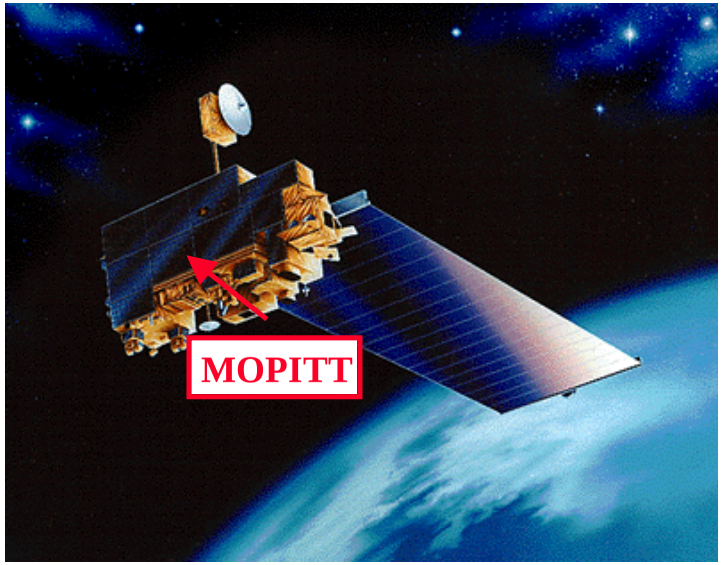
MOPITT Data Validation Summary Chart

Jinxue Wang[1], John C. Gille[1], James R. Drummond[2]
Henry Reichle,[3] Gary Davis [4] and
the MOPITT Correlative Team
(1) NCAR/ACD, Boulder, Colorado
(2) Department of Physics, University of Toronto, Canada
(3) North Carolina State University
(4) University of Saskatchewan, Canada

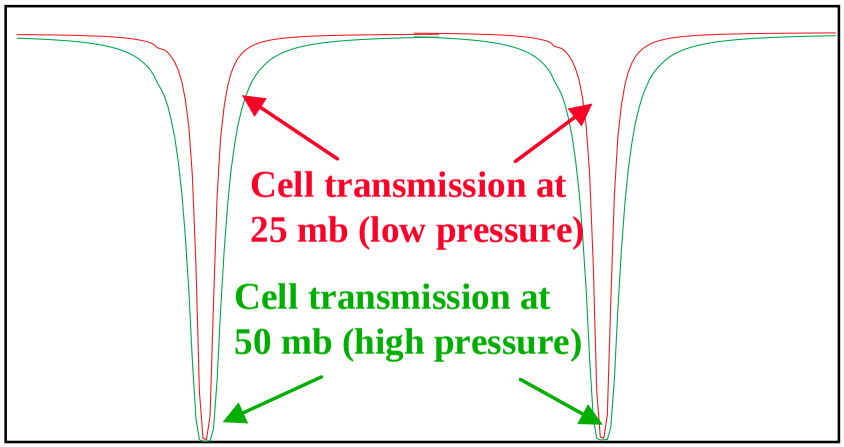


Outline

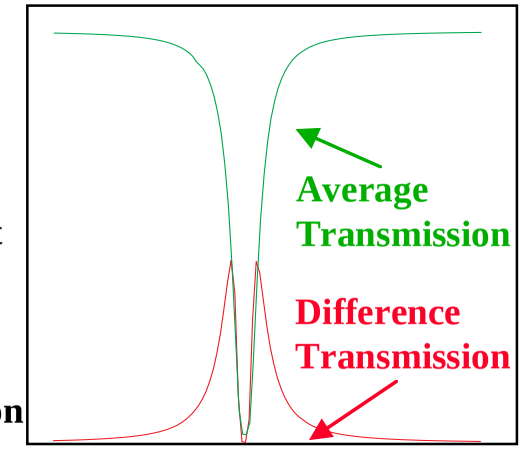
- Description of MOPITT Science Data Products
- Data Validation Plan and Strategies
- Planned Correlative Measurements
- Pre-launch MOPITT Validation Exercise (Pre-MOVE)

Summary of MOPITT Channel Characteristics

Channel #	Primary Purpose	Modulator Type	Cell Pressure (mb)	Cell Temperature (K)	Cell Length (mm)	Spectral Band	Center Wavenumber (cm^{-1})
1	CO	LMC1	200	300	2 - 10	CO thermal	2166 (52)
2	CO	LMC1	200	300	2 - 10	CO solar	4285 (40)
3	CO	PMC1	50 -100	300	10	CO thermal	2166 (52)
4	CH_4	LMC2	800	300	2 - 10	CH_4 solar	4430 (140)
5	CO	LMC3	800	300	2 - 10	CO thermal	2166 (52)
6	CO	LMC3	800	300	2 - 10	CO solar	4285 (40)
7	CO	PMC2	25 - 50	300	10	CO thermal	2166 (52)
8	CH_4	LMC4	800	300	2 - 10	CH_4 solar	4430 (140)



Equivalent Average & Difference Transmission



Standard Data Products

- **Standard MOPITT scientific products**

  - Level 1 data products

    - Calibrated and geo-located radiance.

  - Level 2 data products

    - Tropospheric CO profile. Average mixing ratio at 7 tropospheric pressure levels with a nominal horizontal resolution of 22kmx22km: surface, 850 mb, 700 mb, 500 mb, 350 mb, 250 mb, 150 mb.

    - CO total column.

    - CH_4 total column.

  - Level 3 data products (experimental at launch)

    - Gridded global CO distribution (global maps).

