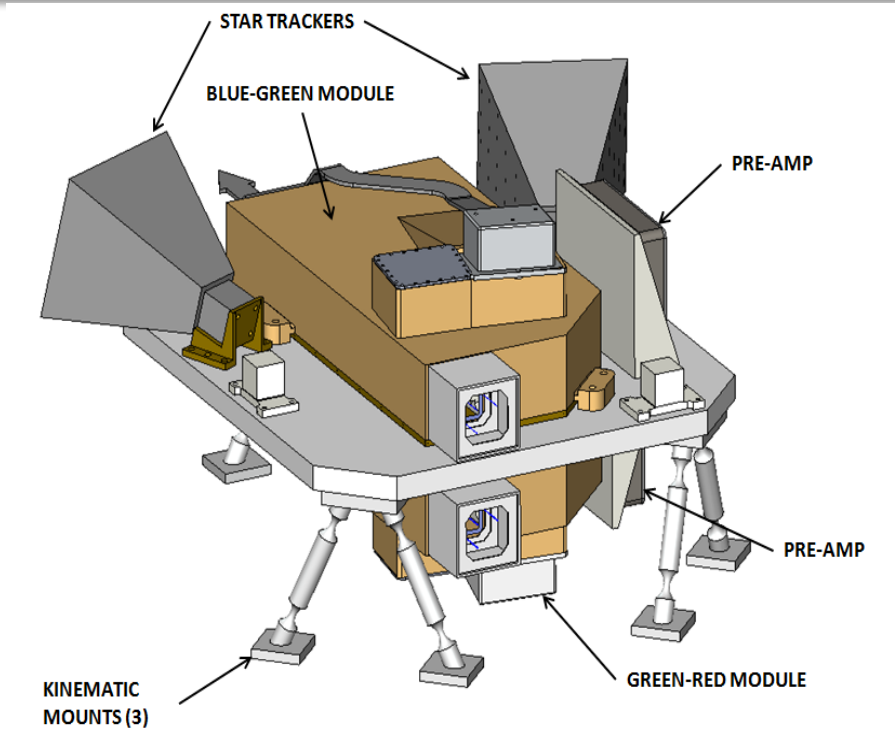


Vertically resolved stratospheric ozone and nitrogen dioxide measurements used for surface air quality prediction

June 12, 2015
University of Crete, Heraklion

Outline

1. How we got to where we are
2. The objectives
3. The Optical Spectrograph and InfraRed Imaging System (OISRIS) – A limb profiling instrument
4. Recent limb-nadir work done to better quantify tropospheric NO_2 columns using OSIRIS and OMI measurements
5. The Canadian Atmospheric Tomography System – Its µCATS incarnation
6. Recent data assimilation studies

The Back Story

- In the recent past Environment Canada became interested in assimilating TEMPO measurements for the purpose of air quality forecasting specific to Canada
- Dealing with the stratospheric component of NO_2 and O_3 is always going to be an issue
- Canada was studying a limb profiling mission called ALiSS that included the CATS instrument and if coordinated with TEMPO this project could have provide very useful stratospheric information
- ALiSS was de-scoped but the Canadian Atmospheric Tomography System still struggles on in the form of µCATS

The Back Story

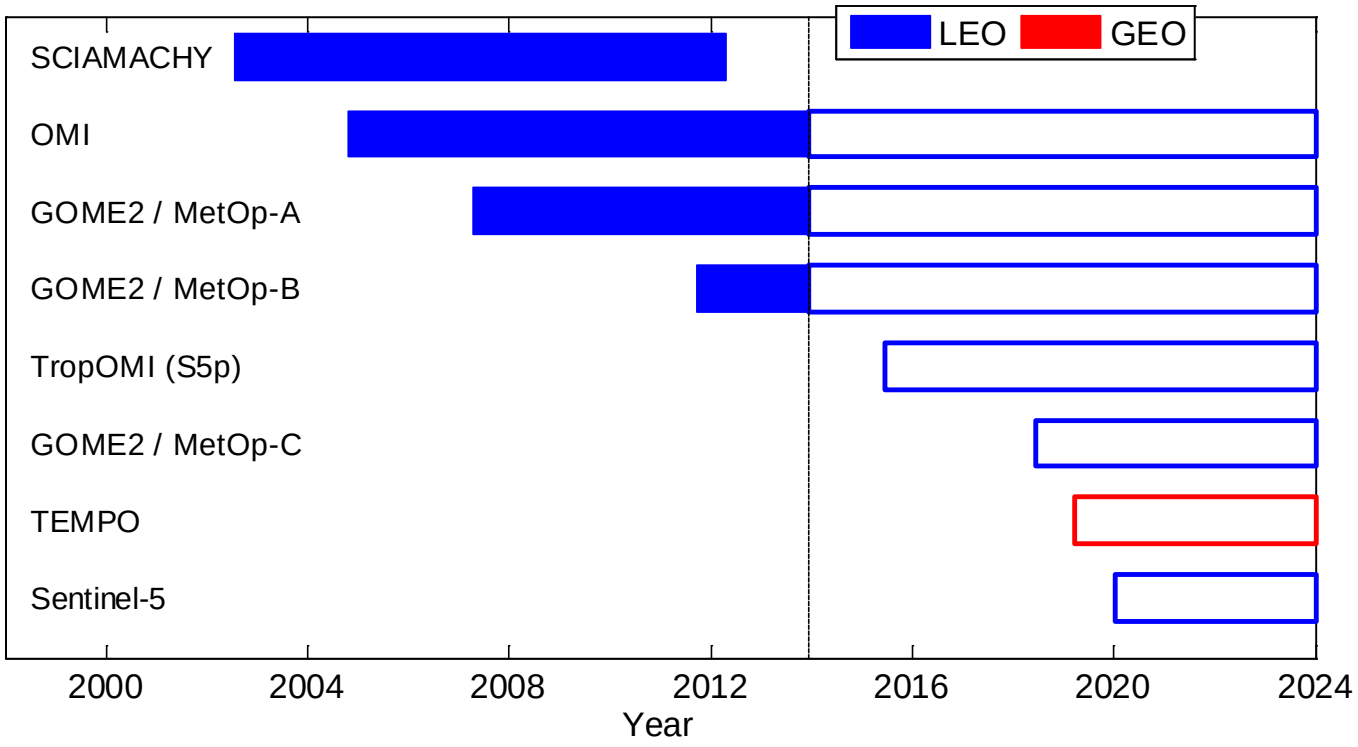
The partners include:

