Research Laboratory

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SPARC DA / IPY Workshop

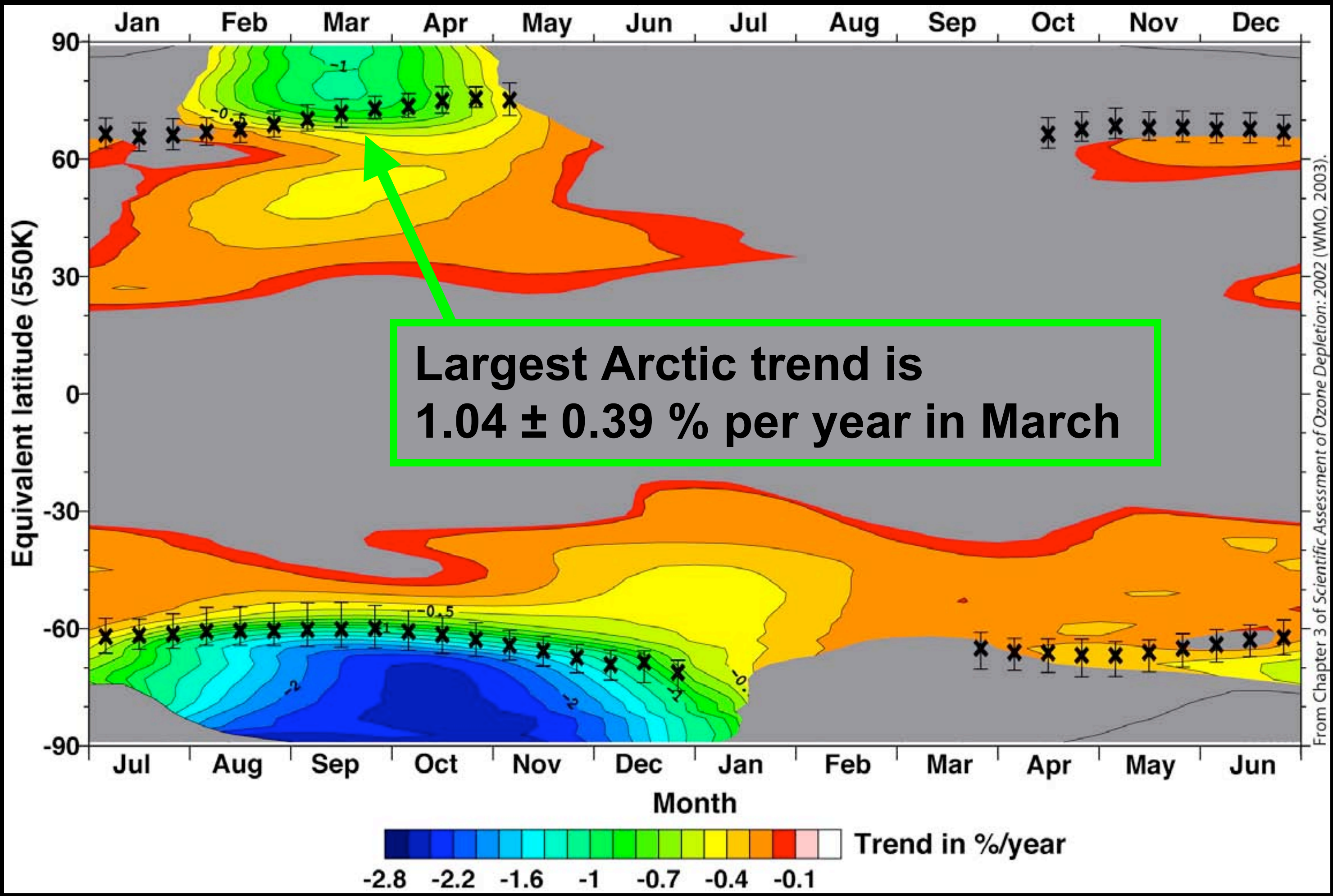
Toronto, 4-7 September 2007

Overview

- Polar Stratospheric Ozone Trends
- The Need for Arctic Measurements
- The PEARL at Eureka
- The Arctic Middle Atmosphere Chemistry Theme
- Measurements: Initial and Historical
- Outlook

Seasonal Total Ozone Trends

Total ozone column trends as a function of equivalent latitude and season using TOMS and GOME data for 1978-2000

