We will act with resolve and urgency to meet our shared multiple objectives of reducing greenhouse gas emissions, improving the global environment, enhancing energy security, and cutting air pollution in conjunction with our vigorous efforts to reduce poverty.

- G-8 Gleneagles Communiqué, July 2005

An energy policy is also an environmental policy is also an economic policy. They are not separate policies.

- William Rosenberg, Harvard University Belfer Center for Science and International Affairs

Space Applications to Monitor the Impact of Energy Generation and Use on Air Pollution

Symposium on Space Applications for Sustainable Development
Graz, Austria: 12-15 September 2006

Lawrence Friedl
NASA Applied Sciences Program
Science Mission Directorate

Extending the societal and economic benefits of Earth science research and technology ...

Space Applications to Monitor the Impact of Energy Generation and Use on Air Pollution

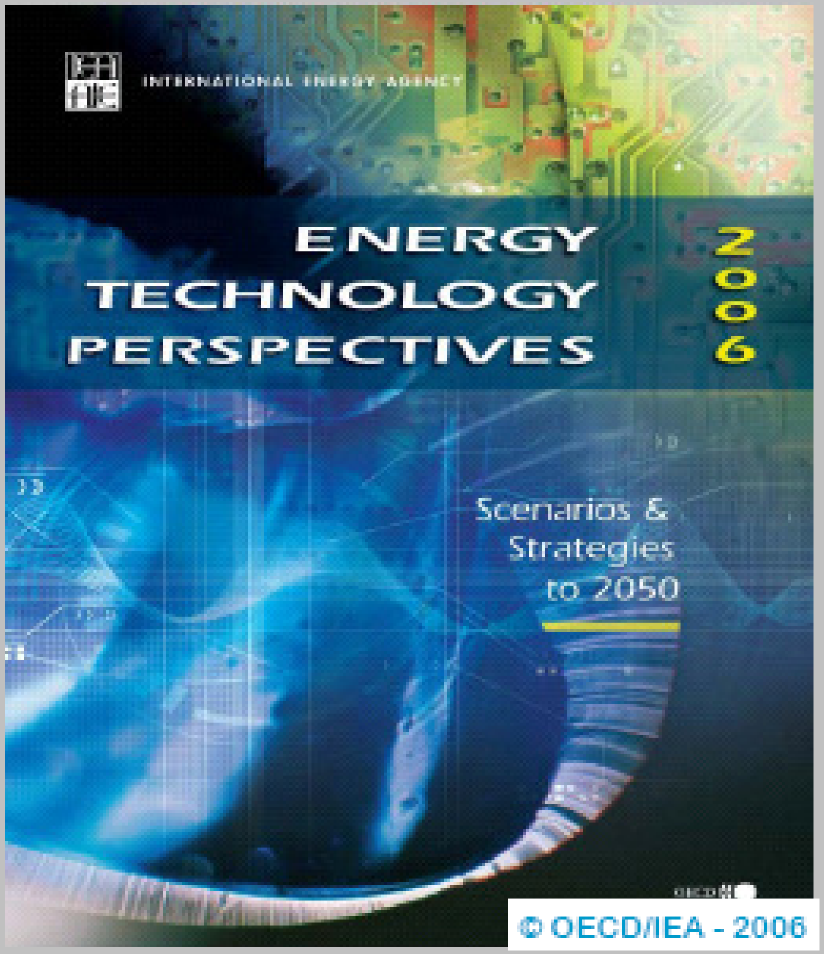
Energy Technology Perspectives and Scenarios

Earth System Science and Observations
- Capabilities to measure and model pollutants
- Energy-related and other pollutants

Applications of Satellite Observations
- Air quality forecasting
- Long-range transport of pollutants
- Carbon management

Earth Science for Society: Opportunities and Data Access
- Group on Earth Observations

Energy Technology Perspectives
Scenarios and Strategies to 2050



INTERNATIONAL ENERGY AGENCY
AGENCE INTERNATIONALE DE L'ENERGIE

Global scenarios to illustrate potentials for different technologies in

- Power Generation
- Transport
- Buildings and Appliances
- Industry

<u>Scenarios analyzed:</u>

- Baseline Scenario
- Accelerated Technologies (ACT) under different policies
- TECH Plus

Energy Technology Perspectives

Scenarios and Strategies to 2050

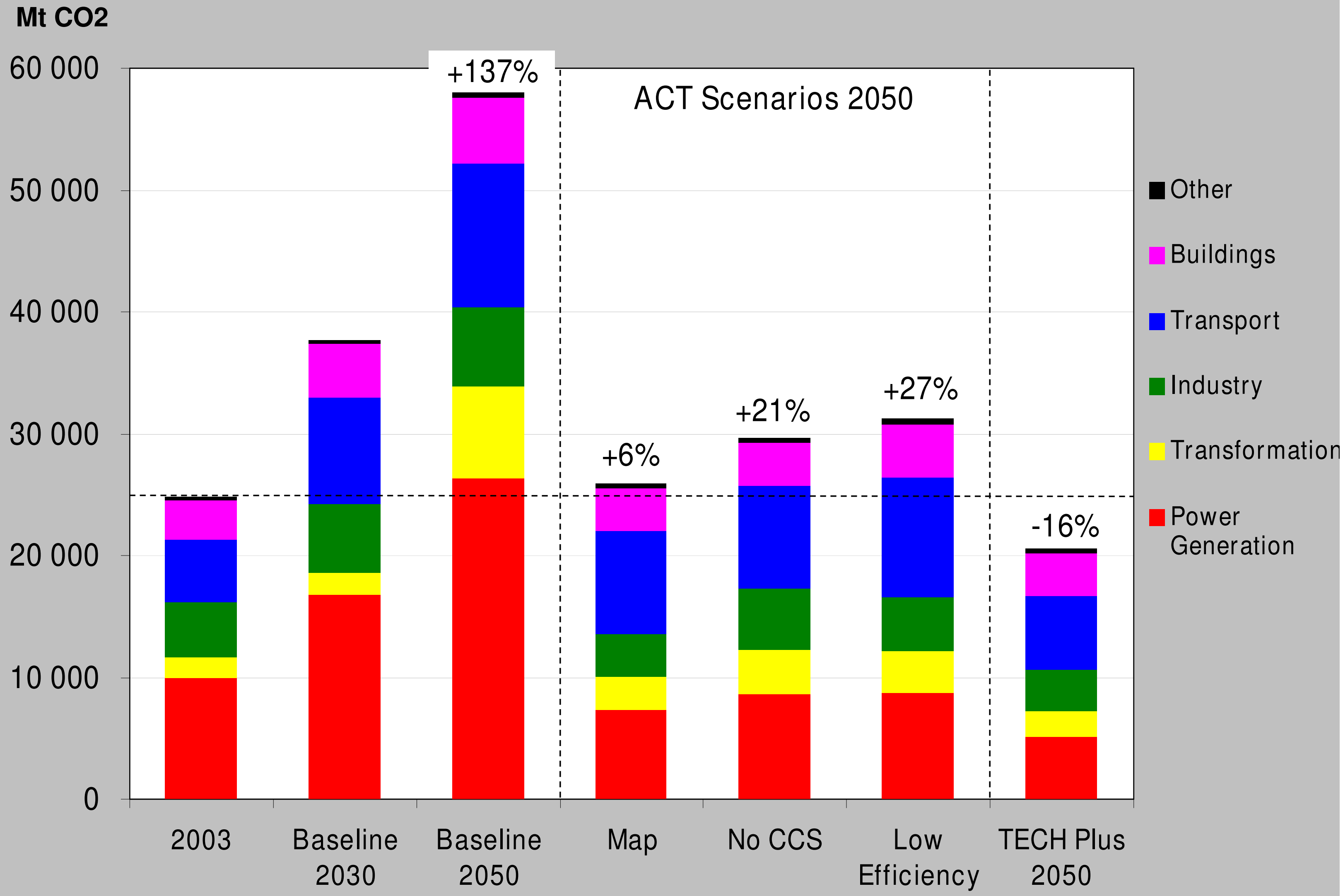
Technology Assumptions

Scenario	Renewables	Nuclear	CCS	H_2 fuel cells	Advanced biofuels	End-use efficiency
ACT Map			Relatively optimistic across all technology areas			2.0 % p.a. global improvement
ACT Low Renewables	Slower cost reductions					
ACT Low Nuclear		Lower public acceptance				
ACT No CCS			No CCS			
ACT Low Efficiency						1.7 % p.a. global improvement
TECH Plus	Stronger cost reductions	Stronger cost reductions & technology improvements		Break-through for FC	Stronger cost reductions & improved feedstock availability	