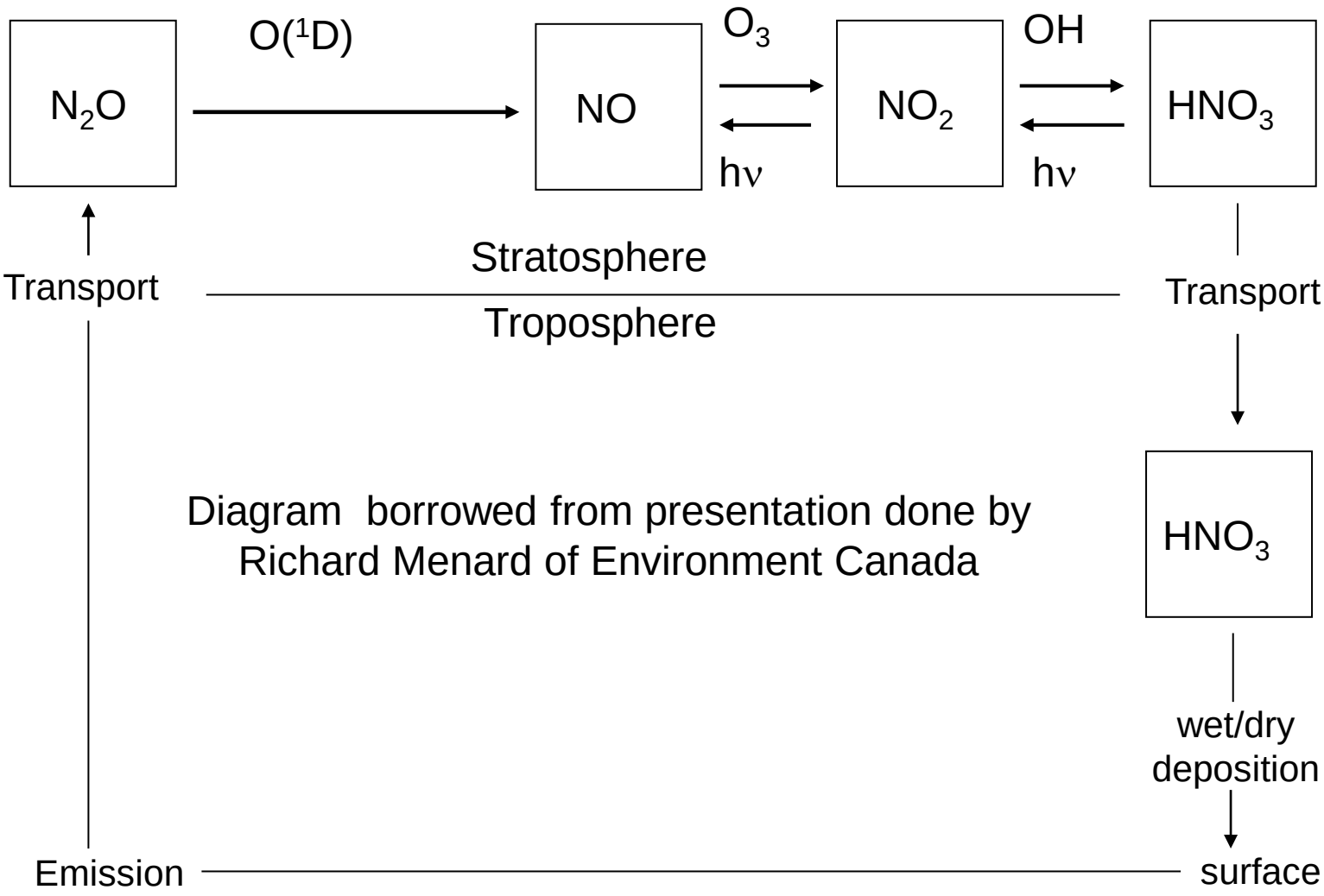
- The University of Saskatchewan where the CATS idea originated and the data will be processed in NRT using standard OSIRIS and tomographically adapted processing techniques
- The Canadian Space Agency from which the micro-satellite program originated
- Environment Canada as end users of the CATS data
- Canadian Industry
- Perhaps other Canadian funding agencies such as NSERC and CFI
- Hopefully ESA through the Third Party Mission Program?

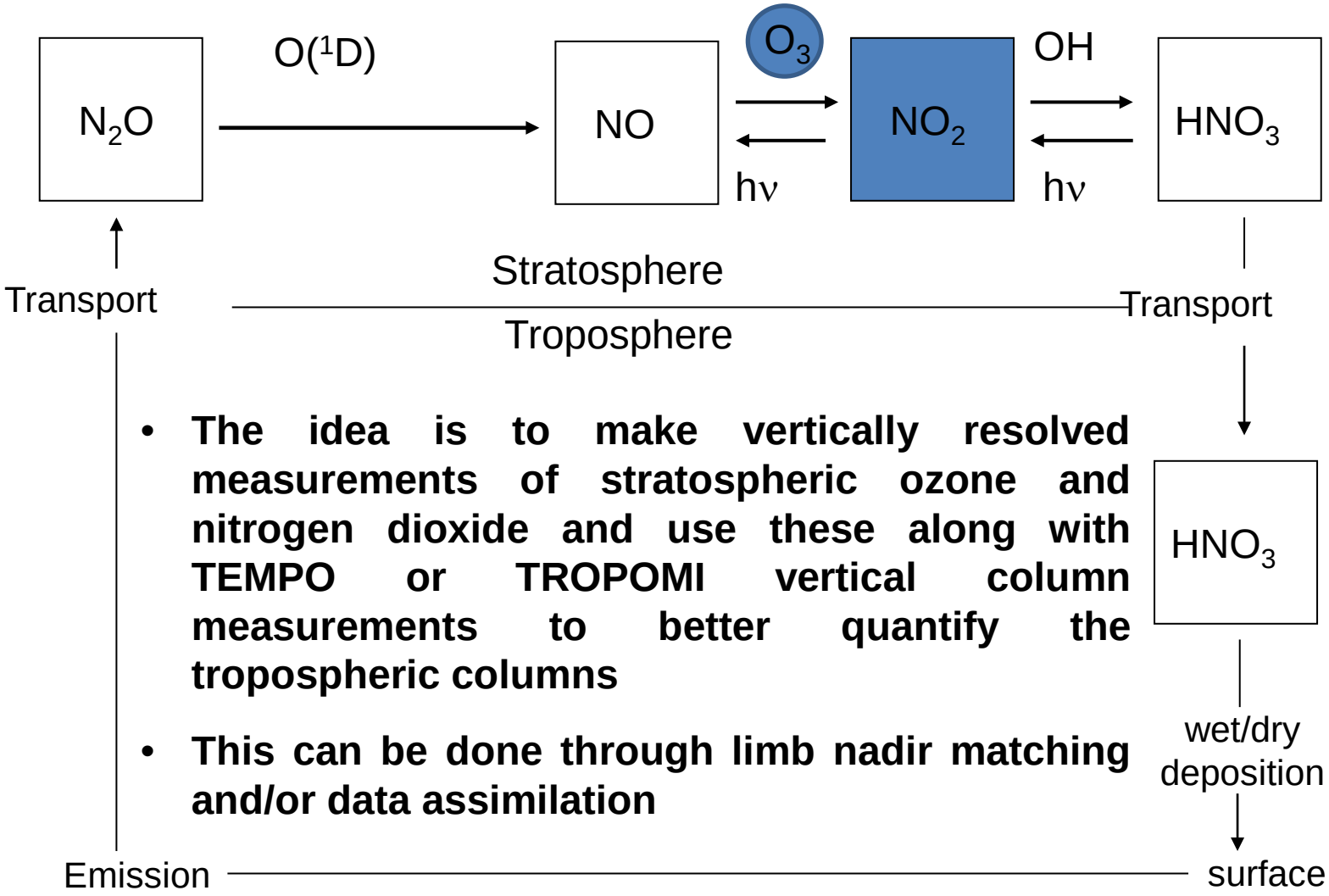
The Objectives of Some Ongoing Studies

Current and Planned Nadir Looking Missions

UV/visible nadir-viewing instruments providing information on species relevant to air quality including O_3, NO_2, SO_2, …




N_2O
$O(^1D)$
NO
O_3
NO_2
OH
HNO_3
hν
hν
Transport
Stratosphere
Troposphere
Transport
Diagram borrowed from presentation done by
Richard Menard of Environment Canada
HNO_3
wet/dry
deposition
Emission
surface



- **The idea is to make vertically resolved measurements of stratospheric ozone and nitrogen dioxide and use these along with TEMPO or TROPOMI vertical column measurements to better quantify the tropospheric columns**
- **This can be done through limb nadir matching and/or data assimilation**

Approved Limb Looking Missions

The Objective

The objective of the current work is to demonstrate the utility of vertically resolved profiles of NO_2 and O_3 for air quality forecasting!