    - Gridded global CH_4 distribution (global maps).

Overview of Validation Strategy

- **MOPITT measurement accuracy, precision, and resolution will be confirmed by a combination of the following validation activities:**

  (1) Vigorous pre-launch algorithm test and verification.

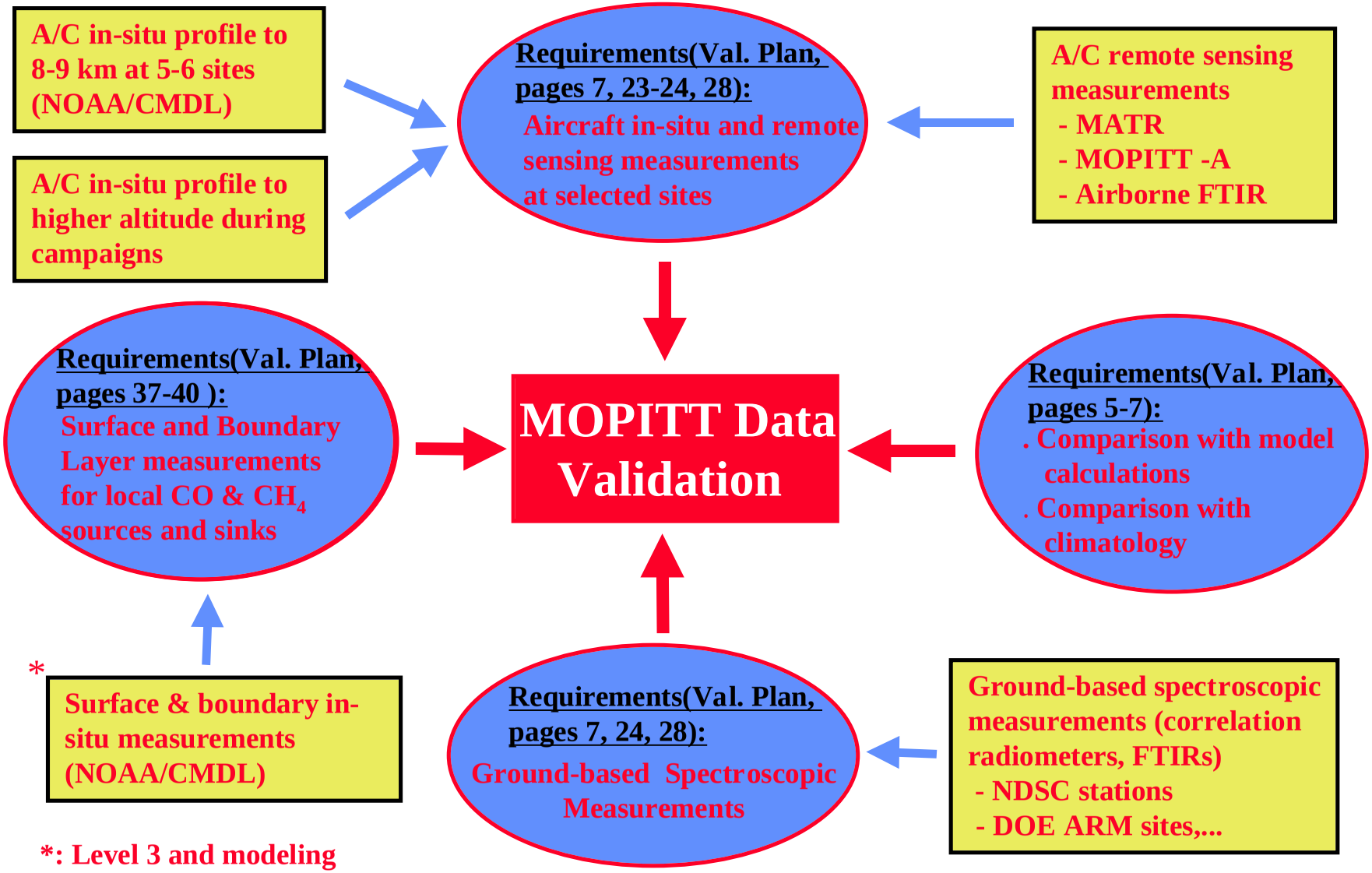
  (2) Validation of MOPITT level 1 data through comparison with model calculations and vicarious calibration with the MOPITT airborne simulator (MOPITT-A), FTIR, MODIS/MAS.

  (3) Comparison of derived products (mainly level 2 data) with correlative measurements.

- **In the planning of validation activities, a step-by-step approach will be used. We will start from simpler situations, learning from and assessing their results before fully addressing more complicated cases.**

Cloud free (clear-sky) conditions			
	Over ocean	**Night**	**simple**
		Day	
	Over land	**Night**	
		Day	
Cloudy conditions			
	Over ocean	**Day**	
		Night	
	Over land	**Day**	
		Night	**complex**

MOPITT Data Validation Requirements and Activities



*: Level 3 and modeling

MOPITT Algorithm Test Radiometer (MATR)

- **Objective**
  - Main objective is for pre-launch algorithm test and verification.
  - Application in level 2 data validation after launch as a ground-based or airborne correlation radiometer.

- **Design**
  - Uses same principle or technique (gas correlation radiometry).
  - Includes a PMC channel and two LMC channels.
  - Data will be used for pre-launch algorithm test and post-launch. level 2 data validation.