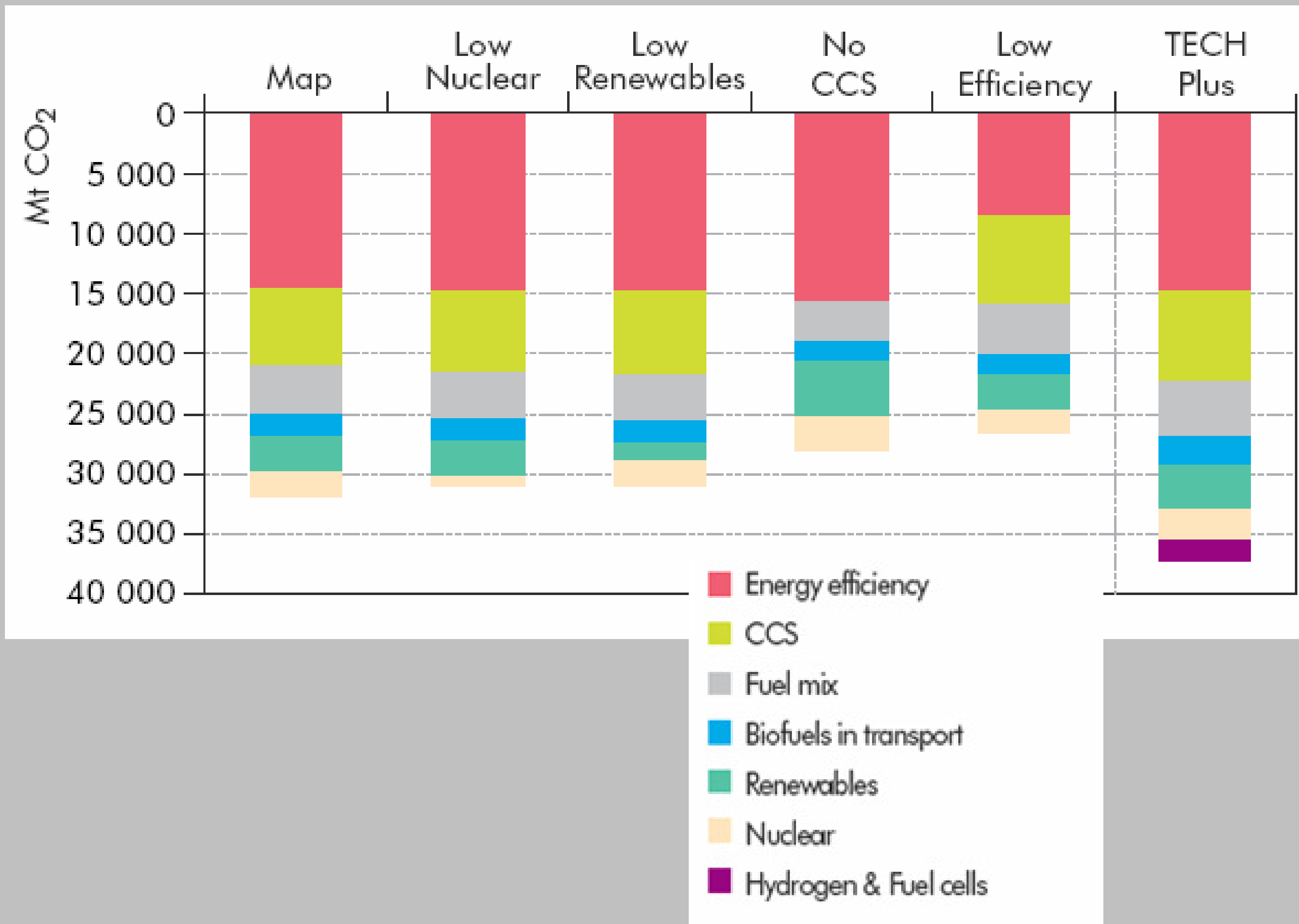
INTERNATIONAL ENERGY AGENCY — AGENCE INTERNATIONALE DE L'ENERGIE

Courtesy of C.Difiglio, US DOE

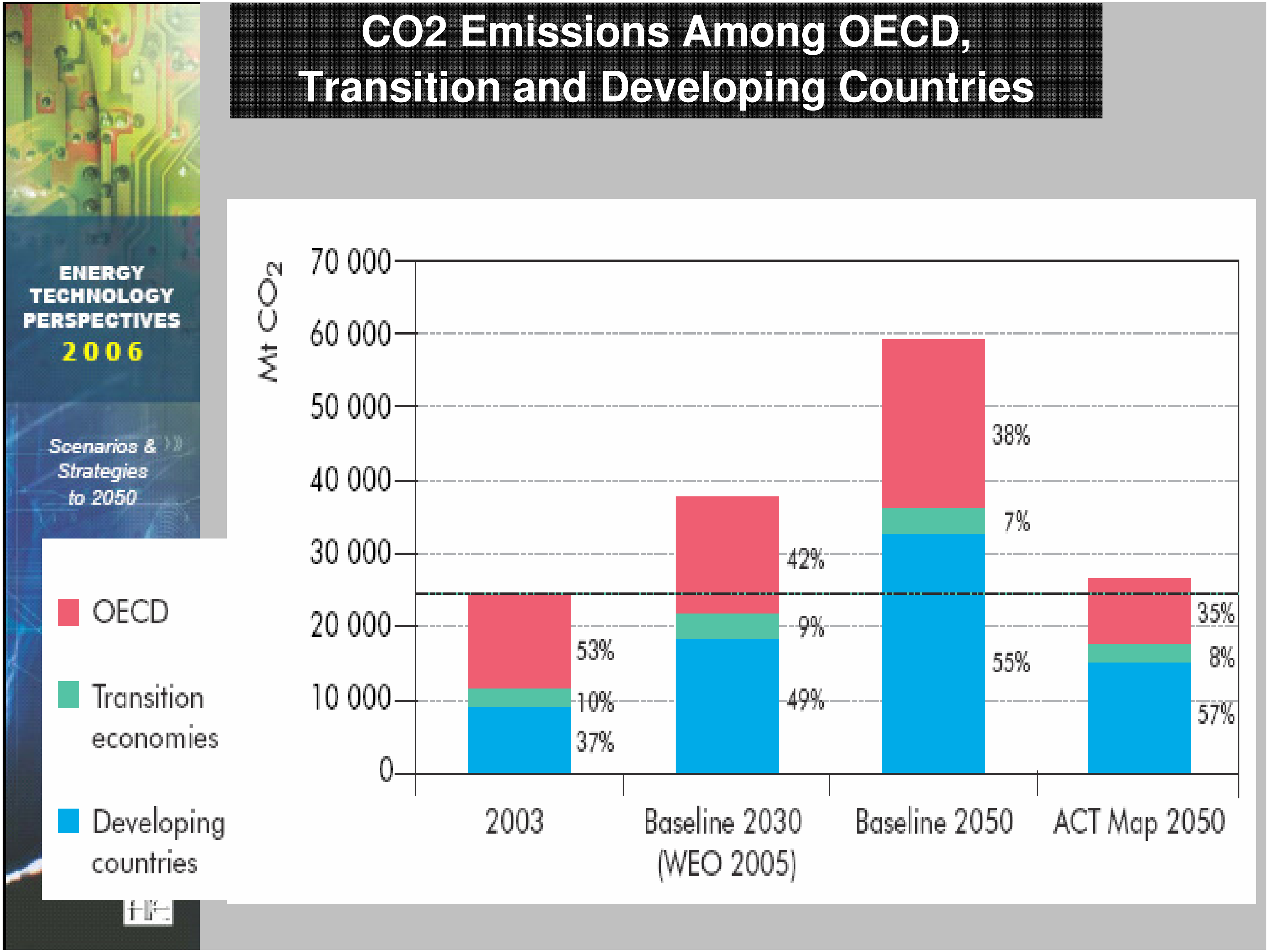
Global CO2 Emissions 2003-2050



Contribution of Technologies to CO2 Emissions *Reduction* - 2050



CO2 Emissions Among OECD, Transition and Developing Countries



Energy Technology Perspectives
Key Findings

Most energy still comes from fossil fuels in 2050, and CO2 emissions can be returned to current levels by 2050..

Power generation can be substantially de-carbonised by 2050; growth in oil and electriicy demand can be halved.

Improving end-use energy efficiency is top priority.

Collaboration among developed & less-developed countries is essential.

Improving end-use energy efficiency is top priority

CCS is key for a sustainable energy future

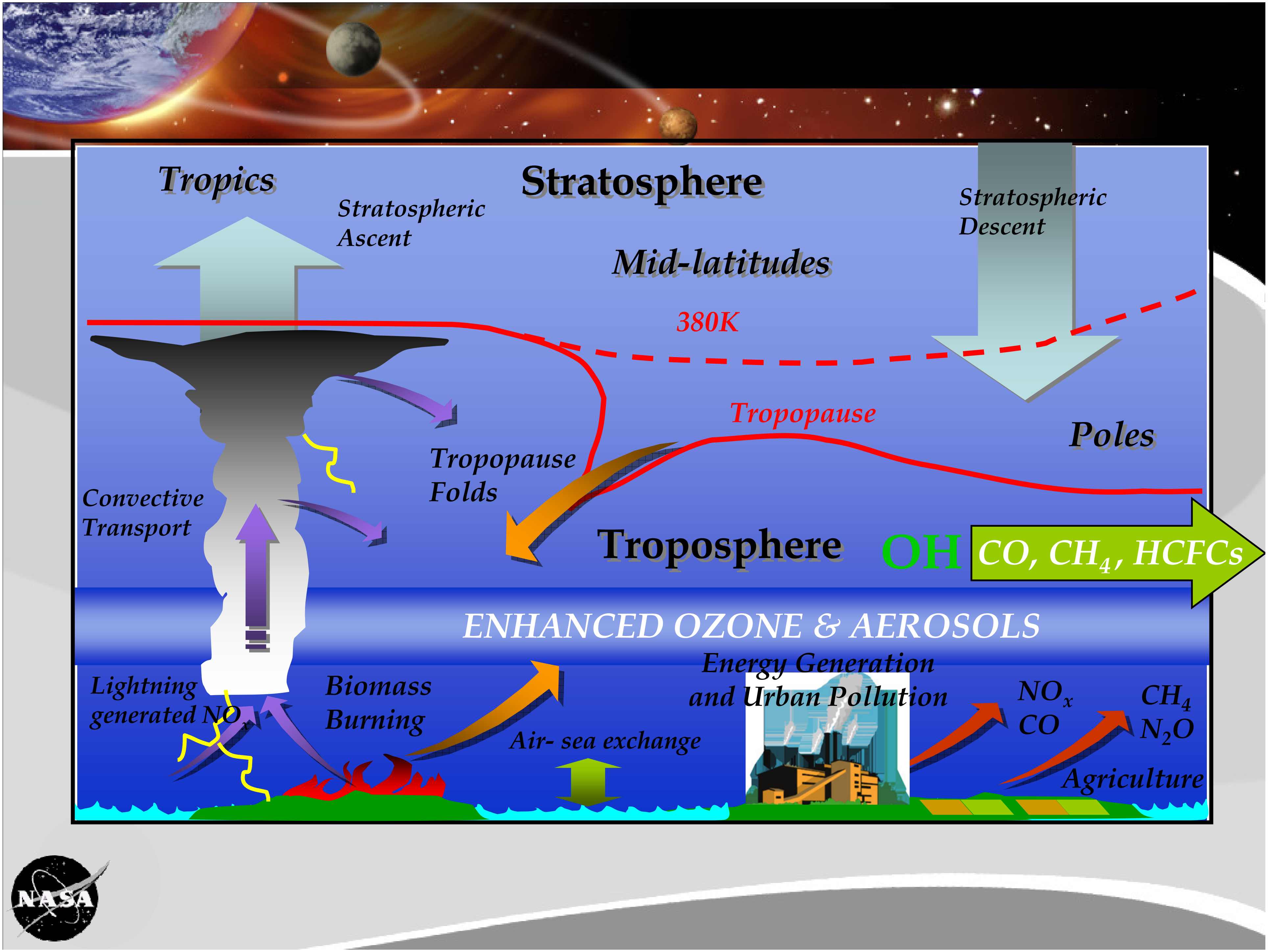
Other important technologies:

- Renewables, including biofuels
- Nuclear
- Efficient use of natural gas and coal

