NASA Trace Gas Products for Air Quality Applications

EPA RTP

September 29 – October 1, 2014

ARSET

Applied Remote SEnsing Training

A project of NASA Applied Sciences

Satellite Remote Sensing of Trace Gases for Air Quality in a Nutshell

- **Surface Monitoring:** Satellite trace gas instrumentation is generally not sensitive to surface pollution compared to aerosol instrumentation, ***with the exception of nitrogen dioxide and sulfur dioxide***

- **Emissions Inventories and Modeling**: Trace gas observations from space have been useful for constraining emissions inventories

- **Vertical profile information in the free troposphere** is also available for some products (e.g. CO) and derived using the pressure dependence of spectral bands

Satellite Remote Sensing of Trace Gases for Air Quality in a Nutshell

Nitrogen Dioxide

Good sensitivity in the planetary boundary layer (PBL): fire smoke, industrial and transportation sources, stationary sources, top –down emissions inventories

Sulfur Dioxide, ozone and formaldehyde

Limited sensitivity in the PBL. Sulfur dioxide is sensitive to large point sources, such as electrical generating units and volcanoes

Carbon Monoxide

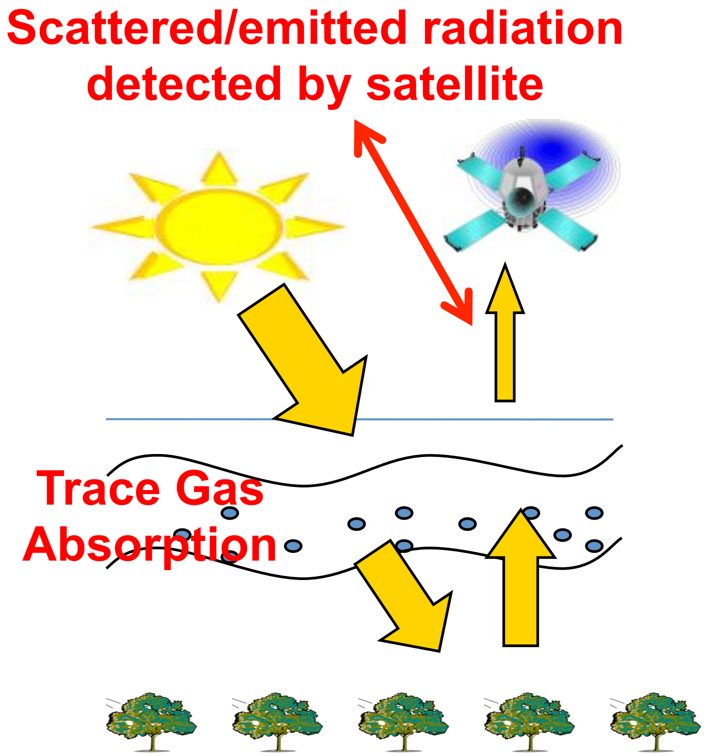
Good mid-tropospheric sensitivity, useful for monitoring long range transport of smoke.

Carbon Dioxide and Methane

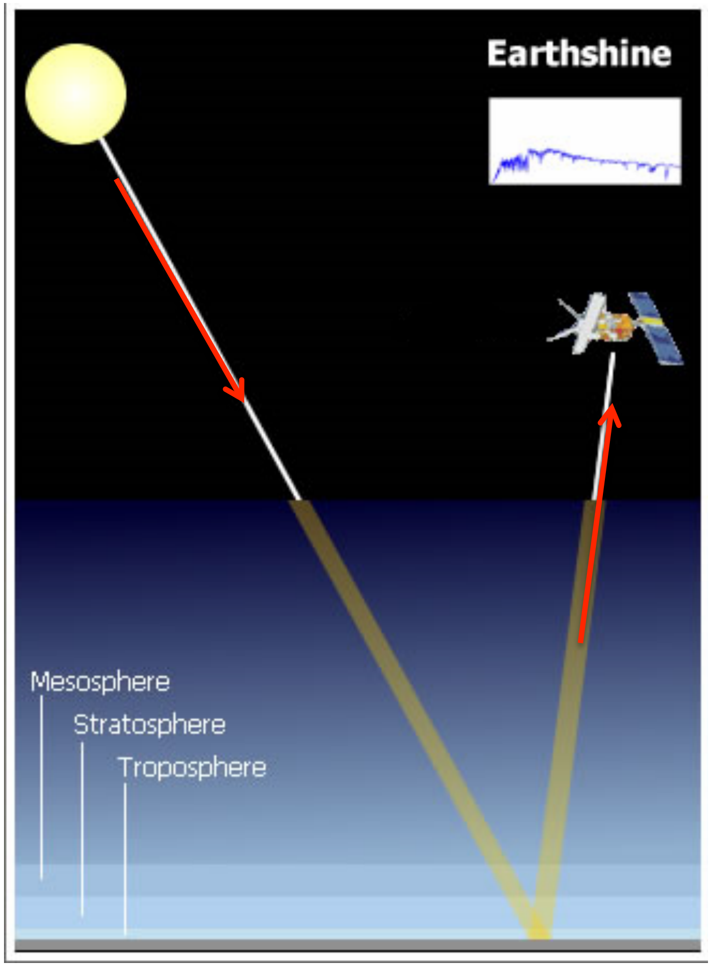
Low spatial resolution but captures global trends

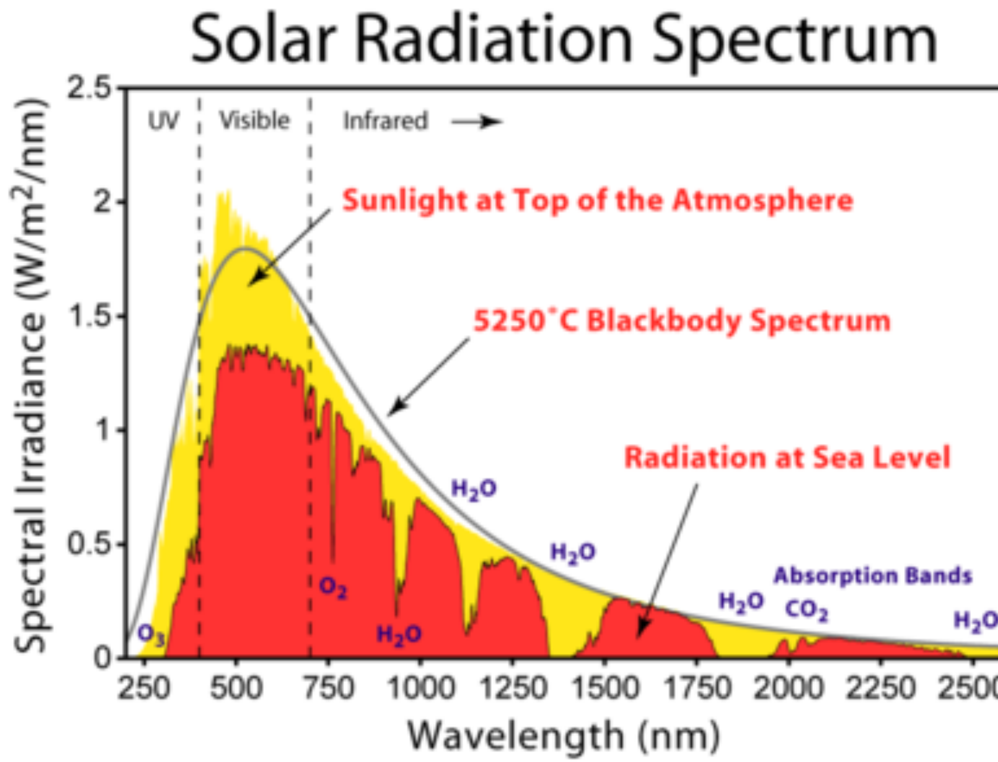
Measuring Trace Gas from Space

1. Satellites detect backscattered solar radiation and/or emitted thermal radiation
2. We know the distinct absorption spectra of each trace gases.
3. By knowing how and by what amount different molecules absorb radiation at different wavelengths, we can identify a "fingerprint" for each atmospheric constituent.
4. Based on the radiation measured by the instrument, retrieval algorithms (a model) are used to infer physical quantities such as number density, partial pressure, and column amount.