The Objective

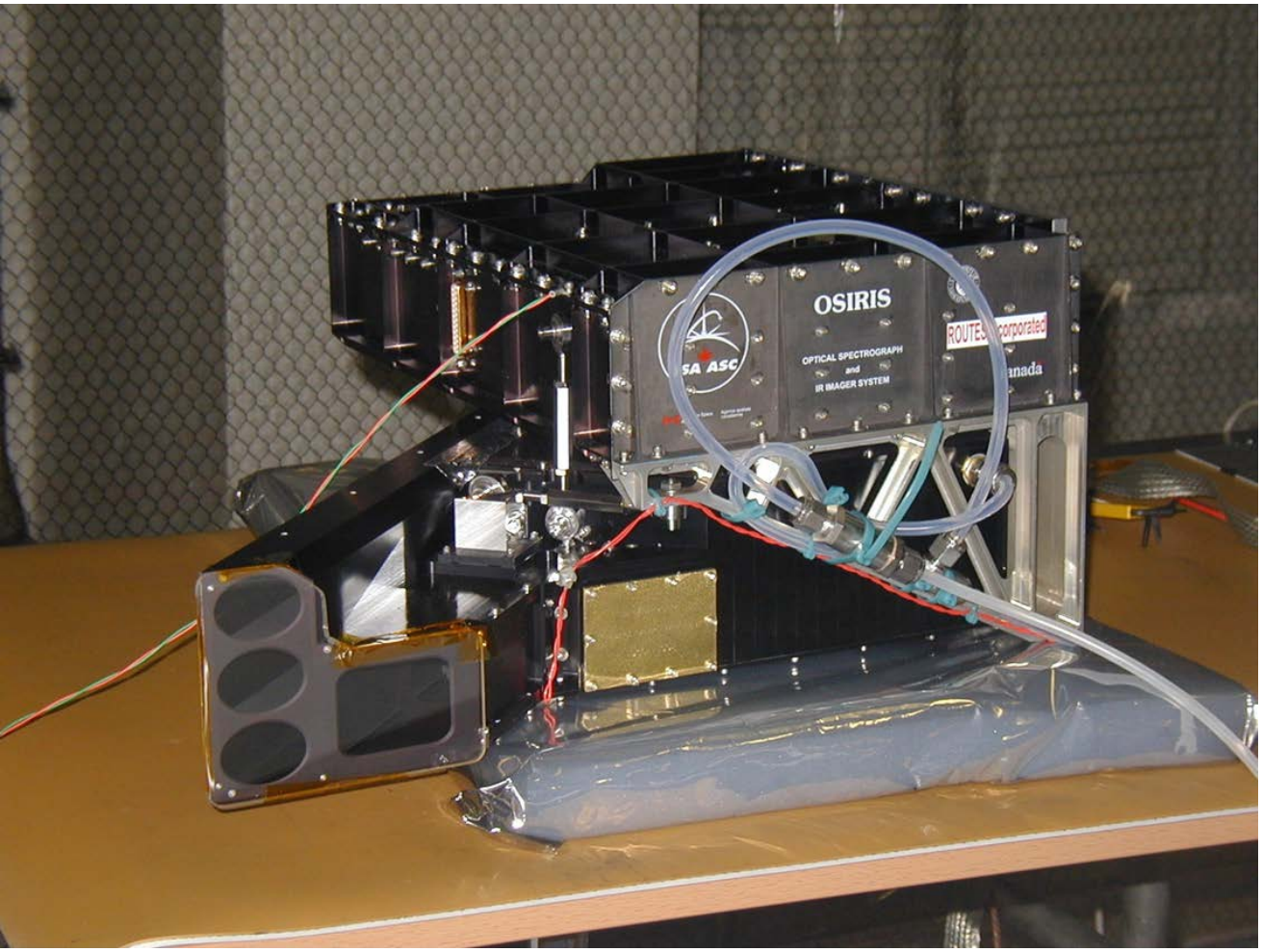
The objective of the current work is to demonstrate the utility of vertically resolved profiles of NO_2 and O_3 for air quality forecasting!

and

then convince funding agencies to support this modest limb profiling mission that will not only provide data that will continue very important stratospheric records but can help in air quality forecasting!

OSIRIS

OSIRIS



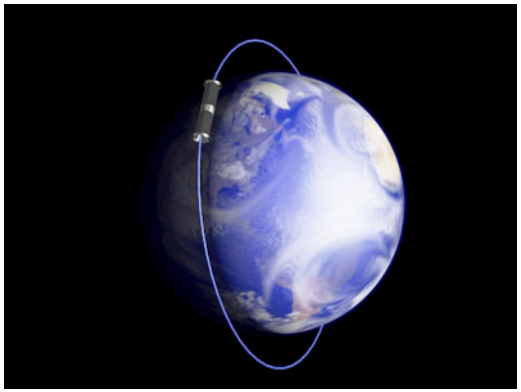
- Designed and built by ROUTES Inc. in Ottawa
- Original PI was Ted Llewellyn from the University of Saskatchewan
- Started in 1993 and was ready in 1999
- Integrated onto the Odin spacecraft in 2000

Odin

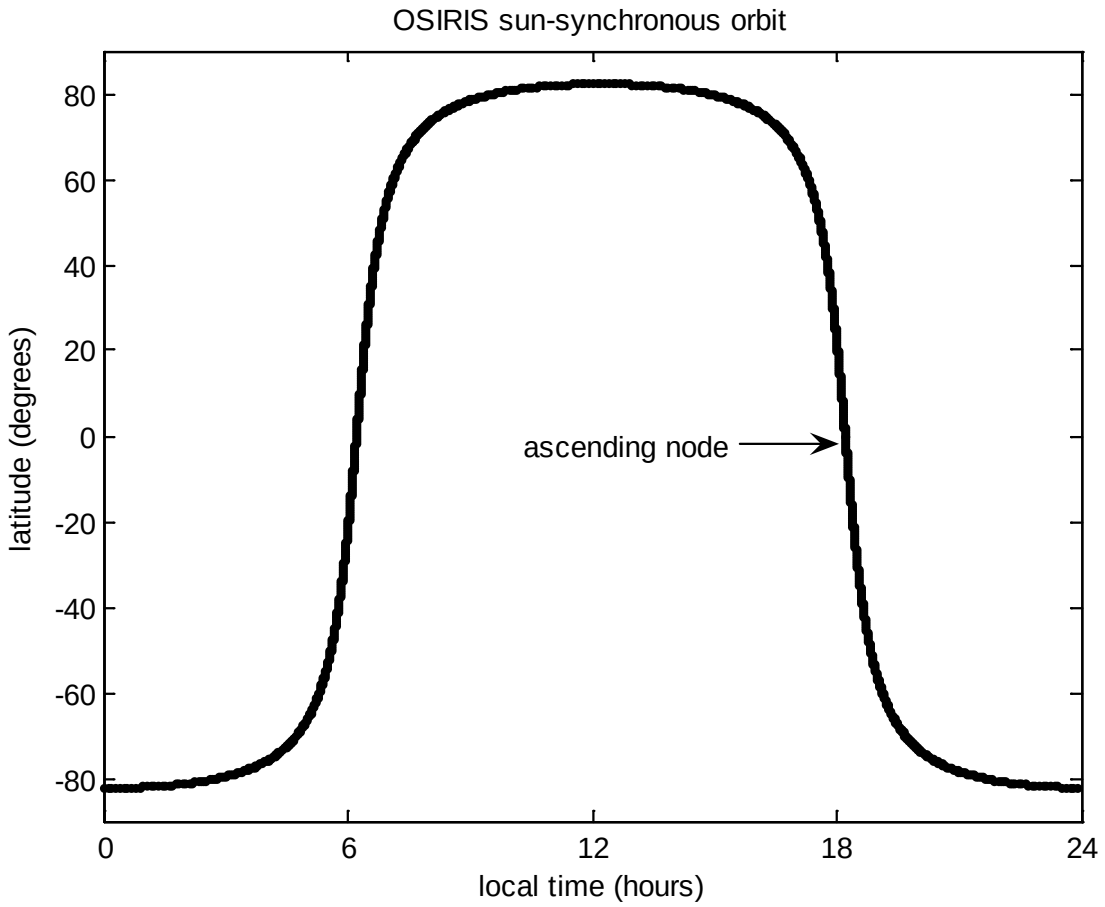
- Designed and built by SSC in Sweden
- Project is an international venture that also includes Finland and France
- Includes a sub-millimeter millimeter radiometer that was also designed for astronomy
- Launched in 2001 out of Russia
- Currently an ESA sponsored TPM

