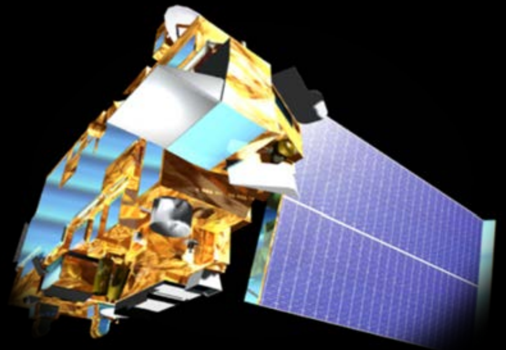

ASP 2016 Summer Colloquium Advances in Air Quality Analysis and Prediction

Introduction to satellite AQ observations

David P. Edwards, NCAR/ACOM

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What do we want to measure?

Primary pollutants:

- *Sulfur dioxide (SO_2)* – burning of coal and oil
- *Nitrogen oxides (NO_x)* – high temperature combustion
- Carbon monoxide (CO) – incomplete combustion
- *Particulate matter (PM10 & PM2.5)* – smoke and dust
- *Lead* – industry and transport
- *Other toxic metals*, POPS, ….

Secondary pollutants:

- *Ground level ozone (O3)*
- *Particulate matter (PM)*

Quantifying Global Change requires Global Observations
These provide the evidence base for science (understanding and prediction) and policymaking

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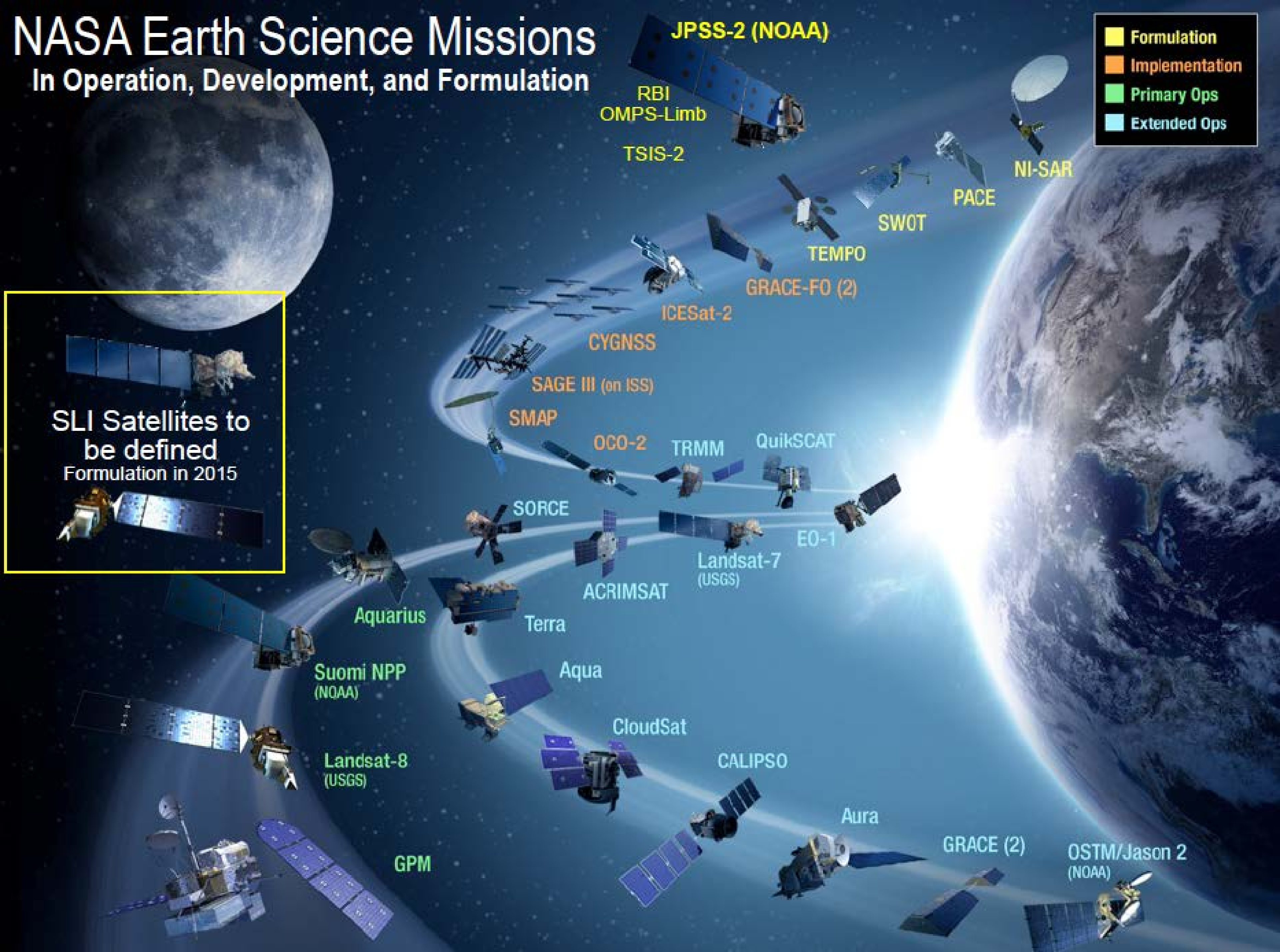
NASA Earth Science Missions
In Operation, Development, and Formulation
JPSS-2 (NOAA)
RBI
OMPS-Limb
TSIS-2
Formulation
Implementation
Primary Ops
Extended Ops
NI-SAR
PACE
SWOT
TEMPO
GRACE-FO (2)
ICESat-2
CYGNSS
SAGE III (on ISS)
SMAP
OCO-2
TRMM
QuikSCAT
SLI Satellites to be defined
Formulation in 2015
SORCE
EO-1
Landsat-7 (USGS)
ACRIMSAT
Aquarius
Terra
Suomi NPP (NOAA)
Aqua
CloudSat
Landsat-8 (USGS)
CALIPSO
Aura
GPM
GRACE (2)
OSTM/Jason 2 (NOAA)

Some things to be thinking about …

- Pollutants: Which can be measured from space?
- Viewing geometries: What are they?
- Retrievals: How are they performed?
- Coverage: How often is there a measurement?
- Vertical information: Is there a pollutant profile?
- Source regions: Can these be identified?
- Transport: Are there observations?
- Trends: Does long-term satellite monitoring reveal any?
- Validation: Do we have confidence in satellite observations?
- Resolutions: What is the spatial and temporal information?
- Upcoming missions: Which are relevant for AQ?
- New information: What are the advances in capability?

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Pollutants: Tropospheric remote sensing

- LEO remote sensing of tropospheric composition is still a relatively new field and great advances have been made in the last decade
- Currently, we observe columns, or partial columns, of several air quality relevant species and make important contributions to the characterization of pollution sources, transport, and variability on weekly to monthly and continental to global scales

UV-VIS: GOME, SCIAMACHY, OMI, GOME-2, MODIS…
  O3, NO2, HCHO, SO2, BrO, aerosol + ….
NIR: SCIAMACHY, MOPITT, MODIS
  CO, CH4, aerosol +….
TIR: MOPITT, AIRS, TES, IASI
  CO, O3, CH4, HNO3+ ….