CO2 Storage – Need monitoring to manage risk of releases

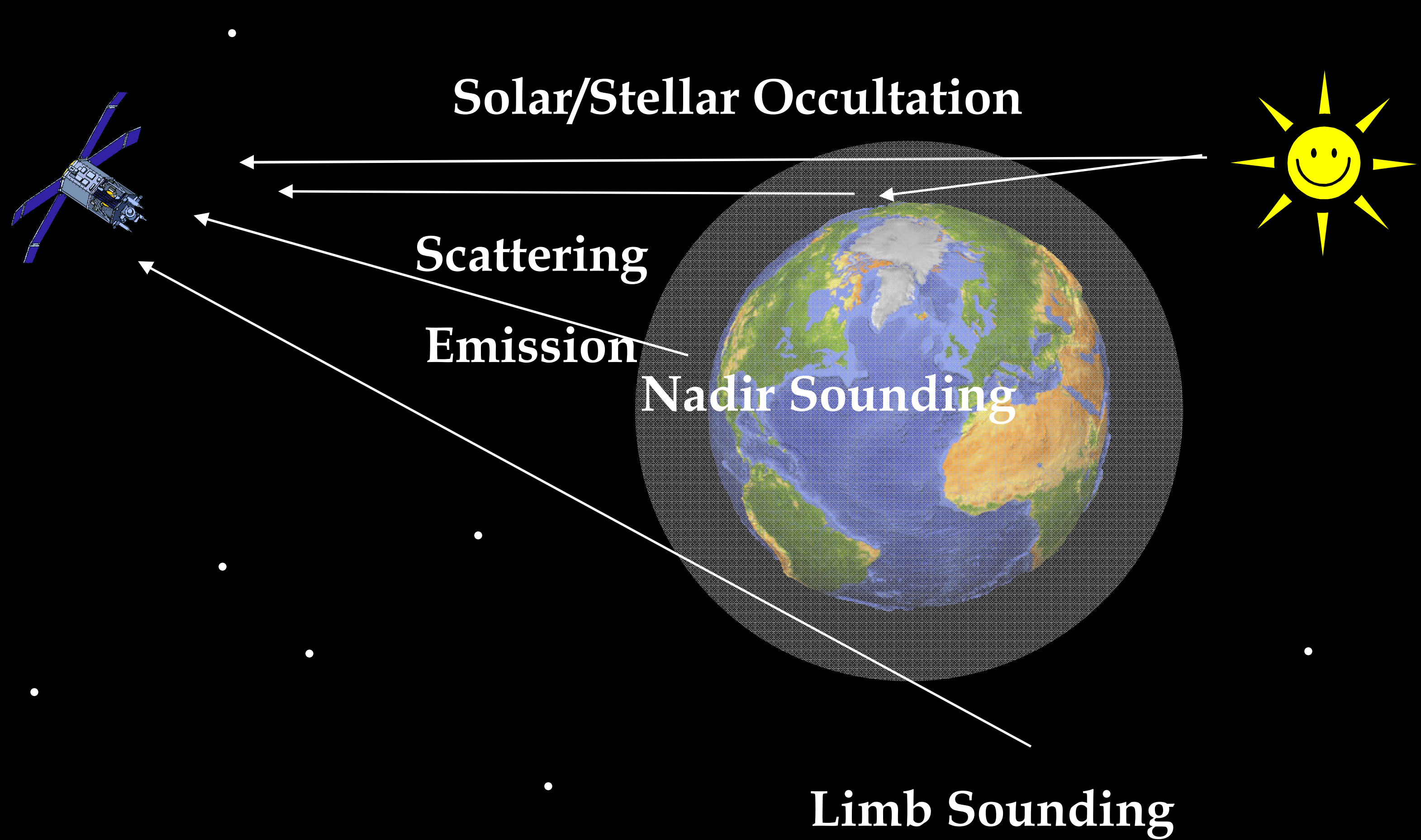
Earth System Science
& Observations

- Satellites & Models
- Energy-related & other pollutants

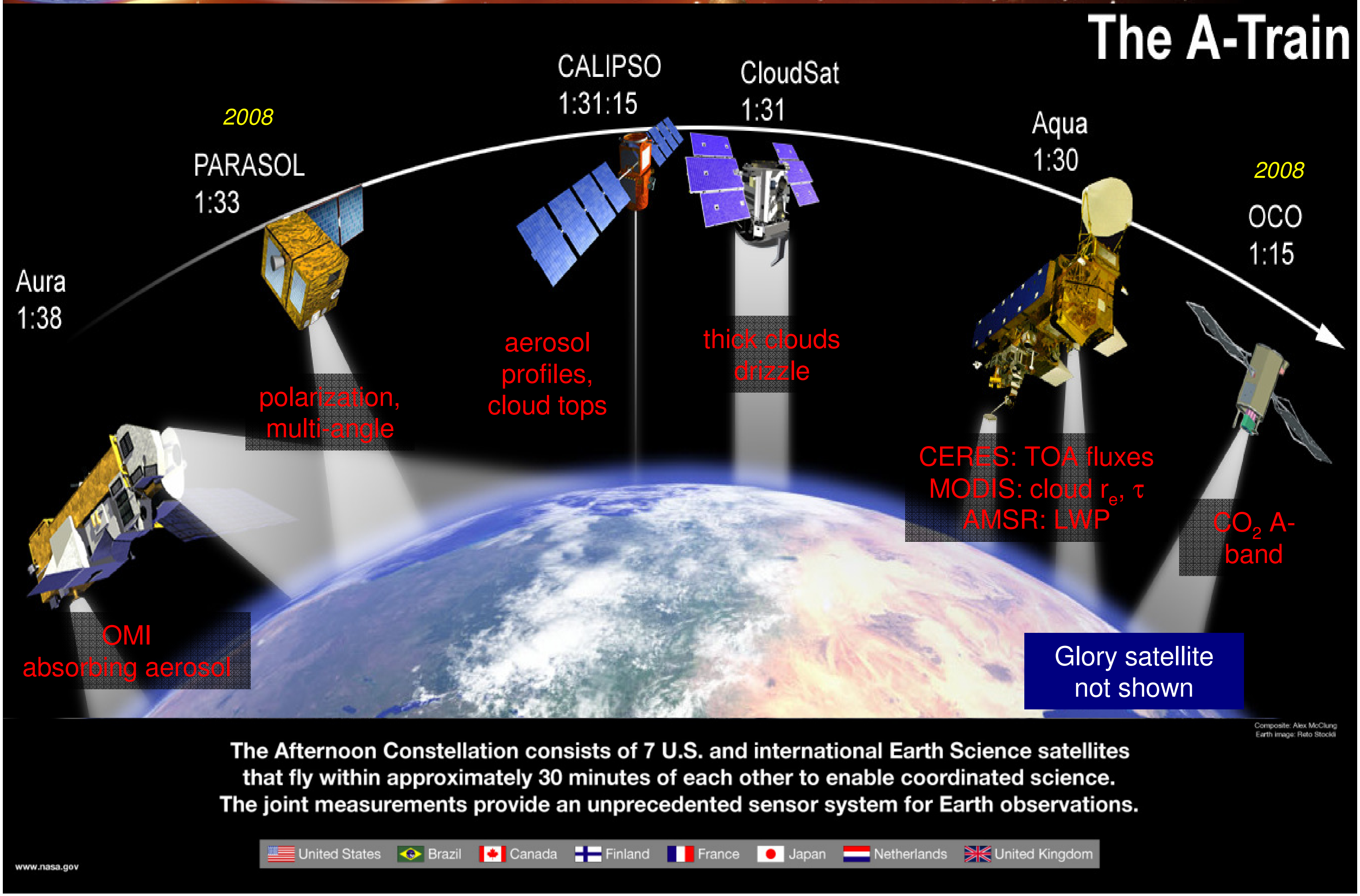

Tropics
Stratosphere
Stratospheric Ascent
Stratospheric Descent
Mid-latitudes
380K
Tropopause
Poles
Tropopause Folds
Convective Transport
Troposphere
OH
CO, CH_4, HCFCs
ENHANCED OZONE & AEROSOLS
Energy Generation and Urban Pollution
Lightning generated NO_x
Biomass Burning
Air- sea exchange
NO_x
CO
CH_4
N_2O
Agriculture

NASA Observing Spacecraft for Earth System Science Research

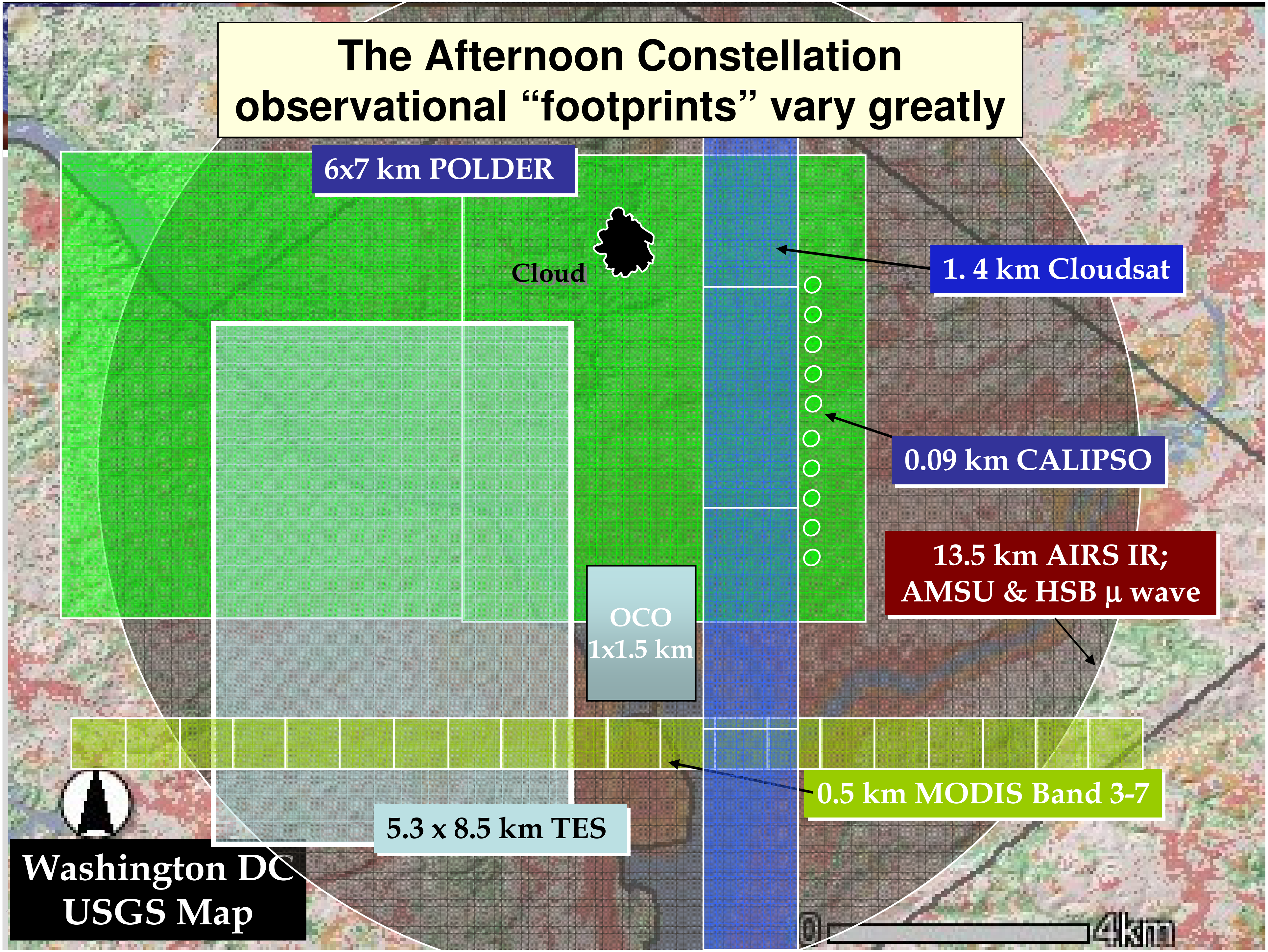
Observing Strategies for Atmospheric Composition