Odin Launch – February, 2001

The Odin Orbit

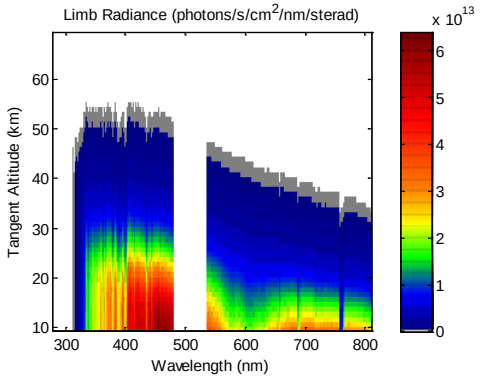


- sun-synchronous
- near-terminator
- 98 degree inclination
- 1800h ascending node
- 0600h descending node
- 96 minute period
- 600 km altitude

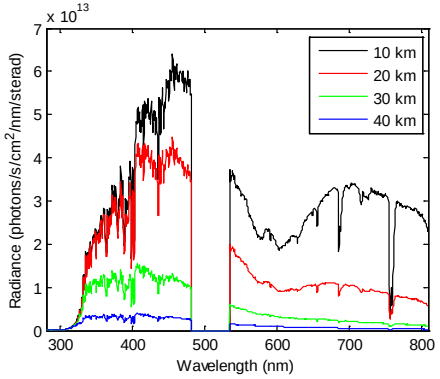


OSIRIS on Odin

Optical Spectrograph and Infra-Red Imager System (OSIRIS)



1) Optical Spectrograph
   - Single line of sight along satellite track
     - Narrow horizontal slit (1 arc minute)
   - Grating spectrograh
     - 280-810 nm, 1 nm resolution
   - Measures spectrum of scattered sunlight
     - Tangent altitudes 0 to 100 km
     - Odin moves to point OSIRIS
2) Infrared Imager
   - Three channel filtered vertical imager
   - 1.26 and 1.27 micron Singlet Delta O_2
   - 1.53 micron OH Meinel



O_3

Dust

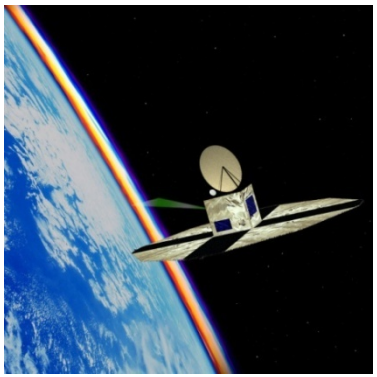
Forest Fires

NO

NO_2

BrO

Noctilucent Clouds



Sodium

Sulphate Aerosol

The Aurora

OH

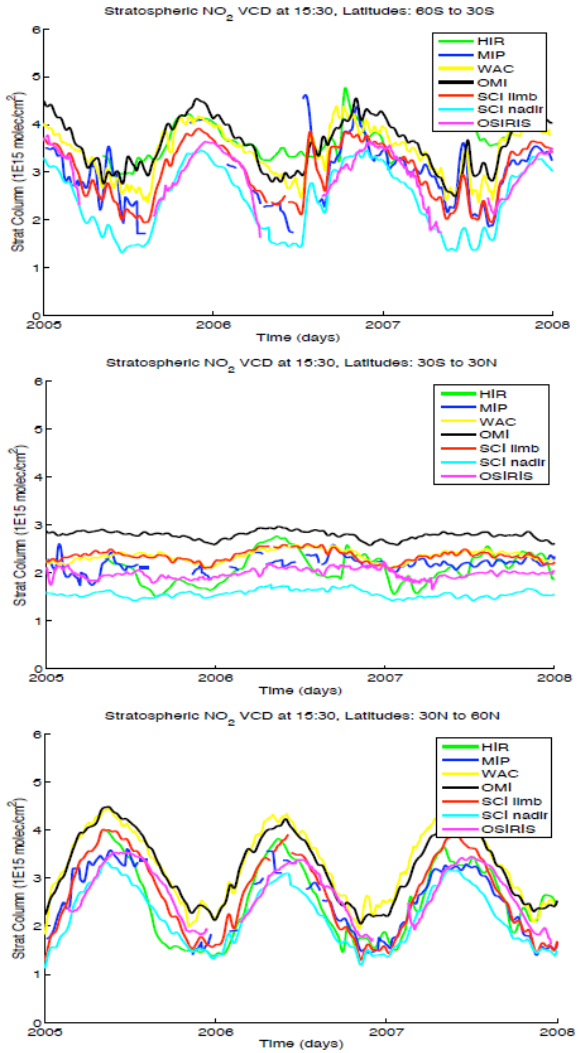
Subvisual Cirrus

OSIRIS – OMI Results

OSIRIS – OMI Limb Nadir Matching

- Proof of concept to see how useful OSIRIS measurements are in improving tropospheric NO_2 amounts inferred from OMI measurements
- Work done by Elise Normand, Cristen Adams and Adam Bourassa at the University of Saskatchewan in collaboration with Chris McLinden at Environment Canada Downsview
- This ongoing work is currently funded by an EC Grant

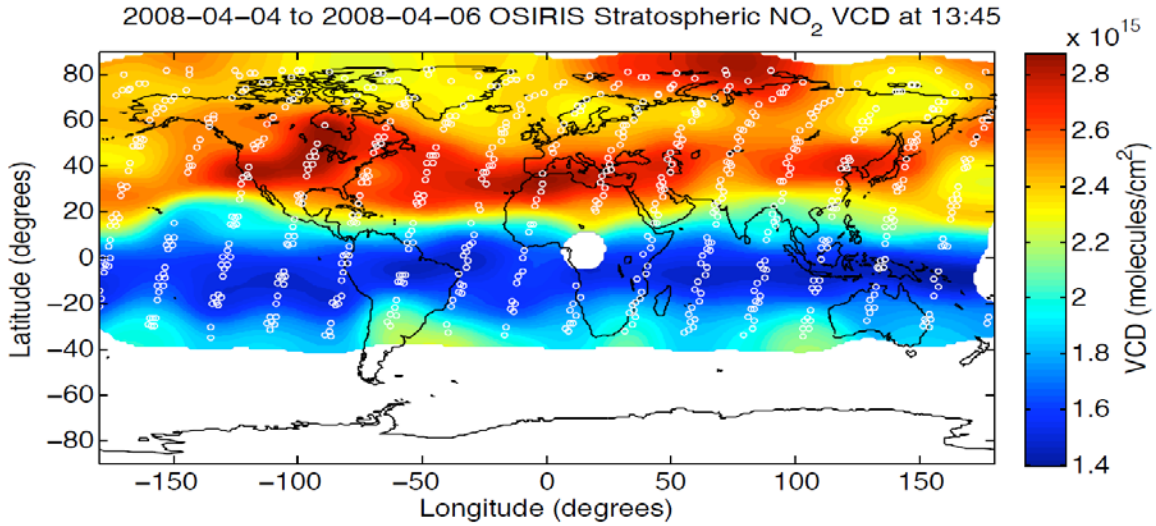
OSIRIS NO_2 Measurements are of High Quality