- **Pre-launch flight schedule**
  - Version 1 test flight took place in June, 1996 on NASA T-39 Sabreliner.
  - Version 1 second flight took place in September, 1996 also on Sabreliner.
  - Version 2 test flight was conducted in February, 1998 over California coast and participated in the first Pre-launch MOPITT Validation Exercise (Pre-MOVE).

- **Post-launch flight schedule**
  - Two campaigns are planned for FY1999.
  - Two campaigns are planned for FY2000.

MOPITT Airborne Simulator (MOPITT-A)
Development Funded by Canadian Space Agency (CSA)

- **Primary Objective**
  - Validation of MOPITT data products
  - Essential for vicarious validation of MOPITT Level 1 data products (calibrated radiance). Vicarious calibration of radiance.
- **Accuracy and Precision**
  - Same or better radiometric accuracy as MOPITT
  - Same or better channel radiance accuracy as MOPITT
  - Traceable to "standards"
- **Horizontal Coverage**
  - Need to cover MOPITT footprint (22 km x 22 km)
  - Less critical in uniform areas
- **Vertical Coverage**
  - Thermal channels: need to match MOPITT signal functions (contribution functions)
  - Solar channels: need to get above the entire column

Aircraft carrying MOPITT-A needs to fly at or above 18-20 km

- **Post-launch flight schedule (collaboration with other teams)**
  - First mission (test flight on ER-2) is planned for July-October, 1999.
  - Plan to participate in the SAFARI-2000 program in 2000.

Pre-launch Activities

- **Forward model development and test.**

  (1) Collecting and analysis of existing CO measurements (NOAA/CMDL, Cape Grim, MAPS, A/C campaigns, ground-based spectroscopic measurements,..) and temperature & H2O profiles (e.g. TIGR2) for forward model and algorithm development.

  (2) Compare the parameterized MOPITT retrieval forward model with line-by-line calculations for a variety of atmospheric conditions, including extremes of possible T, CO, H_2O profiles.

  (3) MATR will be used to obtain data for both forward model and retrieval algorithm verification.
  - **The measured radiance will be compared with forward model calculated radiance.**
  - **Cloud and surface characteristics signatures in the MATR signal will also be investigated for potential use in MOPITT cloud clearing.**

  (4) Between flights, MATR will also be used for ground-based measurements, such as solar absorption in the 2.3 μm bands of CO and CH_4 .
  - **These measurements will be compared with forward model calculations, the U. of Toronto ground-based correlation radiometer, and ground-based FTIR measurement.**

Pre-launch Activities

- **Verification of spectral line parameters and solar irradiance data.**

  (1) Laboratory measurement using FTIR and tunable diode laser spectrometers (TDLS).

  (2) Analysis of ATMOS solar spectra.

  (3) Calculations by Dr. Robert Kurucz at Harvard-Smithsonian Center for Astrophysics.

  Spectral range: 4100 - 4700 cm-1

  Resolution: 0.005 cm-1

  Spacing: 0.005 cm-1

  (4) Update line parameters using results from NASA EOS coordinated research effort.

- **Retrieval algorithm development and test.**

  (1) Prior CO profile measurements (e.g., CMDL, Cape Grim, TRACE-A, STRATOZ-III) are being assembled to provide a representative CO profile covariance. These can be used to test the retrieval algorithm and conduct retrieval simulations.

  (2) Retrieval using simulated MOPITT measurements to test robustness of the retrieval code for a variety of geographical and seasonal scenarios.

  (3) Retrieval test and validation using MATR and correlative measurements. The retrieved CO & CH_4 profiles and columns will be compared with correlative measurements during MATR flights.

Pre-launch Activities

- **Forward model and algorithm validations with *real measurements*.**

  (1) MOPITT algorithm validation using IMG (high resolution interferometer) observations.

  -> The new Digital Gas Correlation (DGC) method allows the test of MOPITT Level 2 algorithm using high resolution FTIR observations, such as IMG data.
  -> Investigate the characteristics and signatures of surface, clouds, and aerosol in MOPITT spectral bands.

  (2) Verification of aerosol and cirrus clouds effect on MOPITT measurement.

  -> AVIRIS data.
  -> MAS data.
  -> HIS data.

- **Pre-launch validation exercise**

  (1) The first Pre-launch MOPITT Validation Exercise(Pre-MOVE) was conducted from March 2 to March 6 at the Department of Energy(DOE) ARM site (details later).

  (2) The second Pre-launch MOPITT Validation Exercise(Pre-MOVE) is tentatively planned for May 1999 in the Boulder/Denver area.

Post-launch Activities

- **Aircraft In-situ CO and CH4 profiling.**

  (1) Long-term A/C CO and CH4 profiling at selected sites (Validation AO selection).

-> Site	Location	Environment
Harvard Forest Massachusetts	42.54 N/72.18 W	Continental polluted forest regions
Barrow, Alaska	71.32 N/156.6 W	High northern latitude pollution from Europe
Carr, Colorado	40.15 N/104.13 W	Continental, northern plains
Mauna Loa, Hawaii	19.53 N/155.58 W	Oceanic, northern central Pacific
American Samoa	14.57 S/170.57	Oceanic, southern eastern Pacific

-> Biweekly (i.e. every 2 weeks) measurements of CO and CH4 profiles at 5 carefully selected sites.

-> Samples collected at predefined altitudes (approximately 500 m intervals over an altitude range of 0.3 to 8-9 km) using portable, automated equipment aboard small aircraft.