How Satellites Measure Trace Gases

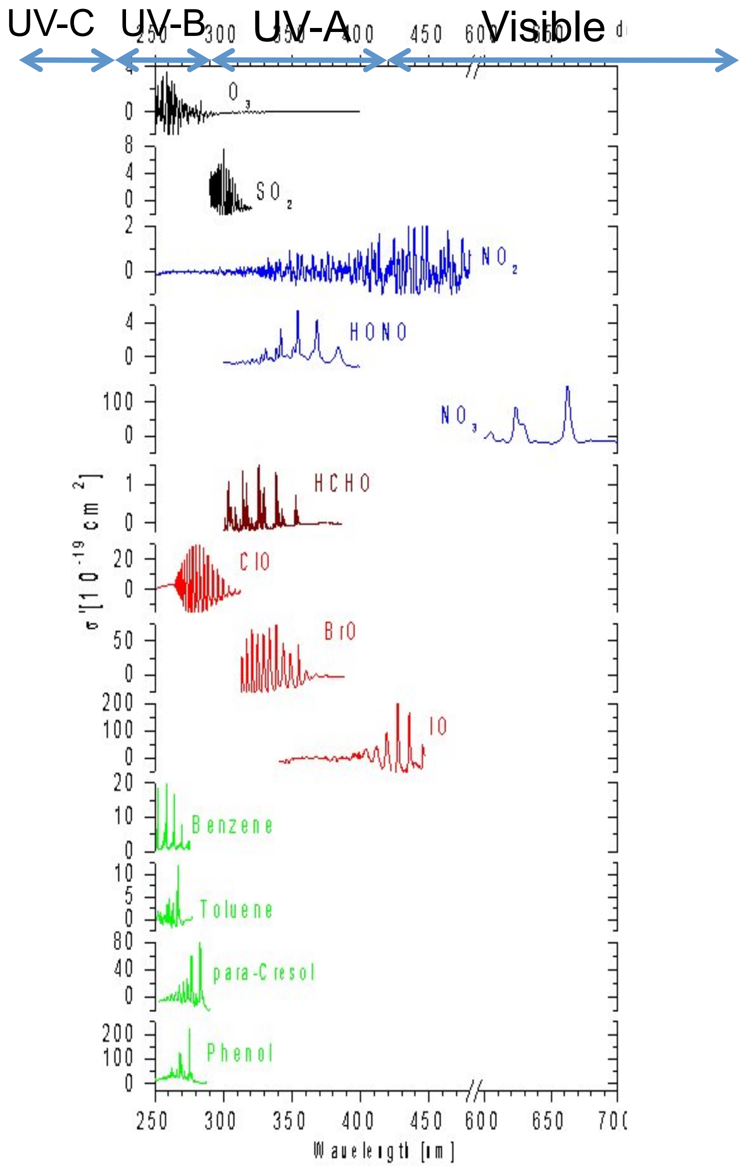


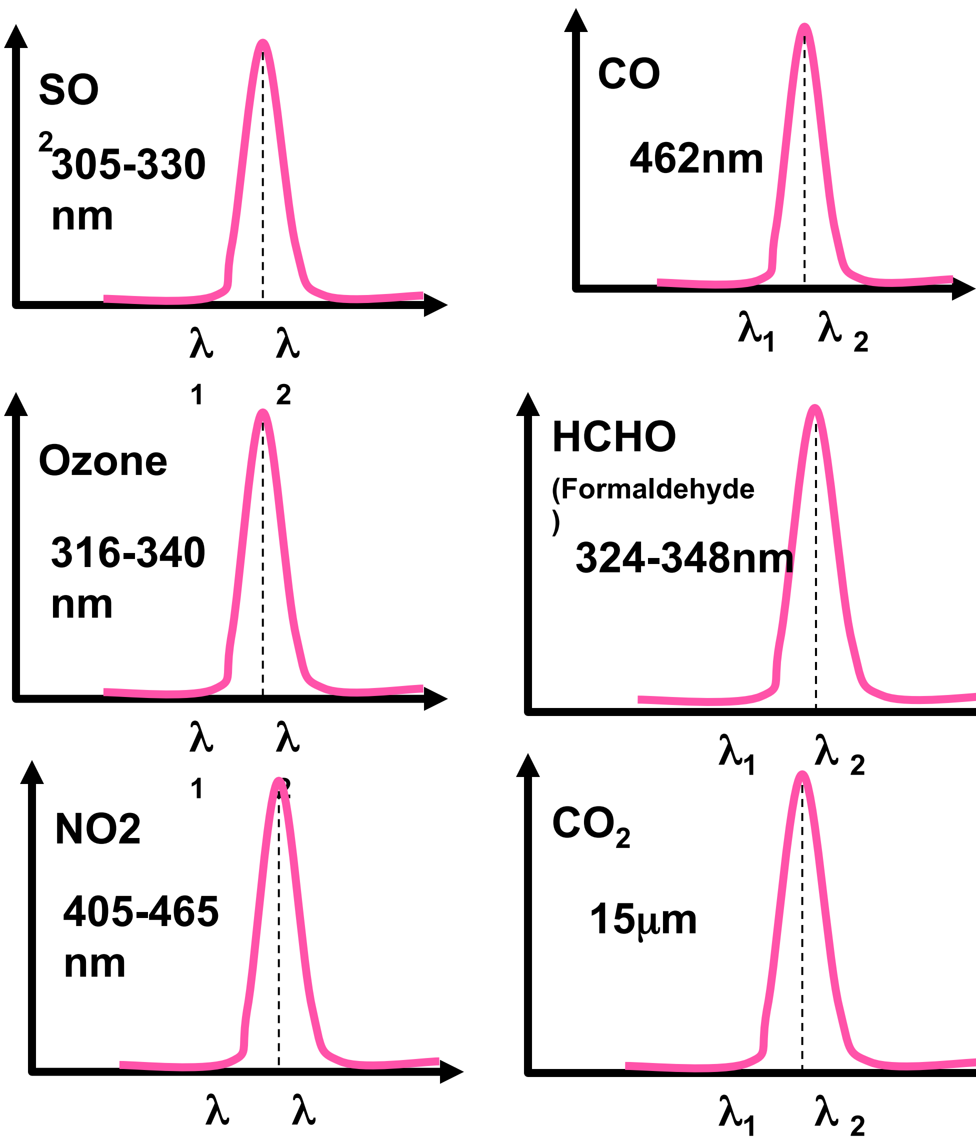


Unlike remote sensing of aerosols that use the signature of aerosol scattering, remote sensing of trace gases uses the signature of gas absorption.

All satellite remote sensing measurements of the troposphere are based on the use of electromagnetic radiation and its interaction with constituents in the atmosphere.

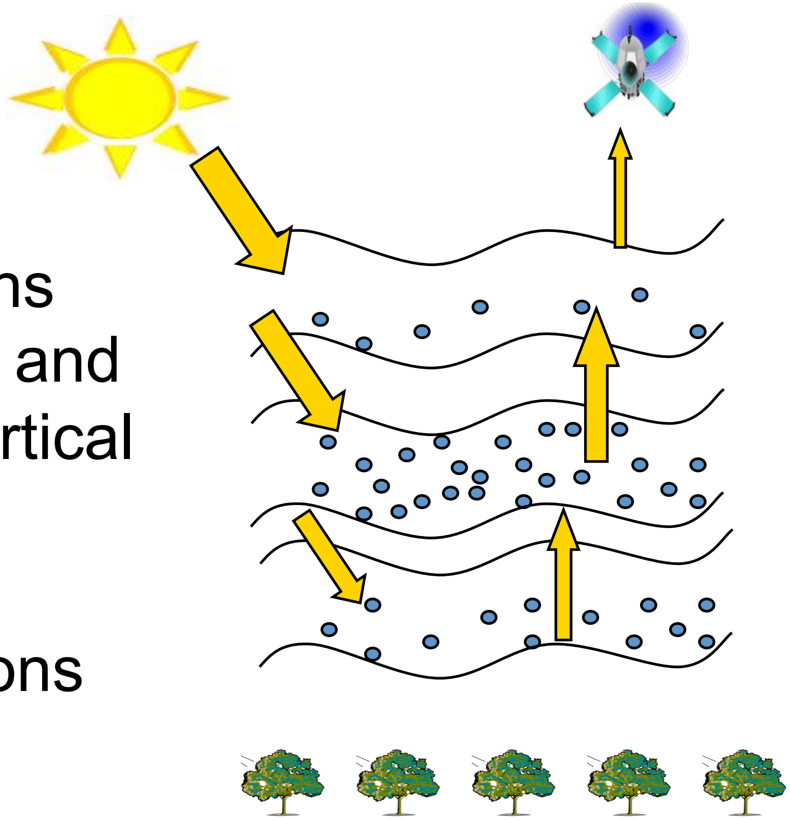
Satellite measurements take advantage of distinct absorption spectra





Vertical Distribution of O_3, SO_2, and NO_2

Very little information on the vertical distribution of the species, usually providing just the tropospheric column amount.



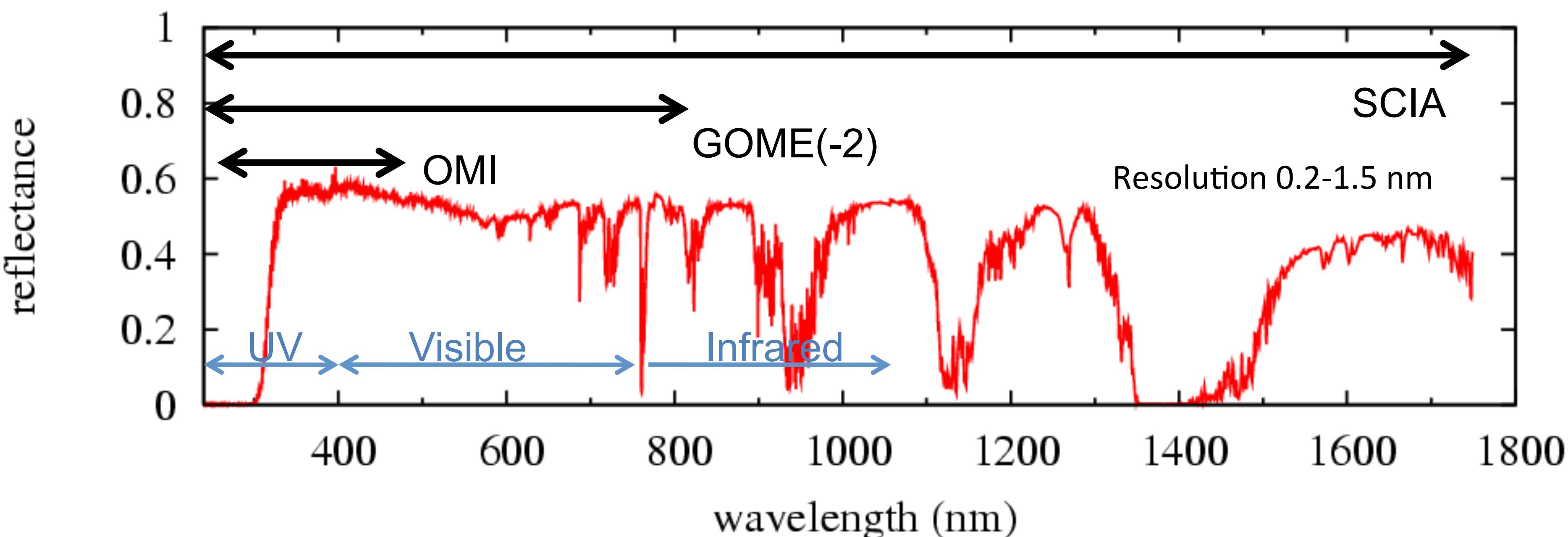
Observations at different wavelengths (technique of combining UV, visible, and IR measurements) provide some vertical information:

- The penetration depth of photons increases with increasing wavelengths
- Example: volcanic plumes of SO2

Hyper-spectral Instruments

Satellite UV-visible spectrometers

• GOME	ERS-2	240 – 800 nm
• SCIAMACHY	Envisat	240 – 1750 nm
• OMI	EOS-Aura	270 - 500 nm
• GOME-2	Metop-A	240 – 800 nm



Data Formats and Resolutions

Data Level	Description
Level 0	Raw data at full instrument resolution.
Level 1A	Raw data including radiometric and geometric calibration coefficients and geo-referencing parameters (e.g., platform ephemeris) computed and appended but not applied to Level 0 data.
Level 1B	Level 1A data that have been processed to sensor units (not all instruments have Level 1B source data).
Level 2	**Derived geophysical variables at the same resolution and location as Level 1 source data.**
Level 2G and 3	**Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.**
Level 4	Model output or results from analyses of lower-level data (e.g., variables derived from multiple measurements).

Spatial Resolution: Trace Gases

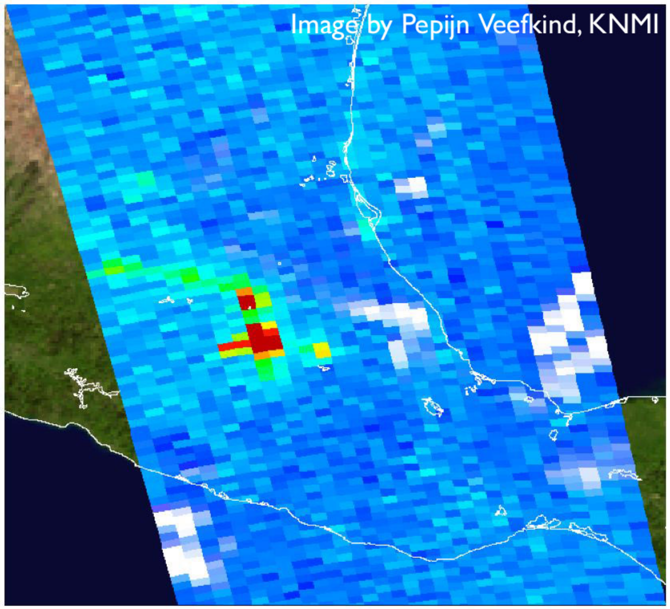
- The spatial resolution of current satellite instruments (10's of km diameter) is good enough to map tropospheric concentration fields at local to regional scales and fine enough to resolve individual power plants and large cities.
- For those species having short atmospheric life times (e.g. NO_2), the averaging over larger satellite pixels can lead to significant dilution of signals from point sources, complicating quantitative analysis and separation of emission sources.
- For quantitative analysis – Level 2 and high-resolution gridded Level 3 data are optimal.