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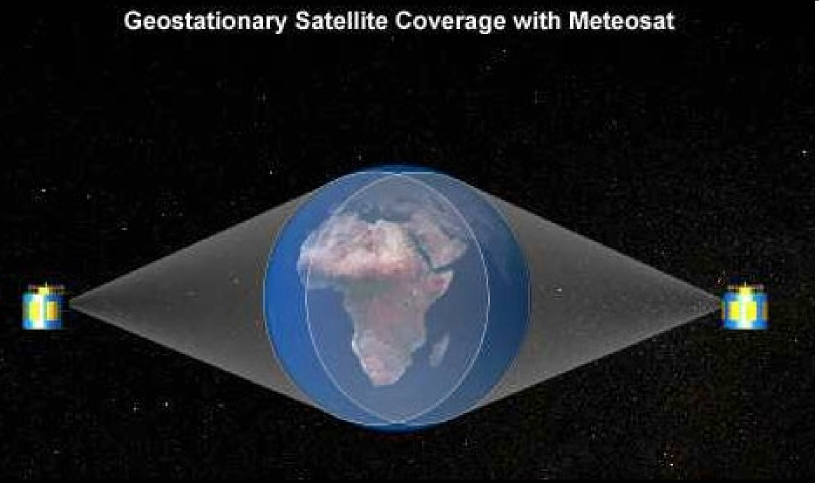
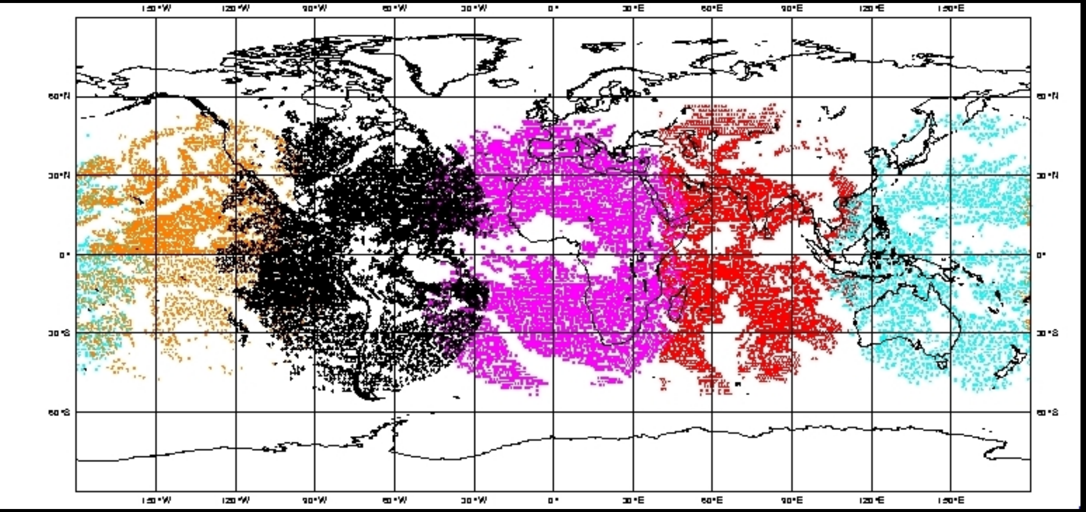
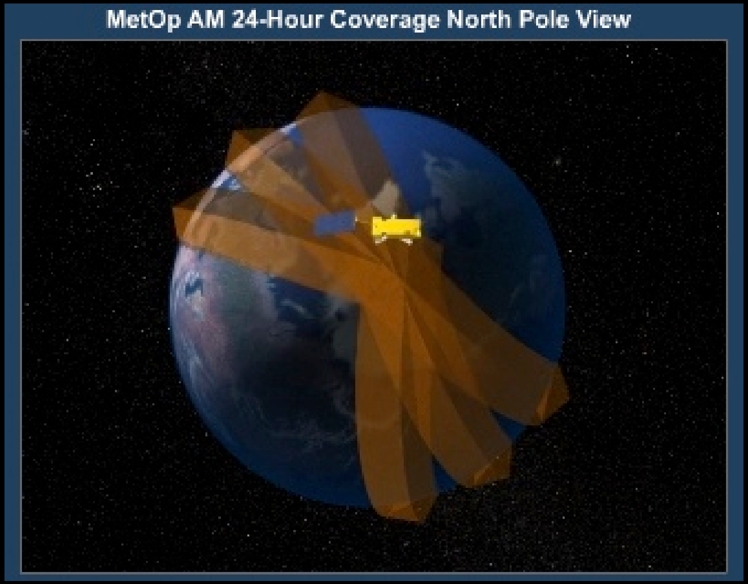
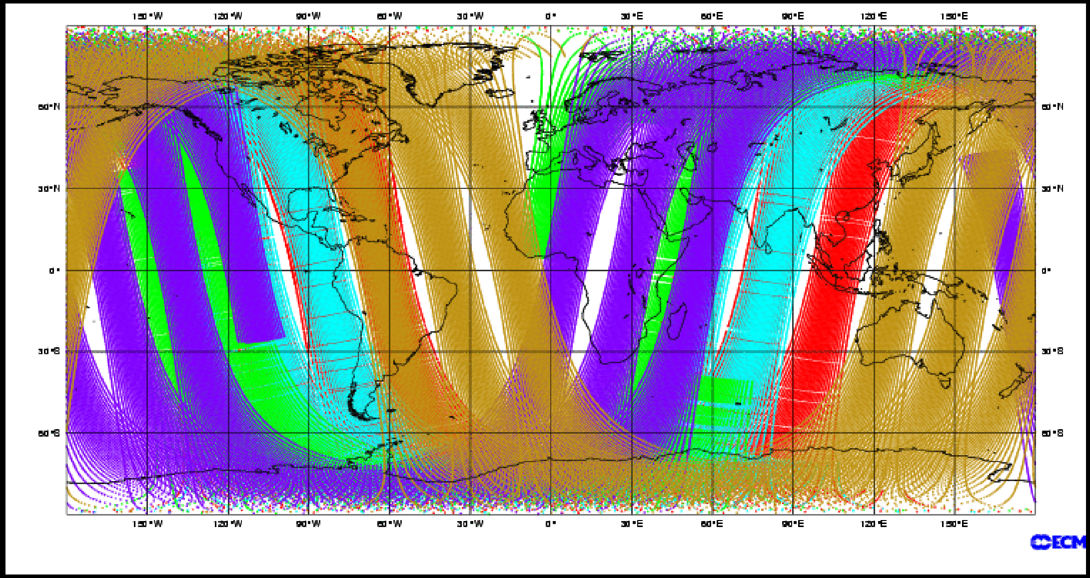
Viewing geometry: LEO and GEO



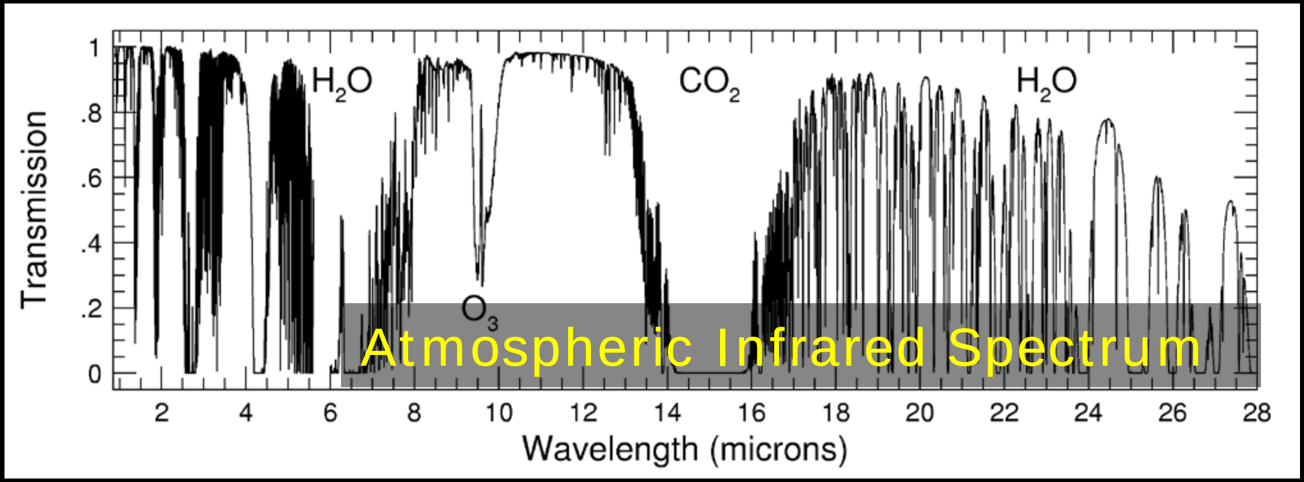


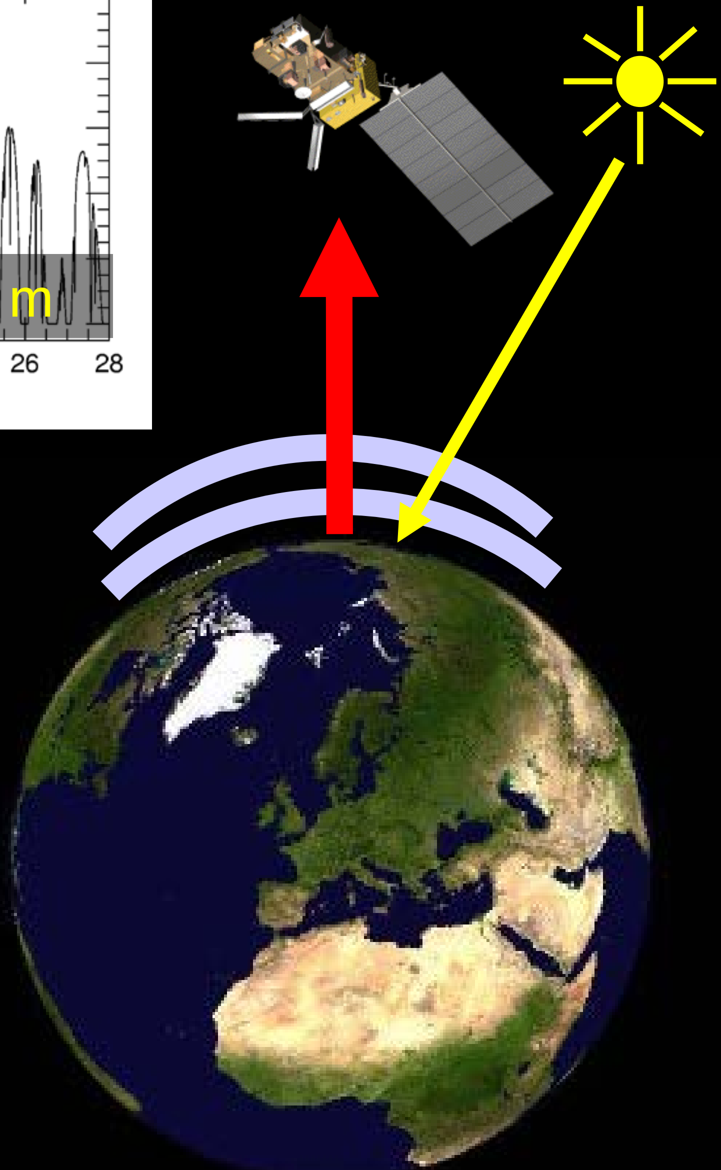




Courtesy Cathy Clerbaux, CNRS

Viewing geometry: Nadir remote sensing





- Reflected radiation from the Sun, and thermal emission from the Earth surface and atmosphere, pass through the atmosphere en route to the satellite sensor
- Absorption, emission and scattering radiative processes determine the top-of-atmosphere radiance
- The sensor samples this radiance with particular characteristics