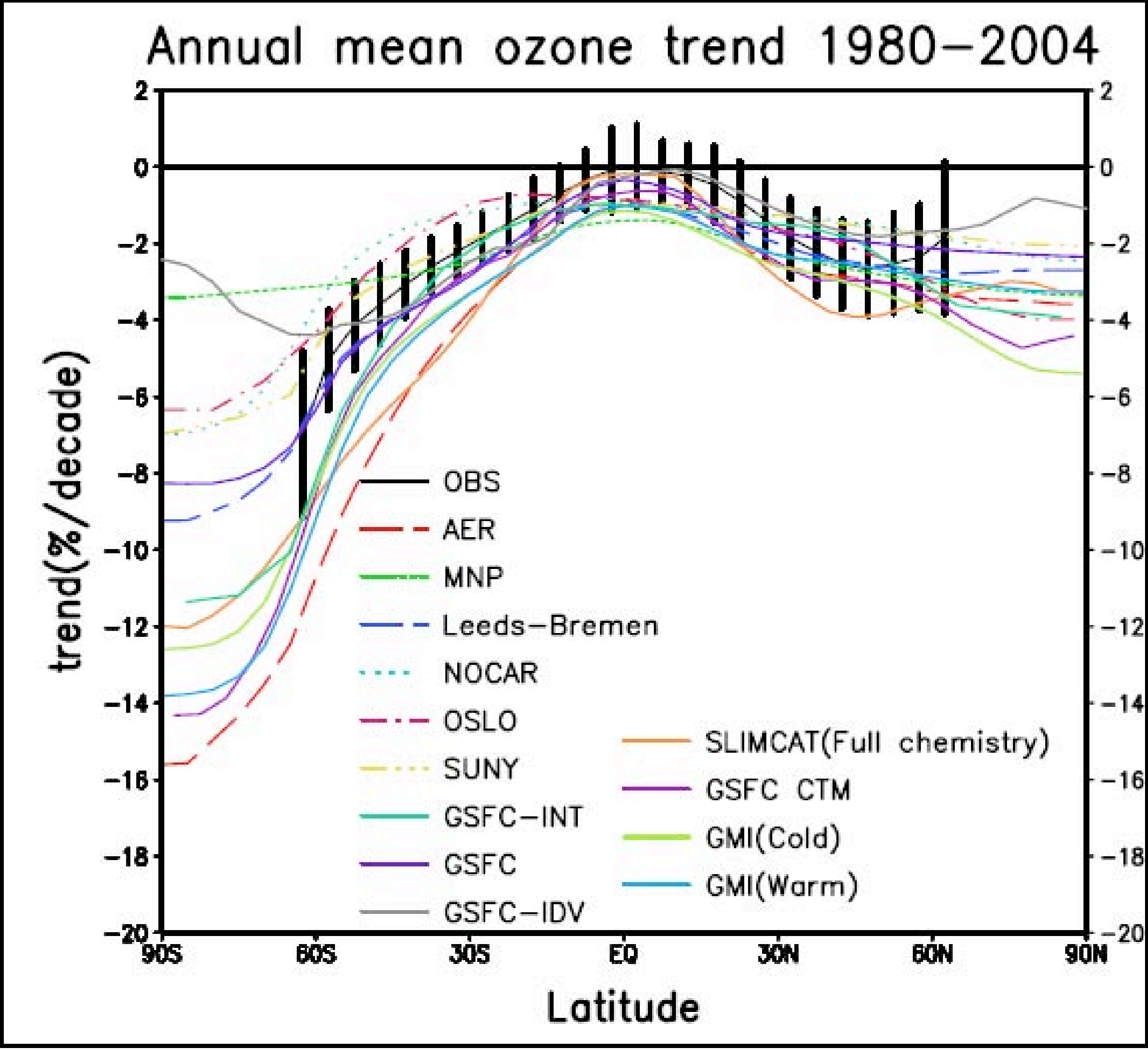


x - mean position of vortex edge

Eq. Latitude - a potential vorticity coordinate with vortex centre at 90°

WMO Ozone Assessment 2002

Latitudinal Total Ozone Trends



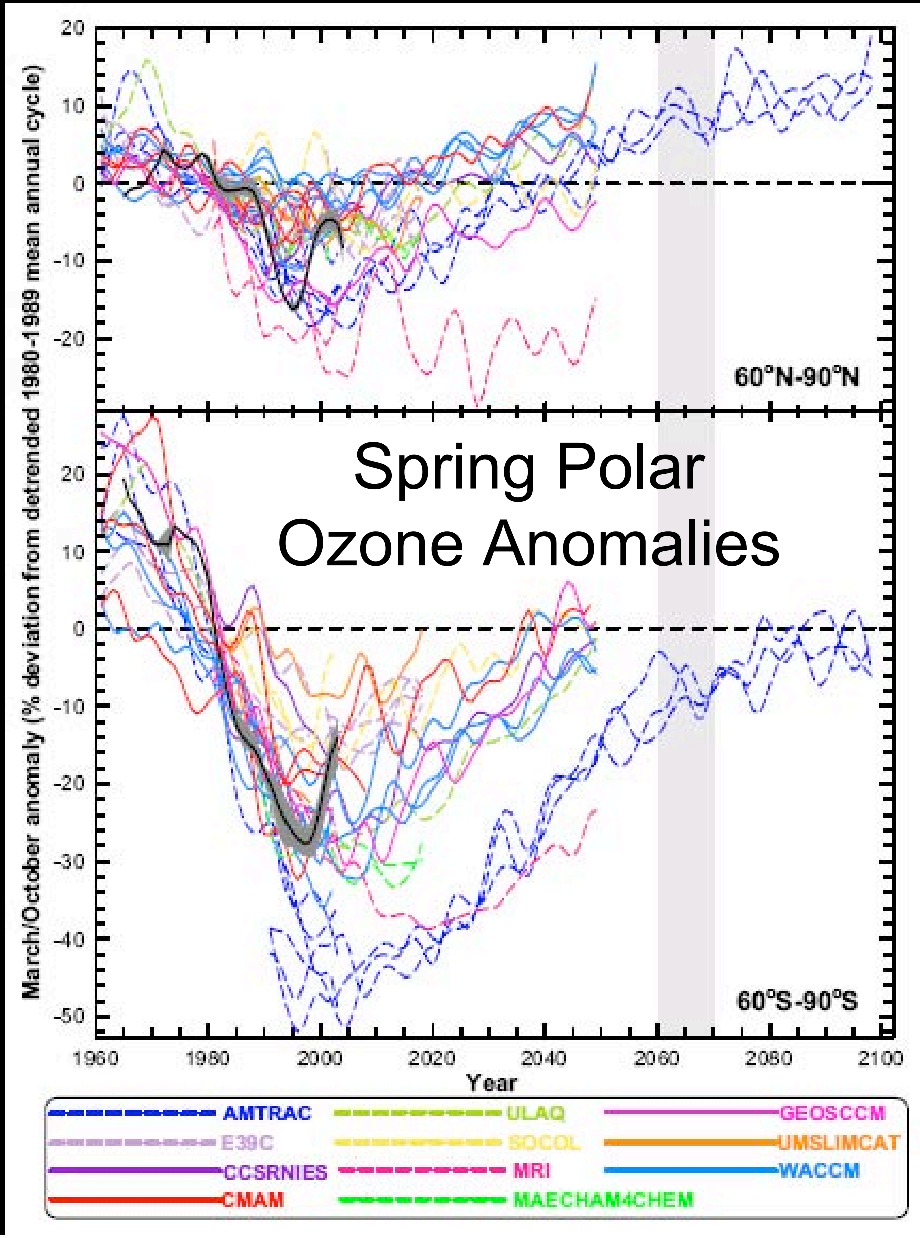
Measured and modelled latitudinal total ozone trends

WMO Ozone Assessment 2006

Polar Ozone - Predictions

Gradual recovery of ozone is anticipated as stratospheric chlorine decreases

- → Ozone turnaround in the Arctic is likely before 2020
- → Vunerable to perturbations, such as aerosols from volcanoes
- → Coupled to stratospheric cooling
- → Extreme Arctic ozone loss is not predicted



WMO Ozone Assessment 2006

The Need for Arctic Measurements

"… the frequency of measurements deep in the Arctic vortex remains low. The situation is unsatisfactory given the highly non-linear sensitivity of Arctic stratospheric ozone to cold winters. … Chemical and dynamical perturbations caused by strong volcanic eruptions make it impossible to derive a linear trend [in total ozone], which highlights the importance of continuous measurements throughout the expected recovery of the ozone layer during the coming decades."

IGOS 2004 Atmospheric Chemistry Report

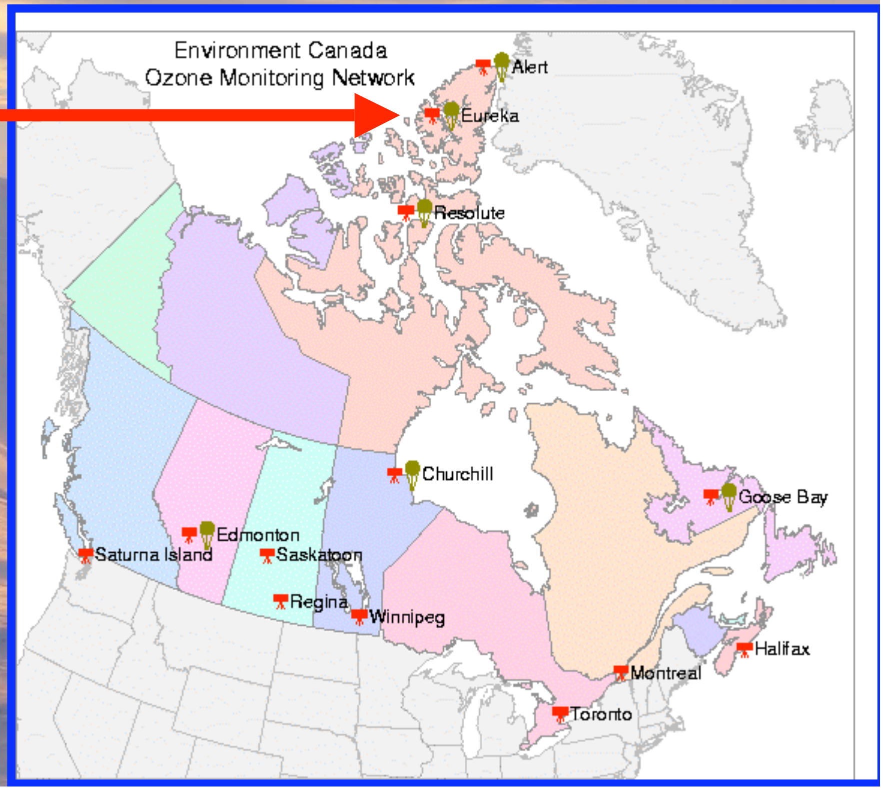
The Need for Arctic Measurements

"With regard to the Arctic, the future evolution of ozone is potentially sensitive to climate change and to natural variability, and will not necessarily follow strictly the chlorine loading. There is uncertainty in even the sign of the dynamical feedback to WMGHG changes. … Progress will result from further development of CCMs [chemistry-climate models] and from comparisons of results between models and with observations."