Advantages of using Level 3 vs Level 2 data are:

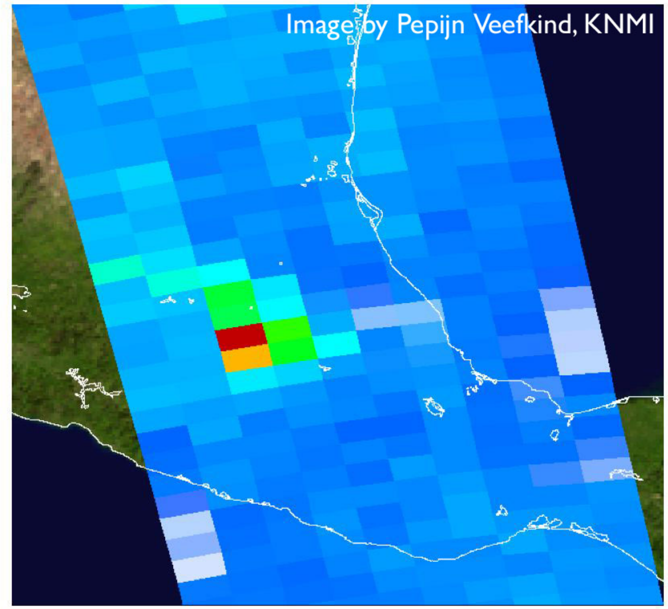
- Uniform grid
- One file per day
- Smaller sized files
- Quality flags and filtering criteria have been applied

Perspective …

Spatial Resolution



OMI 24x13 km^2



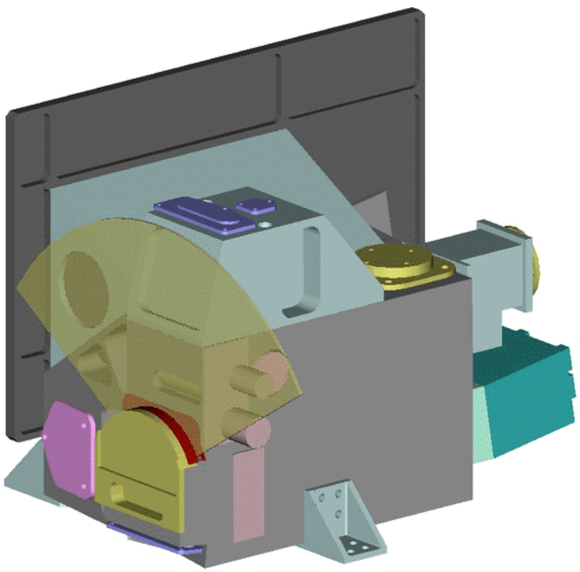
Approx. GOME-2 72x39 km^2

Mexico City, Jan. 20, 2005

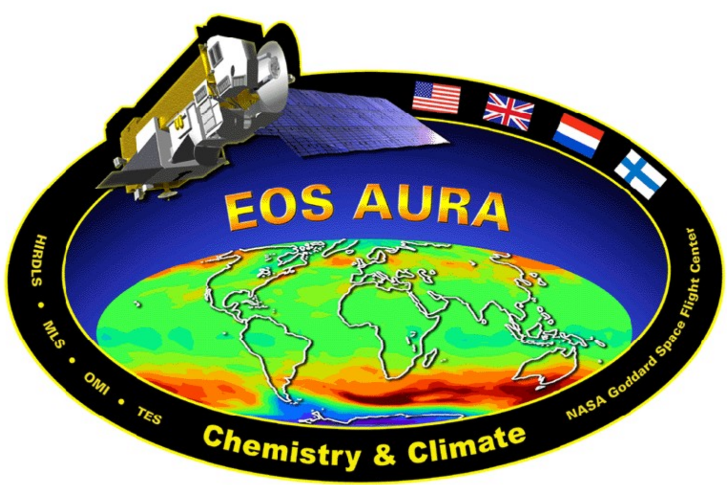
Quantification of gas abundances

Satellite Tracer	Units
OMI O_3, SO_2	Dobson Units
OMI NO_2 Column Amounts (also AIRS and MOPITT CO)	Molecules/cm^2
AIRS and MOPITT CO Vertical Levels	Volume mixing ratio

OMI Ozone Monitoring Instrument



- Launched on July 15, 2004 on the NASA EOS Aura Satellite
- Nadir-viewing UV/Visible
  - 270-310 nm @ 0.6 nm
  - 310-500 nm @ 0.45 nm
- 1:40 PM equatorial crossing time
- 13x24 km^2 at nadir
- Daily global coverage.



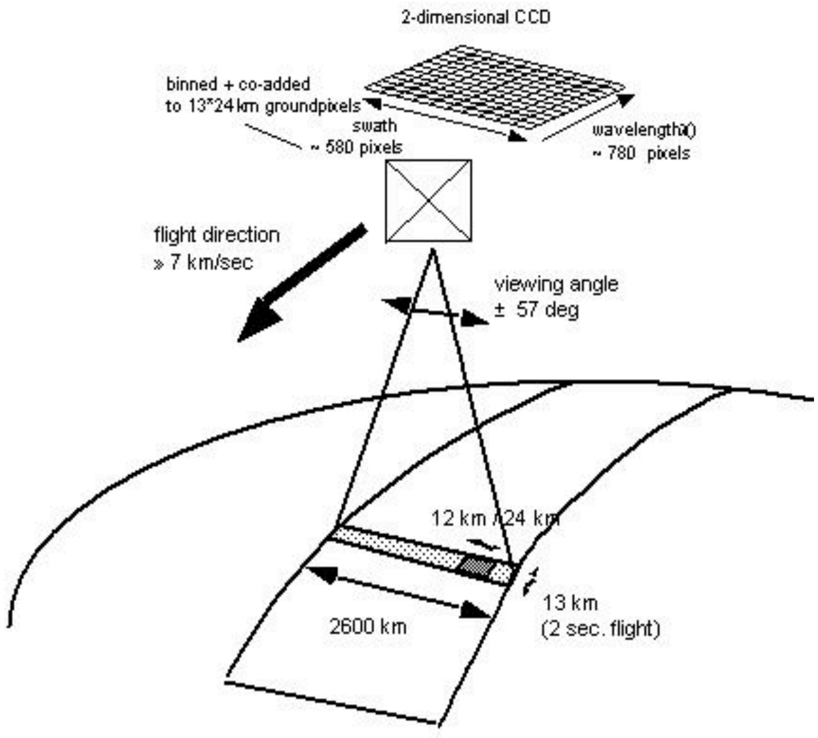
Products:

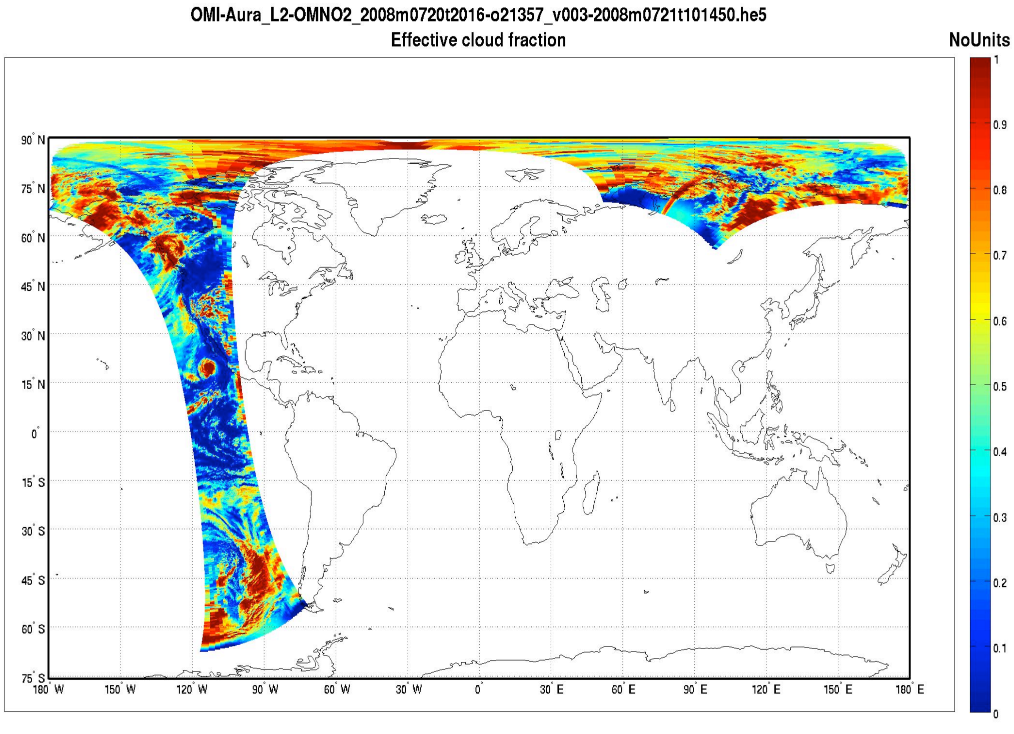
Total Column O_3
Tropospheric Column O_3 (experimental
But not applicable in the mid-latitudes)
Aerosol optical depth (in UV)
Column Formaldehyde
Column NO_2
Column SO_2

Data Granule

The product file, called a **data granule**, covers the sunlit portion of the orbit with an approximately 2600 km wide swath containing 60 binned pixels or scenes per viewing line.

During normal operations, 14 or 15 granules are produced daily, providing fully contiguous coverage of the globe.



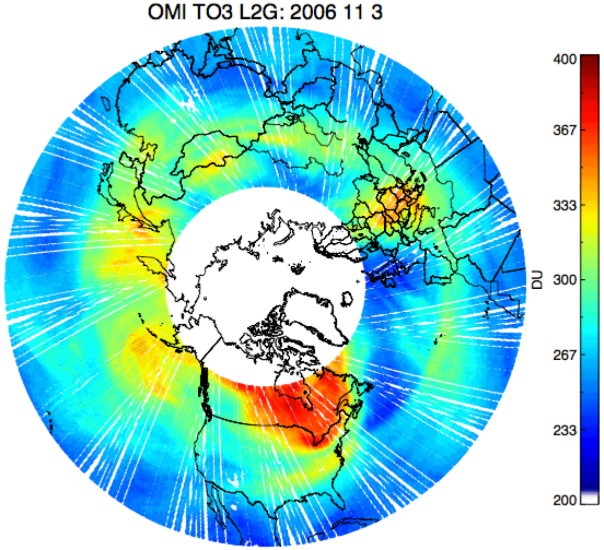


Important information regarding OMI

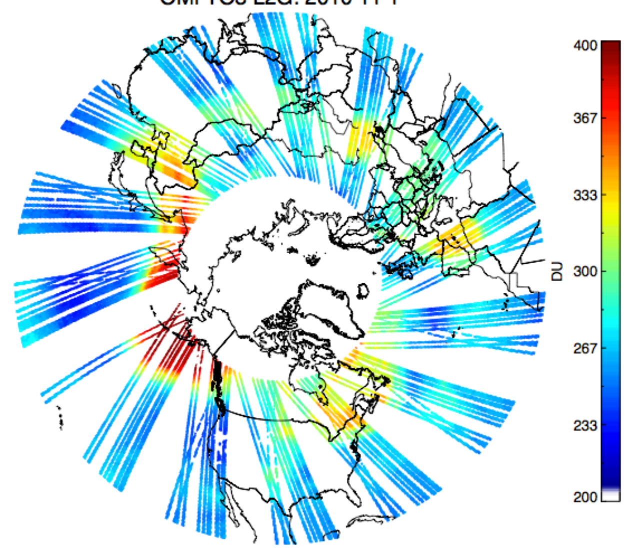
Almost 50% data loss since 2008
(row anomaly effect)

Affects O_3, SO_2, and to some extent NO_2 OMI Products

OMI TO3 L2G: 2006 11 3



OMI TO3 L2G: 2010 11 1



OMI Ozone and Formaldehyde

OMI Ozone in the Troposphere

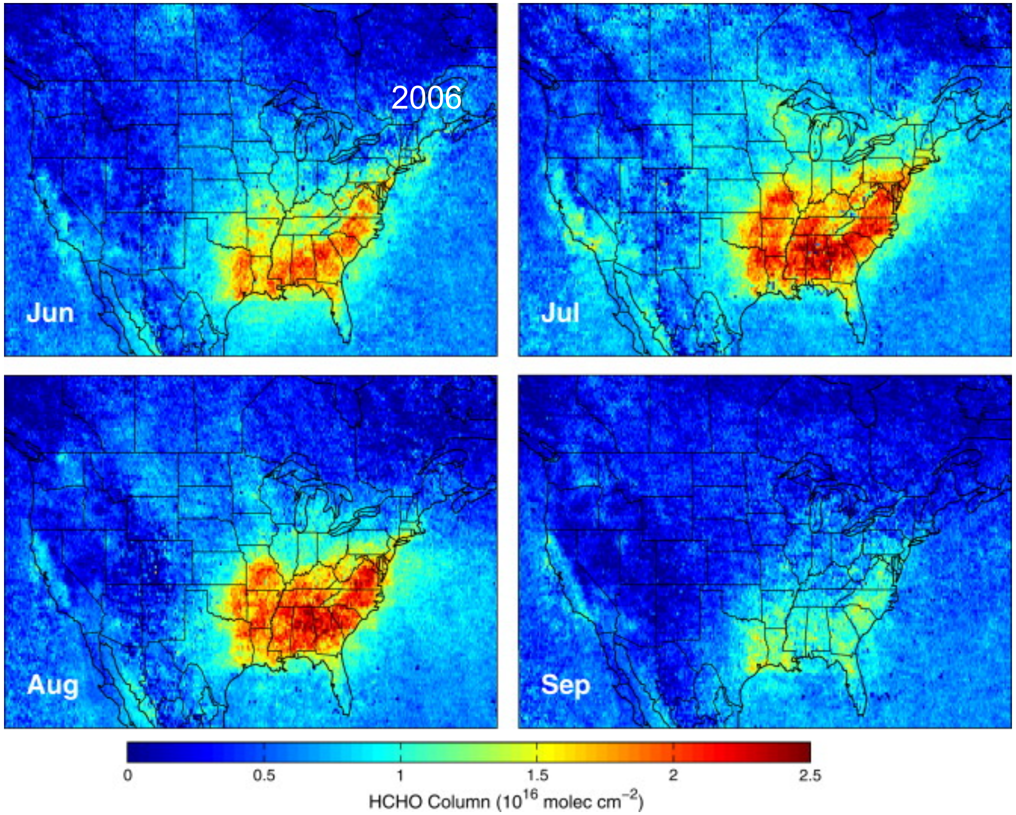
OMI is NOT sensitive to ozone near the surface. There are tropospheric ozone products in development but it currently cannot be used for AQ monitoring.