Courtesy Cathy Clerbaux, CNRS

Retrievals: The basic process

What we want and what is new:

For required atmospheric parameter $\mathbf{x}$

New Observations $\mathbf{y}_{obs}, \mathbf{S}_{obs}$

Auxiliary Observations:

- o Met. fields
- o Cloud fields
- o Surface data

What we think we already know:

The Physics of the Measurement:

Forward Model $\mathbf{y}_{mod} = \mathbf{F}(\mathbf{x}_{mod})$

Measurement sensitivity $\mathbf{K} = \dfrac{\partial \mathbf{y}_{mod}}{\partial \mathbf{x}}, \ \mathbf{S}_{mod}$

a priori data $\mathbf{x}_a, \mathbf{S}_a$

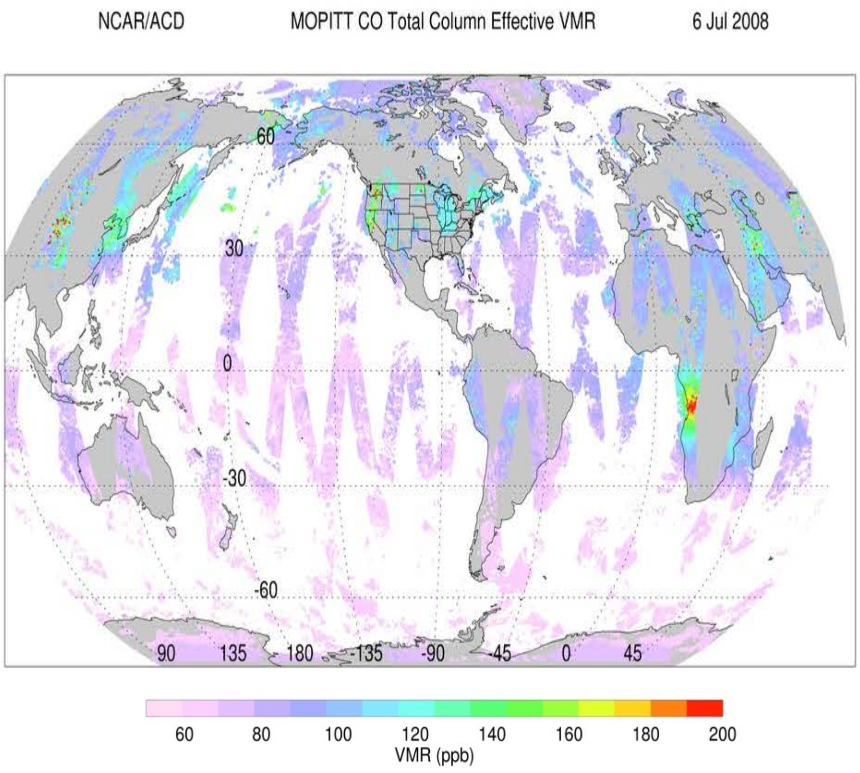
A cost function is minimized to obtain an “optimal estimate” of $\mathbf{x}$ given the new observation & our prior knowledge of the atmosphere

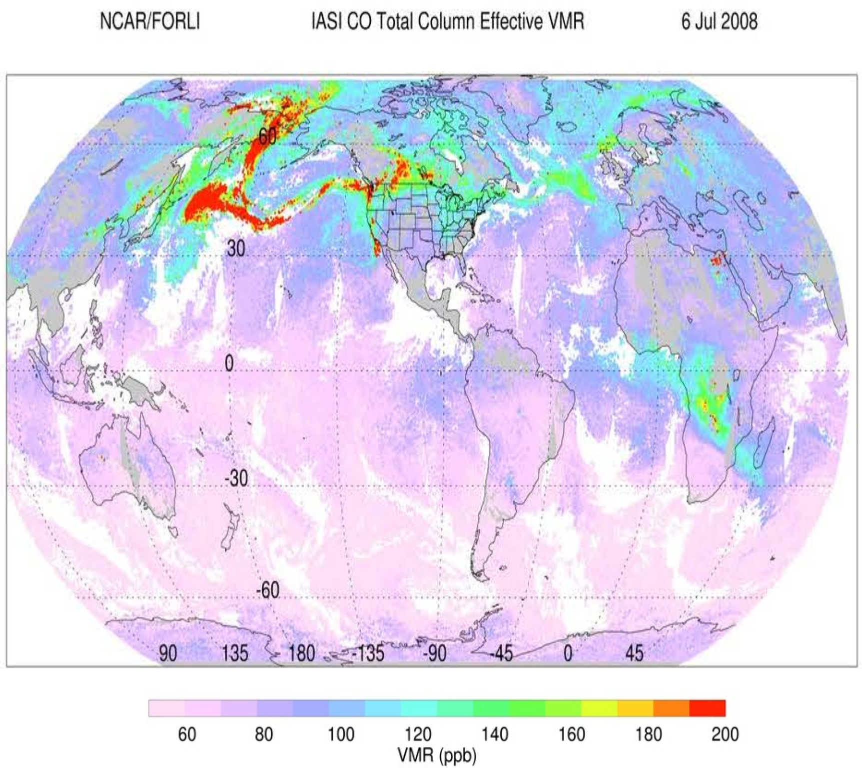
$$\mathbf{x}_{ret}, \ \mathbf{A} = \frac{\partial \mathbf{x}_{ret}}{\partial \mathbf{x}}, \ \mathbf{S}_{ret}$$

Coverage: The LEO orbit

The sensors **MOPITT** and **IASI** both measure tropospheric carbon monoxide using **nadir** geometries and **infrared** bands

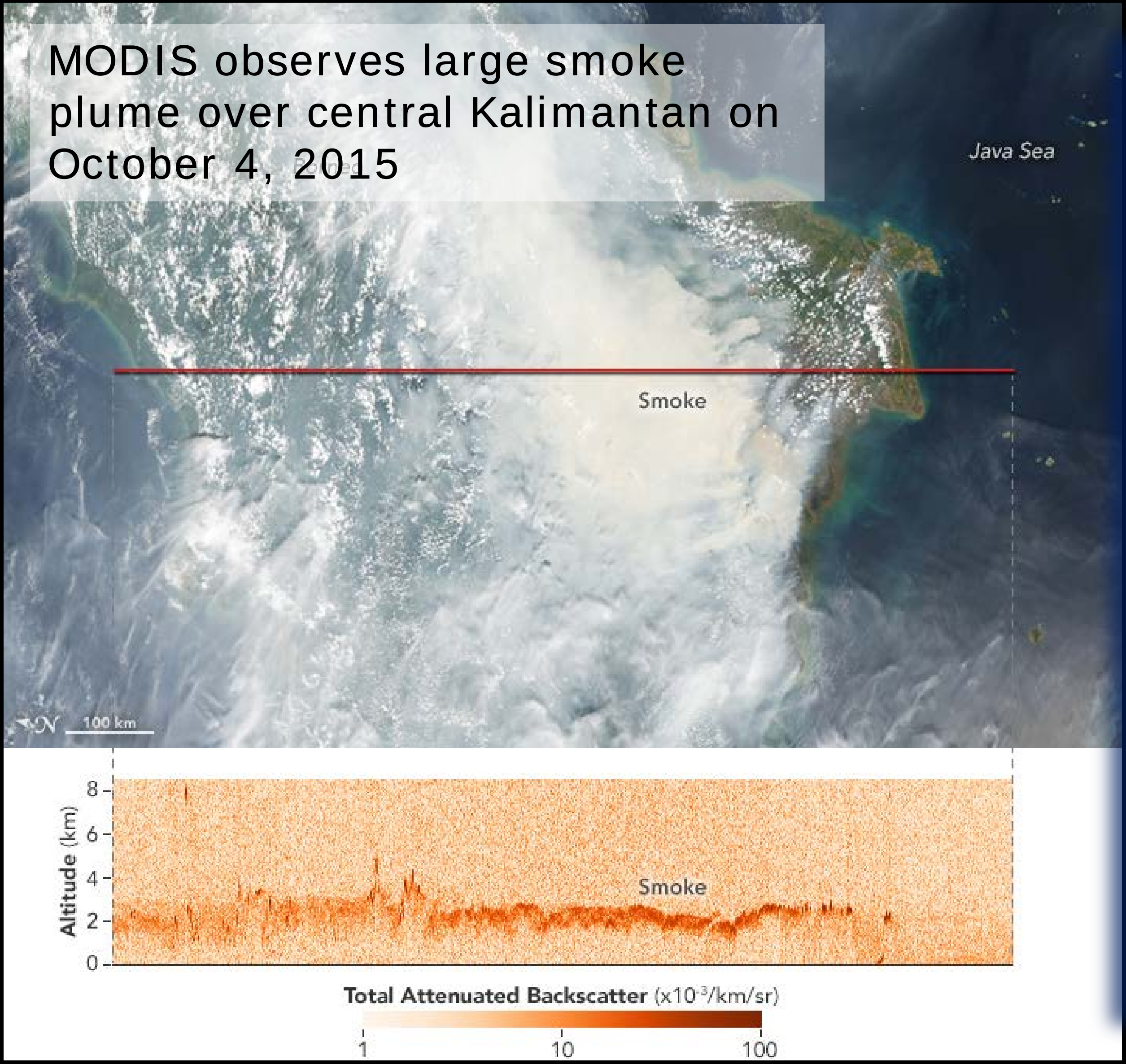
Terra / MOPITT	**MetOp / IASI**
Covers the globe in 3 days (narrow swath)	Covers globe in one day (wide swath)