IPCC/TEAP 2005, Special Report on Safeguarding the Ozone Layer and the Global Climate System

The PEARL at Eureka

- **Polar Environment Atmospheric Research Laboratory**
  - → Formerly Environment Canada's Arctic Stratospheric Ozone Observatory
  - → Now run by the Canadian Network for Detection of Atmospheric Change (CANDAC)
  - → Began operating in August 2005

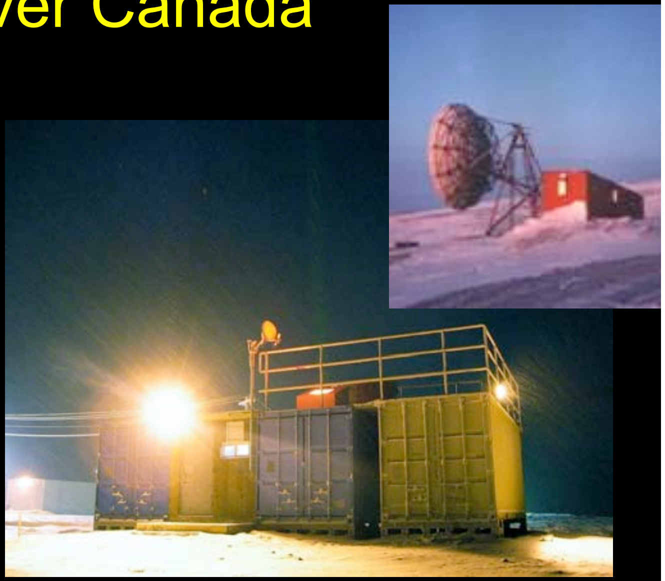


- **Located on Ellesmere Island in Nunavut, 15 km from the Eureka Weather Station (80°N, 86°W)**

CANDAC
Canadian Network for the Detection of Atmospheric Change

Canadian Network for Detection of Atmospheric Change

- Network of university and government researchers dedicated to studying the changing atmosphere over Canada
- Initial emphasis is on the Arctic
  - → PEARL is the first CANDAC site
- CANDAC facilities at Eureka
  - → Three labs: PEARL, ØPAL, and SAFIRE
  - → Dedicated C-band satellite link
- Future goals include
  - → Coordinating research-level atmospheric measurements
  - → Integrating satellite, aircraft, balloon, ground-based measurements
  - → Developing quality control protocols for these data
  - → Establishing “anchor sites” in different regions



PEARL Objectives

- To measure the atmosphere in the range 0-100 km as comprehensively as possible
  - → stratospheric ozone, climate change, air quality
- To deploy research-grade equipment
- To develop new instrumentation and observing strategies
- To provide a Canadian research presence at this remote location
  - → 1,100 km from the North Pole

PEARL Research Themes

- PEARL research is divided into four themes:
  - → Arctic Troposphere Transport and Air Quality
  - → The Arctic Radiative Environment
    - * Impacts of Clouds, Aerosols and Diamond Dust
  - → Middle Atmospheric Chemistry in the Arctic
  - → Waves and Coupling Processes
- Other significant research activities
  - → Satellite Validation
  - → Sudden Events

Instruments

PEARL

- Stratospheric Ozone Lidar
- DA8 FTS/ 125HR FTS
- Aerosol Mass Spectrometer
- UV-Vis Spectrometer
- Michelson E-Region Wind Interferometer (ERWIN)
- Spectral Imaging Interferometer (SATI)
- All Sky Imager
- Sun Photometer
- Brewer Spectrophotometer

ØPAL

- Millimeter Cloud Radar
- High Spectral Resolution Lidar (SEARCH)
- VHF Meteor Radar
- Polar Atmospheric Emitted Radiance Interferometer (P-AERI)
- Sun and Star Photometer
- Tropospheric Ozone Lidar
- Rayleigh/Mie/Raman Lidar

SAFIRE

- WindTracker Radar
- Baseline Surface Radiation Network Instrumentation
- Flux Tower

Arctic Middle Atmosphere Chemistry Theme

Science Questions

- What is the chemical composition of the Arctic stratosphere above PEARL?
  - → How and why is it changing with time?
- How is the chemistry coupled to dynamics, microphysics, and radiation?
- What is the polar stratospheric bromine budget?
  - → Significant source of uncertainty
  - → BrO + ClO cycle estimated to contribute up to half chemical loss
- How will the polar stratosphere respond to climate perturbations?
  - → Particularly while Cl and Br loading is high
  - → How will changes in atmospheric circulation affect polar ozone?
  - → Cooling (more ozone depletion) or warming (less)?

Arctic Middle Atmosphere Chemistry Theme

Primary Composition Instruments

- Bruker 125HR Fourier transform infrared spectrometer (FTS)
  - → Direct solar (and lunar) absorption, 700-4500 cm^{-1} at high resolution
- UV-visible grating spectrometer
  - → Zenith-scattered (and direct) solar absorption, 300-600 nm
- Stratospheric ozone lidar → Differential Absorption Lidar (DIAL)
- Brewer spectrophotometer → Ozone total columns
- Polar Atmospheric Emitted Radiance Interferometer (P-AERI)
  - → Emission, 400-3300 cm^{-1} (3-25 μm) at low spectral resolution

Measurements

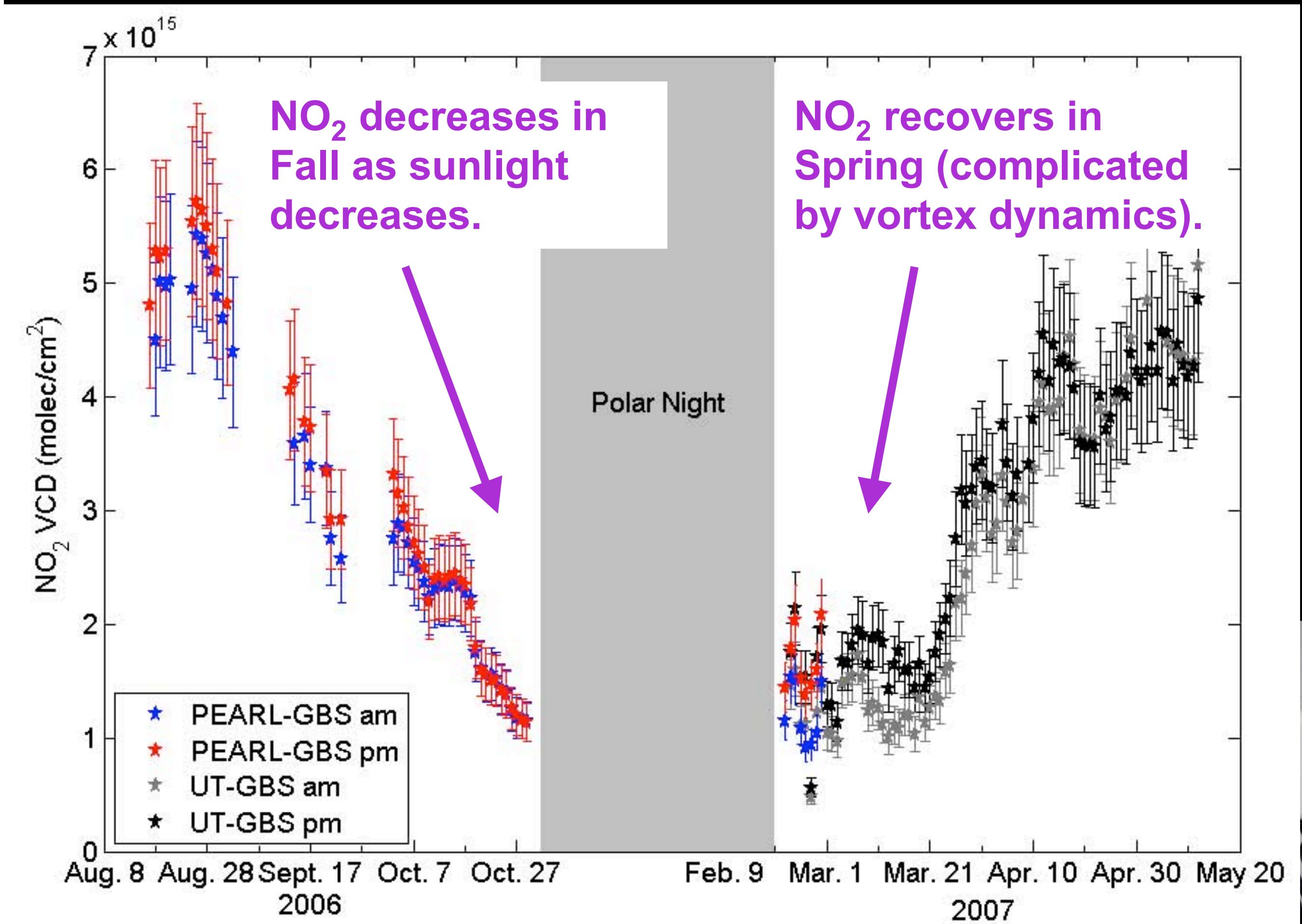
- Reactive species, source gases, reservoirs, dynamical tracers
  - → O_3, NO, NO_2, HNO_3, N_2O_5, NO_3, N_2O, $ClONO_2$, HCl, OClO, BrO, HF, CFCs, CH_4, H_2O, CO, OCS, ...
- Total columns and some information on vertical distribution