Retrieval of boundary layer O_3 from satellite remote sensing remains a daunting task.

OMI Formaldehyde (CH_2O)

Data is reliable for the 2004-2009 time period only. Data re-processing is planned to account for the growing background noise and row anomalies.

HCHO is a proxy for isoprene emissions.



Source: Randall Martin, Satellite remote sensing of surface air quality, Atmos. Environ. 42(34), 7823-4843, 2008.

- Planetary Boundary Layer (PBL) and Volcanic SO_2

- Tropospheric Column NO_2

OMI SO_2 in the boundary Layer

Data Set Short Name = OMSO2e

Product Level = 3

Begin Date = October 1, 2004

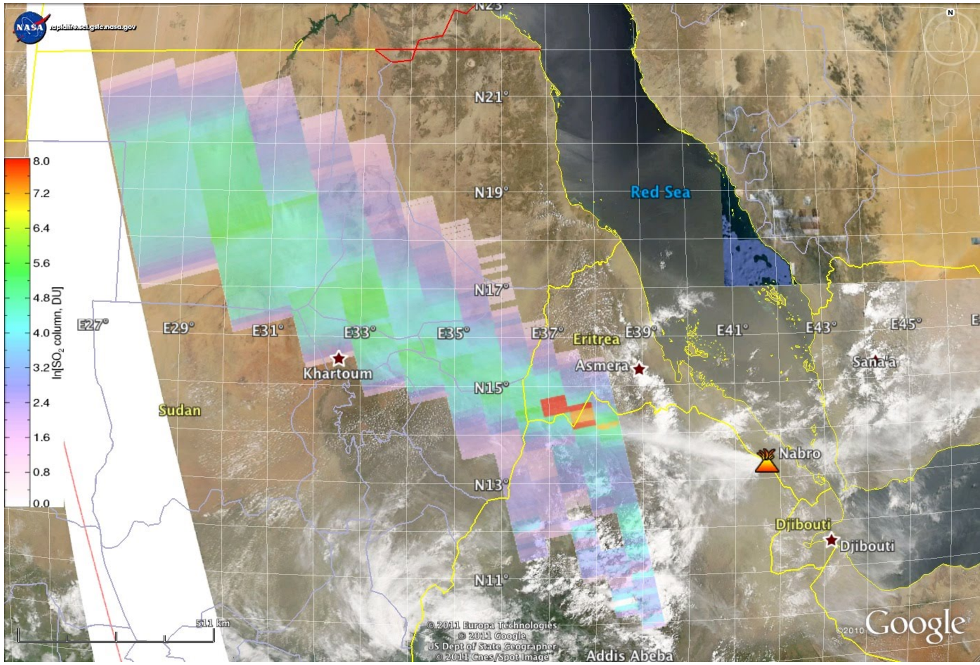
Resolution = 0.25°lon x 0.25°lat

Version = 003

Cloud-screened best measurement

Production Frequency: Daily

Granule (File) Coverage: 15 orbits
File Size(Approx): 5 MB



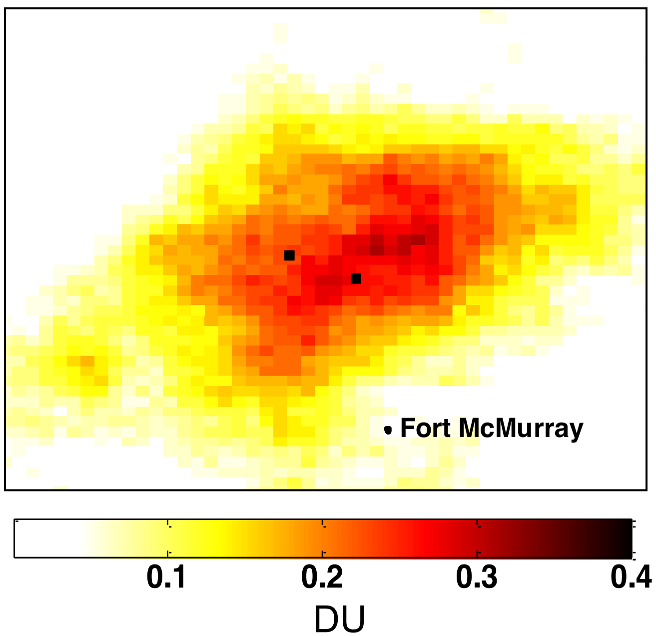
Aqua MODIS visible image of the Nabro (Eritrea) eruption on June 13, 2011 and the SO2 plume overlaid.

Contains **best** pixel data, screened for OMI row anomaly, clouds, and other data quality flags.

Data here: http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/OMI/omso2e_v003.shtml

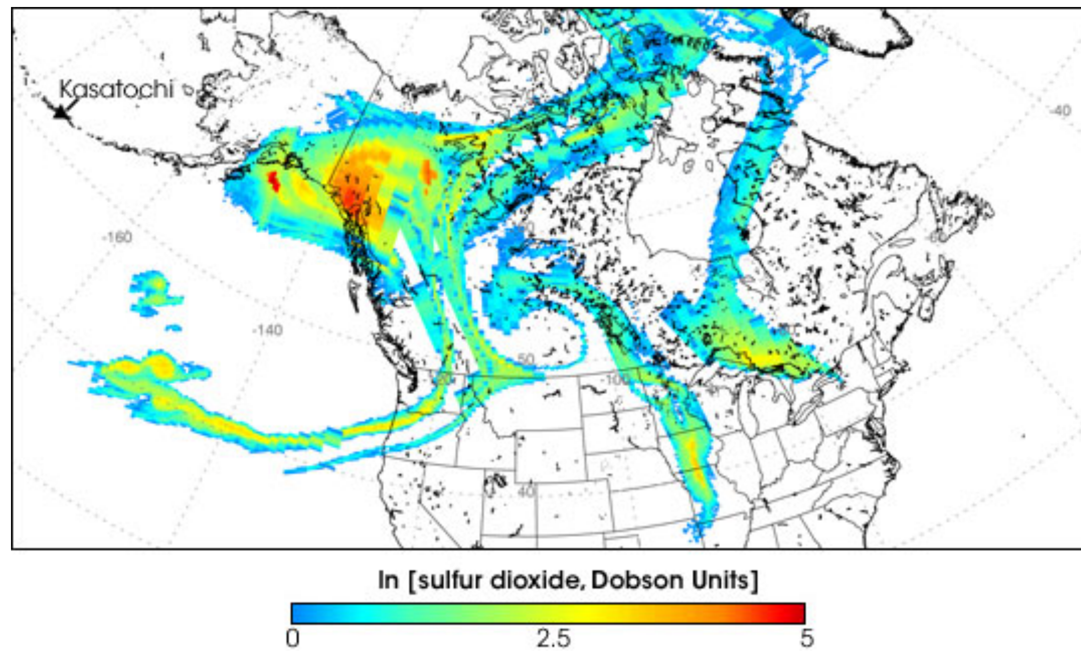
Perspective: What is considered high SO_2?

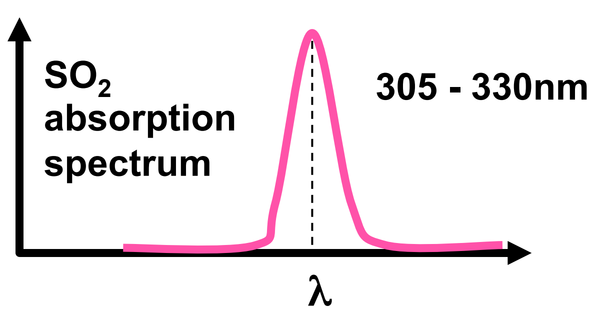
2005-2010 mean over the Canadian oil sands



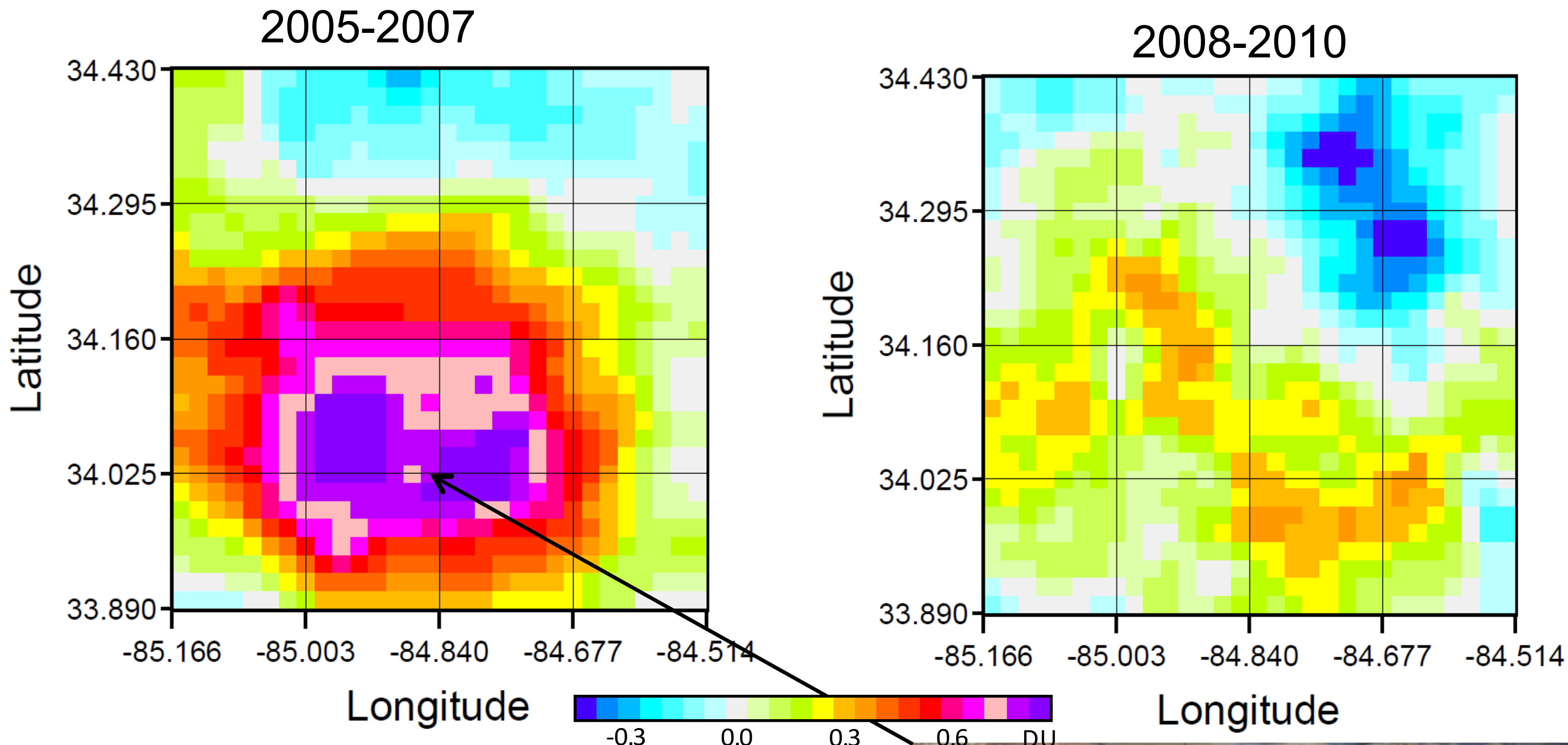
McLinden, C. A., et al. (2012), Air quality over the Canadian oil sands: A first assessment using satellite observations, Geophys. Res. Lett., 39, L04804, doi:10.1029/2011GL050273.