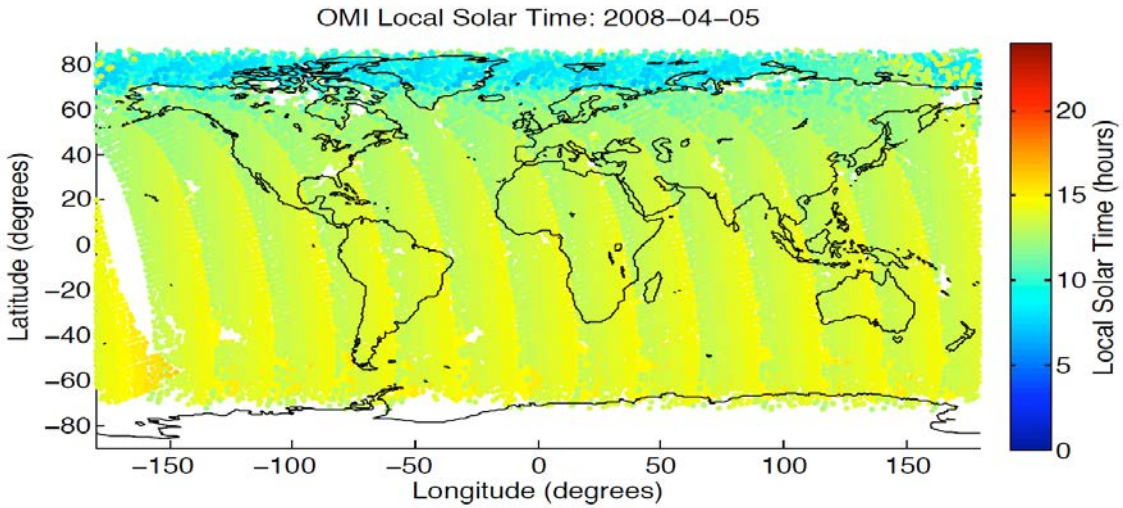
- OSIRIS measures mainly at 0600h and 1800h local time
- When translated to 1530h local time the OSIRIS integrated stratospheric column measurements agree well with others.

Figure taken from Normand et al. work that is in progress. It is adapted from Belmonte Rivas et al. (2014)

OSIRIS NO_2 and OMI Local Times



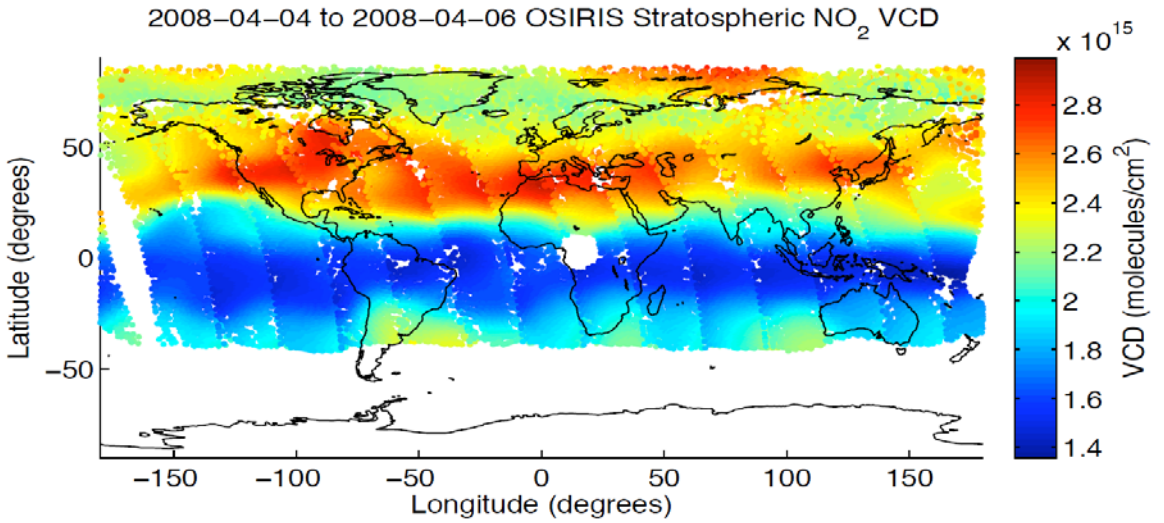
- The OSIRIS measurements translated to 1345h local time and averaged over a three day period
- Smooth spatial interpolation



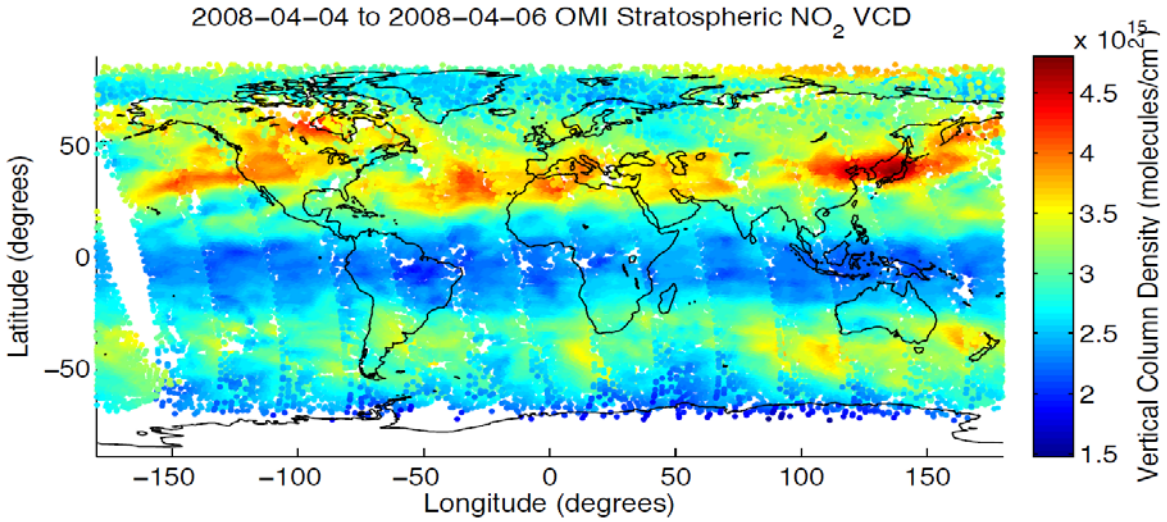
- The local time for each OMI measurements.
- Note the different local times at cross track locations