2006-2007 AMAC Highlights

- February-March 2006 - ACE Arctic validation campaign
- March 2006 - installation of SEARCH / U of Idaho AERI
- July 2006 - installation of new Bruker IFS 125HR FTS
- August 2006 - installation of new UV-visible grating spectrometer
- August-October 2006 - first data from both instruments
- February-March 2007 - ACE Arctic validation campaign
- July 2007 - Bruker / Bomem intercomparison campaign
- August-September 2007 - NDACC Aura validation campaign
- Ongoing - daily measurements, implementation and optimization of retrieval algorithms, initial analysis

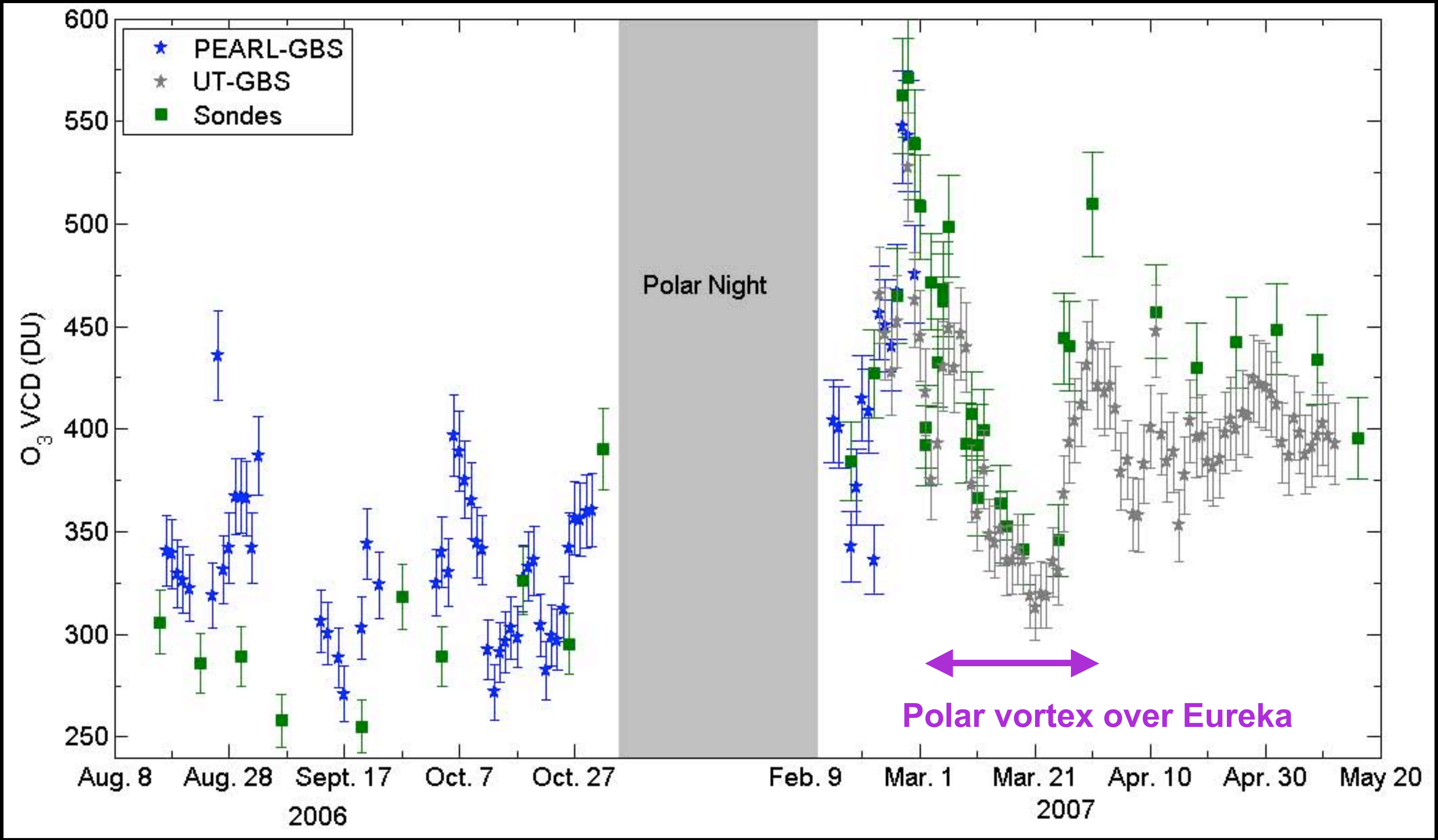
See posters by Rebecca Batchelor and Annemarie Fraser.

UV-Visible Spectrometer: NO_2



Annemarie Fraser
(see poster)

UV-Visible Spectrometer: O_3



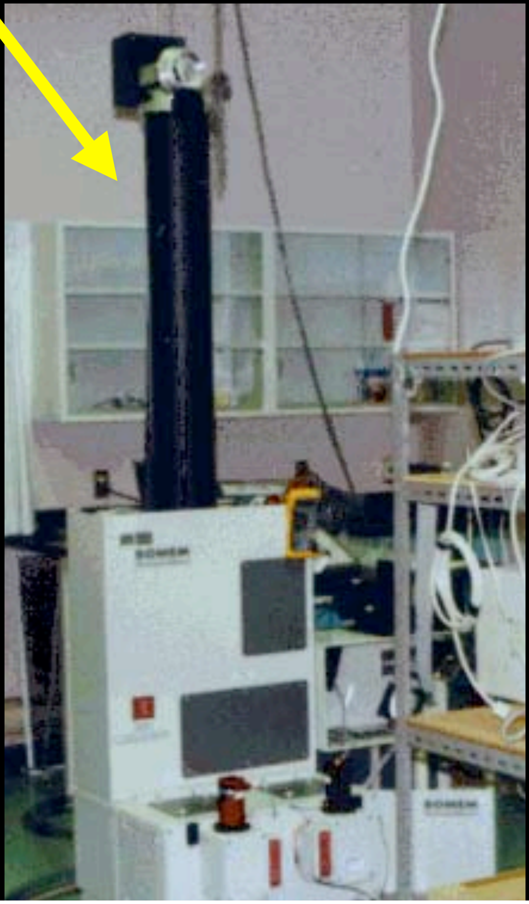
Annemarie Fraser
(see poster)