Courtesy Jerome Barre, NCAR

Vertical information: Active systems

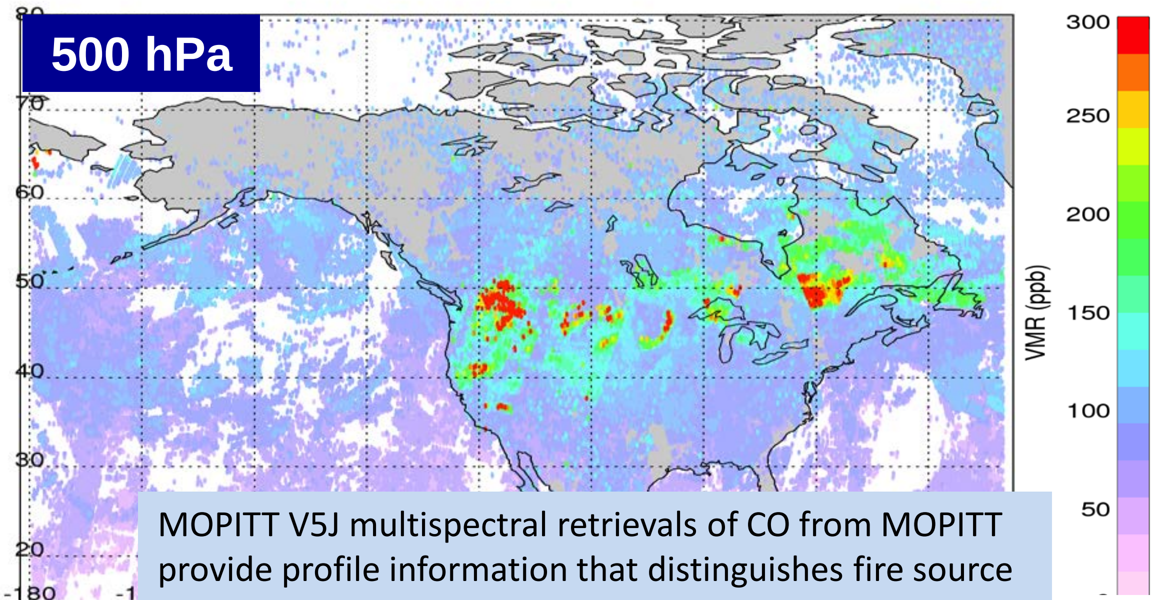


CALIPSO/CALIOP lidar active remote sensing

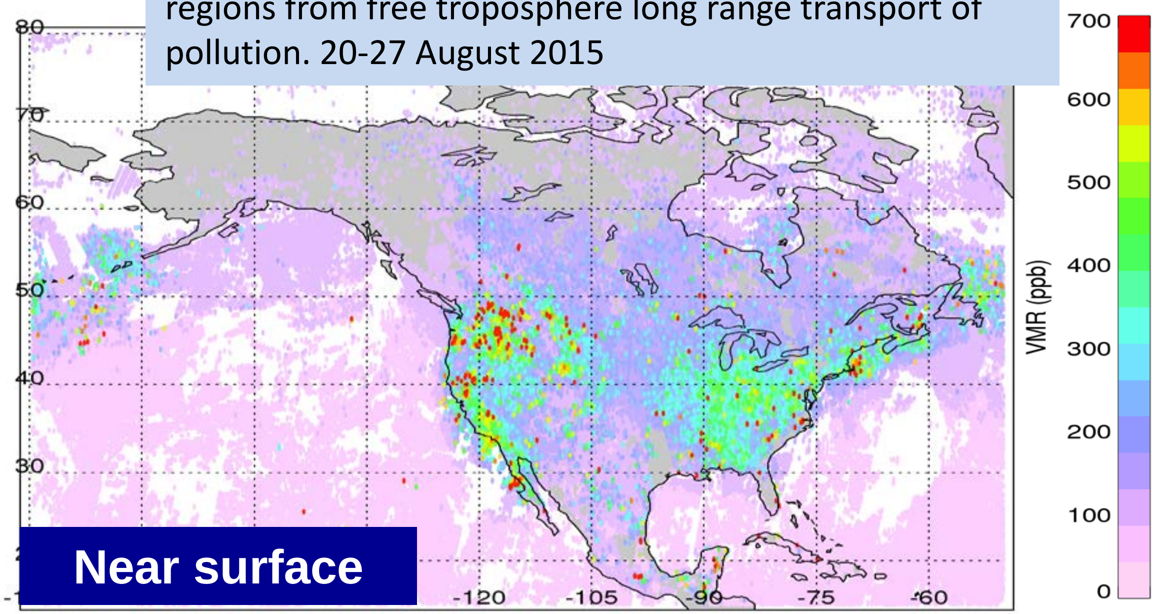
Smoke plume height obtained by reflecting laser pulses off the land surface and determining how long it takes for back-scattered light to return to the sensor

Smoke injection height is important in determining downwind AQ impact

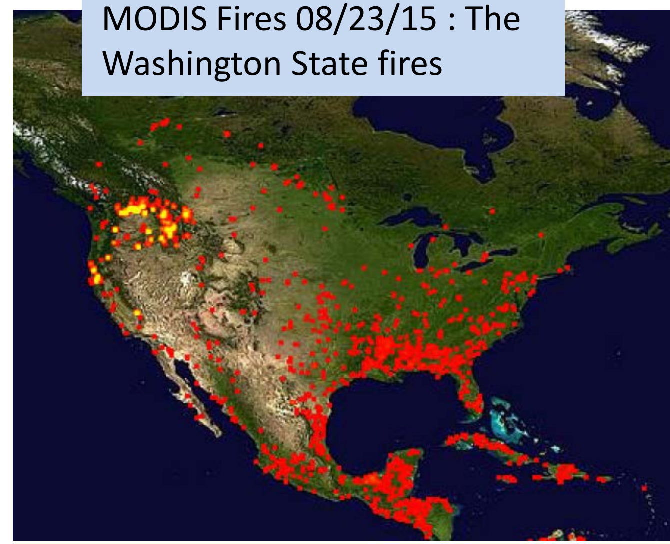
Vertical information: Multispectral retrievals



MOPITT V5J multispectral retrievals of CO from MOPITT provide profile information that distinguishes fire source regions from free troposphere long range transport of pollution. 20-27 August 2015