OSIRIS and Modelled Stratospheric NO_2

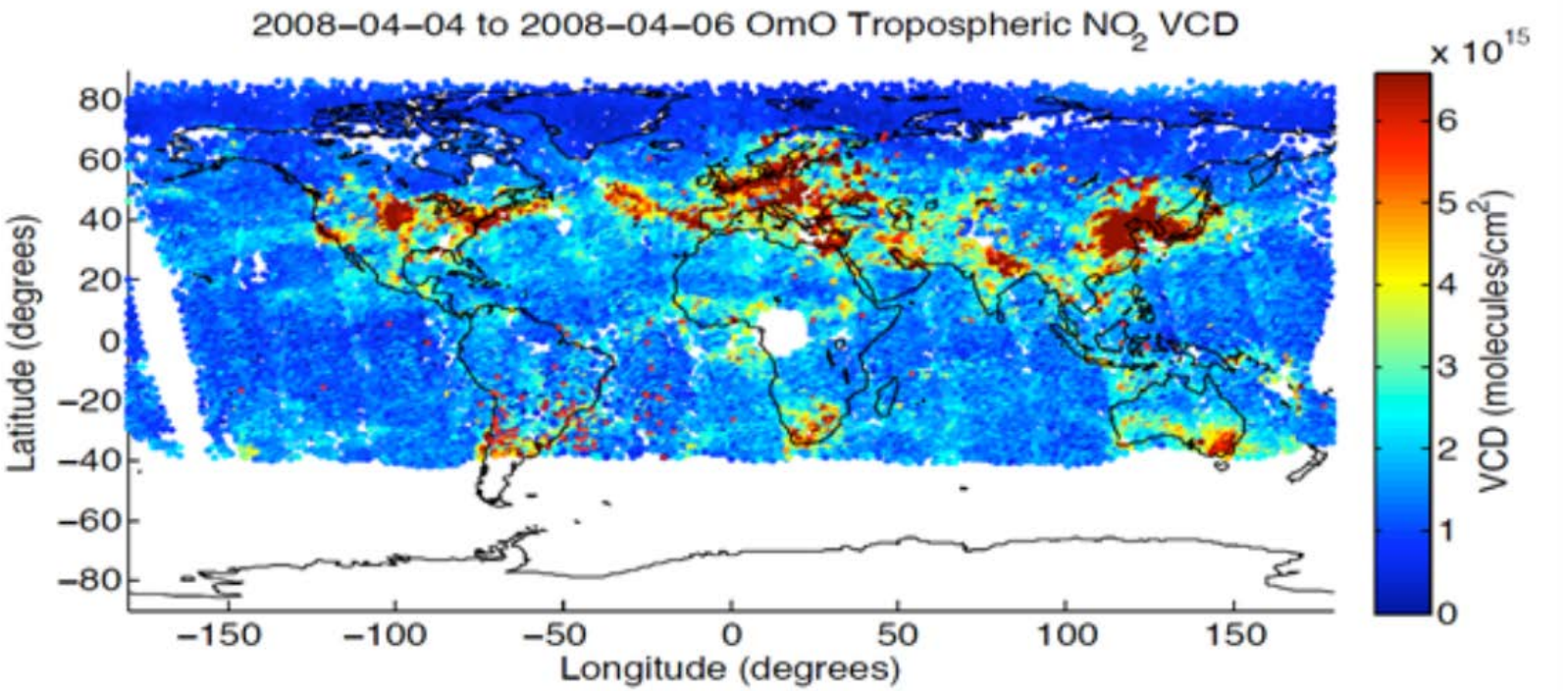
- The OSIRIS measurements averaged over a three day period and translated to OMI measurement local time



- The model of the stratospheric column used to infer tropospheric NO_2 from OMI total column measurements



OSIRIS Improves OMI Tropospheric NO_2 Product?



- The tropospheric component using the measured OSIRIS stratospheric column
- There are almost no negative values
- Work is ongoing to produce a validated OMI minus OSIRIS (OmO) data product

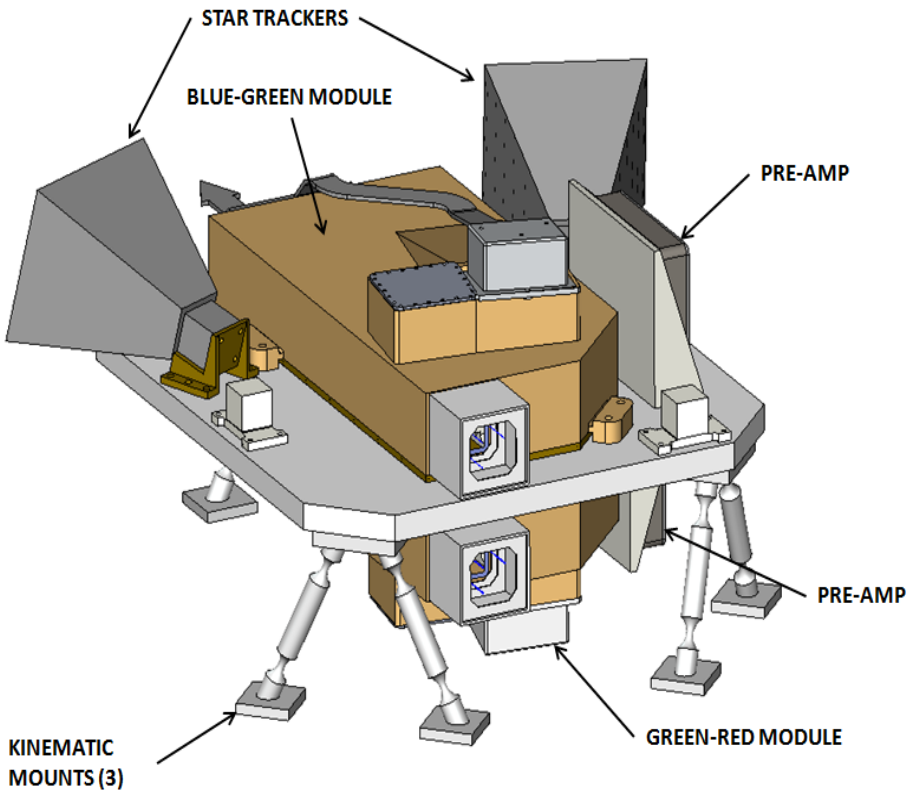
- Proof of concept seems to work
- OSIRIS vertical profile measurements can be used to infer tropospheric NO_2 from OMI total column measurements

µCATS

The Canadian Atmospheric Tomography System

- One of five concepts being studied by the Canadian Space Agency
- Small, low-cost yet can still be of high value to other government departments like Environment Canada
- We are currently looking at ways of cutting the cost to the CSA and it may be desirable to embed the project within the University system in order to draw in other sources of funds including the Canadian Foundation for Innovation (CFI) and NSERC

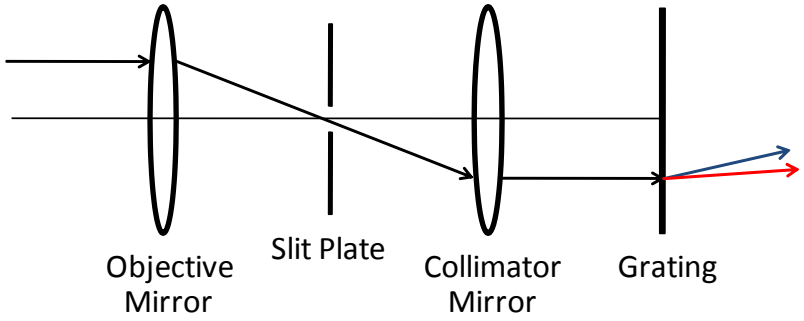
The CATS Instrument

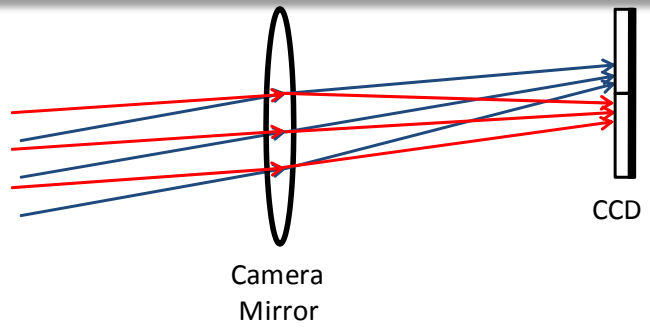


- Two modules on a common optical bench. One module measures from 280 nm to 550 nm (the Blue-Green module) with approximately 0.6 nm resolution while the other measures from 500 nm to 1000 nm (the Green-Red module) with approximately 1.1 nm resolution.

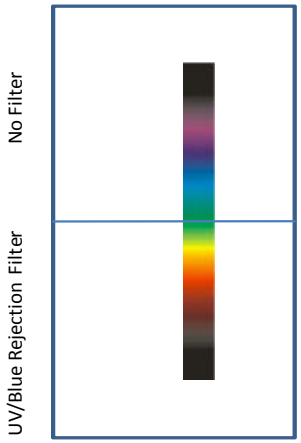
- Two star trackers are mounted directly to the optical bench for precise and accurate pointing knowledge.