-> Collaborators(NASA AO): Paul Novelli *et al.*, NOAA/CMDL

Post-launch Activities

- **Aircraft In-situ CO and CH4 profiling (continued).**

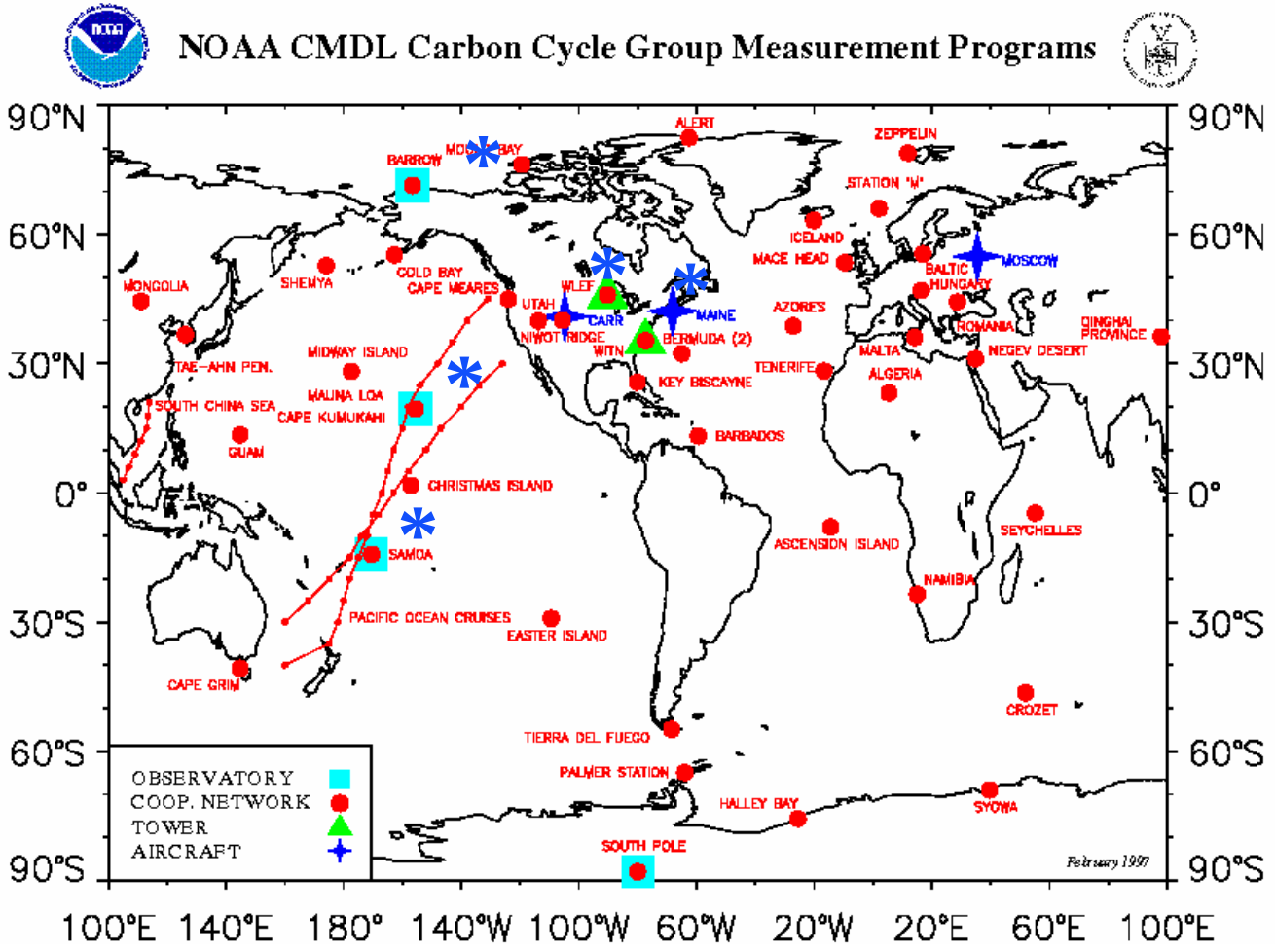
(2) A/C CO and CH4 in-situ profiling campaigns in Africa (SAFARI-2000).

-> In-situ measurements of CO and CH4 profiles in South Africa in August-September 1999.

-> In-situ measurements of CO and CH4 profiles in South Africa during the wet season (January - February) in 2000.

-> In-situ measurements of CO and CH4 profiles in South Africa during the dry season (August - September) in 2000.

Aircraft Profiling Site for MOPITT Validation



- **Only 1-2 surface sampling sites in Africa.**
- **No profile measurement sites in Asia, south America and Africa.**

***: Aircraft in-situ profiling sites selected for MOPITT CO and CH4 validation.**

Post-launch Activities

- **Airborne remote sensing measurements.**

(1) MATR validation campaigns (Mark Smith, ~ 1-2/year)
- **U.S. MOPITT team activities.**
- **Next campaign (Pre-MOVE II) is planned for the Spring of 1999.**
- **Plan to participate in the SAFARI-2000 campaign in 1999 and 2000.**

(2) MOPITT-A validation campaigns (Jim Drummond, ~ 1-2/year)
- **Canadian MOPITT team activities.**
- **Plan to conduct a test flight on ER-2 in August-September 1999 in collaboration with MODIS team (Yoram Kaufman) and USDA Forest Service Fire Laboratory.**
- **Plan to participate in SAFARI-2000 NASA ER-2 flights in 2000.**

(3) MODIS and AIRS (EOS/PM) validation campaigns with HIS and NAST-I (Validation AO selection).
- **Collaborator (NASA AO): Wallace McMillan, UMBC.**

Post-launch Activities

- **Ground-based spectroscopic measurements (spectrometers & FTIRs)**

(1) CO and CH4 retrievals from FTIR solar absorption measurements at 12 selected sites.