Spring 2007 Campaign: 3 FTSs

R. Batchelor
R. Lindenmaier
A. Harrett
R. Mittermeier

New Bruker 125HR

Existing Bomem DA8

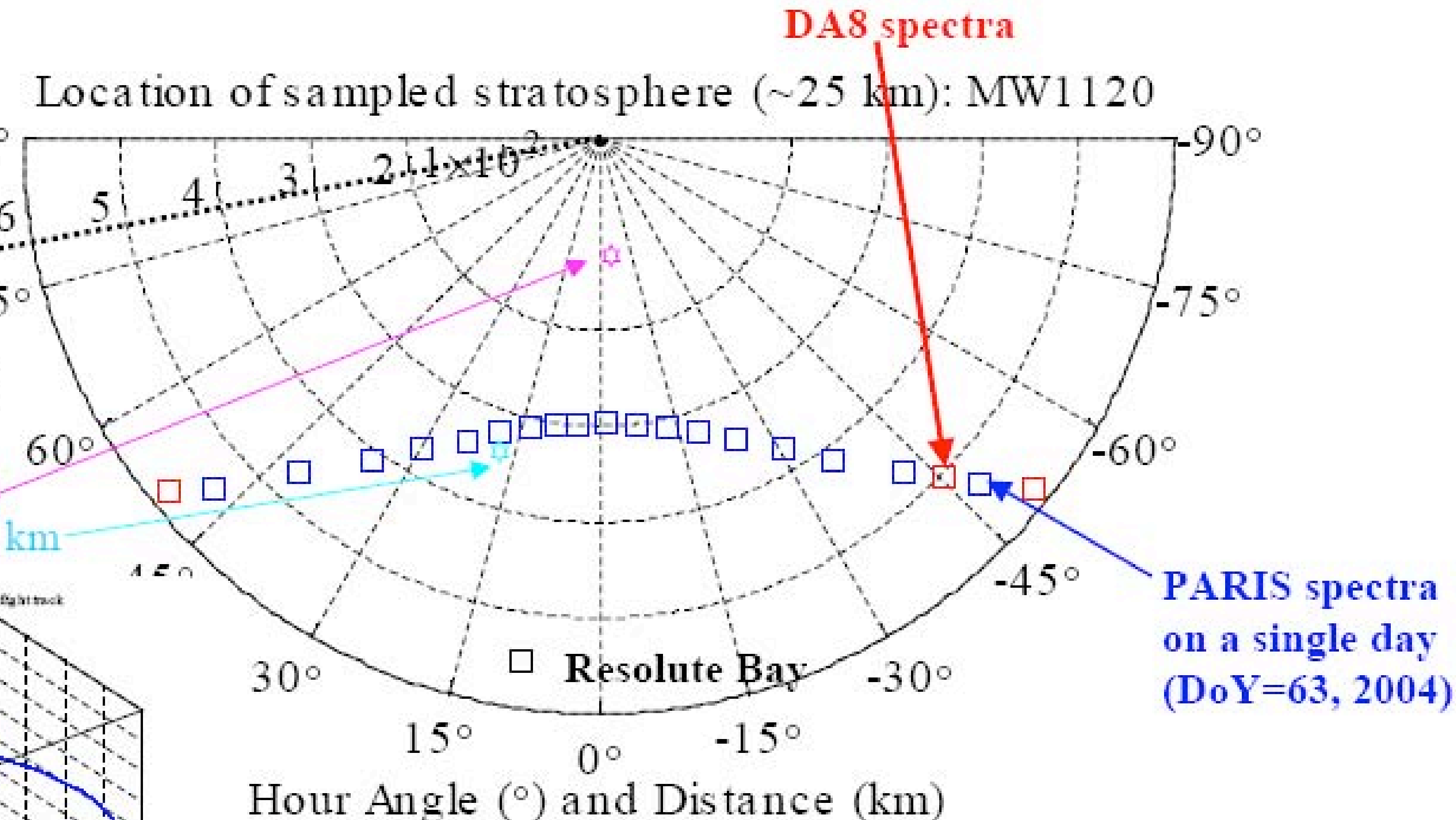


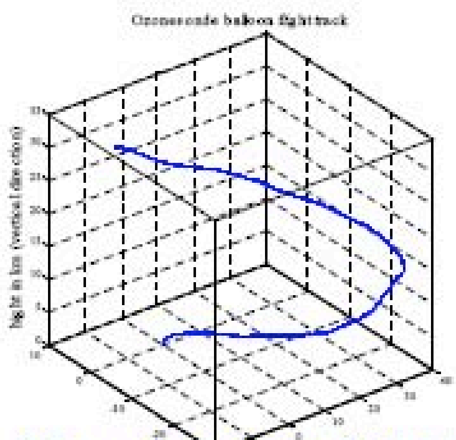
PARIS-IR
(adaptation
of ACE-FTS)

Analysis of DA8 FTS Archive

- Bomem DA8 FTS
  - → Installed at Eureka (AStrO) in 1993
  - → Operated by EC (Hans Fast, Richard Mittermeier)
  - → NDACC Arctic Primary Station instrument
- Goal: To reanalyse the full DA8 data set (1993-2007) using a consistent approach (SFIT-2) to retrieve total column amounts, partial columns, and vertical mixing ratio profiles
  - → Daily p and T profiles from radiosondes, NCEP, MSIS
  - → *A priori* volume mixing ratio profiles and covariances from ozonesonde archive, HALOE, SPARC 2000
  - → Spectral fitting regions based on ACE-FTS v2.2 and prior values
- Initial focus on analysis of 2004-2006 data
  - → O_3, NO, NO_2, HNO_3, HF, HCl, $ClONO_2$, CH_4, N_2O
  - → Averaging kernels, degree of freedom for signal, and error budgets

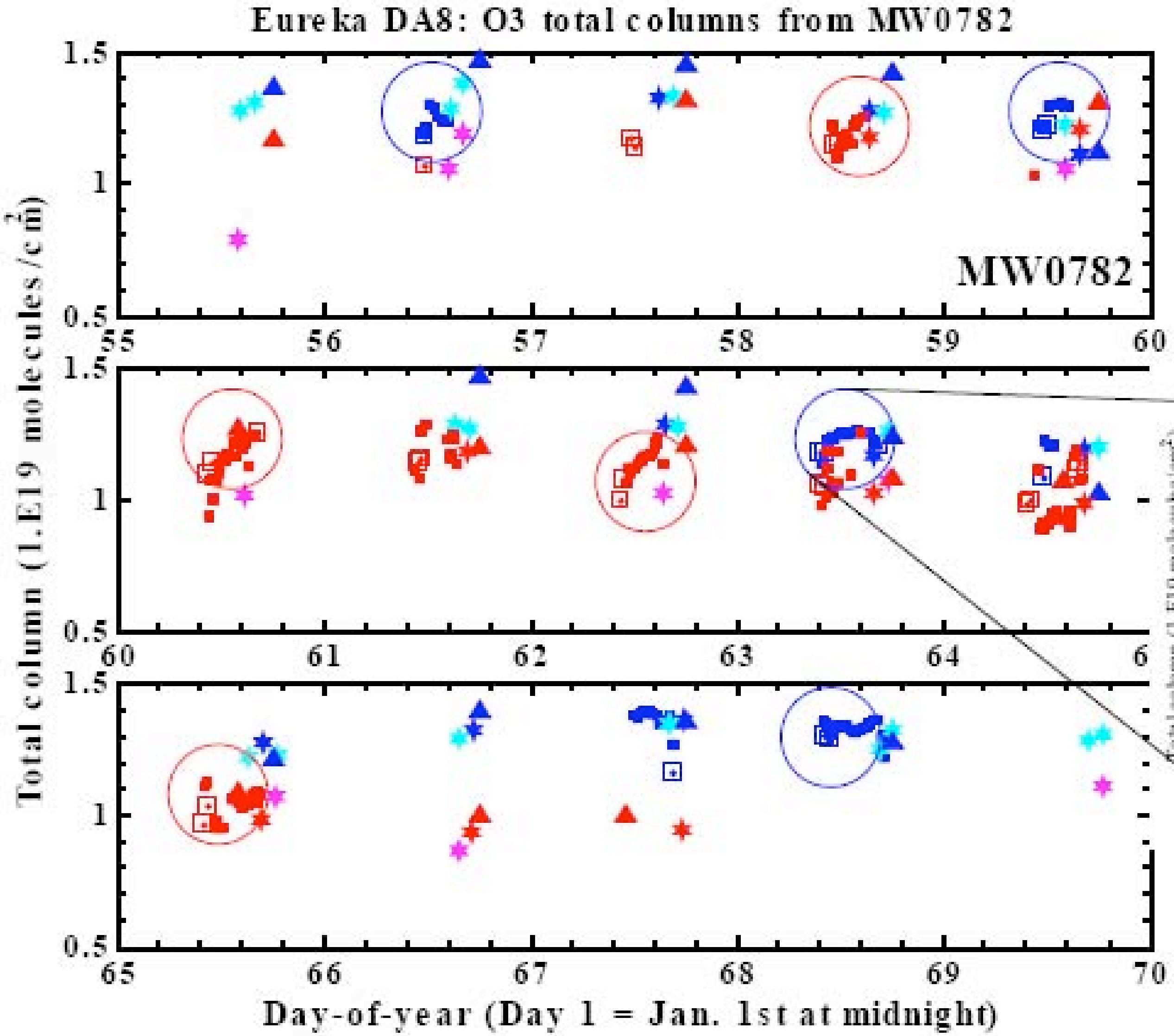
Geographic distribution of atmospheric samplings (relative to the observation site, **Eureka on Mar. 3, 2004**)