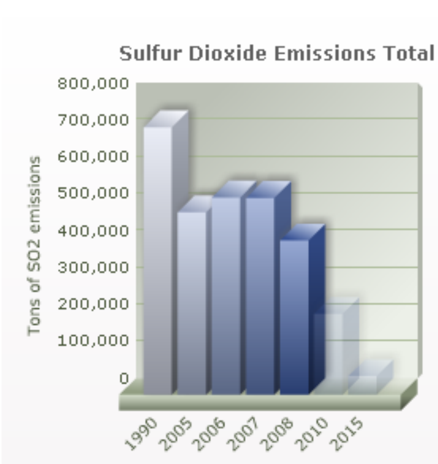
OMI SO_2 from the Kasatochi Volcano eruption in the Alaskan Aleutian Islands on 2008 August 8 continued to spread eastward on August 12.





US Source #1.Bowen Coal Power Plant, Georgia (3500 MW), SO_2 emissions: 170 kT in 2006



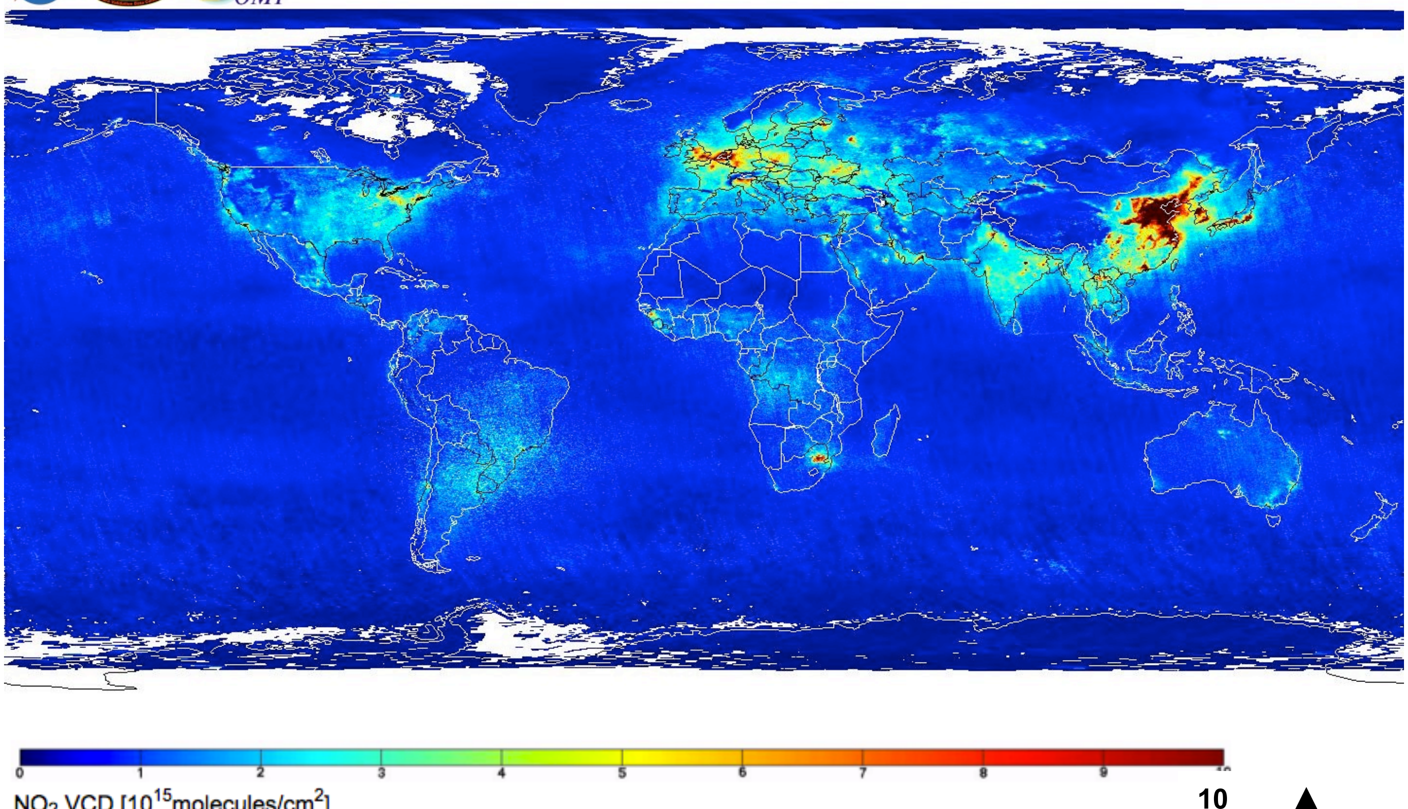


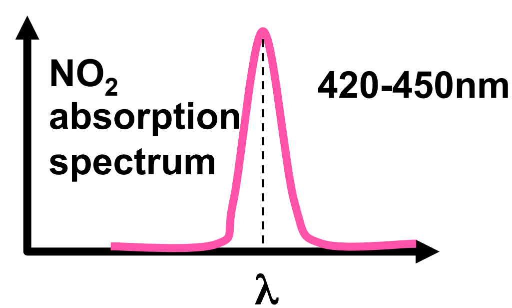
"In **2008**, the mammoth construction program yielded the first scrubbers, sophisticated equipment that will reduce our overall systems emissions by as much as 90 percent"
Georgia Power website

V. Fioletov, et al., 2011

OMI NO_2

March 2011

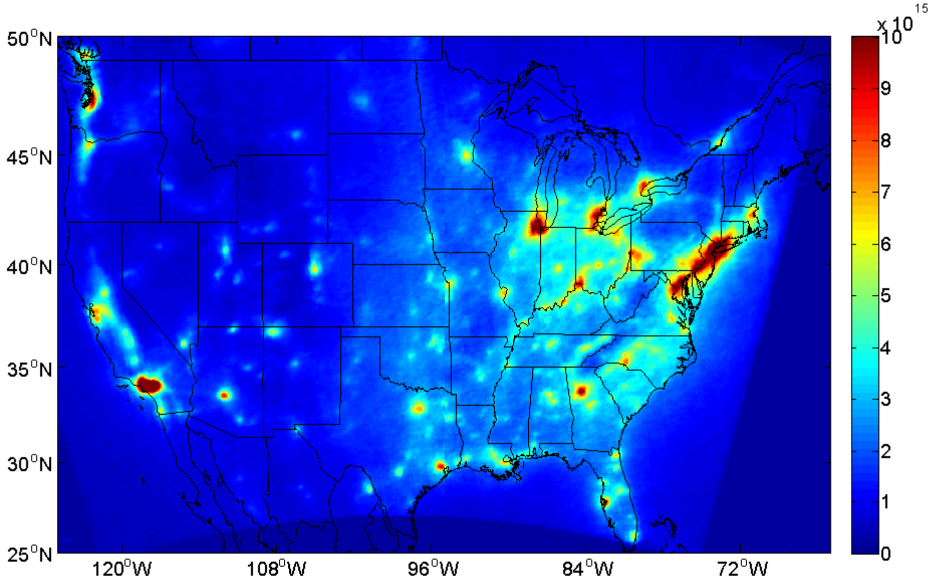




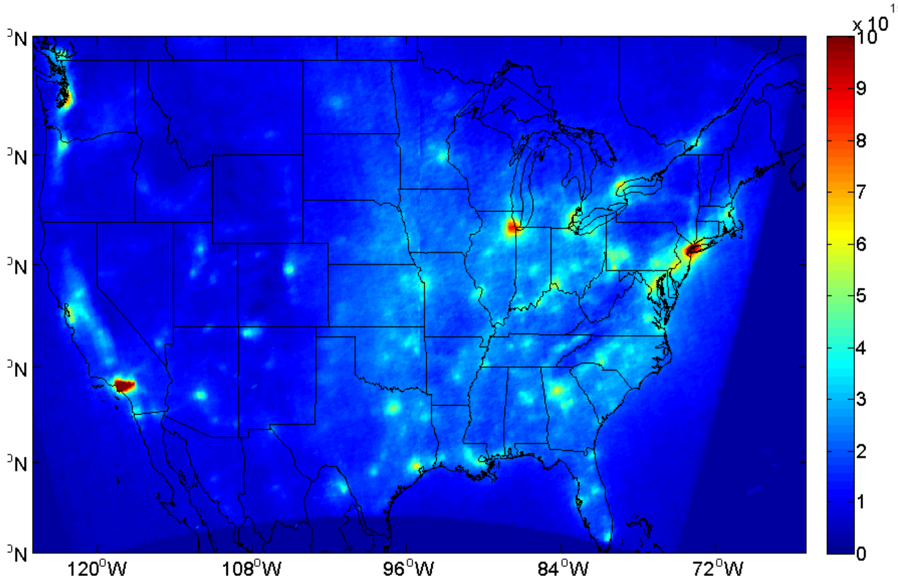
NO_2 Trends

Tropospheric Column NO_2 retrieved using the Berkeley algorithm
Credit: Ron Cohen, UCB

Summer 2005



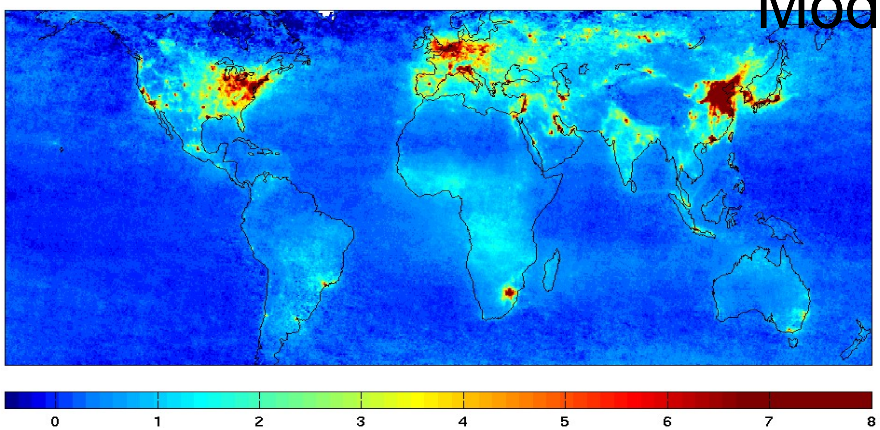
Summer 2011



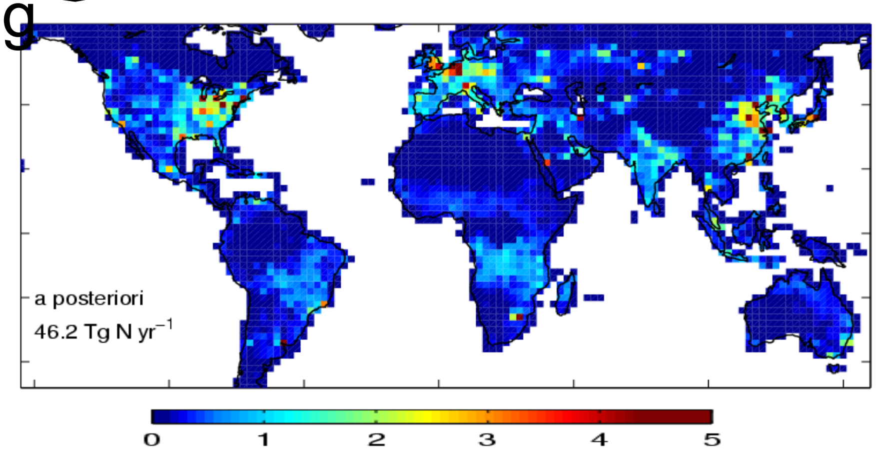
NO_2 Emission Inventories are Notoriously Difficult to Determine