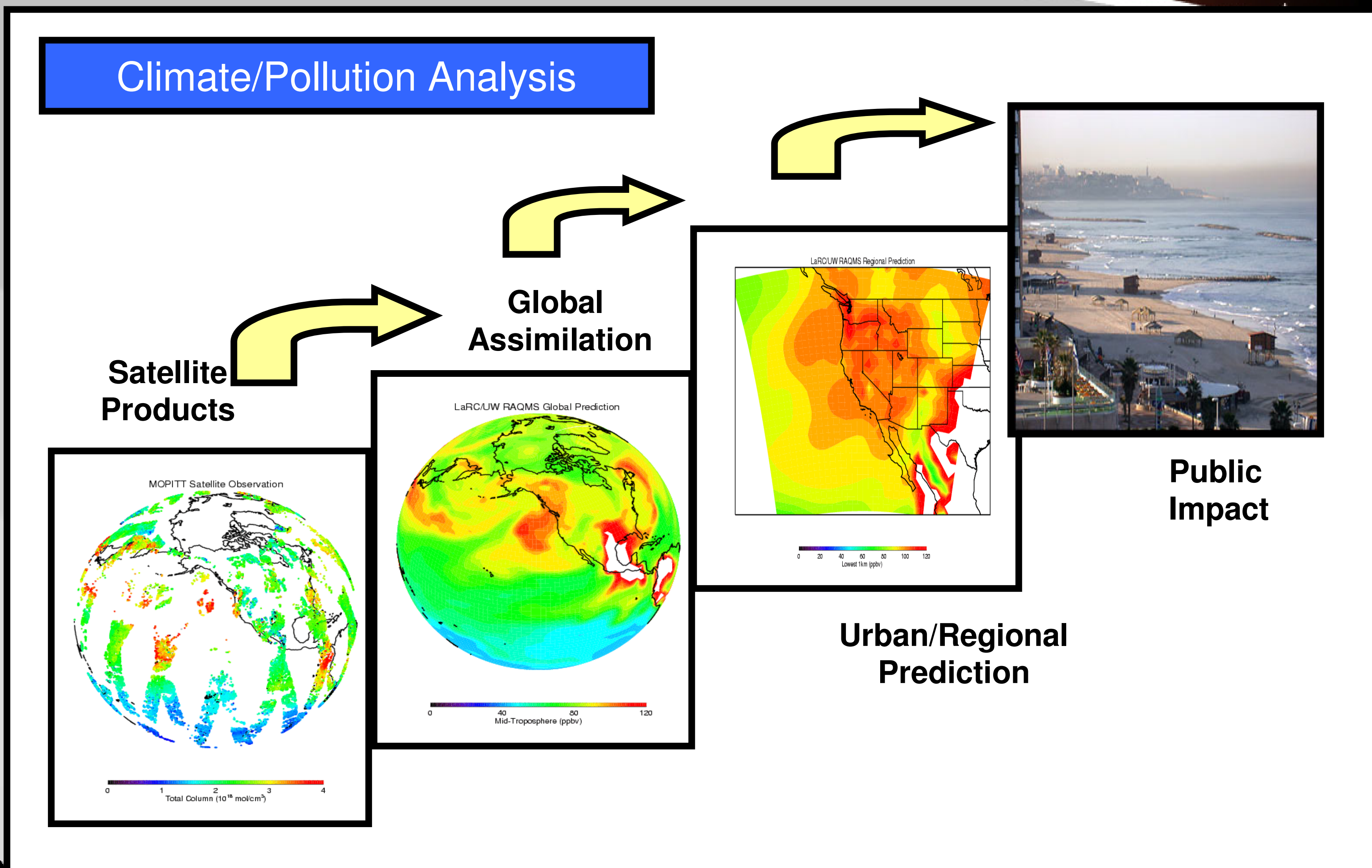
“A-Train” Satellite Systems



The Afternoon Constellation observational "footprints" vary greatly

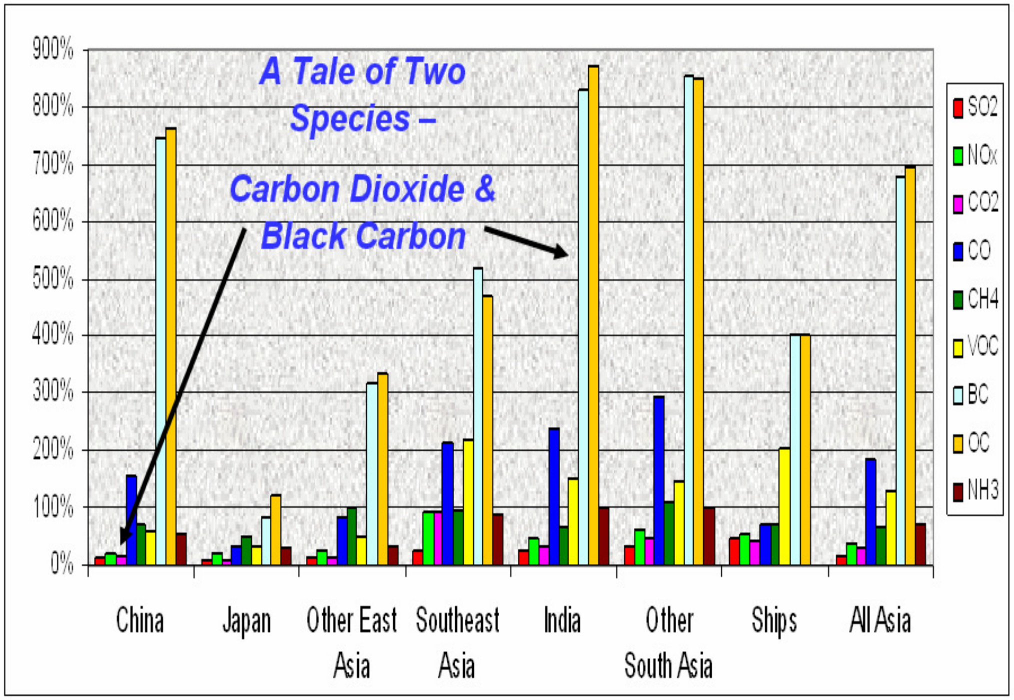


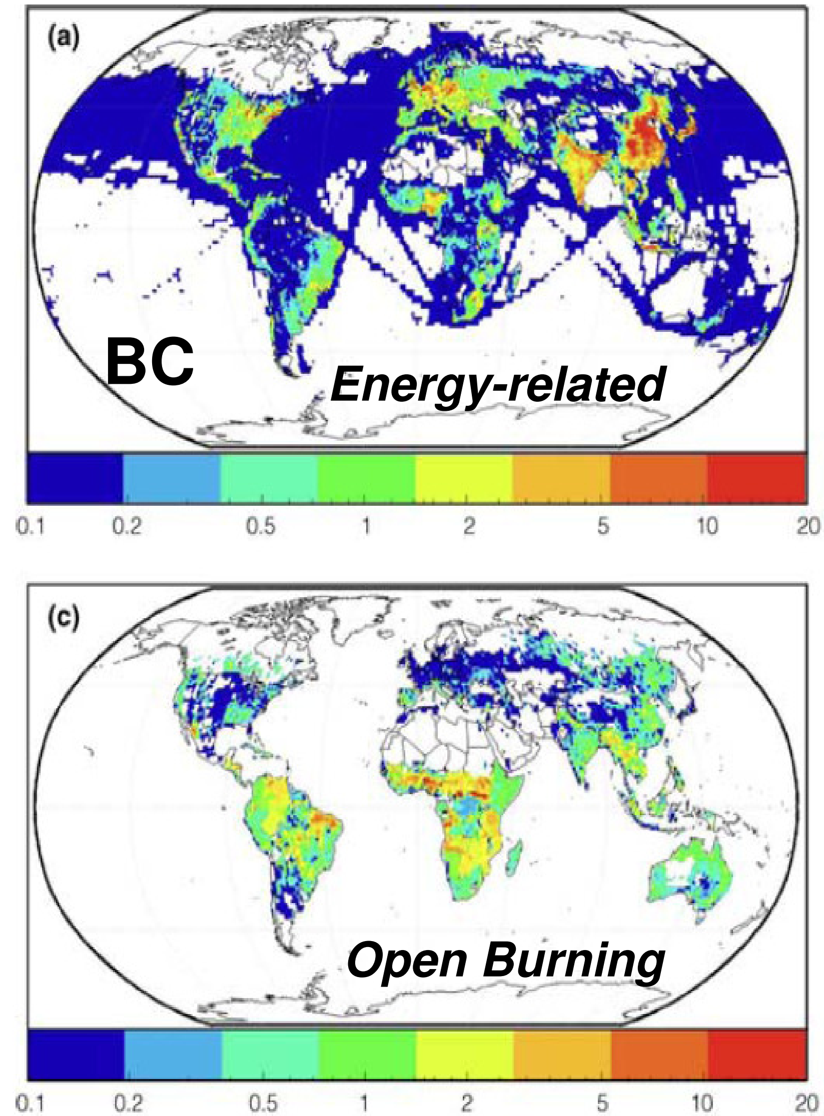
Data Assimilation: Global to Local



Measurements & Capabilities

Emission Estimates for Particles
Significant Uncertainties



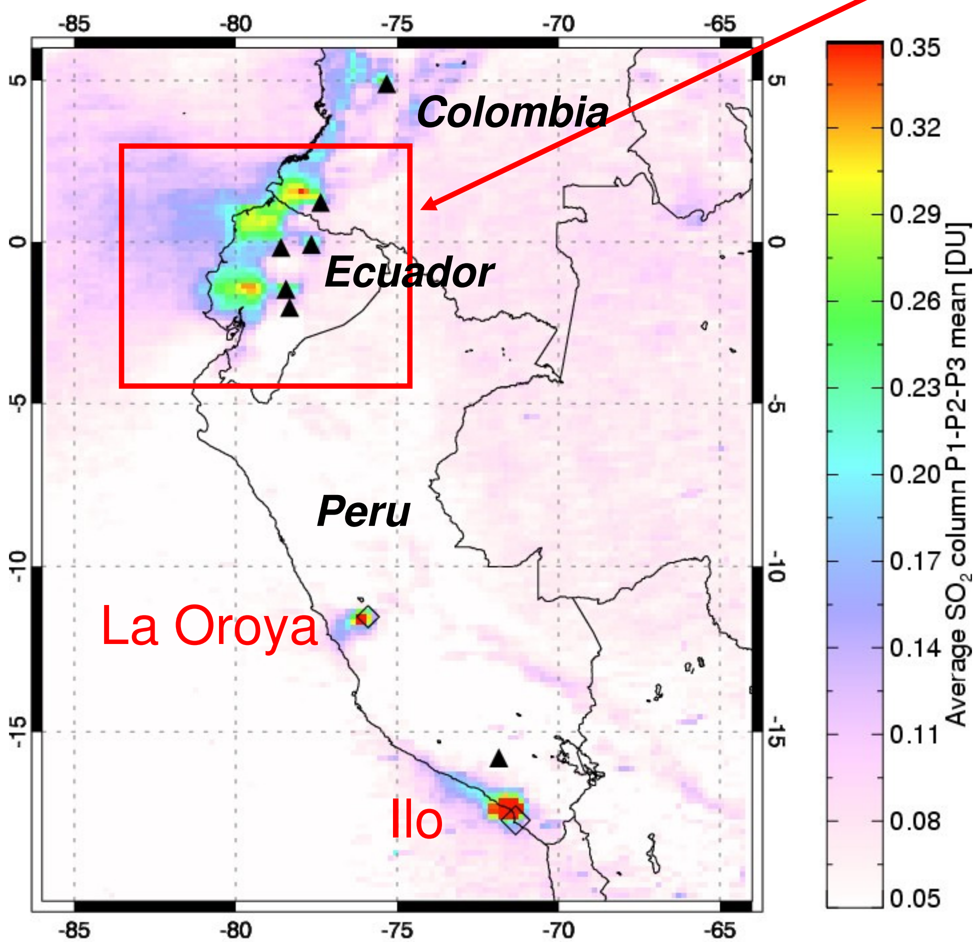


Important to remember – the lifetime of aerosols in the atmosphere is on the order of days, while that for CO2 is many decades

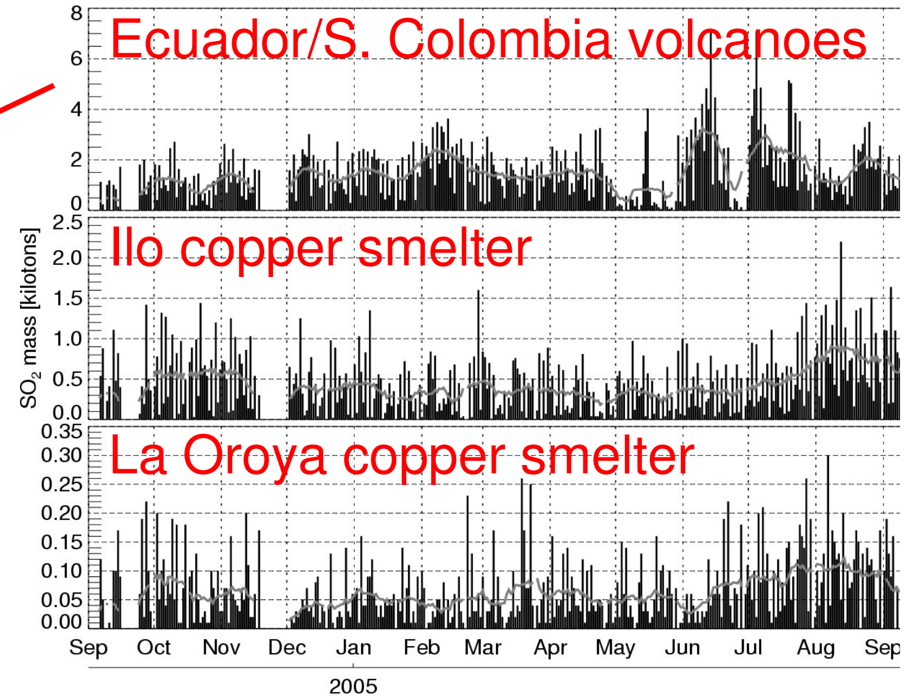
Courtesy of G.Carmichael, U.Iowa

OMI: SO_2 emissions from smelters and volcanoes

Average OMI SO_2 vertical column
Sep 2004 - June 2005



Carn *et al.*, in prep



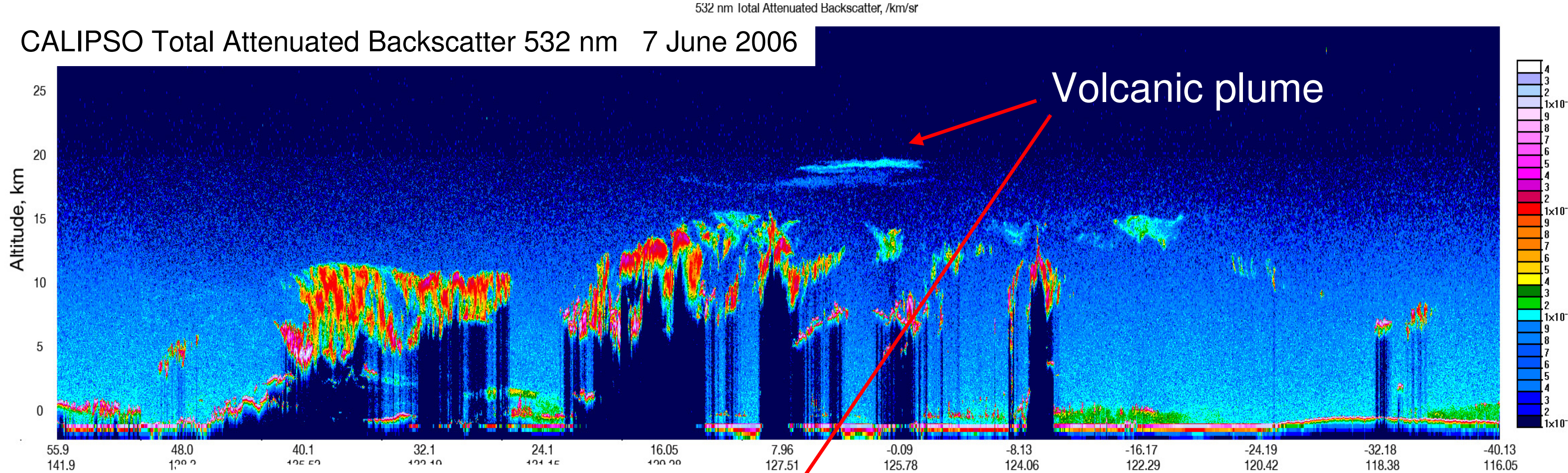
Daily SO_2 burdens for 3 source regions
Sept. 2004 - June 2005

- Daily monitoring of SO_2 emissions is possible with OMI.
- The Peruvian copper smelters are among the world's largest industrial point sources of SO_2.