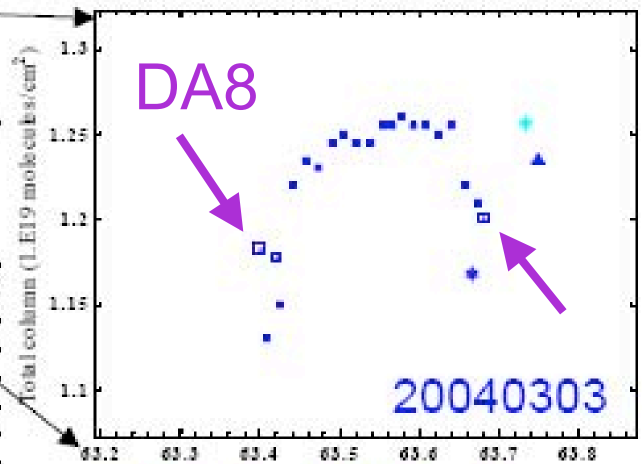


O3-sonde balloon flight track (< 40 km)

2004-2005 Ozone Columns



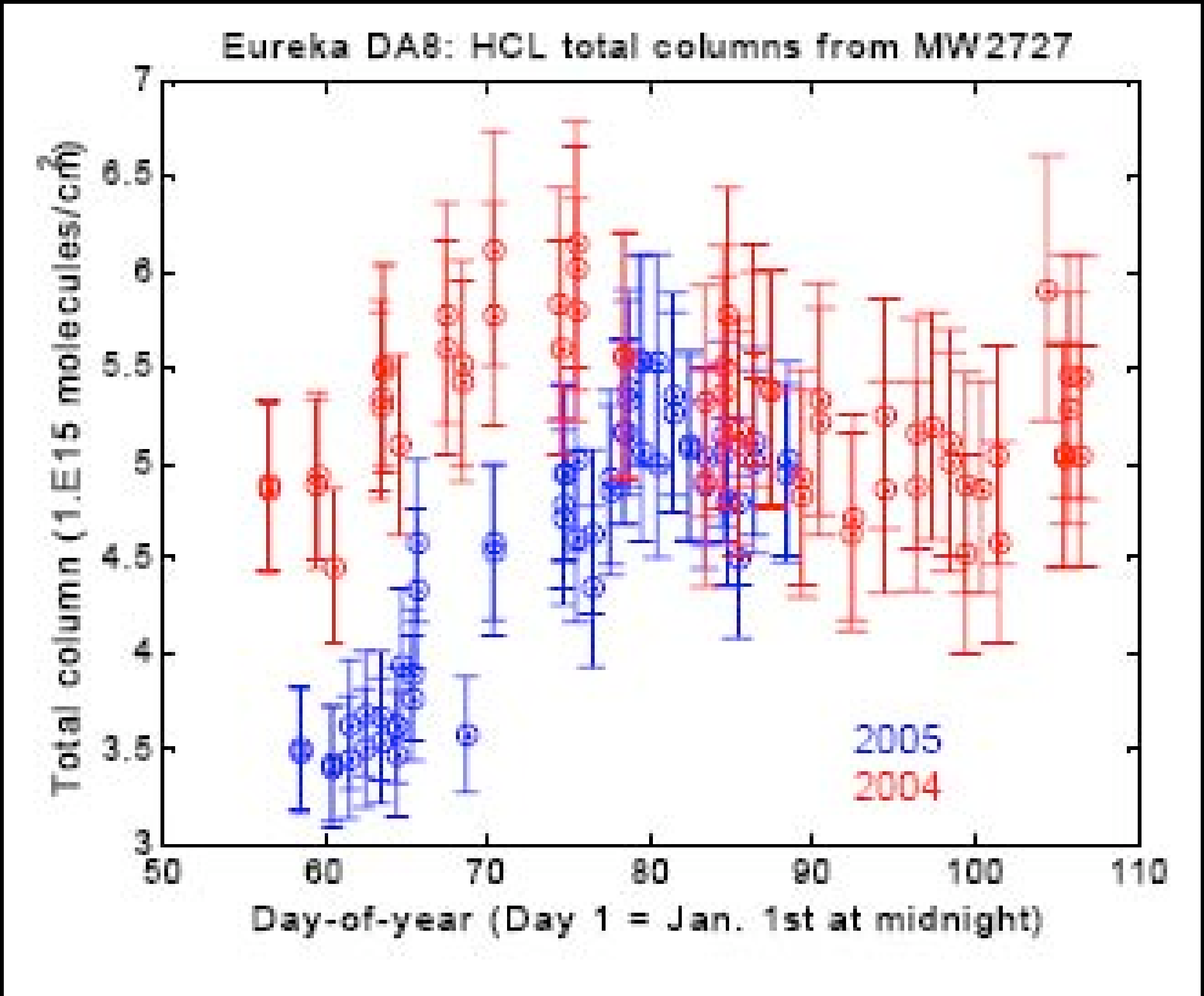
2004 and 2005
DA8 (□, □)
PARIS (■ , ■)
ACE-FTS < 200 km (*, *)
< 500 km (*, *)
Ozonesonde (▲, ▲)