Satellite Observations of NO_2 for Emission Inventory Development

Inverse Modeling



Satellite Tropospheric NO_2 (10^{15} molec cm^{-2})



NO_x emissions (10^{11} atoms N cm^{-2} s^{-1})

Martin et al., 2006

Application of Satellite Observations to NO_x Emission Inventory updates

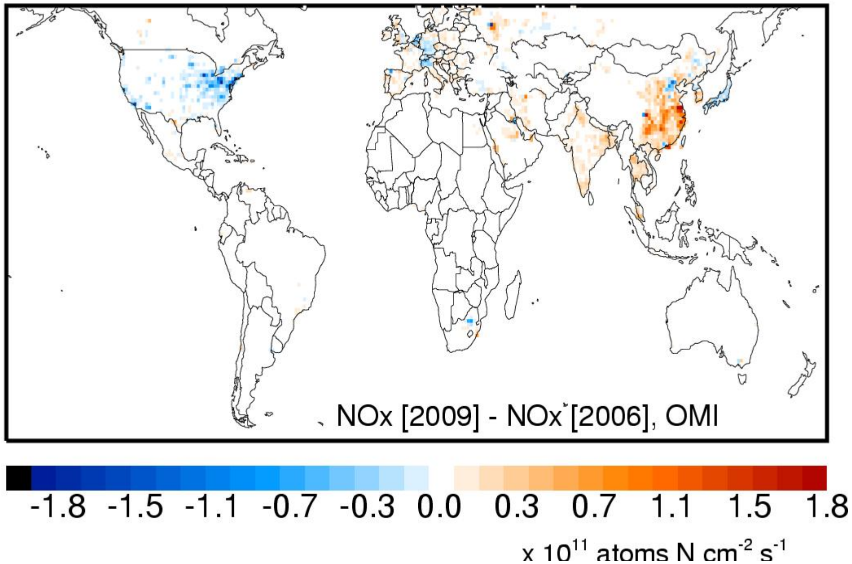
Use CTM to Calculate Local Sensitivity of Changes in Trace Gas Column to Changes in Emissions

Fractional Change in Emissions

$$\Delta E = B$$

Local sensitivity of column changes to emissions changes

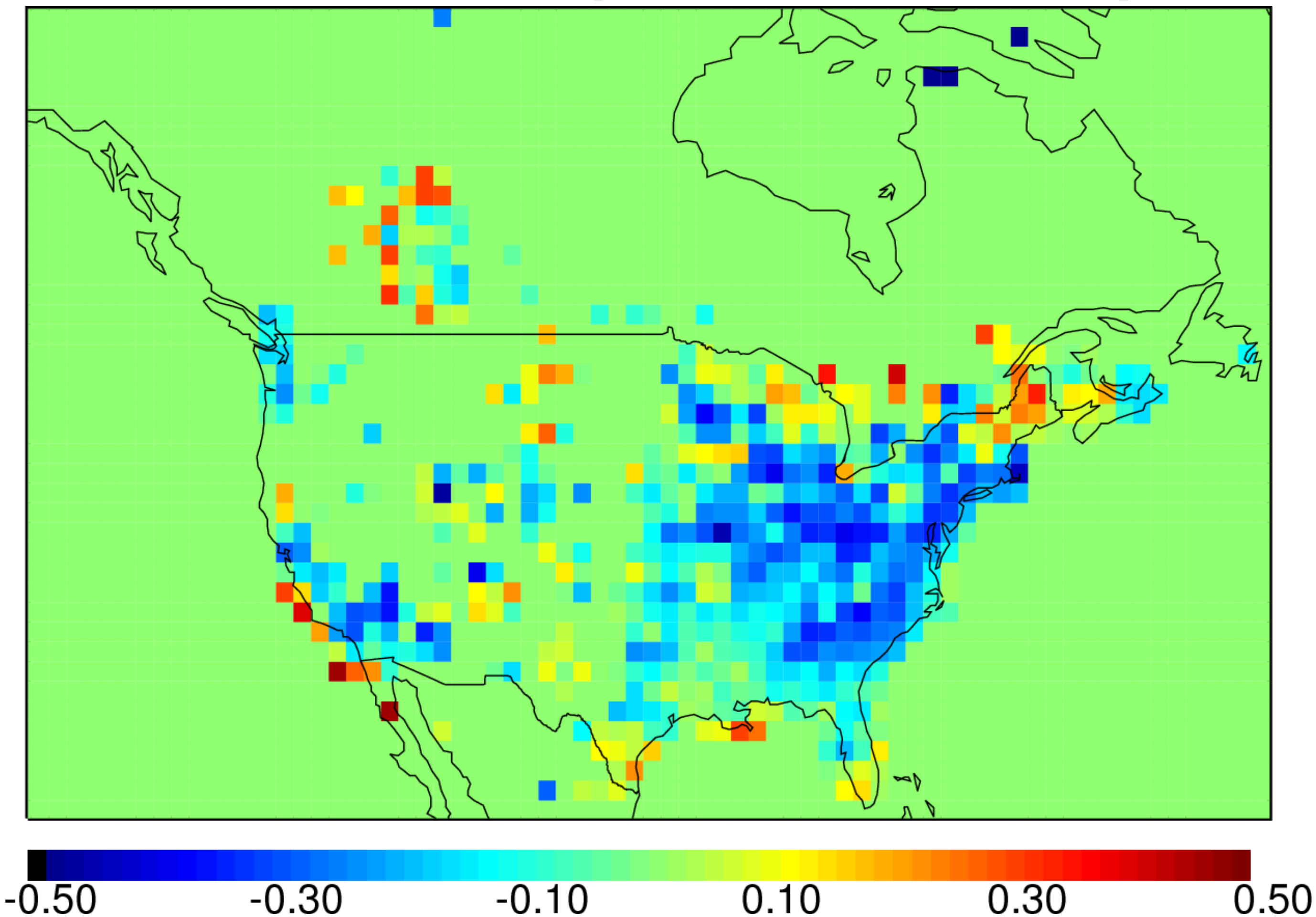
Forecast Inventory for 2009 Based on Bottom-up for 2006 and Monthly OMI NO_2 for 2006-2009



Temporary Dataset Until Bottom-Up Inventory Available

Lamsal et al., GRL, 2011

OMI Derived Fractional NO_2 Emissions Changes in North America (2010 – 2005)

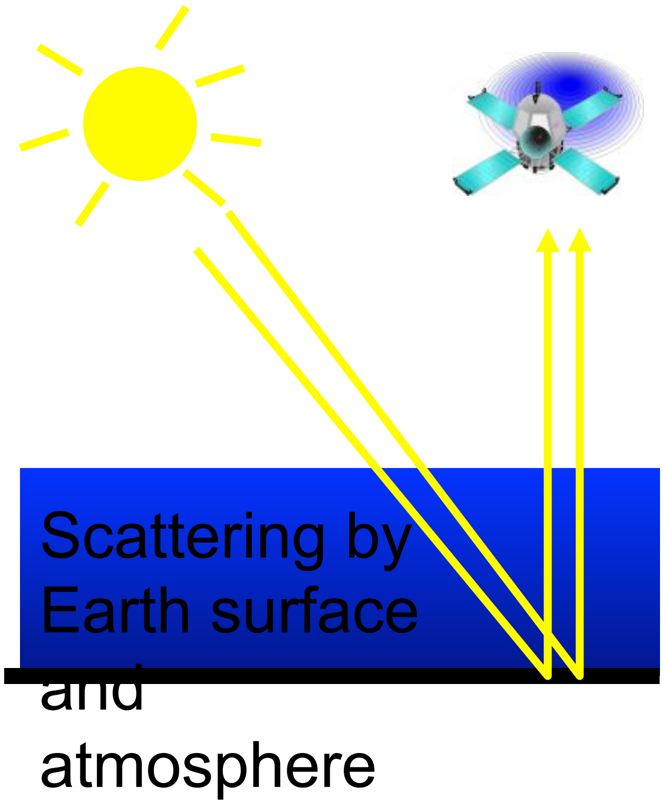


Note: this is a research product and not an official NASA product

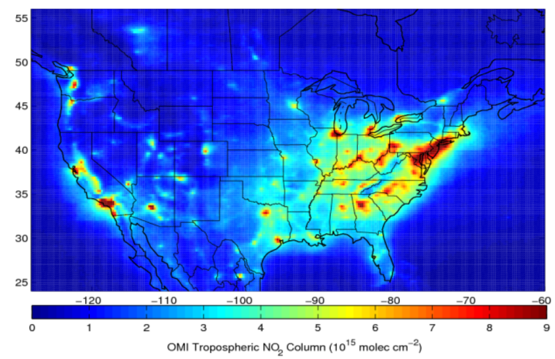
Also available at: http://fizz.phys.dal.ca/~atmos/

Lamsal et al., GRL, 2011

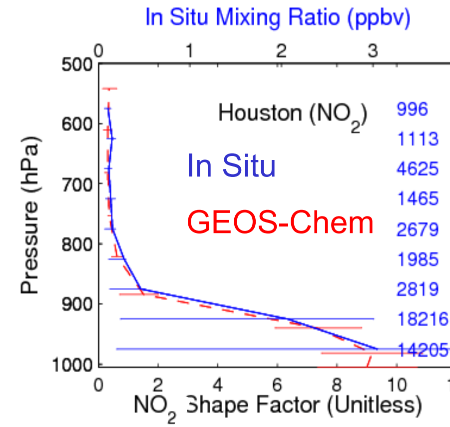
Estimating Satellite based Surface NO_2



NO2 Column



Model Profile



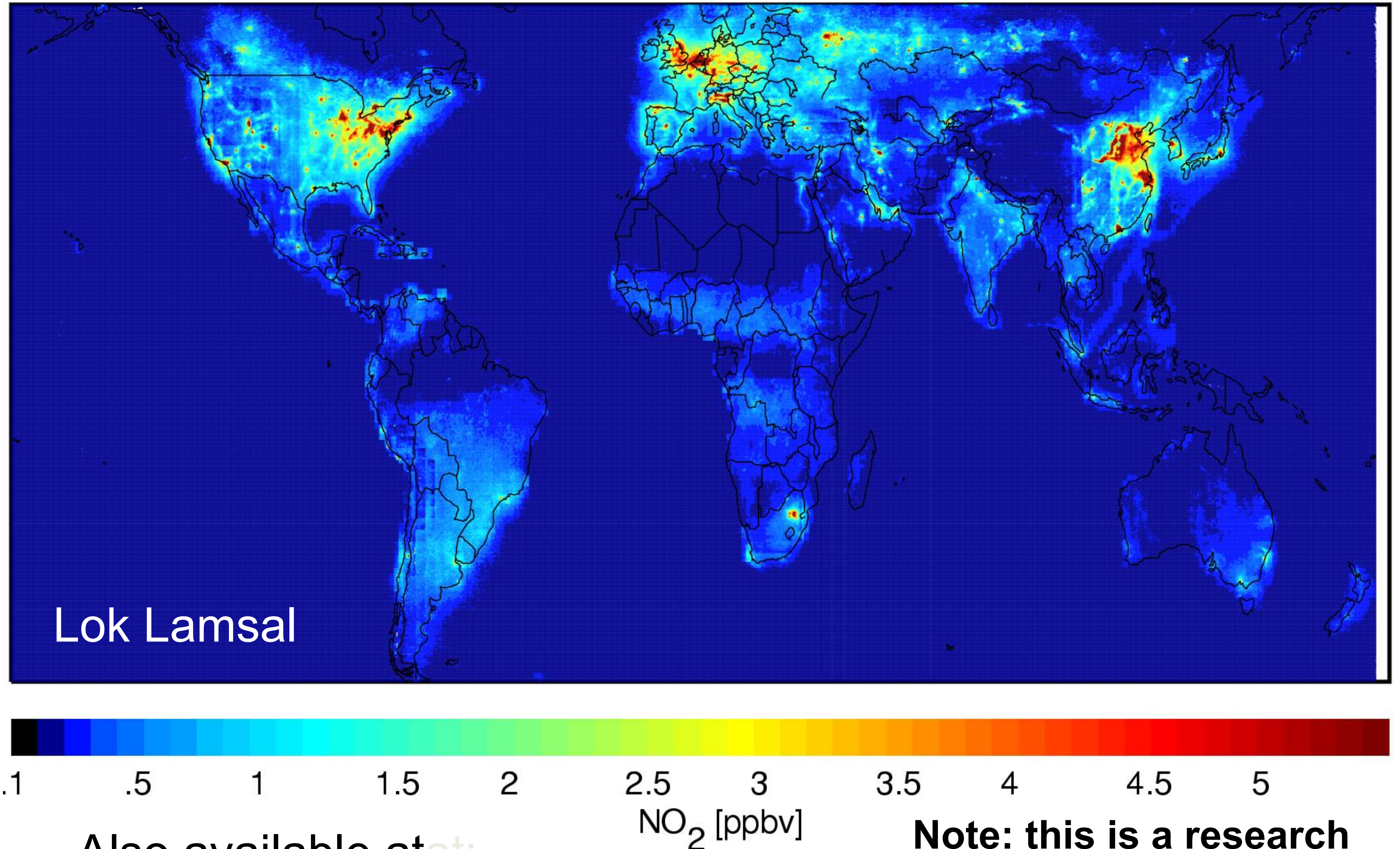
$$S_O = \Omega_O \left[\frac{S_M}{\Omega_M} \right]$$