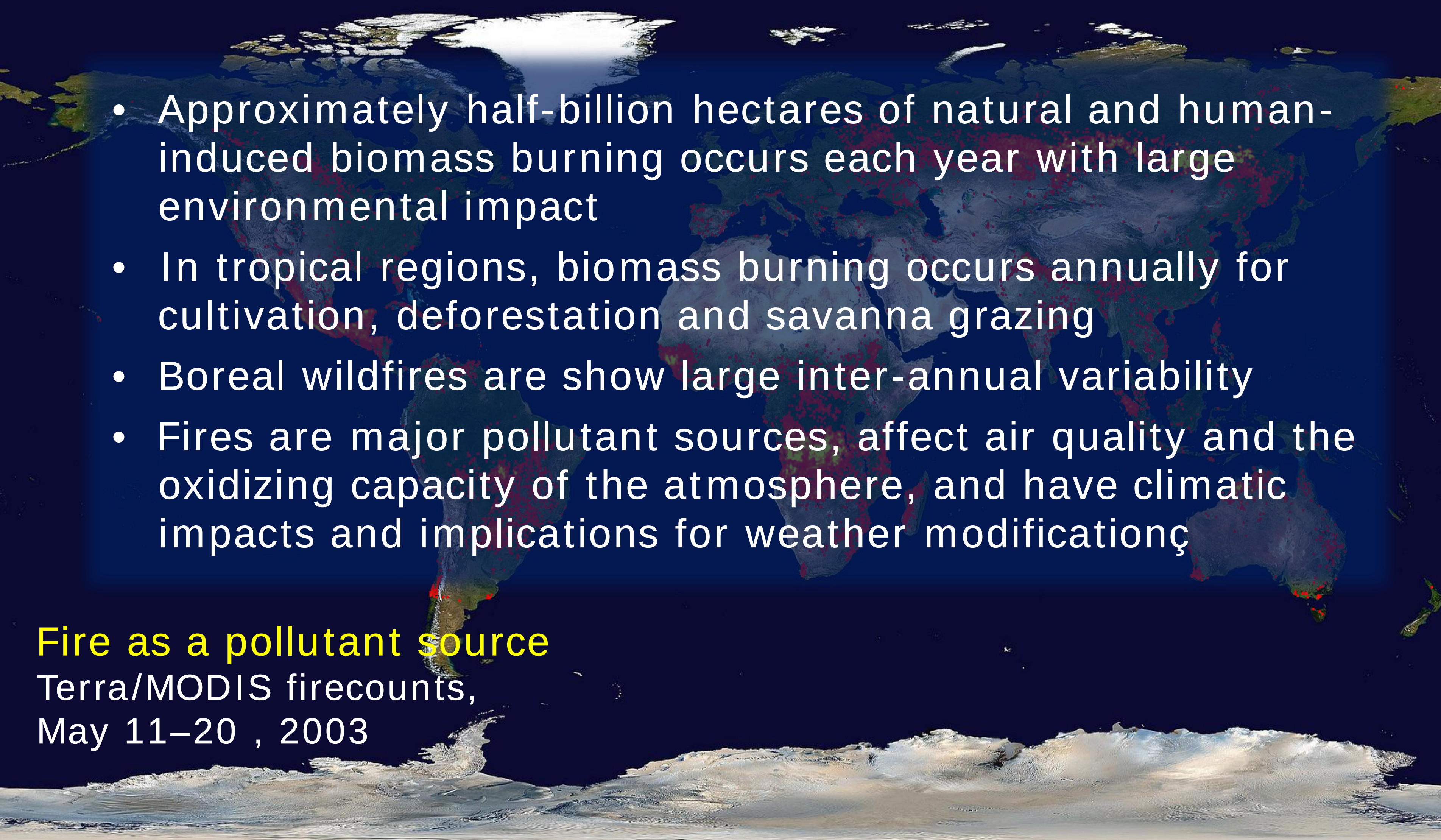


MODIS Fires 08/23/15 : The Washington State fires



Haze over Denver 08/27/15

Source regions: Observations of fires



- Approximately half-billion hectares of natural and human-induced biomass burning occurs each year with large environmental impact
- In tropical regions, biomass burning occurs annually for cultivation, deforestation and savanna grazing
- Boreal wildfires are show large inter-annual variability
- Fires are major pollutant sources, affect air quality and the oxidizing capacity of the atmosphere, and have climatic impacts and implications for weather modificationç

Fire as a pollutant source
Terra/MODIS firecounts,
May 11–20 , 2003

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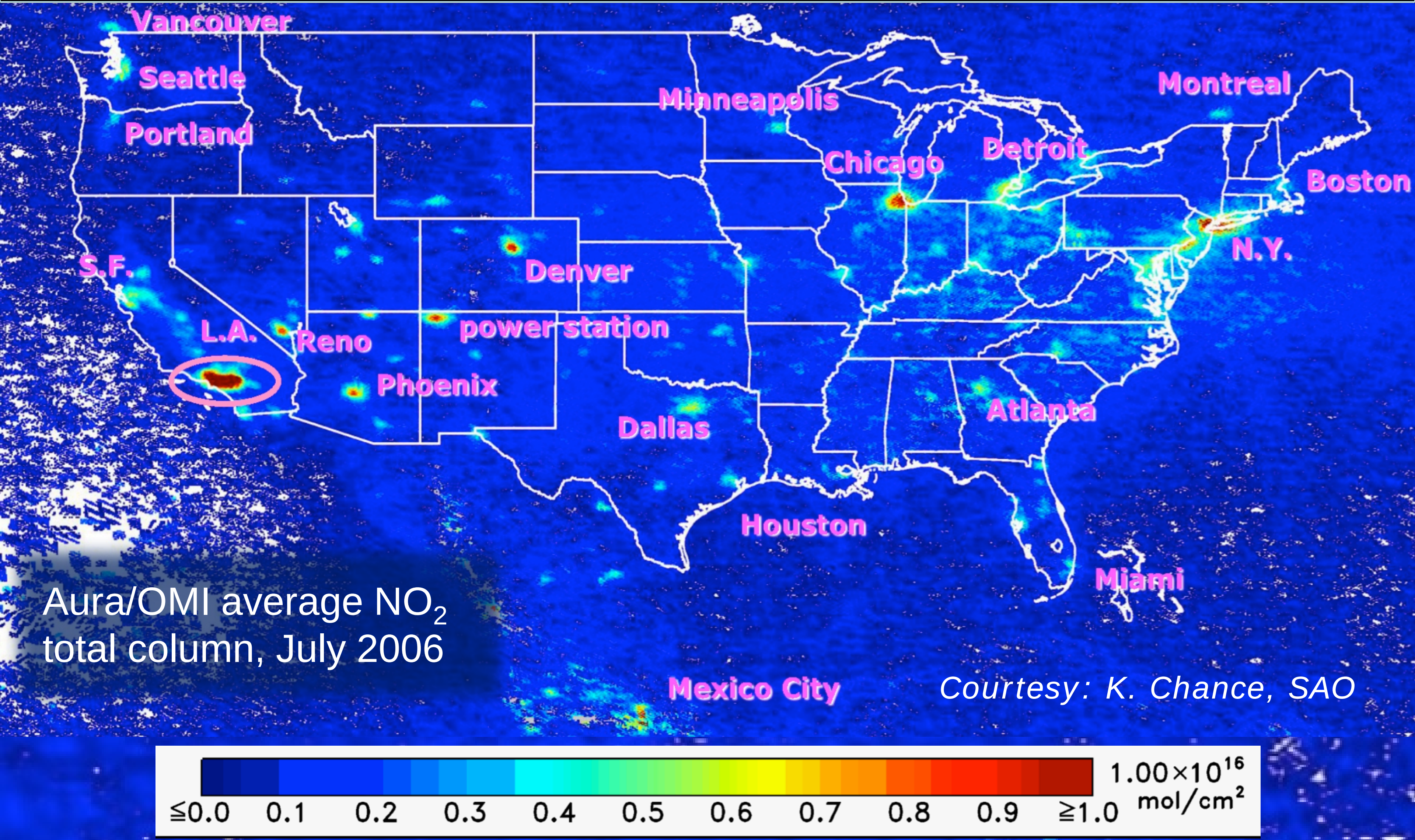
Source regions: Anthropogenic activity



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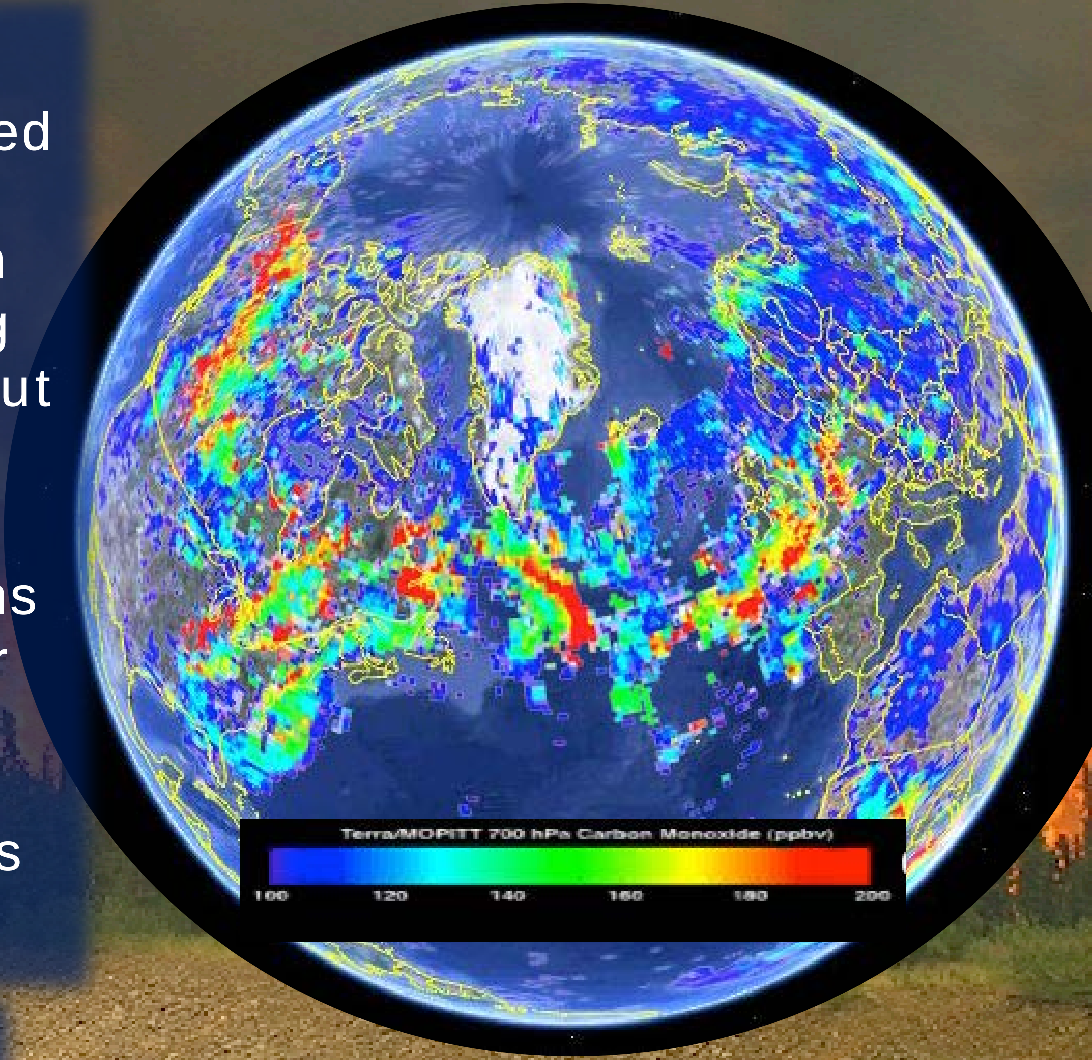
Transport: Long range & intercontinental