-> List of sites (Eureka, Spitsbergen, Harestua, Zvenigorod, Zugspitze, Jungfraujoch, Moshiri, Egbert, Rikubetsu, Kislovodsk, Kitt Peak, Lauder).

-> Frequency of measurements for MOPITT validation will vary from station to station.
(1) Routine NDSC measurements (daily or weekly).
(2) Intensive validation campaigns (2 -3 per year) with daily measurements.

-> Collaborators(NASA AO): Nikita Pougatchev *et. al.*, CNU & NASA Langley.

(2) CO and CH4 retrievals from FTIR solar absorption measurements at 6 sites.

-> List of sites (Antarctica, Wollongong, Mauna Loa, 3 DOE ARM sites).

-> Frequency: probably daily

-> Collaborators (NASA AO, NDSC): Frank Murcray *et. al.*, University of Denver.

Post-launch Activities

- **Surface and boundary layer measurement.**
  - -> 48 sites operated by NOAA/CMDL & collaborators.
  - -> Not critical for level 1 and level 2 data validation.
  - -> Useful for level 3 data validation and modeling activities.

- **Intercomparison with other satellite measurement.**
  - -> Troposphere CO column from SCIAMACHY on ENVISAT-1 to be launched in 1999.
  - -> Free troposphere CO column and possibly profile (2 layers ?) from TES to be launched in December 2002 on the EOS/CHEM platform.

Validation Data Archival Plan

- All validation data will be archived at the National Center for Atmospheric Research(NCAR).

- All validation data obtained by the MOPITT team will be released to DAAC for archive.

- Validation data obtained by collaborators funded by NASA EOS Validation Office will be released to DAAC for archive.

- Validation data obtained by collaborators not funded by NASA EOS program will be released to DAAC for archive with the permission of the data providers.

Pre-Launch MOPITT Validation Exercise (Pre-MOVE)

- **Objectives**
  - -> Better understanding of correlative measurement techniques and associated data processing algorithms.
  - -> Intercomparison of correlative measurement results.
  - -> Test of the readiness of correlative measurements for MOPITT launch.
- **Site Selection**
  - -> DOE/ARM CART site is a heavily instrumented site resulting in good characterization of surface and atmosphere column.
  - -> Availability of SORTI, AERI, lidar, and radiosonde data.
  - -> Excellent logistic support.
- **Experiment time**
  - -> The experiment was conducted on 2-6 March 1998 at the DOE ARM CART site in Lamont, Oklahoma.

Pre-Launch MOPITT Validation Exercise (Pre-MOVE)

- **Instruments and Measurements**

-> MATR from NCAR. MATR was fitted on the Citation aircraft. It flew over the CART site at ~ 39,000 ft. for about 2 hours on March 2, March 3, and March 6, 1998.

-> Automated flask sampling system from NOAA/CMDL. CO, CH4 and CO2 profiles were obtained from 1 km to 8 km (~3000 to 26,000 ft.) at a vertical resolution of ~ 0.3 km on March 6, 1998.

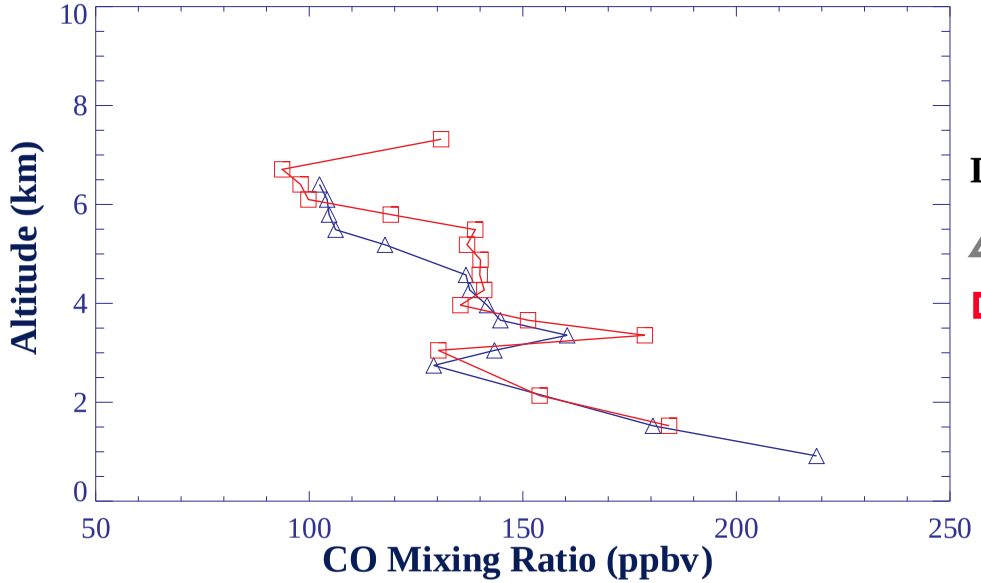
-> University of Toronto (UT) ground-based grating spectrometer. Fairly large number of solar absorption spectra were collected on March 3, 1998.