S → Surface Concentration

Ω → Tropospheric column

Courtesy of Randall Martin

Ground-Level Afternoon NO_2 Inferred From OMI for 2005



Also available at
http://fizz.phys.dal.ca/~atmos/

Note: this is a research product and not an official NASA product

Carbon Monoxide

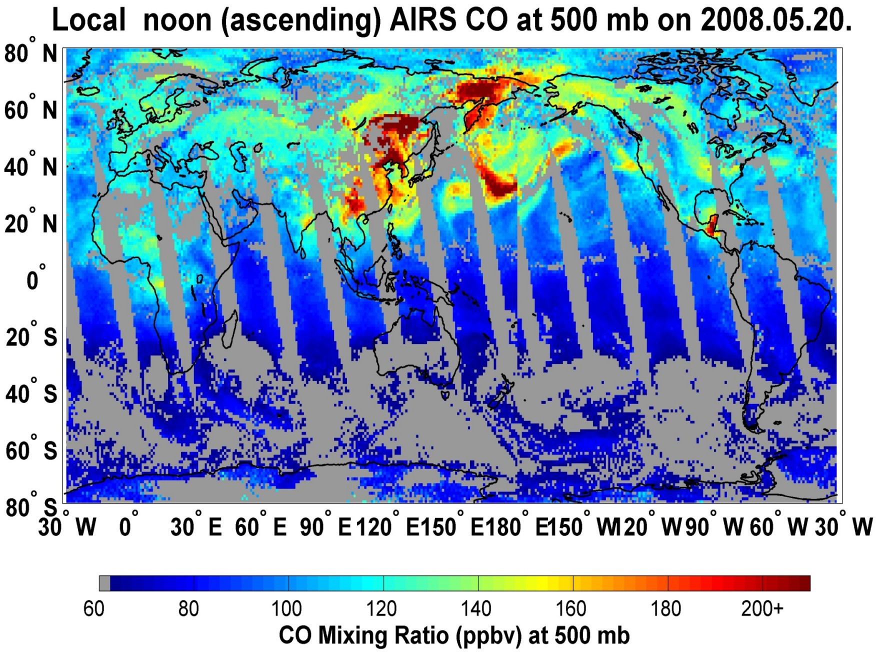
Total Column Density

Also Sensitive to the vertical distribution of CO

Greatest sensitivity to CO variability is at 500 mb

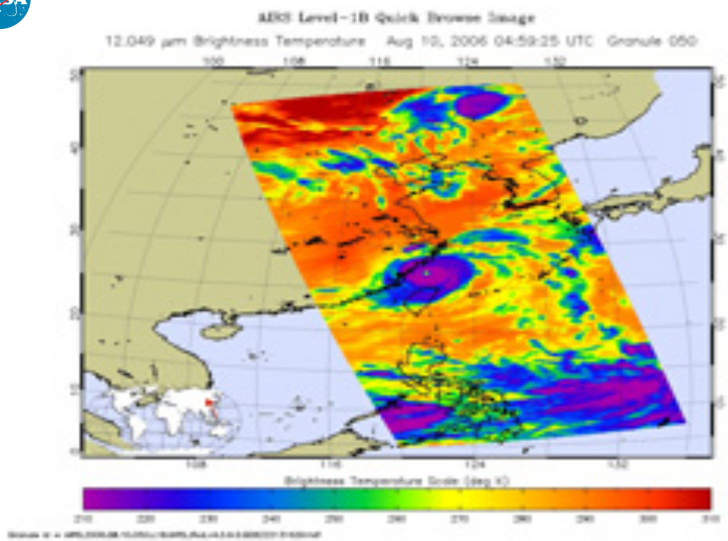
↓

Mixing ratio can be larger away from source

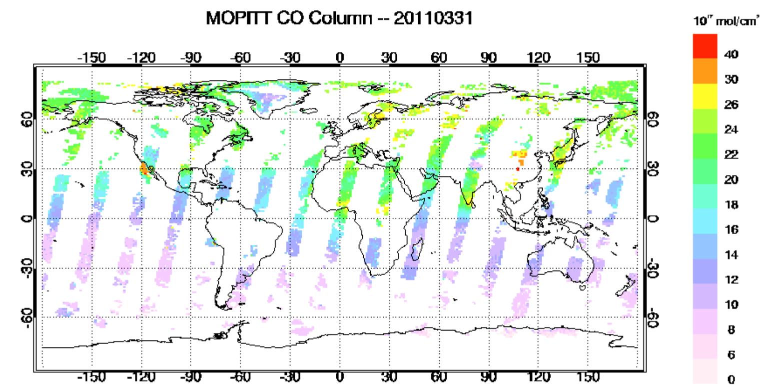


Current CO Sensors

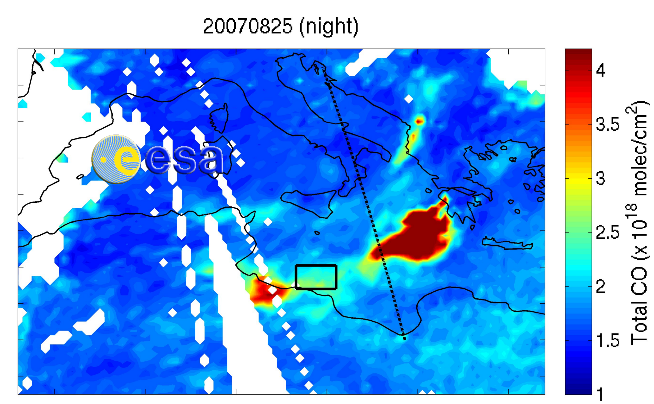
AIRS – Atmospheric Infrared Sounder



MOPITT – Measurements of Pollution in The Troposphere



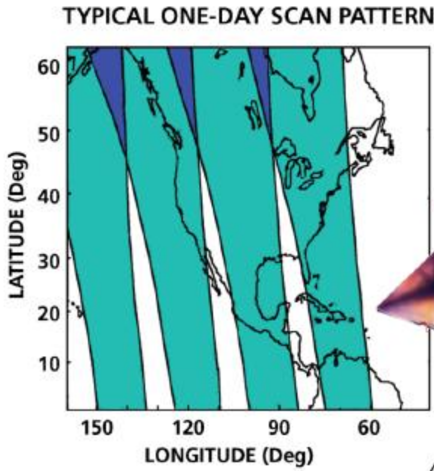
IASI – Infrared Atmospheric Sounding Interferometer

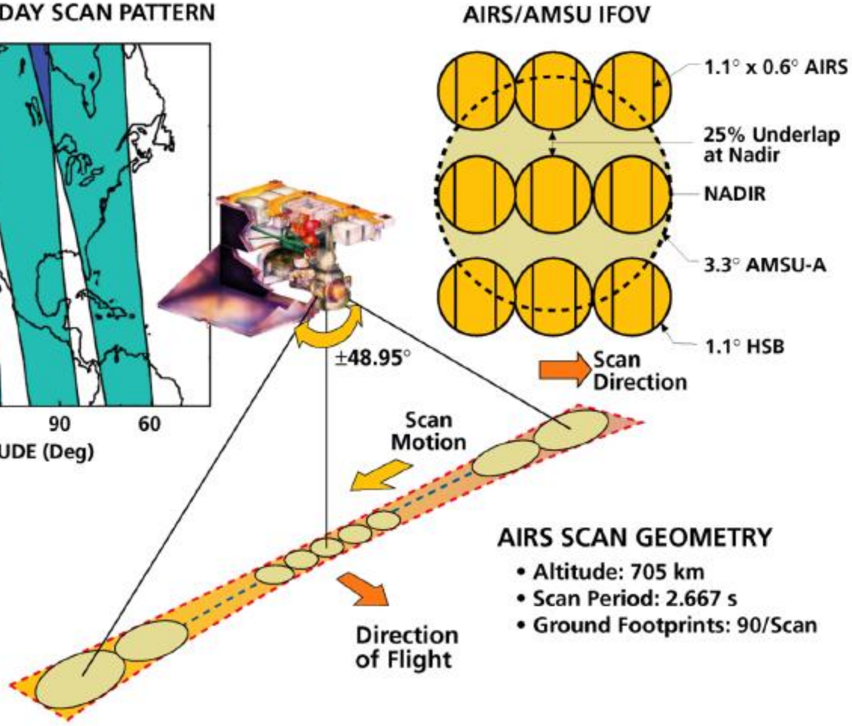


AIRS

- Operational since Sept. 2002
- A nadir sounding instrument.
- Pixel size = 14 km at nadir

  41 x 21 km edges
- Swath width = 1650 km
- Equator Crossing times
  - 13:30 AM (Ascending orbit)
  - 13:30 PM (Descending orbit)
- Column measurements
  - Units = molecules/cm^2
- Profile measurements
  - 9 vertical layers (904.866 hPa – 0.016 hPa)
  - Profile Units = Volume mixing ratio
- Total Column CO measurements provided in units = molecules/cm2
- Data Source: Level 2 pixel and Level 3 gridded 1°×1° resolution
- Current Version 6





HOMEPAGE: http://airs.jpl.nasa.gov

Satellite measurements of Carbon Monoxide (CO) is an excellent tracer of Biomass burning, i.e. forest fires

- Unlike MOPITT, AIRS has excellent global coverage with 'minor' gaps particularly over CONUS!
- One can easily track biomass burning plumes.
  - AIRS swath width is ~ 1650km whereas MOPITT 640km.
  - Twice daily coverage with AIRS (daytime and nighttime).