- Inverse modeling showed that the Alaska fires emitted about as much CO as did human-related activities in the continental USA during the same time period, about 30 Tg CO June-August
- Because of the wildfires, ground-level concentrations of O3 increased by 25% or more in parts of the northern continental USA and by 10% as far away as Europe



Alaska wildfires, summer 2004

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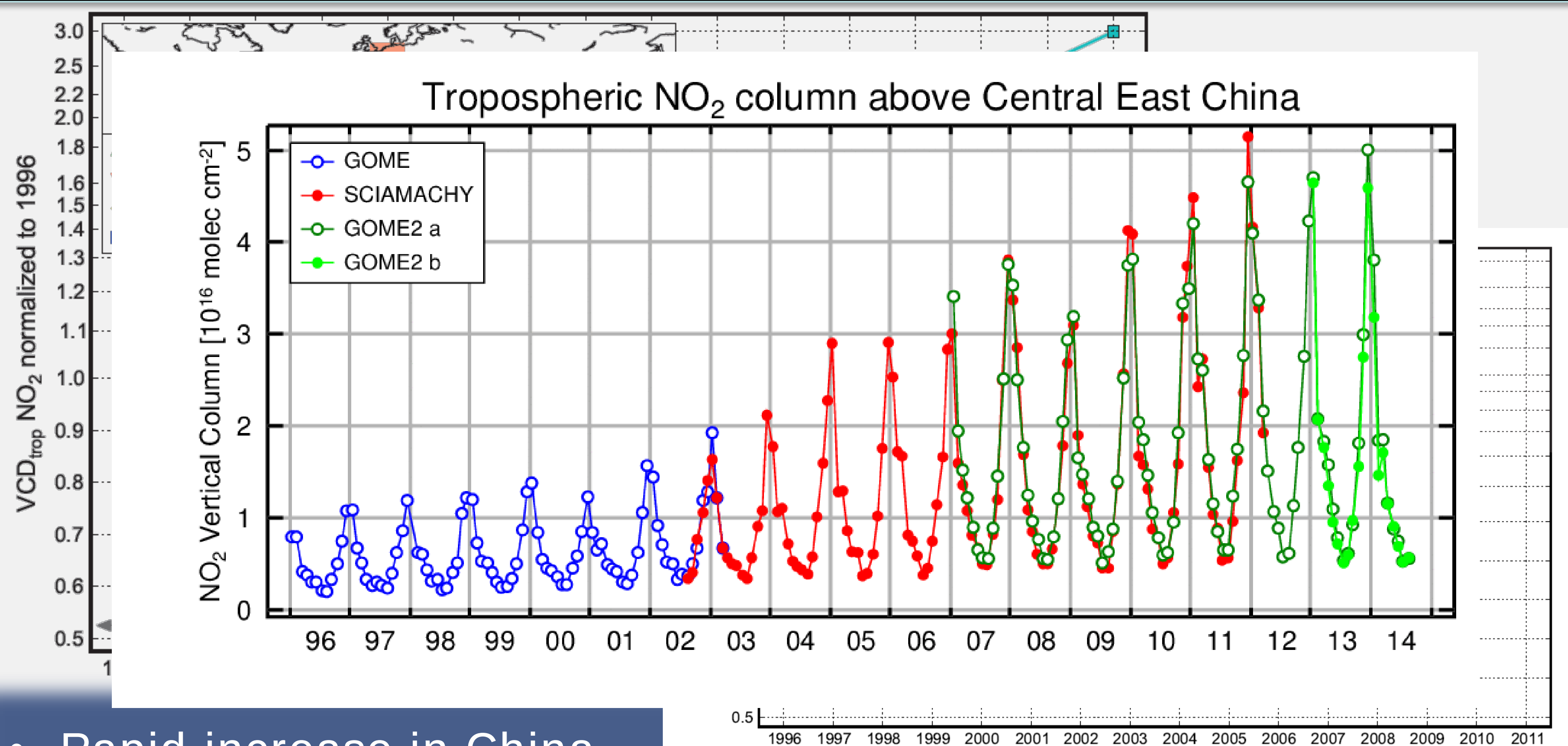
Trends: The change in NO_2 emissions



- Rapid increase in China
- Significant reductions in Europe /USA/Japan
- Qualitative agreement with inventories

Courtesy: A. Richter, U. Bremen;
Hilboll et al., Atmos.Chem.Phys., 2013

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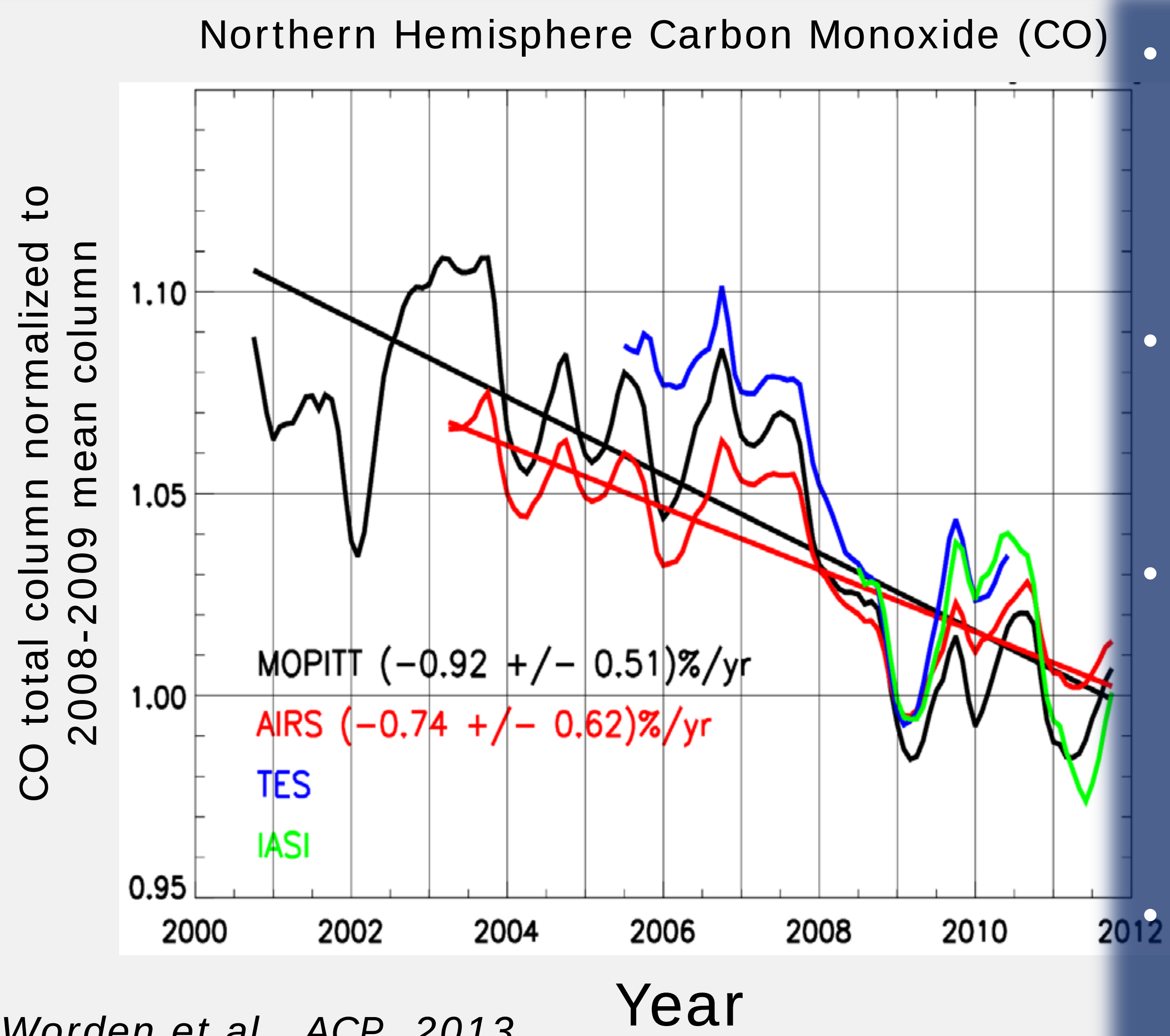
Trends: Decreasing carbon monoxide



Worden et al., ACP, 2013

- Nadir-viewing satellites TIR measurements of total column CO using show consistent inter-annual variability
- Interannual variability driven by fires and the global recession starting late 2008
- Decreasing CO emissions expected in N. America and Europe, but not China, where decreasing CO is also observed
- Longer data records are required to determine significant trends