-> ARM ground-based solar absorption FTIR (SORTI) [http://www.arm.gov/docs/instruments/static/sorti.html]

-> ARM ground-based thermal emission FTIR (AERI) [http://www.arm.gov/docs/instruments/static/aeri.html]

-> Meteorological information by radiosonde and NOAA satellites. ARM program launches radiosonde 3 times per day at 7:00 AM, 12:00 noon and 6:00 PM local time. One extra radiosonde launch were made each day from March 2 to March 6, 1998 to support Pre-MOVE.

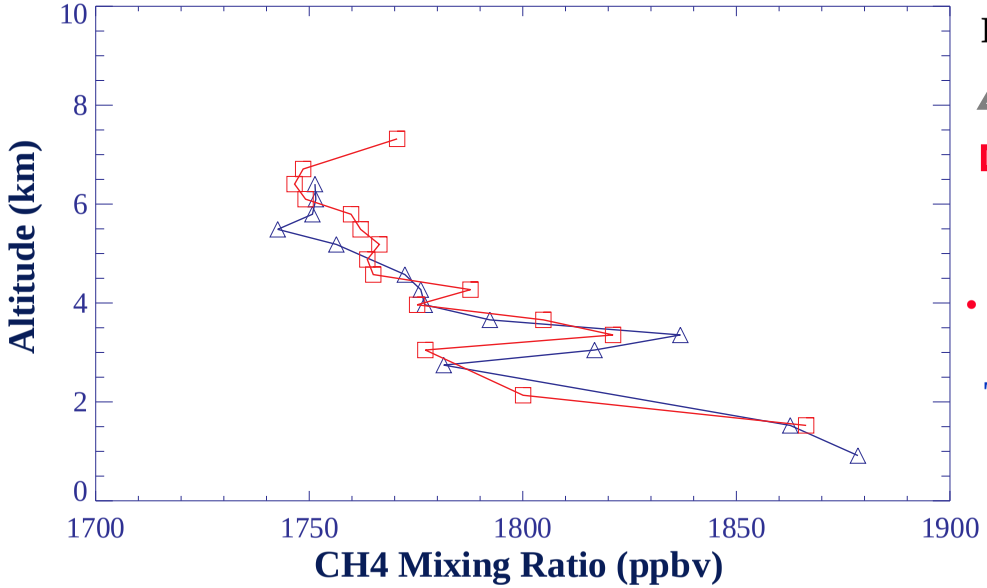
NOAA/CMDL Aircraft Sampling Measurements (March 6, 1998)



DOE ARM site (36.8N, 97.5W)

△ Morning profile (~10 AM)

□ Afternoon profile (~1 PM)



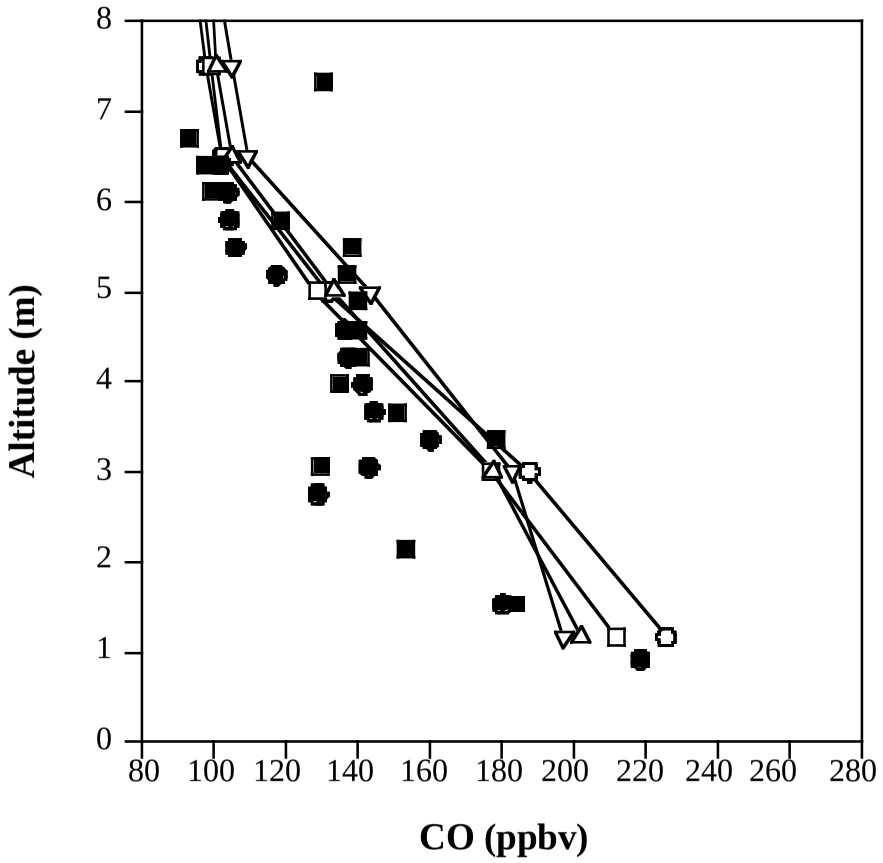
DOE ARM site (36.8N, 97.5W)

△ Morning profile (~10 AM)

□ Afternoon profile (~1 PM)

- **Aircraft sampling were carried out by MOPITT Correlative Team Members Novelli and Gore of NOAA/CMDL.**