Ascending Orbit = Daytime
Descending Orbit = Nighttime

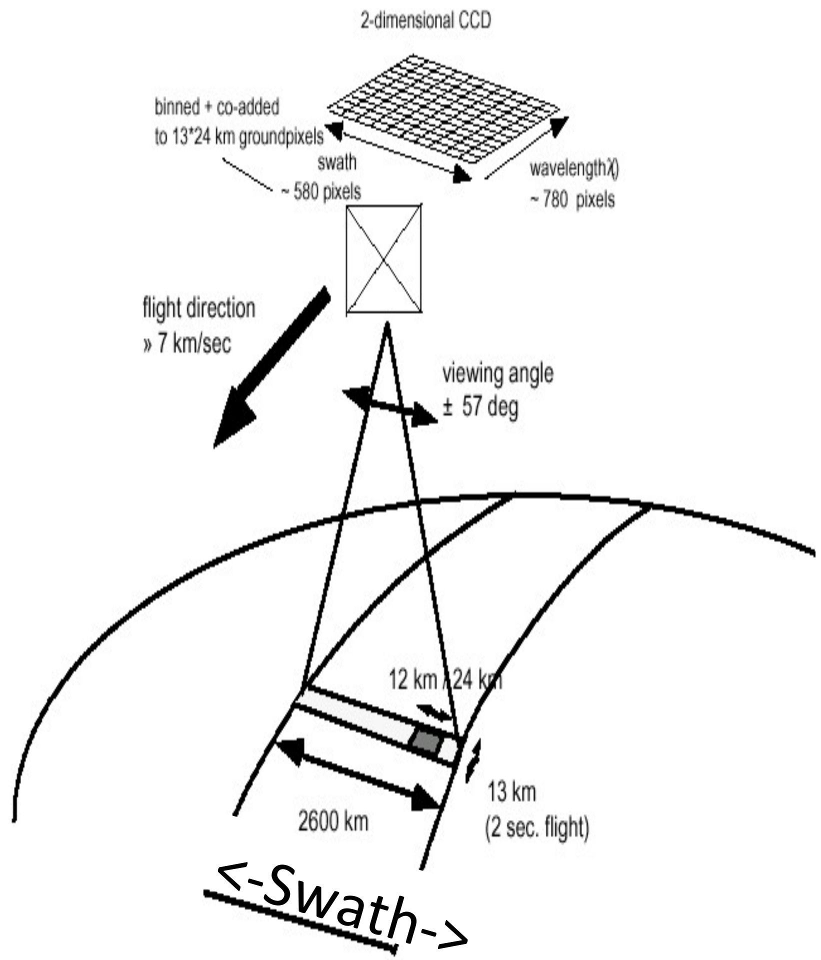
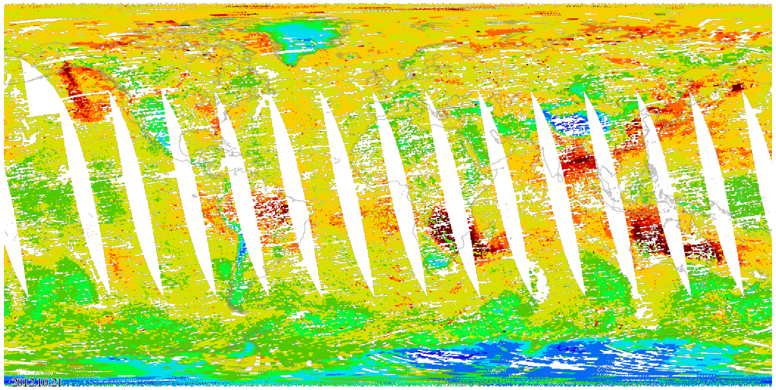


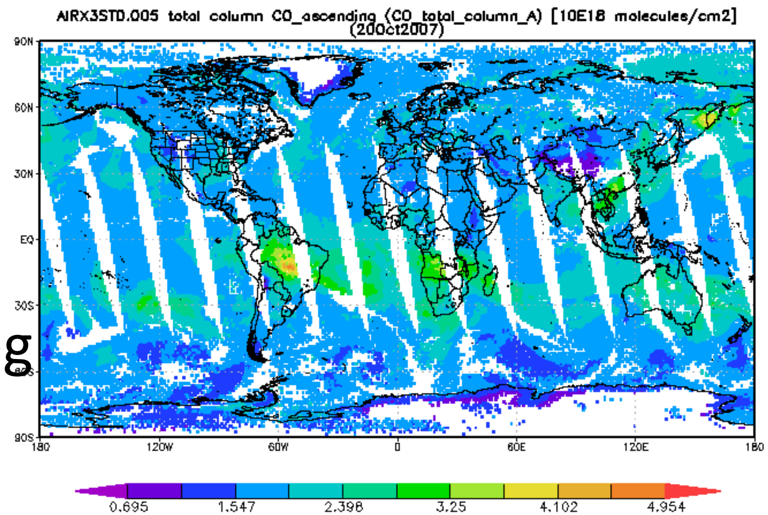
Figure 2.1 Measurement principle of OMI.

AIRS vs MOPITT CO

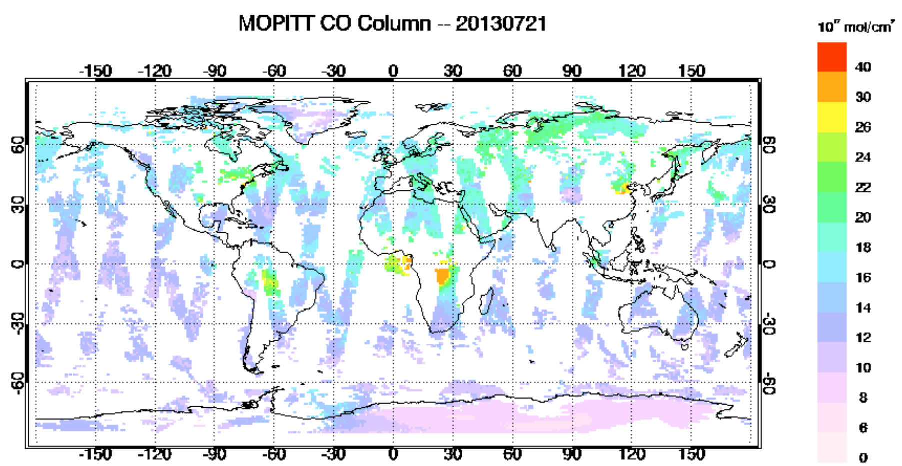


AIRS Level 2
From NRT
Website

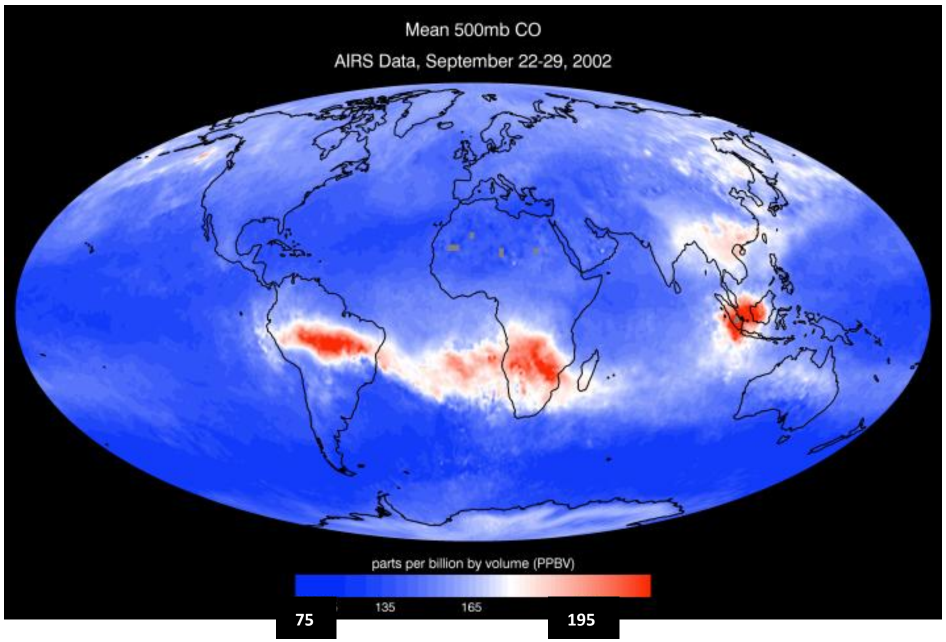
AIRS Level 3 1x1deg
from GIOVANNI



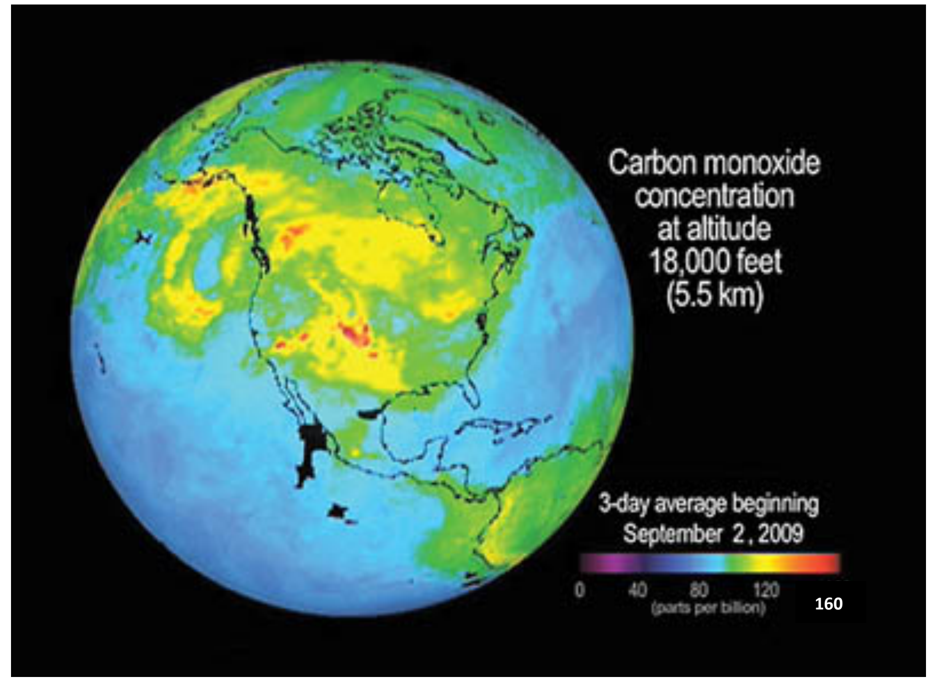
MOPITT
Level 3
1x1deg



Long Range Transport of CO



ppbv



DATA PRODUCT SUMMARIES

OMI SO2 Gridded Product Summary

SO_2 Product	Level	Data Short Name	Sensitivity	Use
PBL SO_2	L3, 0.25^ox0.25^o	OMSO2e	0.6 km	Fossil fuel, industry
TRL SO_2	L2G, 0.25^ox0.25^o	OMSO2G	3 km	Industry outflow
TRM SO_2	L2G, 0.25^ox0.25^o	OMSO2G	5 km	optimized for volcanic degassing with vents at ~5km altitude or above and emissions from effusive eruptions.
STL SO_2	L2G, 0.25^ox0.25^o	OMSO2G	15 km	intended for use with explosive volcanic eruptions

Caveat: Unlike the OMSO2e ‘best’ product. L2G data are NOT screened for clouds, sza, quality flags, row anomalies.

Level 2 pixel (footprint) size at nadir and comparison chart

- **AIRS** — 14 x 14 km
- **MOPITT** — 22 x 22 km
- TES — 8.3 km, 5.3 km
- SCIAMACHY (esa) — 30 km, 60 km
- **IASI** (esa) — 12 x 12 km

	MOPITT	AIRS	TES	IASI	SCIAMACHY
Product/pixel size	22 x 22 Km	14 x 14 km	5.3 x 8.3 KM 100 M between pixels	50 KM 12 x 12 KM	30 x 60KM
Swath width	650 KM	1650 KM	N/A	2200 KM	1000 KM
Global Coverage/ Repeat Cycle	3 Days Composite for global coverage	2X per day (day and night)	16 days Repeat Cycle	2X per day (day and night)	6 Days
Overpass time	10:30 AM	13:30	2:30 AM / PM	9:30 AM/PM	10:00 AM
Product Resolution	L3 1 Degree grid	L3 1 Degree grid	L3 5x8km	NO L3 Product	L3 0.5 Degree grid
Products available	L2 L3 Daily, Monthly	Level 2 (granule) Level 3	L2 granule	L2 NOAA and ESA	2B - swath 3 - global
Vertical sensitivity	Mid and lower troposphere	Mid-Troposphere	mid and lower troposphere	mid troposphere	Total column only
Product accuracy	TIR - 10% Near Surface 30%	10 - 20%	20%	< 10%	10 - 20%
Other notes	TIR and NIR Channels	QA flags in L2 and L3	Report data for clouds 0 -25% Simultaneous trace gas	250 KM sampling ESA Should avg. to 4x5 deg.	