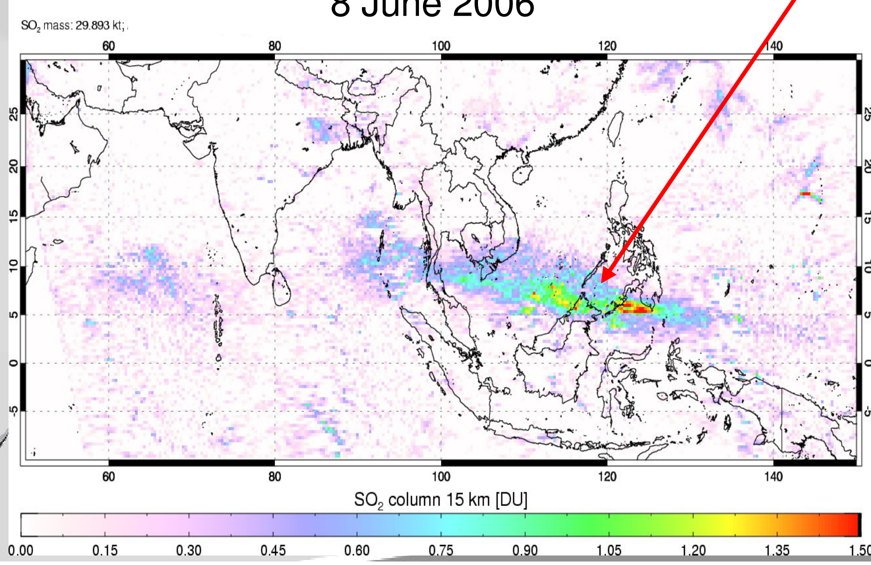
CALIPSO: Space-based LIDAR of Aerosol Layer

Observations of a Volcanic Plume from the Eruption of Soufriere Hills, Montserrat, on May 20

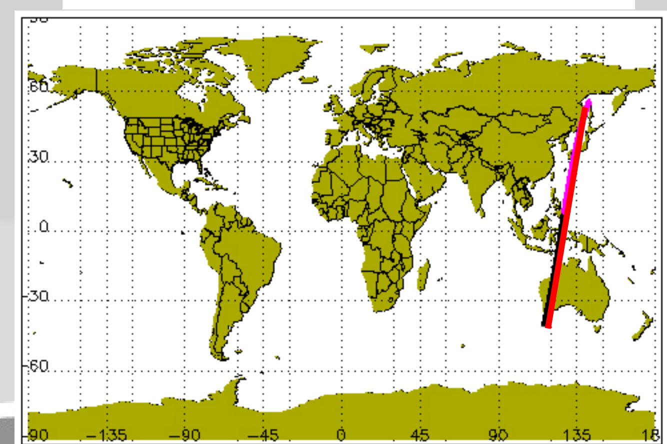
CALIPSO Total Attenuated Backscatter 532 nm   7 June 2006