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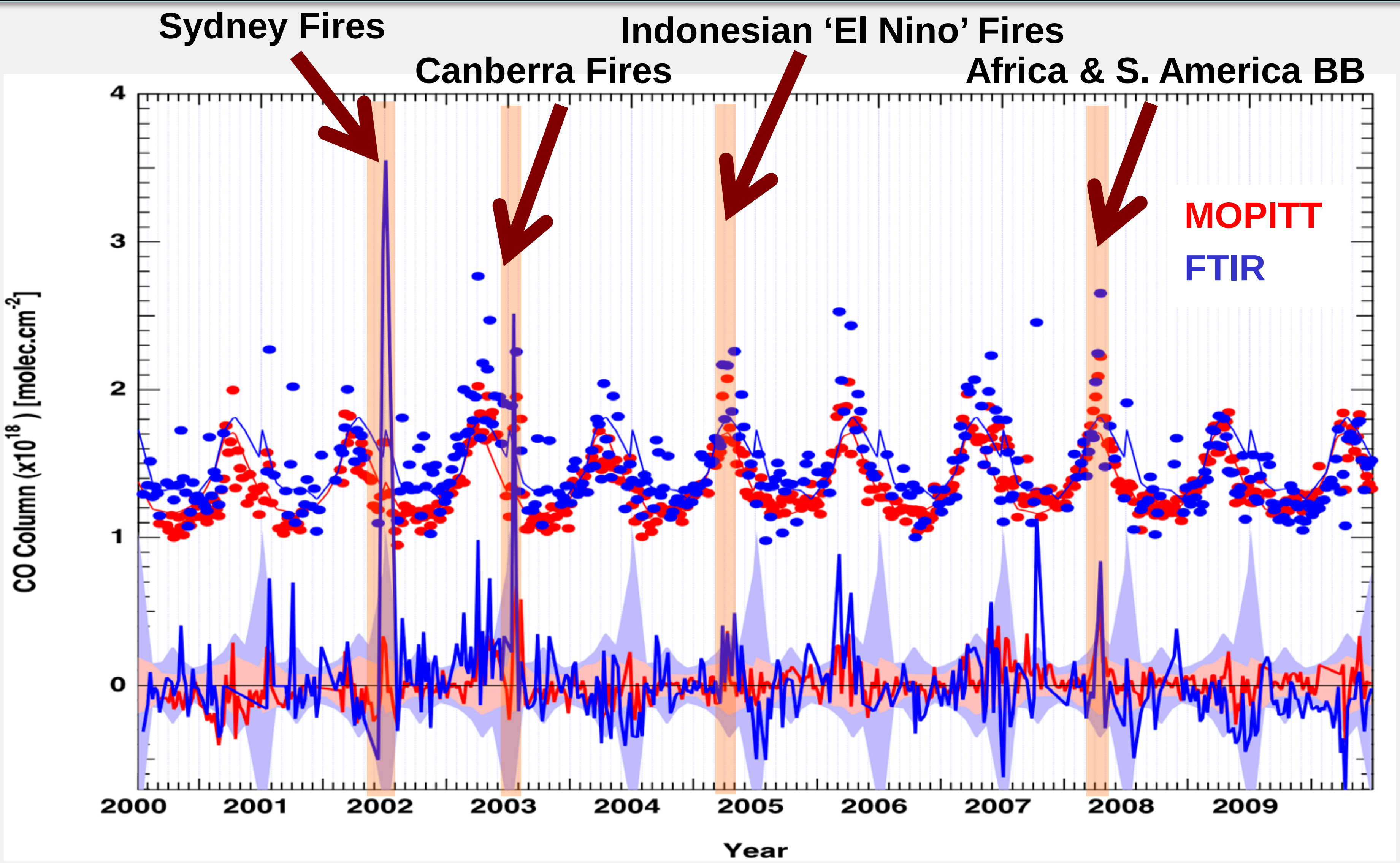
Validation: Intercomparison with other measurements



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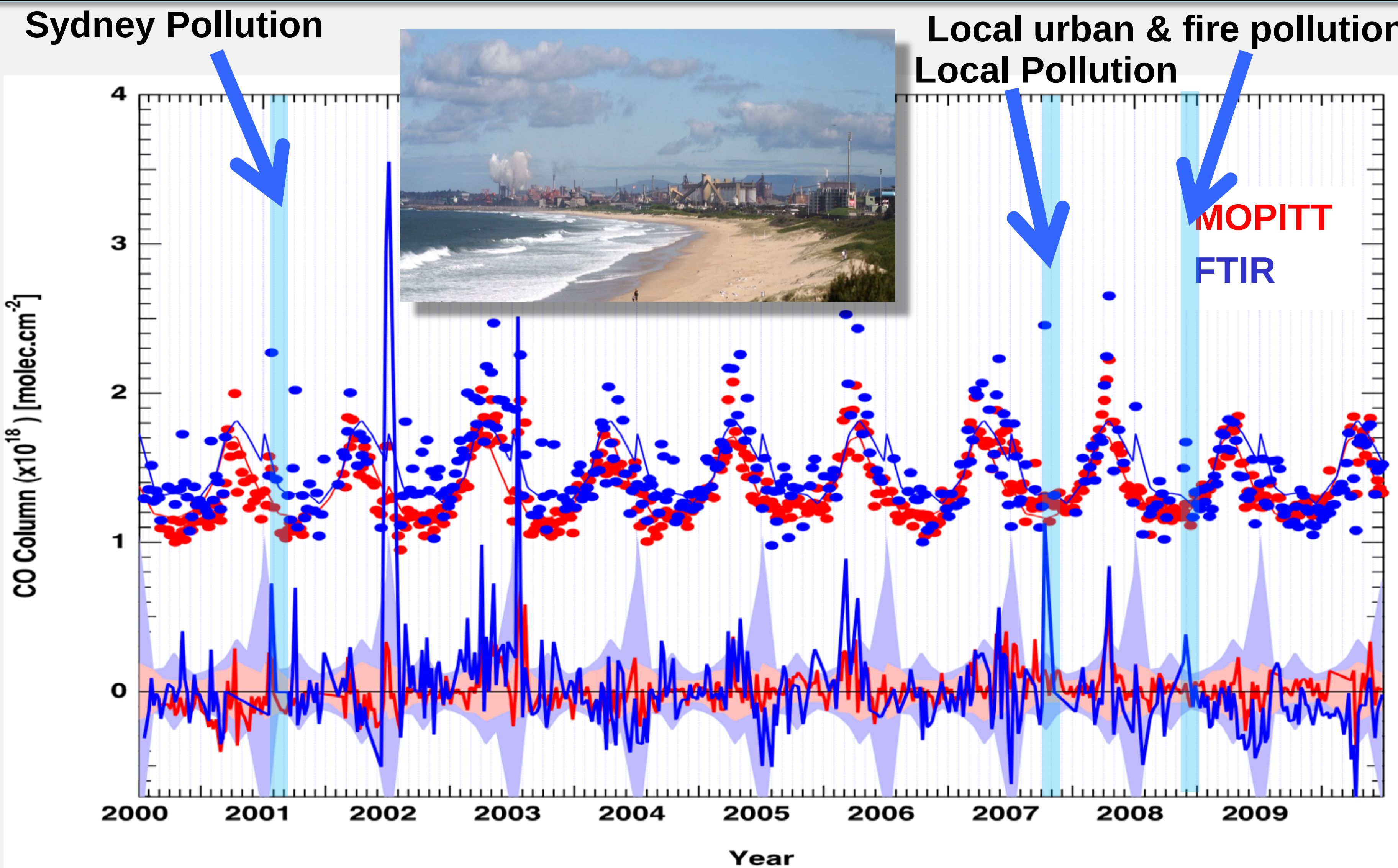
Validation: Intercomparison with other measurements



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Viewing geometry: Why go to GEO?

Current LEO observations provide a long term global view of atmospheric composition, but there are limitations:

- Coverage is global but sparse: At best 1-2 measurements/day
- Orbital constraints, persistent clouds further limit sampling
- Large errors in individual retrievals limit examination of pollutant source and distribution variability on diurnal and regional scales
- Coarse spatial resolution “smears” signatures of local events
- Significant data averaging is common to produce products

A satellite in GEO provides high density hourly observations:

- Sensor can “stare” to obtain sufficient signal
- The hourly measurements with 4 km x 4 km spatial resolution significantly increases the probability of cloud-free observations
- Similar measurement/model scales and continuous near-real-time data delivery will increase uptake of satellite data for regional air quality applications such as chemical weather forecasting and monitoring hazards such as wildfires