Simplified OSIRIS Optics





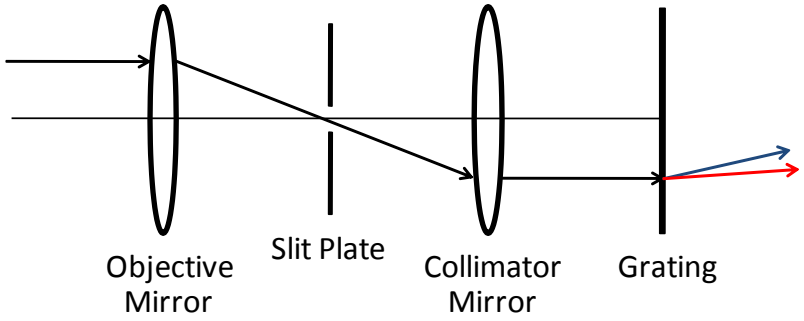
Slit Plate

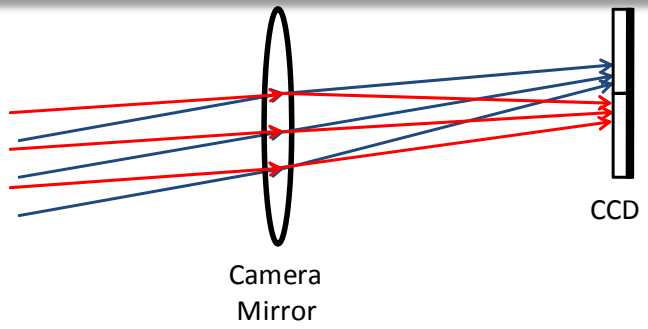


CCD Image

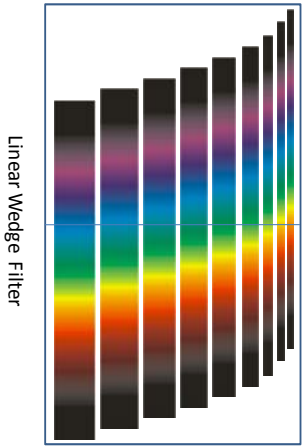
The OSIRIS slit has a 1 arc minute FOV or a vertical projection on the limb of 1 km at the tangent point

Simplified CATS Optics





Slit Plate



CCD Image

- The Blue-Green module will have four slits
- The Green-Red module will have three slits
- These slits will project vertically to approximately 200 m at the limb tangent point
- The scan range is such that one limb scan profile can be collected in 12 seconds

CATS is OSIRIS but with much higher spatial resolution!

Species	Height Range / Vertical Sampling Within UTLS / Horizontal Sampling	Precision	Accuracy
O_3 (cm^{-3})	7-55 km / 200 m / 100 km	+/- 5%	+/- 4%
NO_2 (cm^{-3})	8-40 km / 200 m / 100 km	+/- 10%	+/- 10%
Stratospheric Aerosols (km^{-1})	Tropopause-35 km / 200 m / 100 km	+/- 10%	+/-10%
BrO (cm^{-3})	10-40 km / 200 m / 100 km	TBD	TBD

A group of Canadian researchers are currently working on a CSA sponsored project titled “Assessment of the potential constraints on Stratospheric NO_2 from observations from µCATS”. This group includes:

Dylan Jones, Martin Keller
University of Toronto

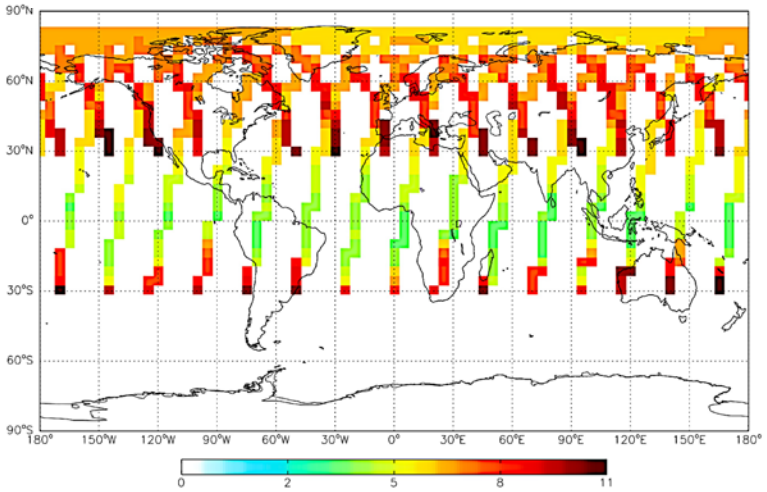
Chris McLinden, Yves Rochon
Environment Canada

Randall Martin
Dalhousie University

Adam Bourassa, Elise Normand, Cristen Adams
University of Saskatchewan

µCATS Observing System Simulation Experiment (OSSE)

NO_2 (ppb) a 30 km for LTAN = 1900, May 25

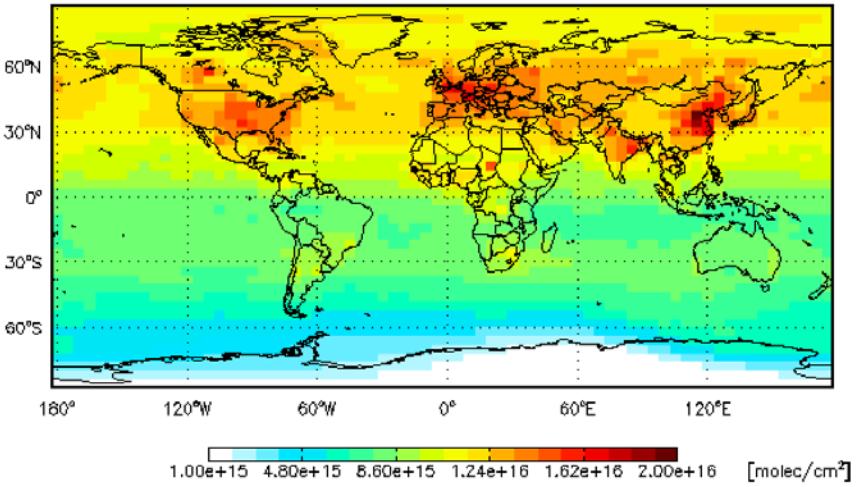


Generate pseudo-data by sampling GEOS-Chem along the µCATS orbit to produce O_3 (10 – 50 km) and NO_2 (10 – 40 km) data.

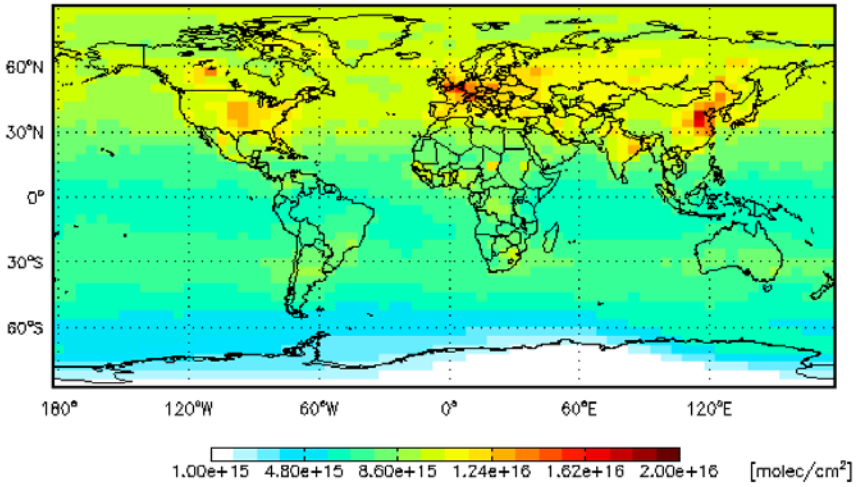
- Use GEOS-Chem with an increased source of stratospheric NOx to provide a biased a priori stratosphere.
- Assimilate pseudo-data for April 1 – May 31, 2013, assuming:
  - NO_2 precision is 1 x 10^8 cm^{-3} for z > 17 km and 2 x 10^8 cm^{-3} for z ≤ 17 km
  - O_3 precision is 5% for z ≥ 26 km and 10% for z < 26 km
  - A 50% uncertainty on the modeled NO_2 concentrations
- Data are assimilated using a sequential Kalman filter (following Parrington et al. [2008]) to optimize the stratospheric NO_2 distribution at a resolution of 4° x 5°.