Note that DA8 columns fall on the track of PARIS-IR

Keeyoon Sung, Dejian Fu

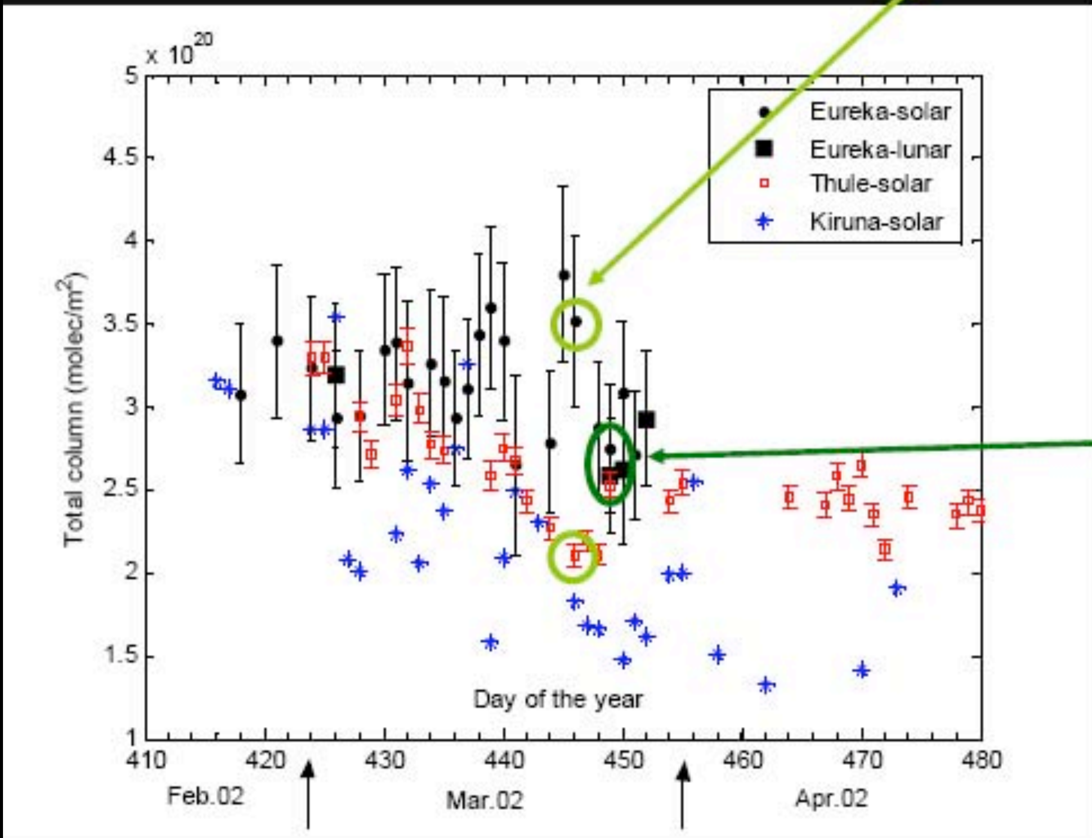
2004-2005 DA8 FTS: HCl

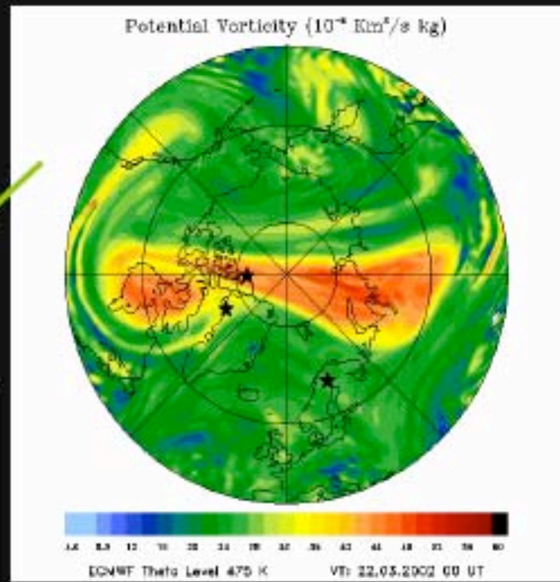


Keeyoon Sung, Dejian Fu

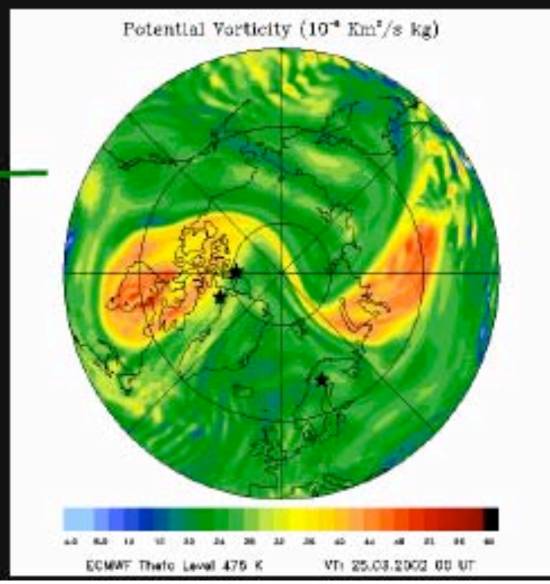
DA8 FTS Measurements: HNO_3

- March 22, 2002 (day 446): Eureka at higher PV and HNO_3 typical of the HNO_3-rich air mass inside the vortex
- March 25, 2002 (day 449): Eureka & Thule similar values for PV and for HNO_3