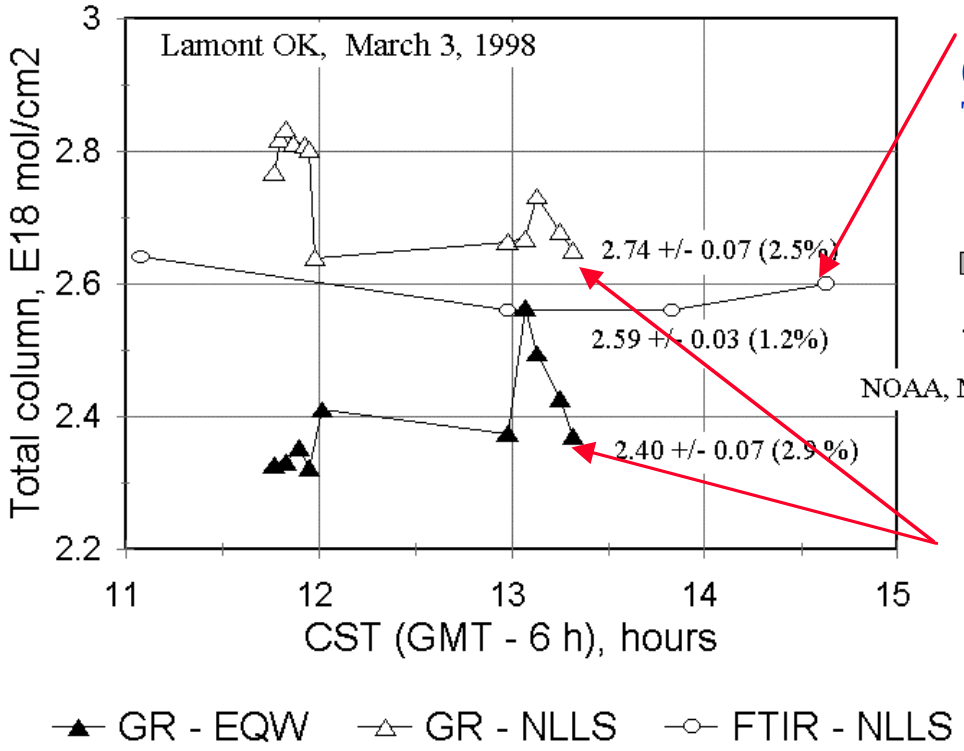
Preliminary Results from Pre-MOVE:
Comparison Between Sampling and Interferometer



- ● In-situ CO profile on the morning of 6 March 1998 by NOAA/CMDL automated flask system.
- ■ In-situ CO profile on the afternoon of 6 March 1998 by NOAA/CMDL automated flask system.
- ○ Retrieved CO profile using ground-based solar absorption FTIR measurements (SORTI) by MOPITT Correlative Team member Pougatchev.

• SORTI spectra were provided by MOPITT Correlative Team members Frank Murcray Thomas Stephen.

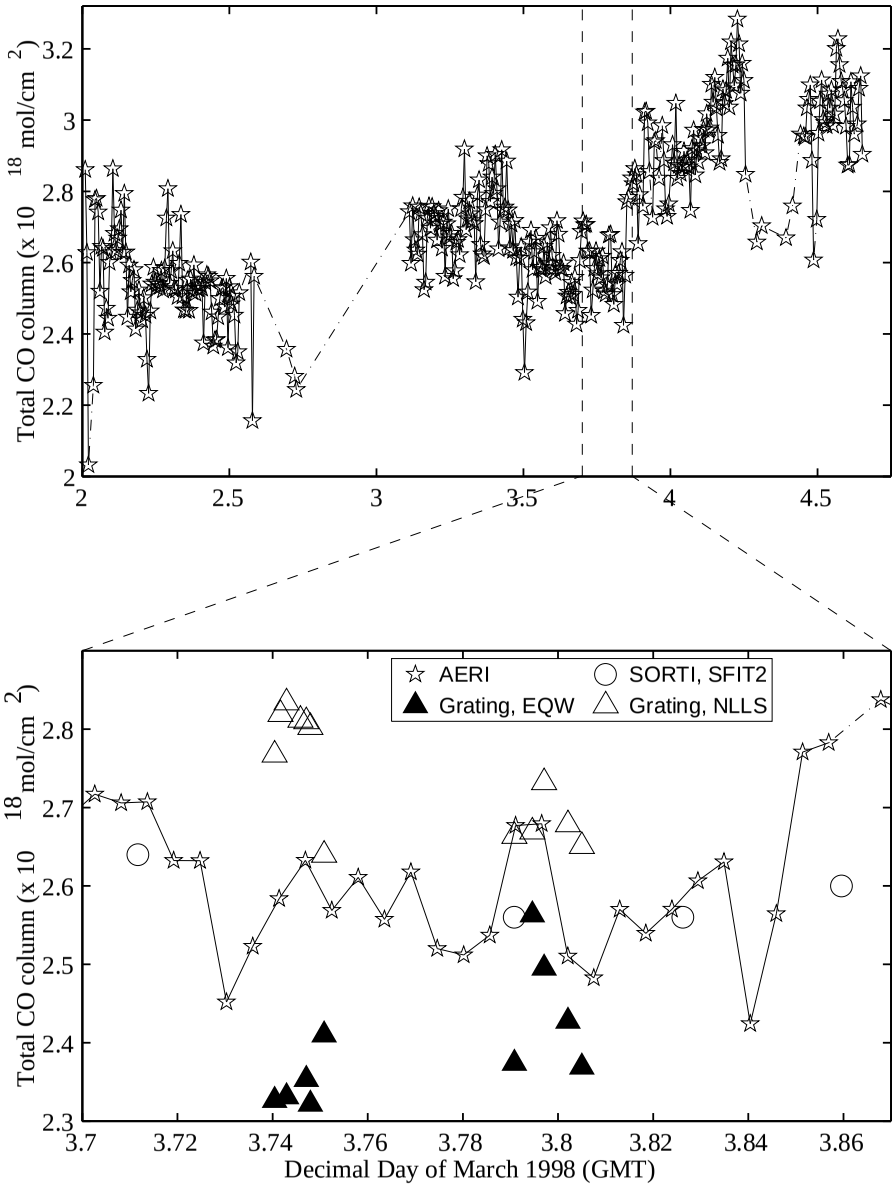
Preliminary Results from Pre-MOVE:
Interferometer, Grating Spectrometer and Sampling



Total CO column retrieved from interferometer spectra (SORTI) by MOPITT Correlative Team member Pougatchev.