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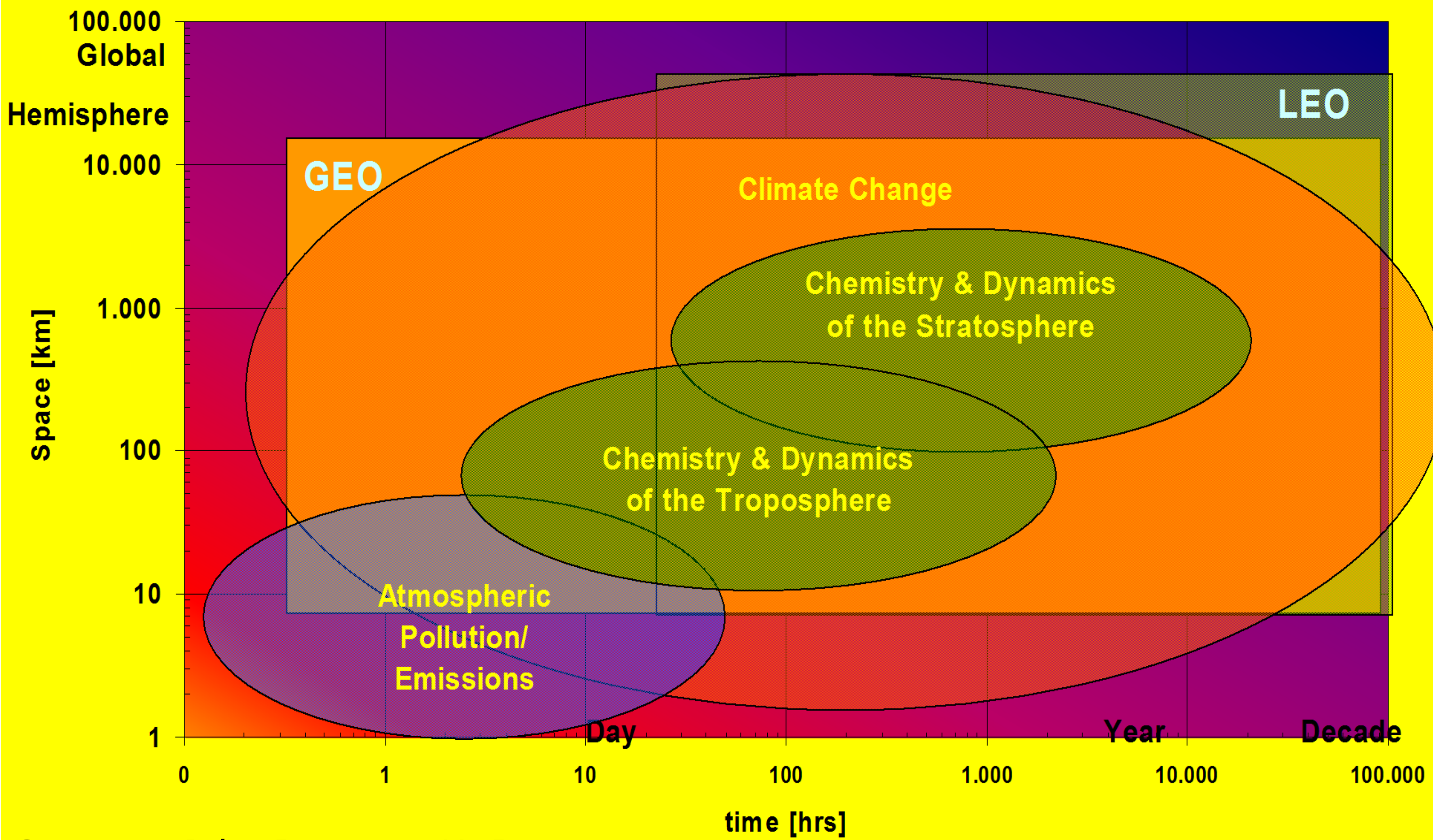
Resolutions: Spatial and temporal scales



Courtesy John Burrows, U. Bremen

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Coverage: The GEO constellation

- Several countries are planning to launch GEO satellites in 2017-2022 timeframe for air quality measurements
- CHRONOS strengthens the GEO air quality constellation with the only CO and CH4 observations for the U.S. component
- Complementary to the UV-vis measurements of TEMPO
- LEO components (IASI, TROPOMI, GOSAT-2) of the constellation provide the global context for CHRONOS observations in assessing regional-to-global emissions and transport

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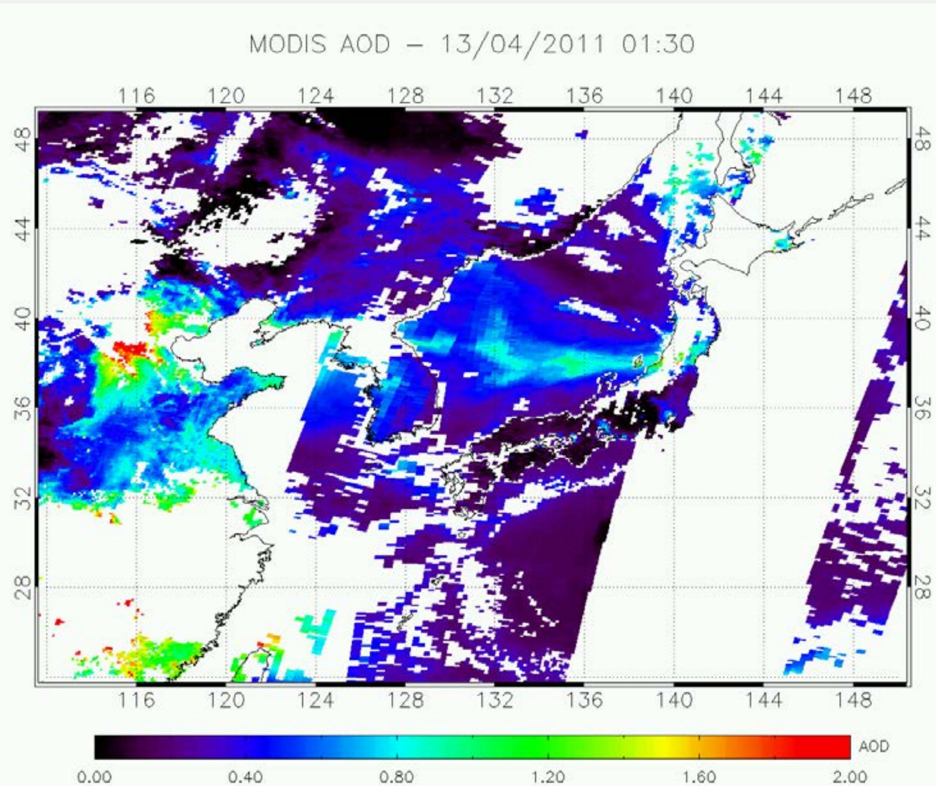
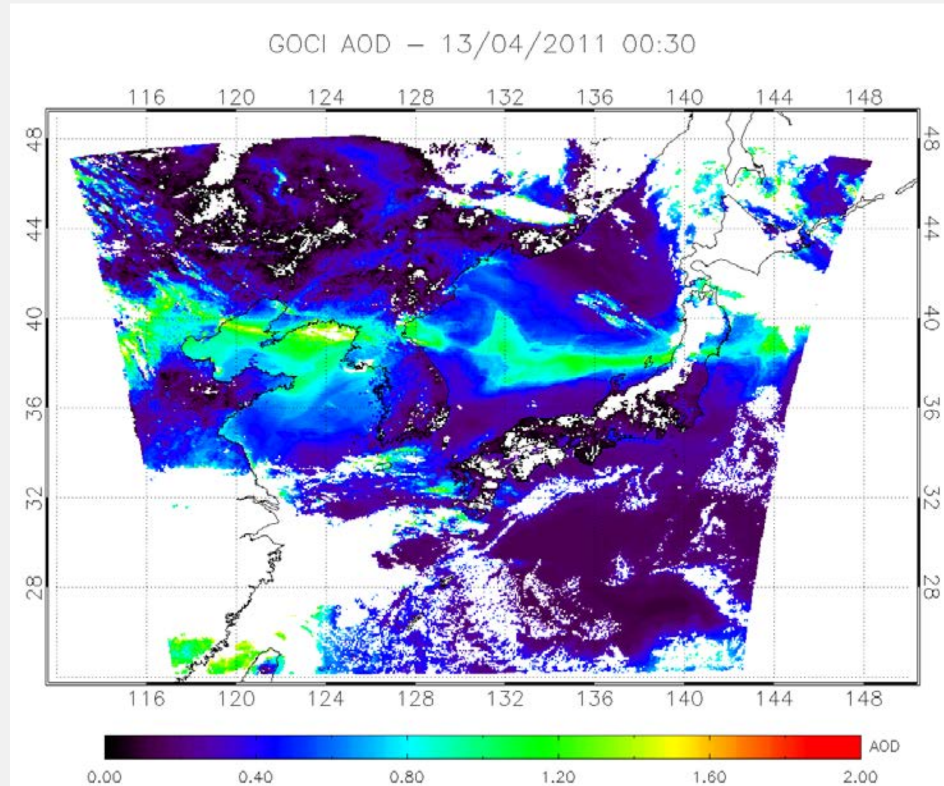
Resolutions: GEO continuous observations

A biomass burning (2011/4/13) example from the GOCI (Geostationary Ocean Color Imager) onboard the Korean COMS satellite launched on June 26, 2010

2 LEOs (2/day)



1 GEO(hourly)



Courtesy Jhoon Kim, Yonsei University

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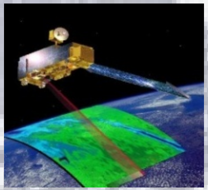
NCAR NSF

Upcoming missions

US/EOS



Terra 1999
MOPITT

Aqua 2002
AIRS

Aura 2004
TES/OMI
+ Calipso/Parasol

EU/EPS

Metop-A 2006
MetOp-B 2012
Metop-C 2017

IASI
GOME-2

US/NPP Suomi

CrIS
OMPS

EU/Sentinel 5 precursor

TROPOMI

EU/EPS-SG-sentinel 5

Metop-SG-A1 | ***IASI-NG***
Metop-SG-A2 | ***UVS***
Metop-SG-A | ***3MI***

+ Geo orbit :
US TEMPO
Korea GEMS
EU/MTG-sentinel 4 : IRS, UVN

Courtesy Cathy Clerbaux, CNRS

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Questions

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