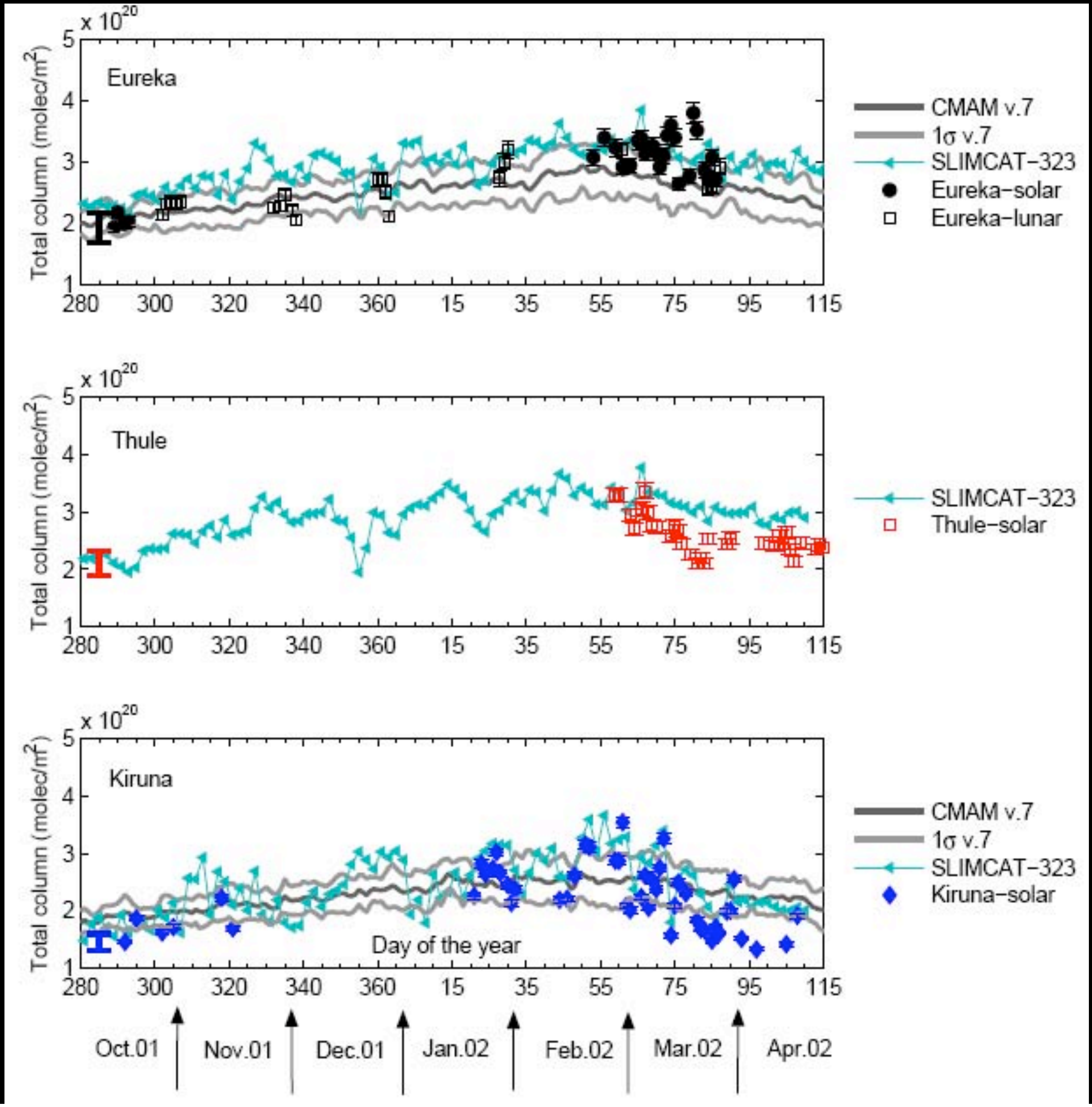




Farahani et al., JGR 2007



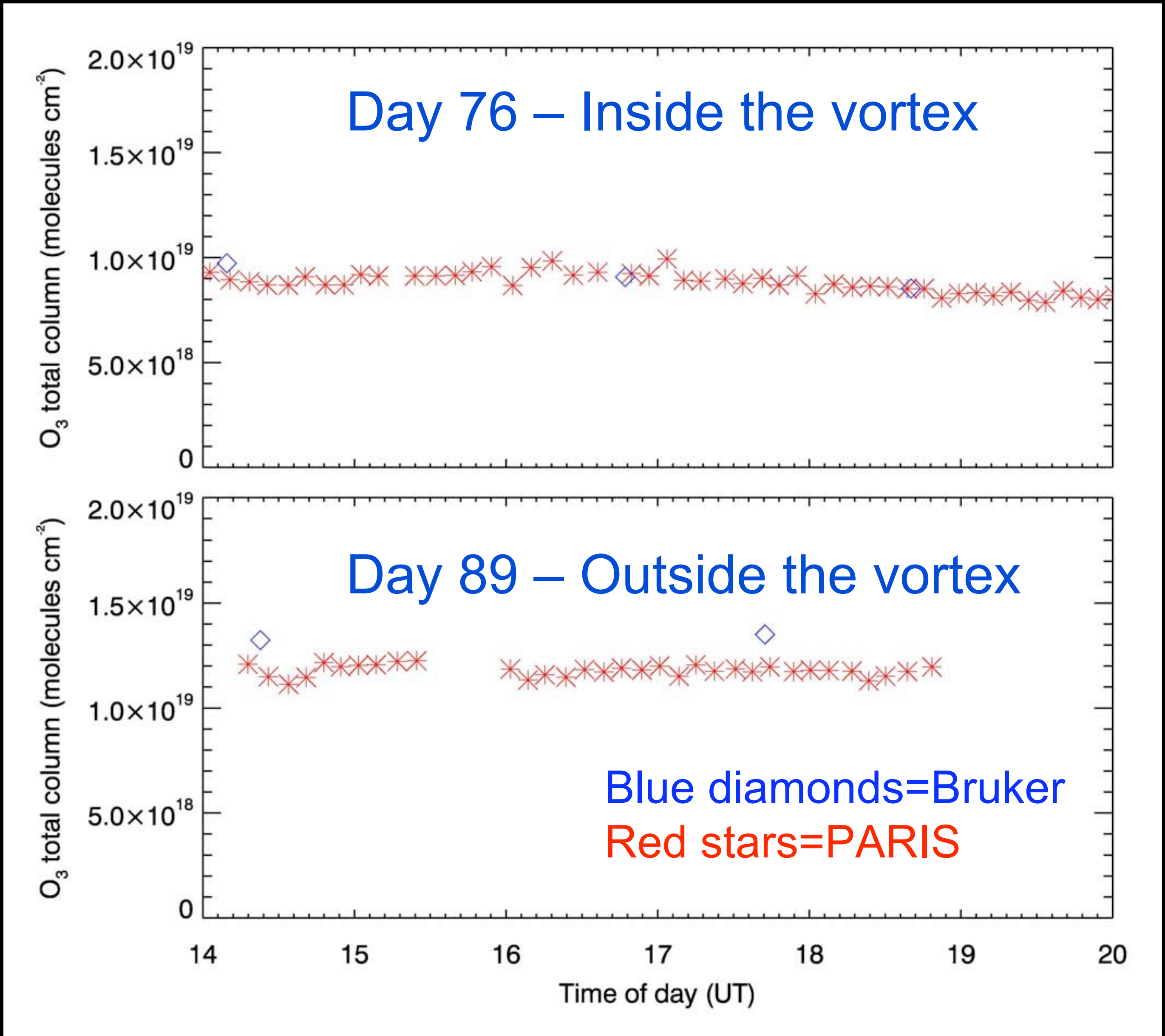
DA8 FTS Measurements: HNO_3



Comparison of solar and lunar DA8 FTS measurements during winter 2001-2002 with SLIMCAT chemical transport model and CMAM

Farahani et al., JGR 2007

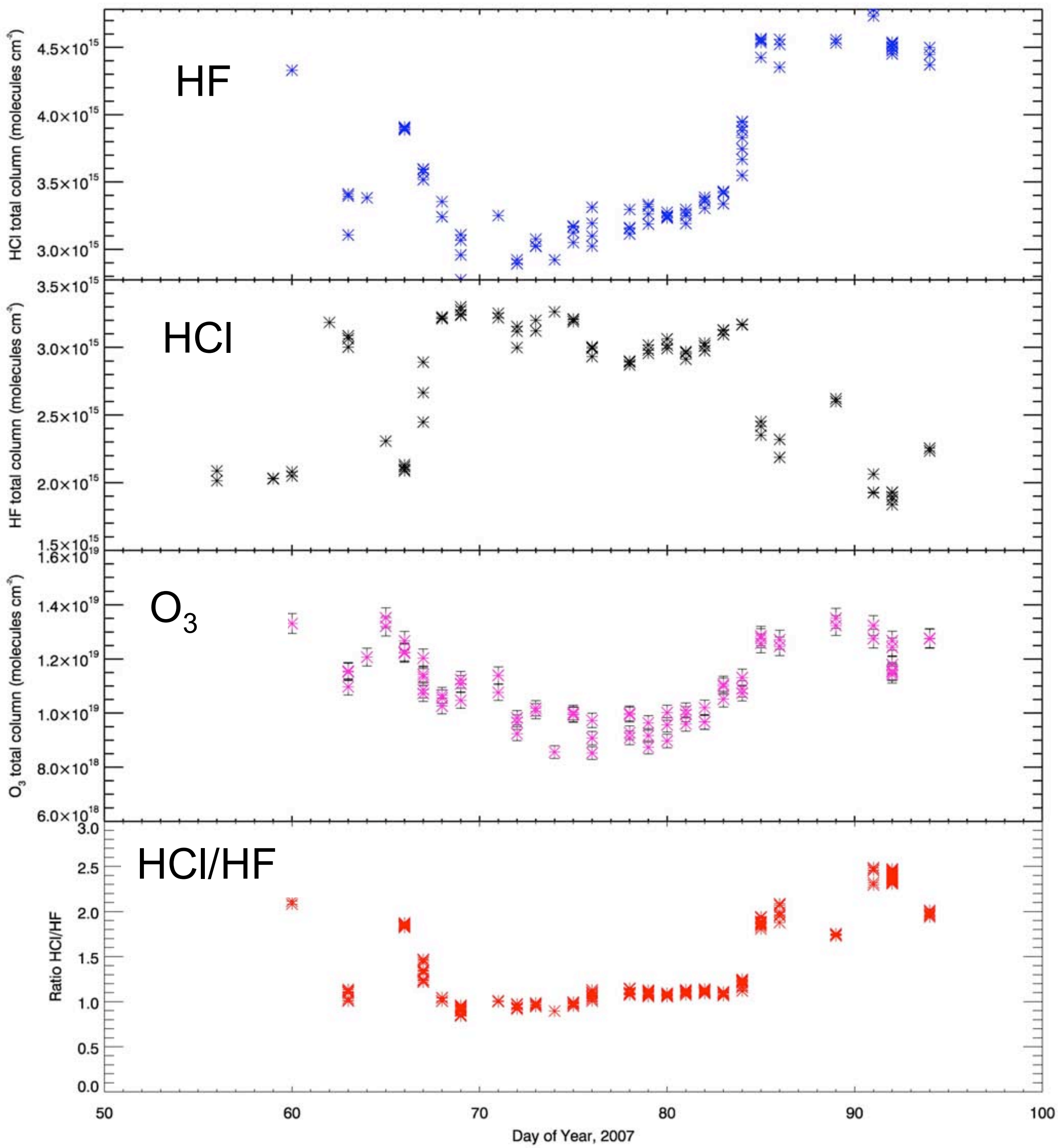
Bruker-PARIS Comparison: O_3



2007
Preliminary
Data

R. Lindenmaier
F. Kolonjari
R. Batchelor

Bruker FTS



2007
Preliminary
Data

R. Batchelor
R. Lindenmaier
(see poster)

Outlook

- Long-term measurements are essential to understanding the chemical state of the Arctic stratosphere and how it is changing with time
  - → Focus of the Arctic Middle Atmosphere Chemistry theme at PEARL
- Instruments currently installed are operating well
  - → NDACC certification for Bruker FTS and UV-visible spectrometer
- Some installation and upgrades to be done
  - → Installation of new sun-trackers for FTS and UV-visible spectrometer
  - → Automation of Bruker FTS measurements
  - → Upgrade and operation of stratospheric ozone lidar
  - → Installation of CANDAC P-AERI
- Integration with complementary measurements at PEARL
- Contributions to IPY atmospheric science

CANDAC / PEARL Co-Investigators

Principal Investigator

- Prof. James R. Drummond, Dalhousie University / University of Toronto

CANDAC Manager of Operations

- Dr. Pierre Fogal, University of Toronto

Theme Leaders

- Prof. Tom Duck, Dalhousie University, The Arctic Radiative Environment: Impacts of Clouds, Aerosols, and “Diamond Dust”
- Prof. Jim Sloan, University of Waterloo, Arctic Tropospheric Transport and Air Quality,
- Prof. Kimberly Strong, University of Toronto, Arctic Middle Atmospheric Chemistry
- Prof. William Ward, University of New Brunswick, Waves and Coupling Processes

Co-Investigators

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- Dr. Hans Fast, Environment Canada
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- Dr. Tom McElroy, Environment Canada
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- Prof. Gordon Shepherd, York University
- Prof. Robert Sica, University of Western Ontario
- Dr. Kevin Strawbridge, Environment Canada
- Prof. Kaley Walker, University of Toronto
- Prof. Jim Whiteway, York University

The following organizations are involved in supporting CANDAC / PEARL: CFCAS, CFI, CSA, EC, MRI, MSC, NSERC, NSIRT, OIT, PCSP, SEARCH