Aura/OMI Column SO_2
8 June 2006

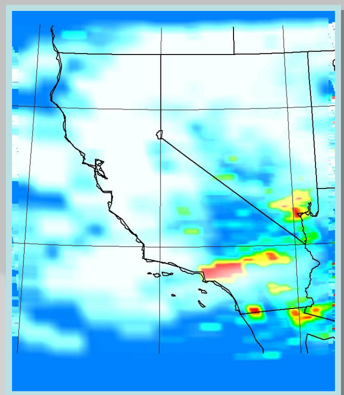


CALIPSO Orbit Track
7 June 2006

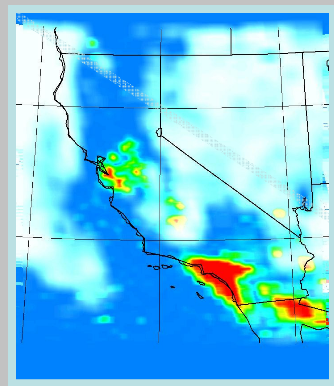


Aura/OMI and NO_2

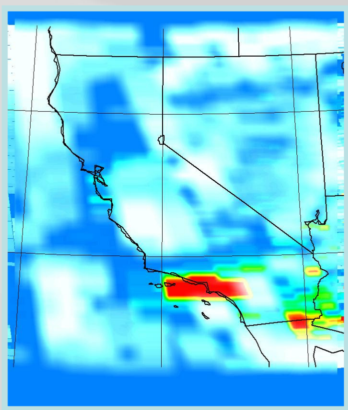
November 11



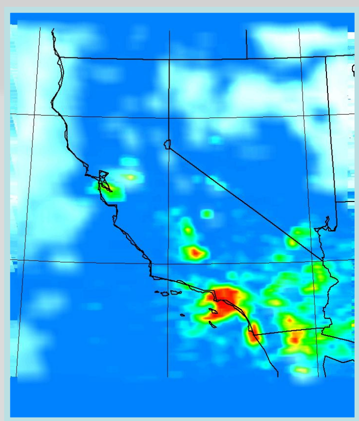
November 12



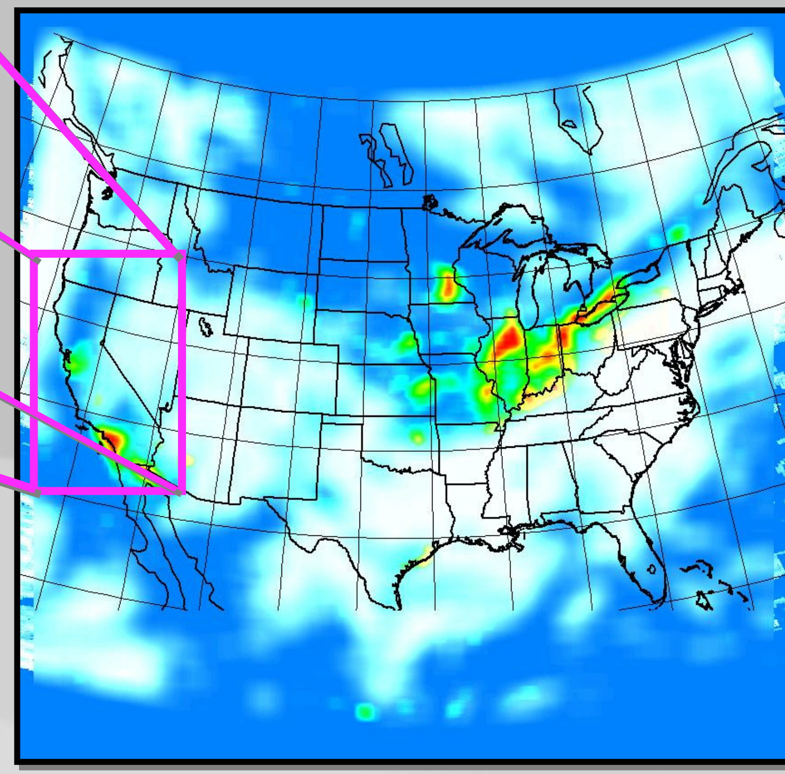
November 13



November 14



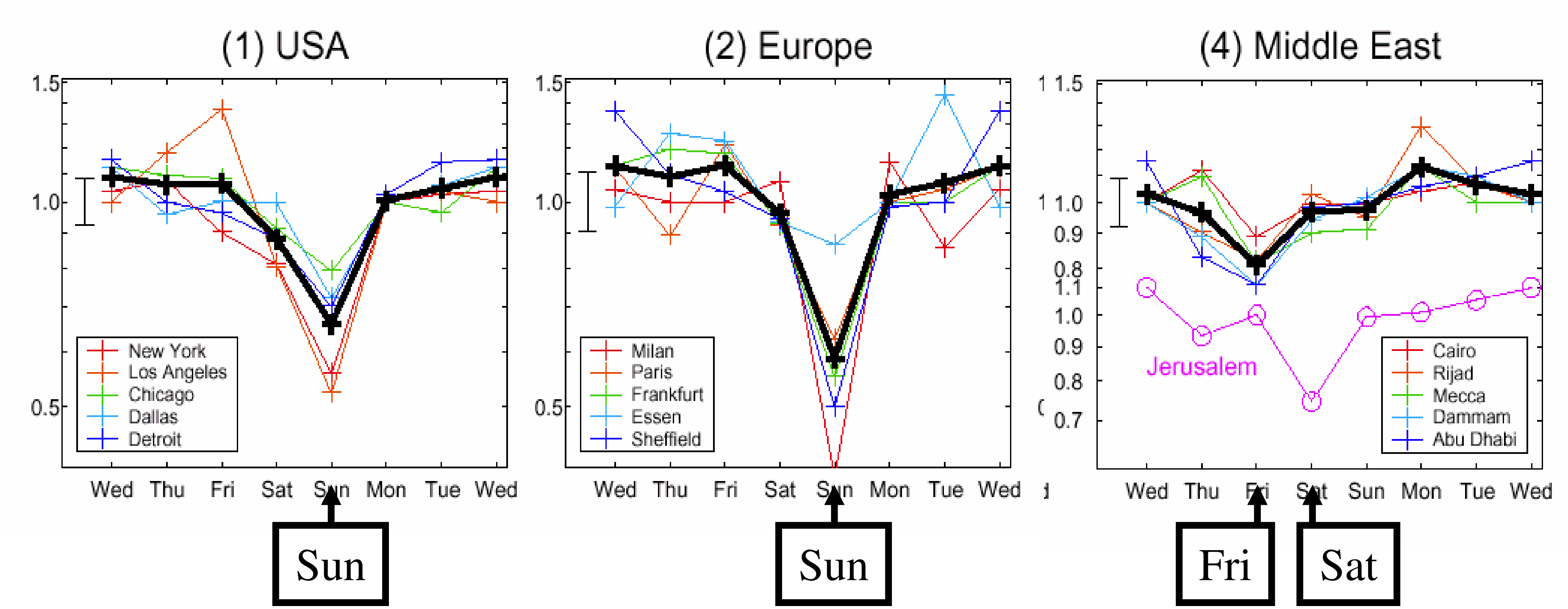
November 12, 2004



OMI 13x24km resolution allows near real time mapping of NO_2

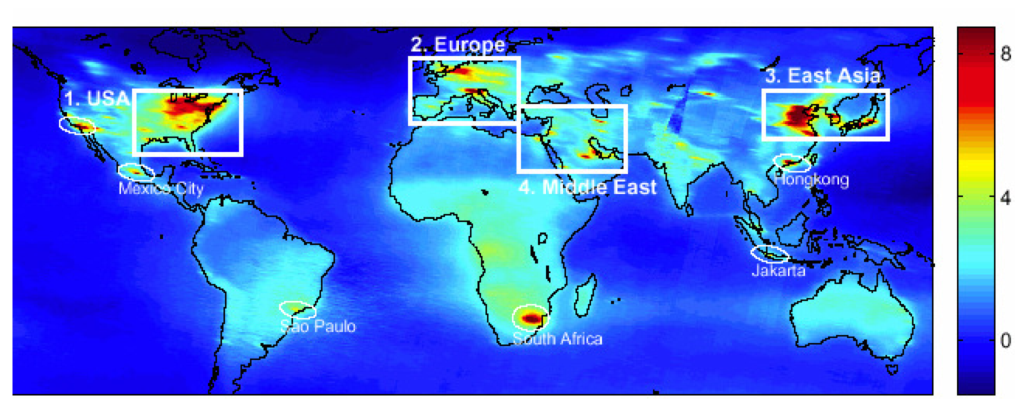
Observing the Sabbath -- or --

Remote Sensing of Anthropogenic Sources



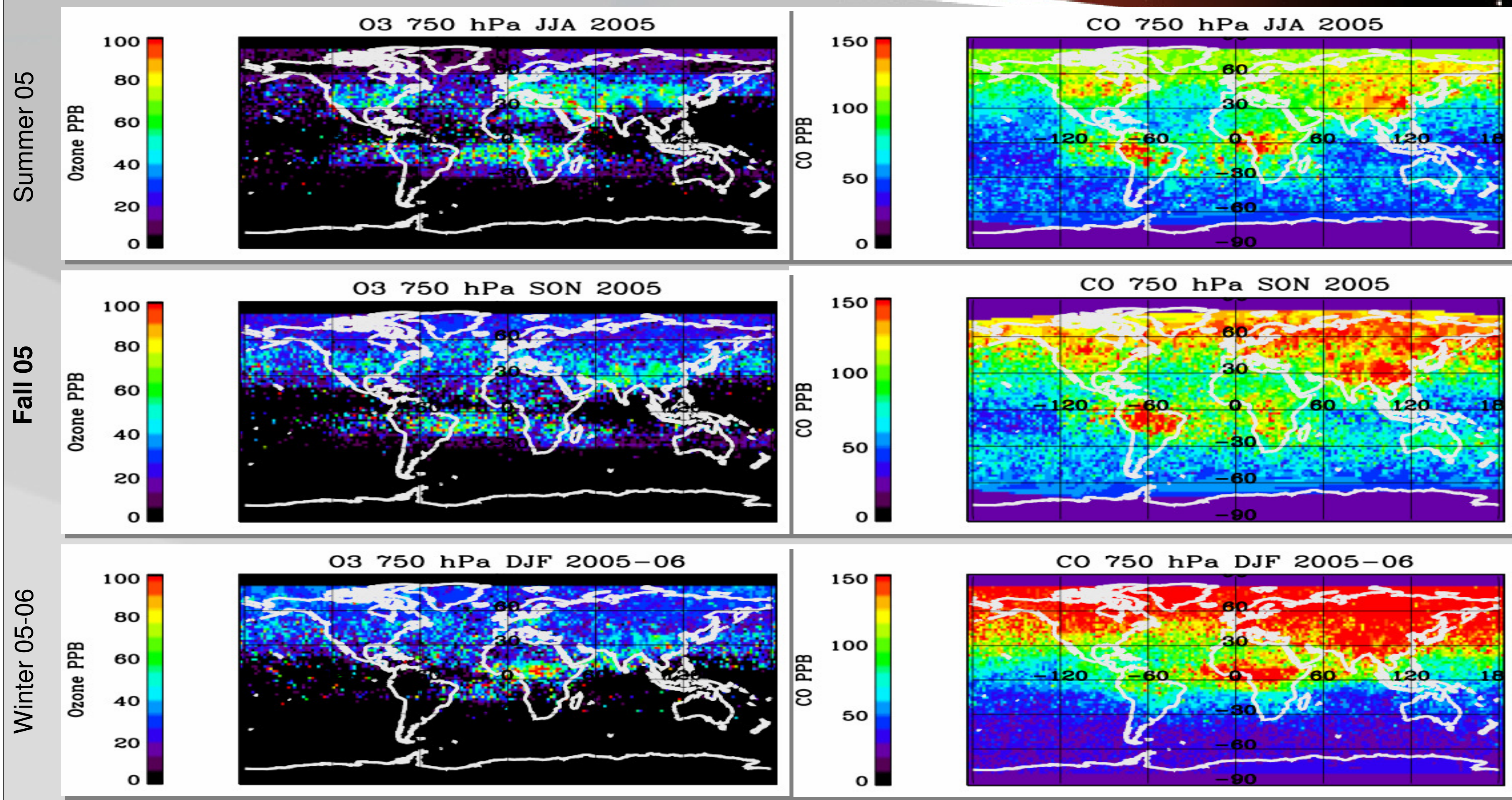
Day of week analysis helps to separate anthropogenic source types.

5-yr weekly average NO2 data from GOME



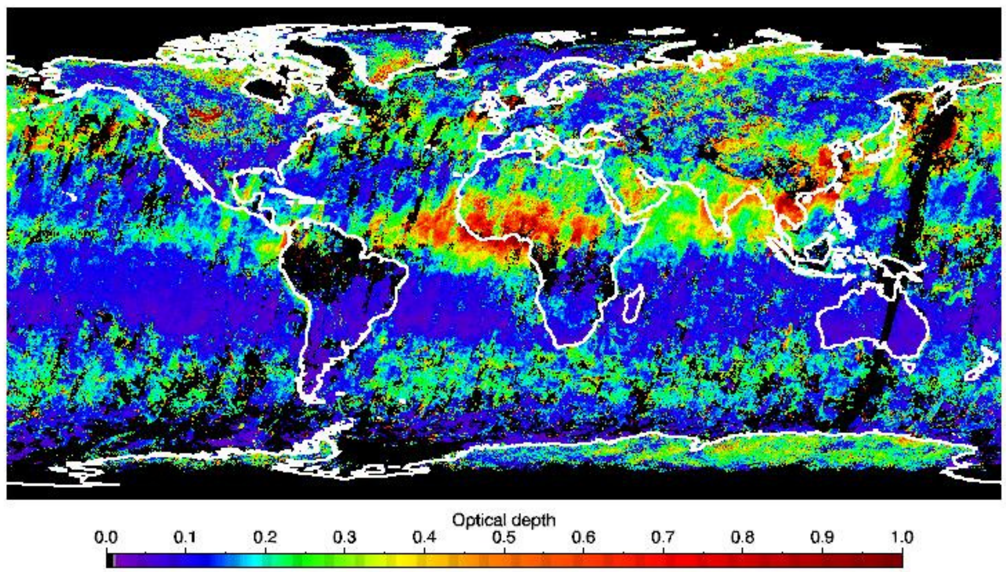
GOME Data from U of Heidelberg Bierle Atmos. Chem. Phys. Discuss, 2003

Ozone & Carbon Monoxide



Aerosols: What can we do from satellites? *Occurrence*

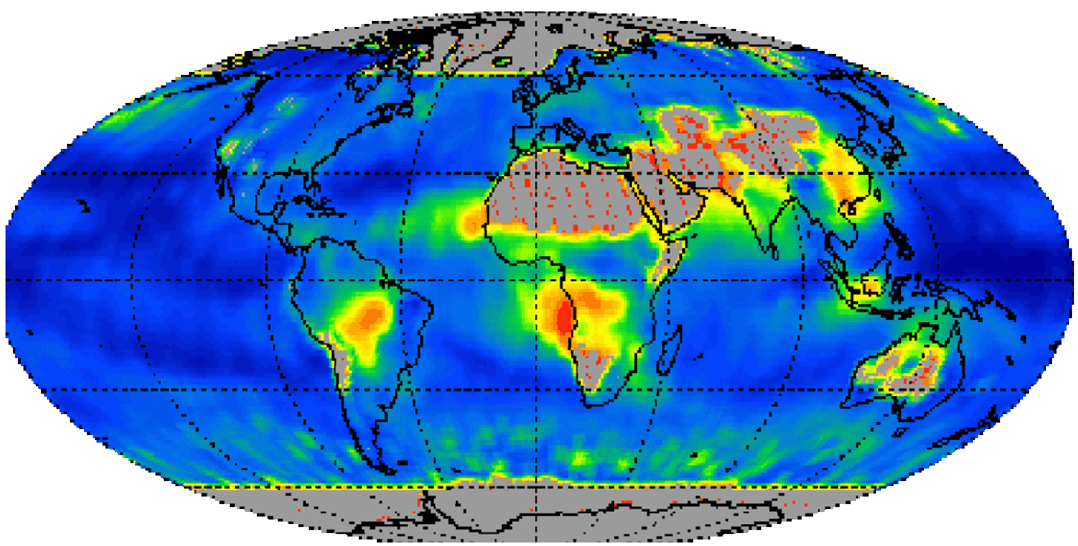
Monthly Global Aerosol Optical Depth Products



MISR Mid-vis AOD

- Land & Water
- Bright Surfaces
- Globe ~ weekly
- ~ 10:30 AM

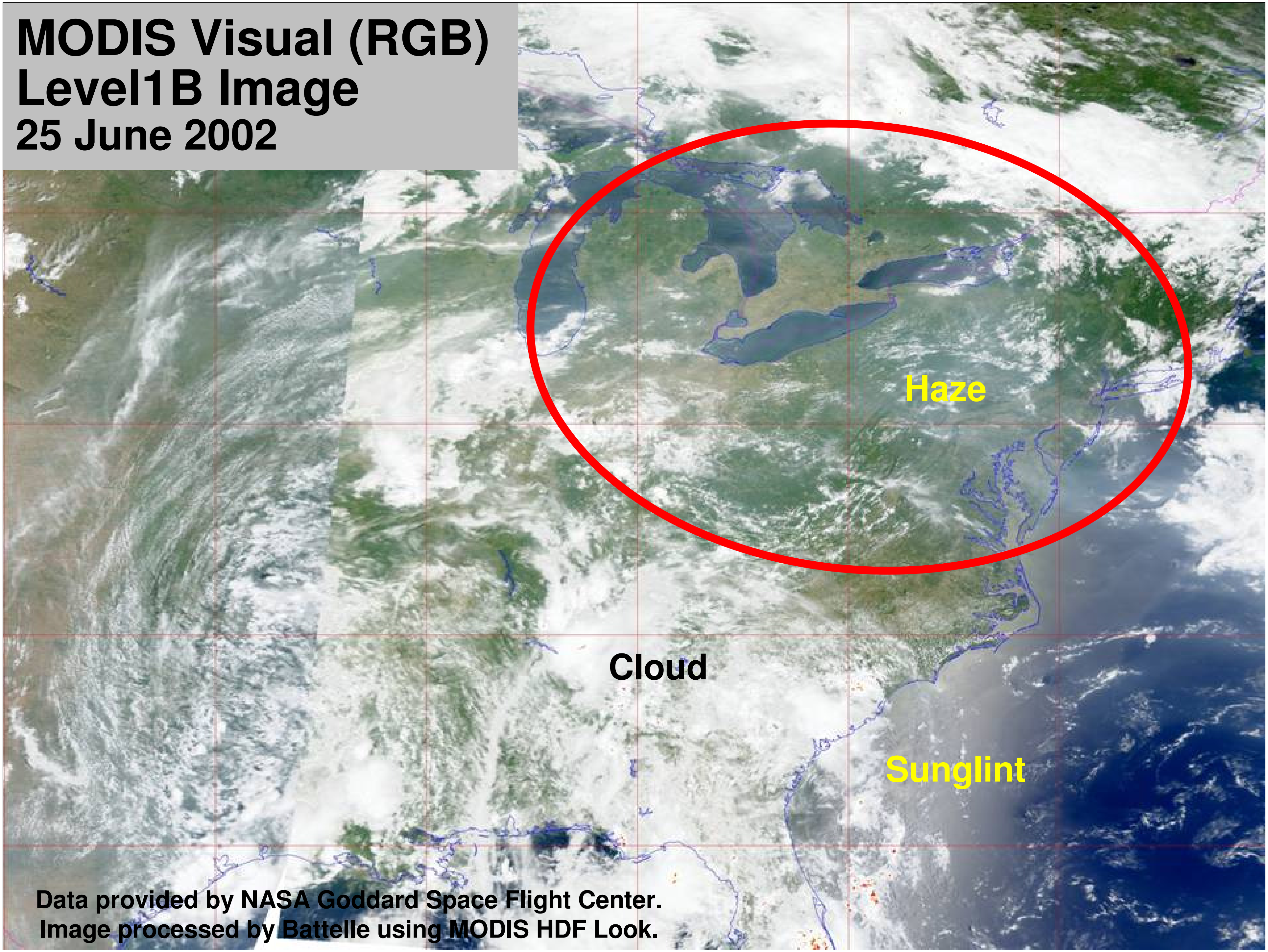
[+ particle size & shape]