Impact of assimilated µCATS data on the stratosphere

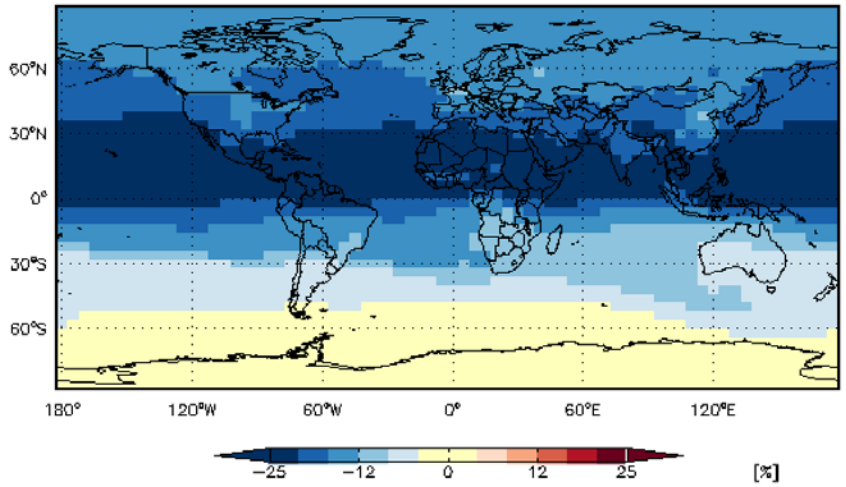
NO_2 column (a priori bias) for May 25, 2013



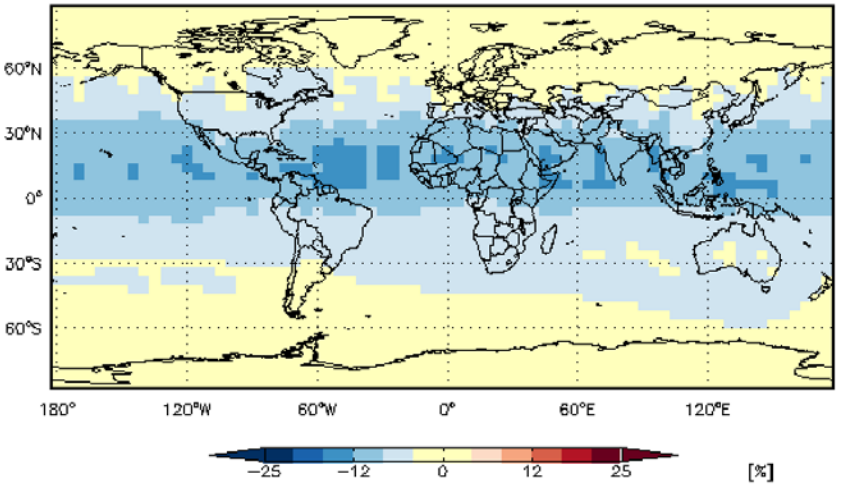
NO_2 column (true state) for May 25, 2013



Relative (%) a priori bias (true – prior)



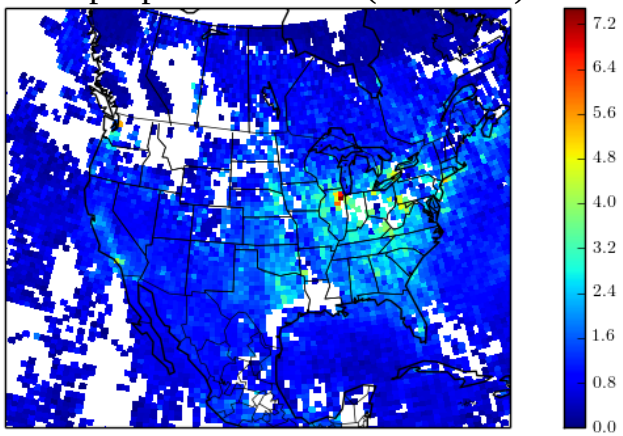
Relative (%) residual bias (true – assim)



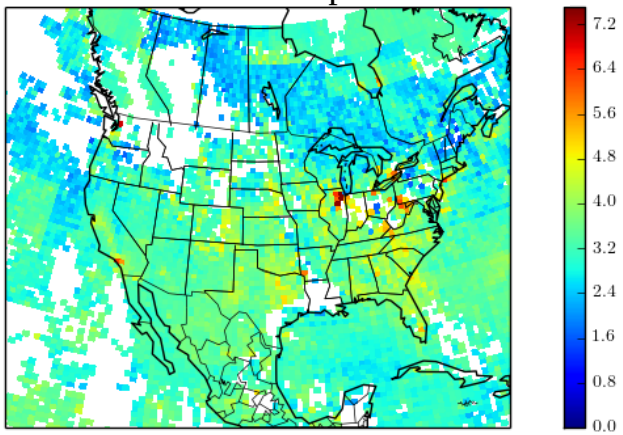
- Assimilation reduced the bias in the northern hemisphere (averaged 30-60N, May 15-31) from 20.4% to 5.6%.
- Properly accounting for the spatial correlations in the assimilation should further reduce the residual bias.

Impact on Tropospheric NO_2 Columns (May 15-31, 2013)

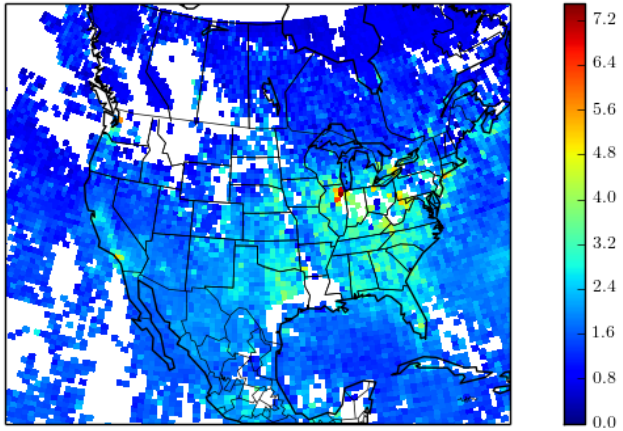
True tropospheric column (10^{15} cm^{-2})



Column with stratospheric bias



Column after stratospheric assimilation



- Biased tropospheric NO_2 columns obtained by transferring the stratospheric bias onto OMI tropospheric NO_2 columns.
- With assimilation of µCATS data in the stratosphere, the impact of the stratospheric bias on the tropospheric NO_2 columns is significantly reduced.

Next Steps

- Refine the stratospheric assimilation to reduce the residual stratospheric bias.
- Quantify the impact of the stratospheric bias on North American NOx emissions through inverse modeling of pseudo-data from TEMPO and TROPOMI with the nested GEOS-Chem model.

Summary

- Work done with OSIRIS vertical profile measurements has indicated that it is possible to use them to improve air quality information
- µCATS will provide much higher spatial resolution measurements without compromising OSIRIS quality
- It is hopeful, that if the CATS measurements are provided in near real time, they can be used along with TEMPO measurements and an assimilation scheme to improve the Canadian AQHI forecast

Thank You