Total CO column retrieved from grating spectrometer measurement by MOPITT Correlative Team members (Yurganov, Tolton and McKernan).

Preliminary Results from Pre-MOVE:
Interferometers and Grating Spectrometer



- **Total CO column densities retrieved from AERI spectra during Pre-MOVE, March 2-5 1998 by MOPITT Correlative Team members (McMillan and He) are presented in the upper panel. Dot-dash lines connect retrievals interrupted by cloudy sky scenes while solid lines connect continuous data points.**

- **The bottom panel shows an expanded view of the time period on 3 March 1998 (GMT) and compares the CO columns retrieved from AERI spectra to those retrieved from coincident ground-based SORTI and UT spectrometer measurement. We are very encouraged by the initial agreement of all these retrievals to +/- 10%.**

Summary

- A comprehensive MOPITT data validation plan is in place. The MOPITT correlative measurement team has been established with support from EOS Validation Office.
- MOPITT correlative measurements include aircraft in-situ measurements at 5 carefully selected sites and during validation campaigns, airborne remote sensing measurements, and ground-based interferometer and spectrometer measurements.
- A Pre-launch validation exercise was conducted at the DOE ARM site in Lamont, Oklahoma to inter-compare different correlative measurements.

The MOPITT team welcome collaborations in MOPITT data validation and tropospheric chemistry studies using MOPITT observations. Please contact Jinxue Wang at jwang@eos.ucar.edu, John Gille at gille@ucar.edu, or Jim Drummond at jim@atmosp.physics.utoronto.ca for Canadian MOPITT validation activities.

MOPITT Validation Plan Version 4.0 is available at NCAR and NASA Validation web site.

Anonymous MOPITT FTP site: eos.ucar.edu /pub

NCAR MOPITT web page: http://eos.acd.ucar.edu/mopitt/home.html

Appendix A: Location of ground-based spectroscopic stations for MOPITT data validation (Pougatchev *et al.*)

Spectroscopic Station	Location(degree)	Elevation(m)	Spectrometer
Atmospheric Environment Service, Eureka, Canada	80.05 N/86.4 W	610	FTIR, Bomem DA8
Alfred Wegner Institute for Polar and Marine Research(Germany) Spitsbergen, Norway	78.90 N/11.9 E	10	FTIR, Bruker 120M
Swedish Environmental Research Institute, Harestua, Sweden	60.00 N/11.0 E	560	FTIR, Bruker 120M
Institute of Atmospheric Physics, Zvenigorod, Russia	55.40 N/36.5 E	200	Grating
Fraunhofer-Institut fuer Atmosphaersche Umweltforschung, Zugspitze, Germany	47.40 N/11.0 E	2964	FTIR, Bruker 120HR
International Scientific Station Jungfraujoch, Switzerland	47.00 N/8.0 E	3580	FTIR
University of Nagoya, Moshiri, Japan	44.36 N/142.3 W	20	FTIR, Bruker 120HR
Atmospheric Environment Service, Egbert, Canada	44.20 N/79.8 W	251	FTIR, Bomem DA8

Appendix A(continued) : Location of ground-based spectroscopic stations for MOPITT data validation (Pougachev *et al.*)

Spectroscopic Station	Location(degree)	Elevation(m)	Spectrometer
University of Nagoya, Rikubetsu, Japan	**43.50 N/143.8 E**	**215**	**FTIR, Bruker 120M**
Institute of Atmospheric Physics, Kislovodsk, Russia	**43.50 N/42.4 E**	**2100**	**Grating**
National Solar Observatory, Kitt Peak, USA	**32.00 N/111.5 W**	**2090**	**FTIR**
National Institute of Water and Atmosphere Lauder, New Zealand	**45.00 S/169.8 E**	**370**	**FTIR**

Appendix B: Location of ground-based spectroscopic stations for MOPITT data validation (Murcray *et al.*)

Spectroscopic Station	Location(degree)	Elevation(m)	Spectrometer
University of Denver & NIWA, Arrival Heights, Antarctica	78.00 S/167.0 E	180	FTIR, Bruker 120M
University of Wollongong, Wollongong, Australia	34.00 S/151.0 E	35	FTIR, Bomem DA8
University of Denver, Mauna Loa, Hawaii	37.00 N/98.0 W	3100	FTIR, Bruker IFS120HR
DOE ARM SGP Site, Lamont, Oklahoma	36.80 N/97.5 W	318	FTIR, Bruker IFS120M
DOE ARM TWP Site, Lamont, Oklahoma	2.06 S/147.4 W	6	FTIR, Bruker IFS120M
DOE ARM NSA Site, Barrow, Alaska	71.32 N/156.6 W	?	FTIR
or Fairbanks, Alaska	64.83 N/147.7 W	150	FTIR, Bruker IFS120M