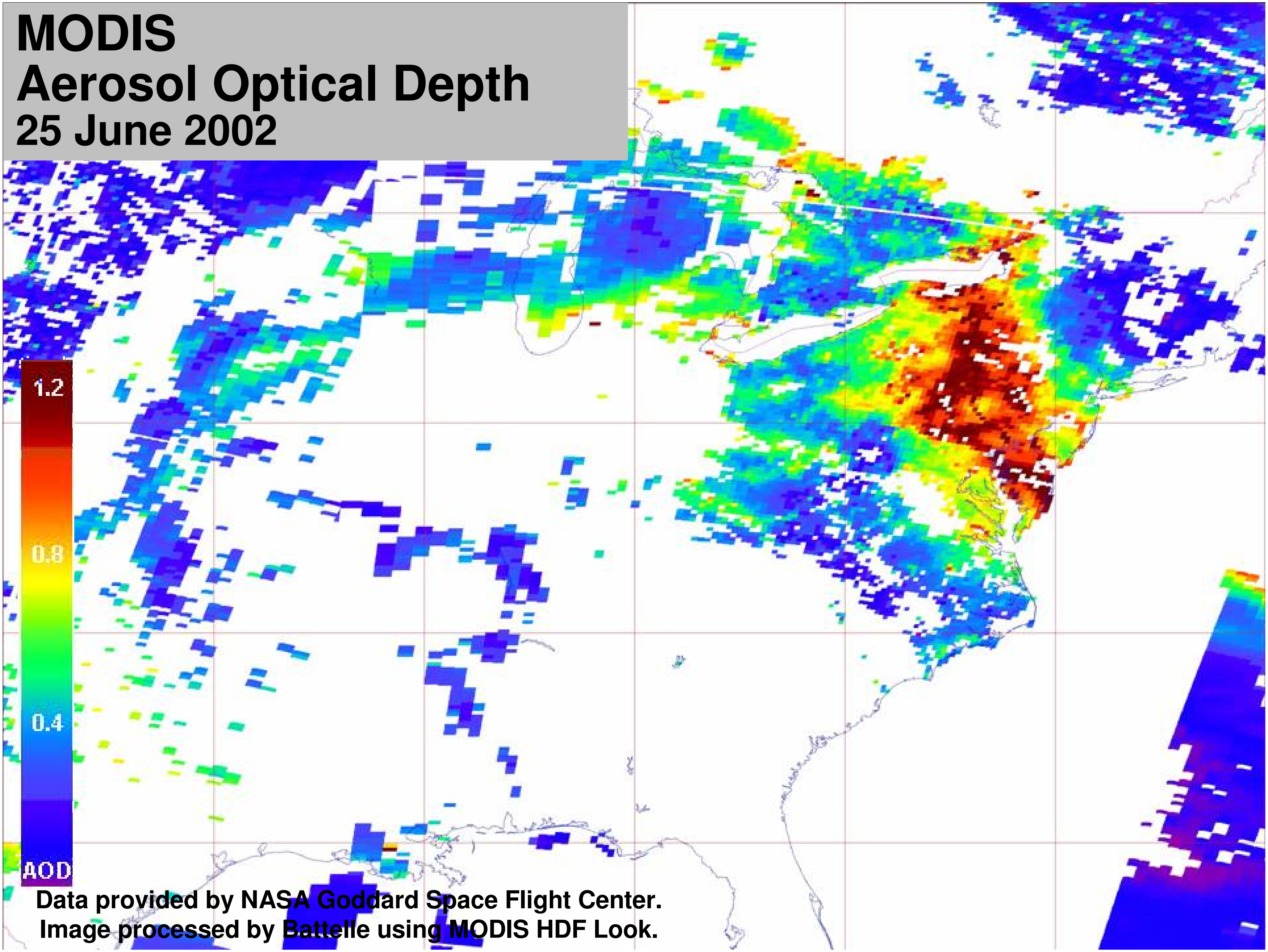


MODIS Mid-vis AOD

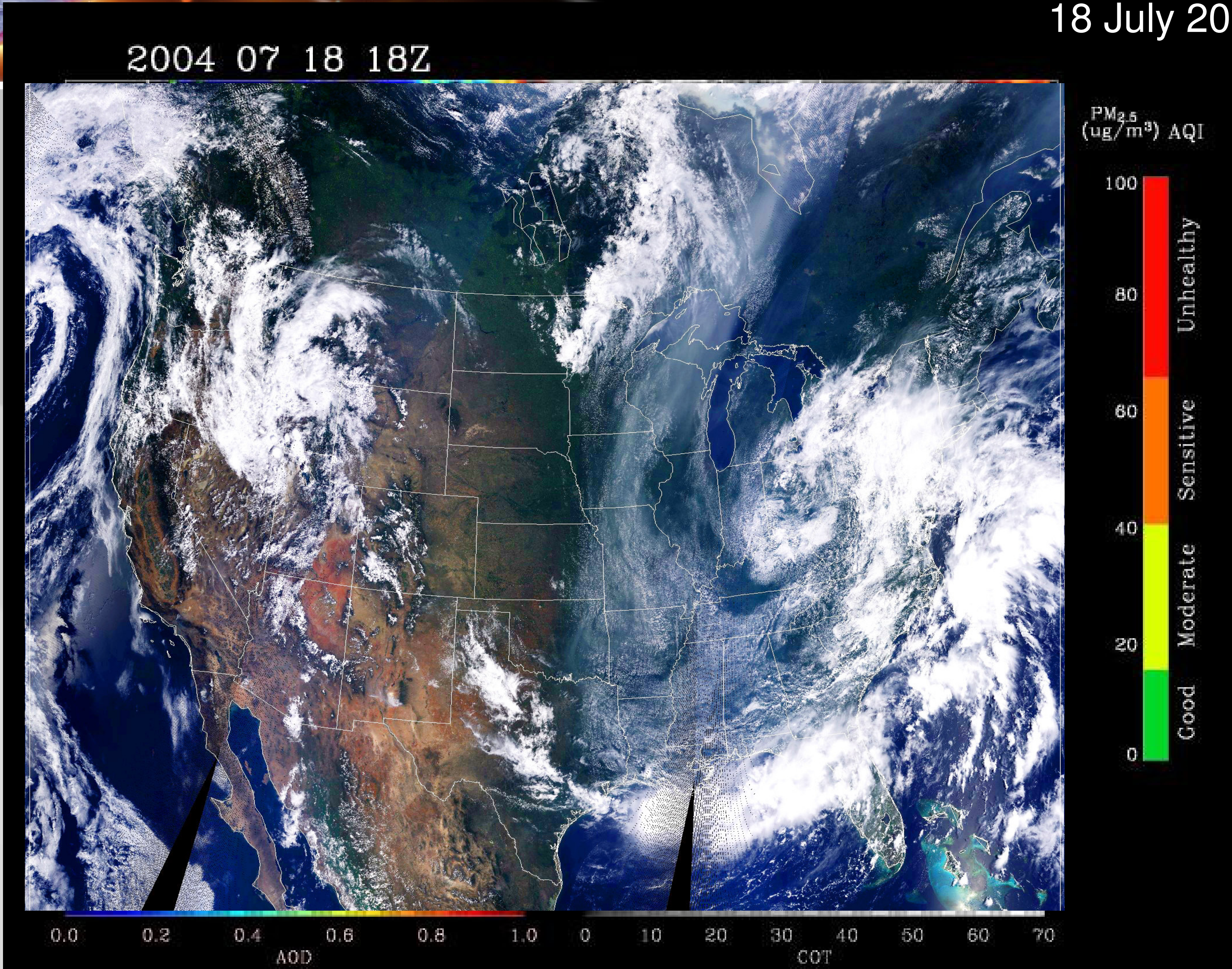
- Water & some Land
- Globe ~ every 2 days
- ~ 10:30 AM & 1:30 PM

[+ fine/coarse mode ratio]


MODIS Visual (RGB)
Level1B Image
25 June 2002
Haze
Cloud
Sunglint
Data provided by NASA Goddard Space Flight Center.
Image processed by Battelle using MODIS HDF Look.

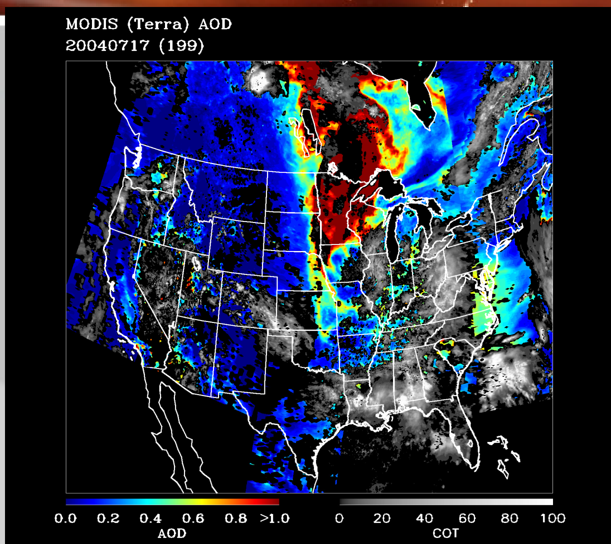

MODIS
Aerosol Optical Depth
25 June 2002
1.2
0.8
0.4
AOD
Data provided by NASA Goddard Space Flight Center.
Image processed by Battelle using MODIS HDF Look.

Smoke from Alaskan/Yukon Fires
18 July 2004

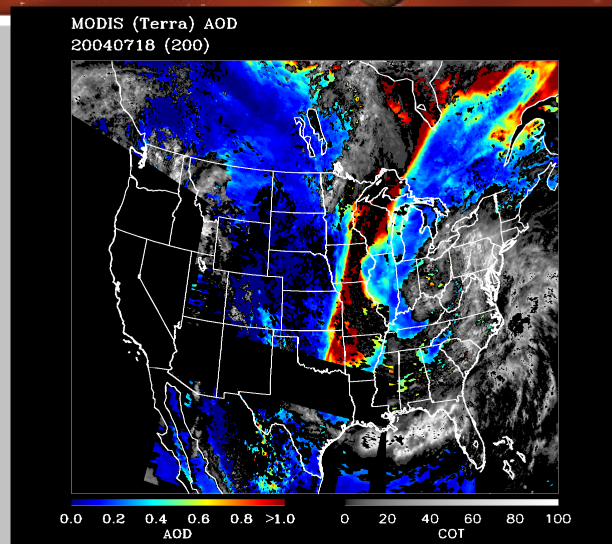


PM2.5 Air Quality Forecasting

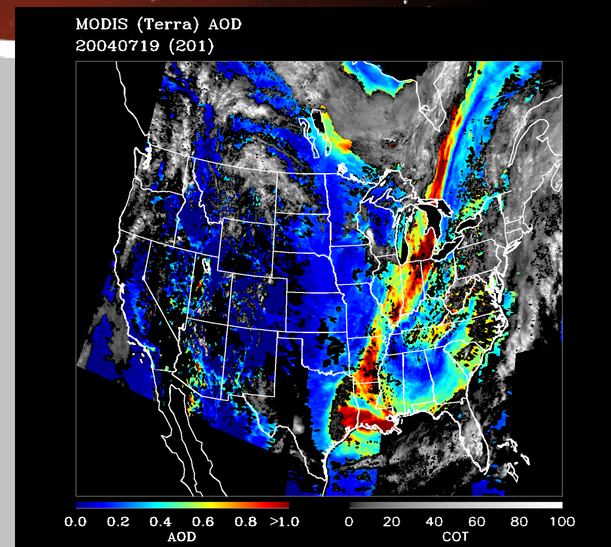
2004 Transport Event: MODIS Aerosol optical depth



7/17

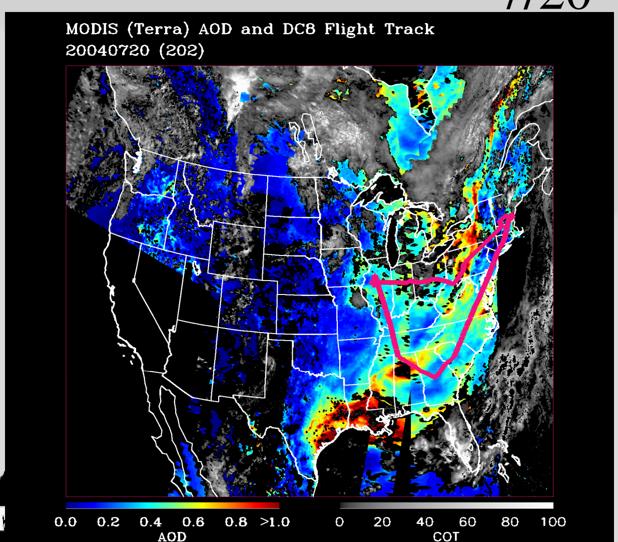


7/18

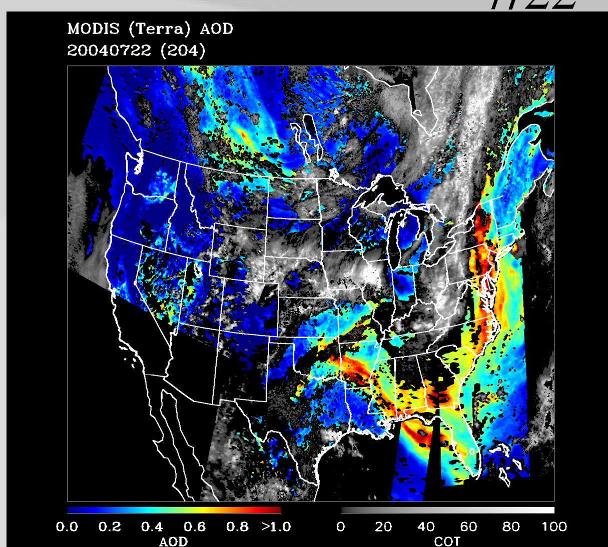


7/19

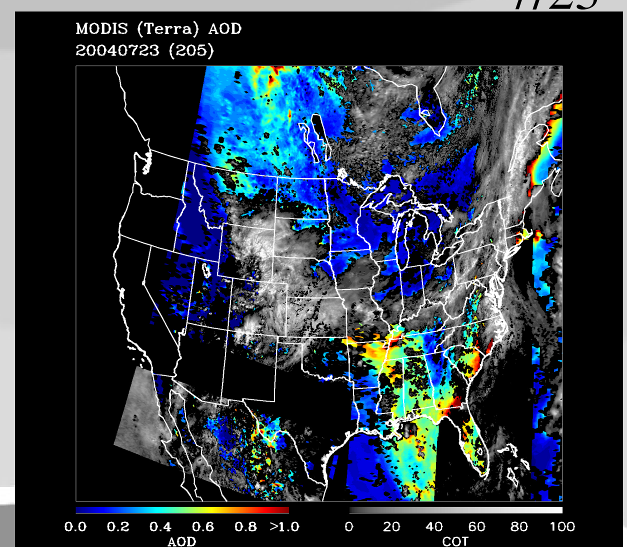
7/20



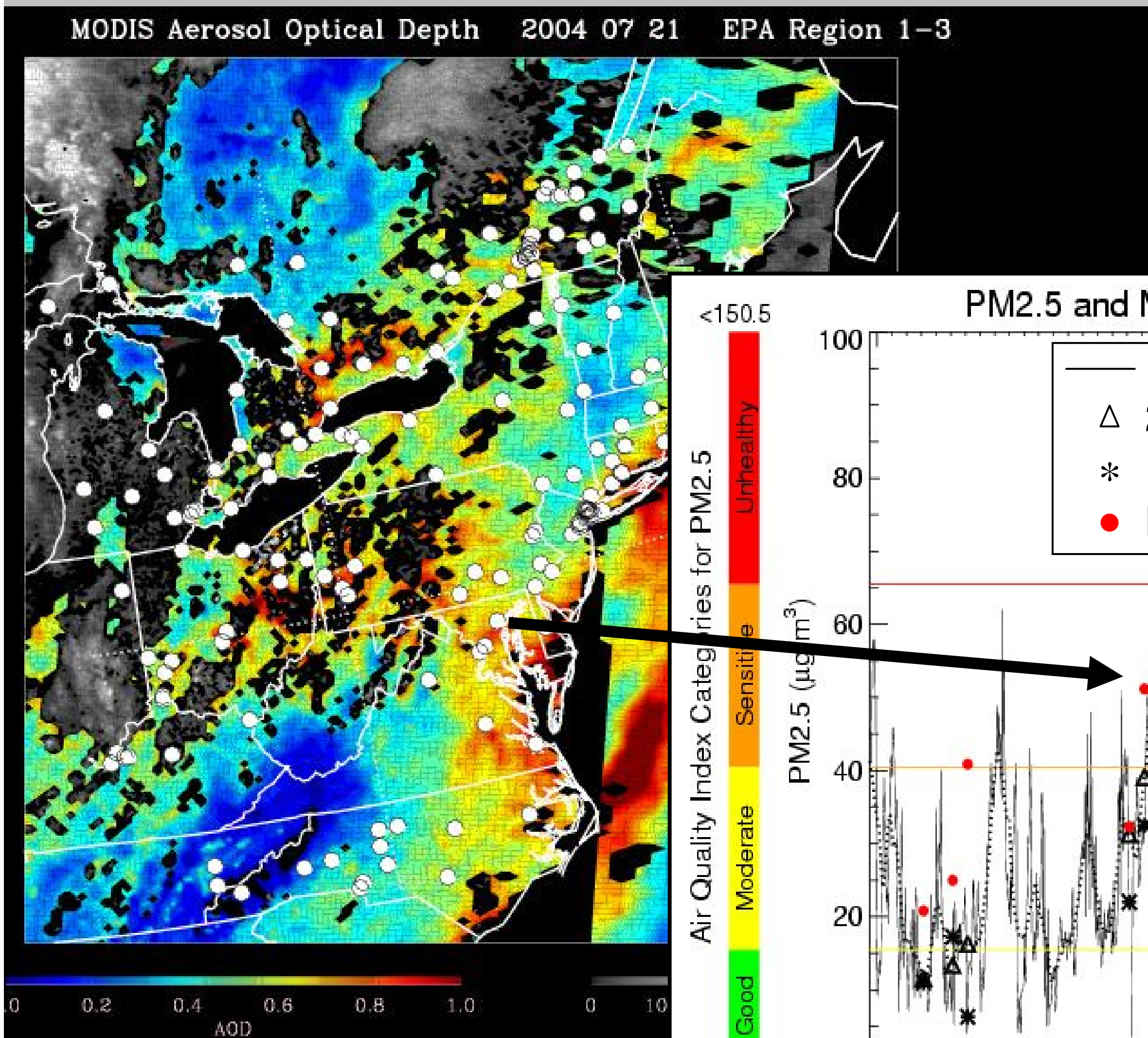
7/22



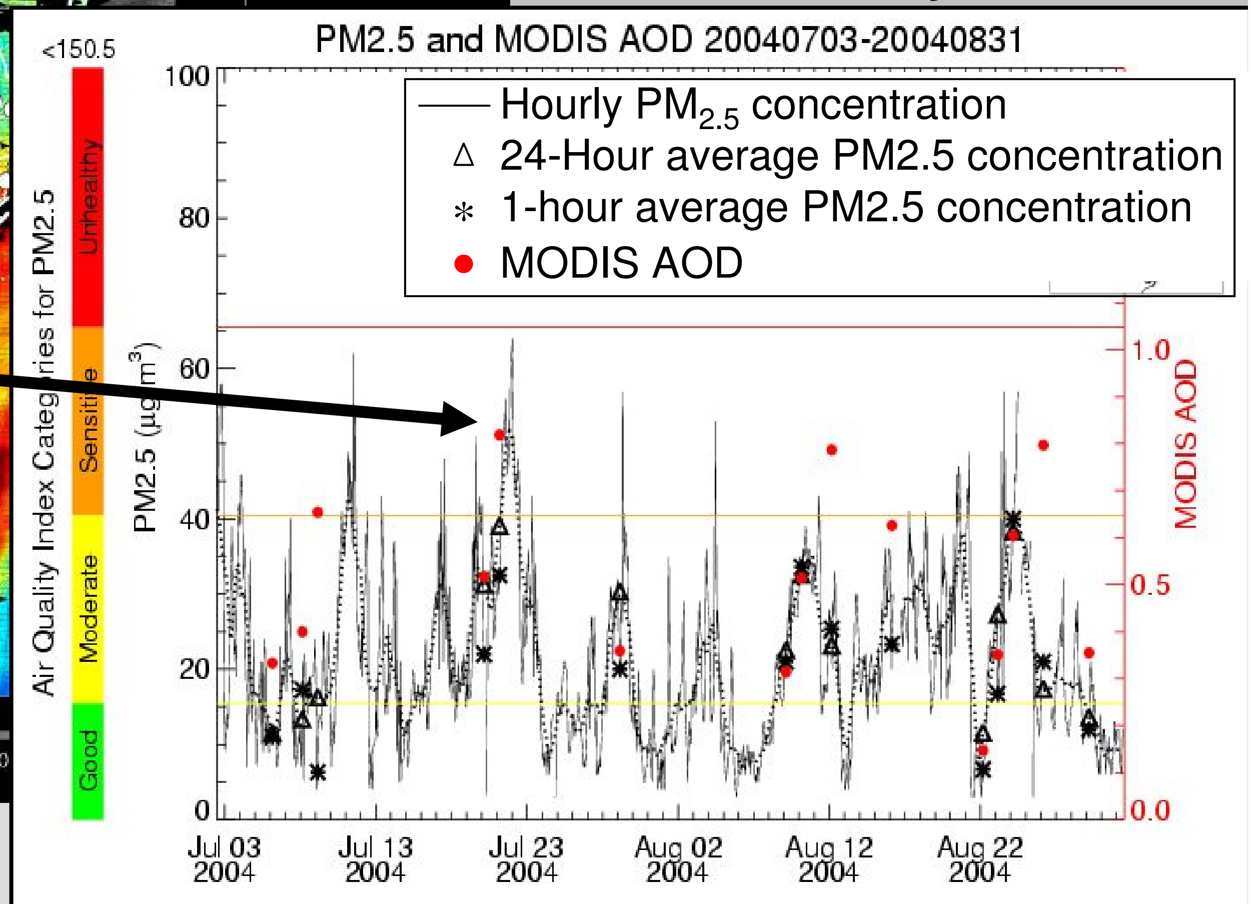
7/23

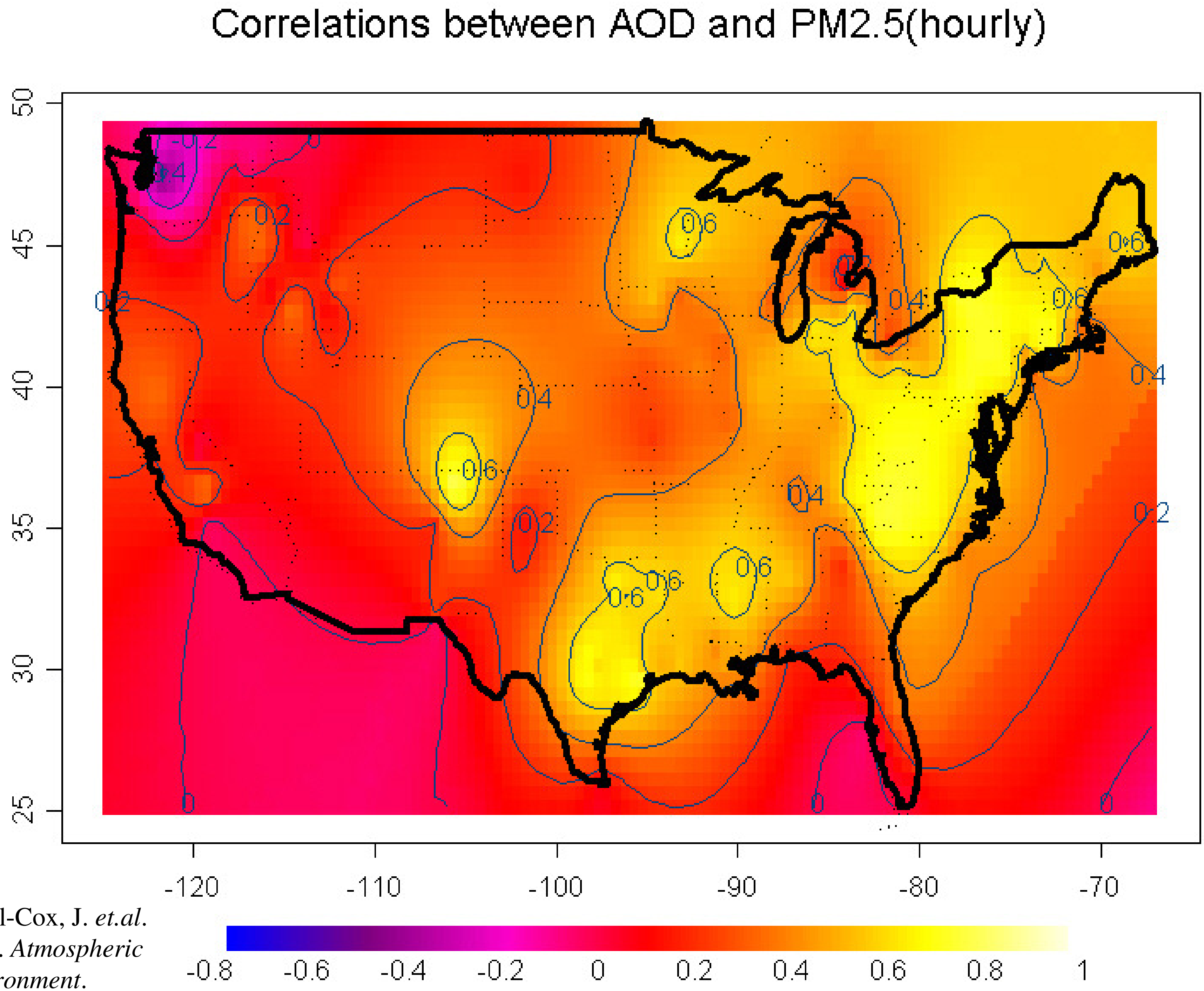


Satellite & Ground Measurements



Baltimore, Maryland, USA



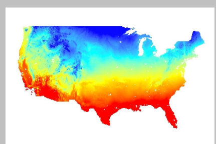


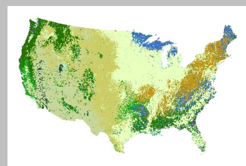
Engel-Cox, J. *et.al*. 2004. *Atmospheric Environment*.

Carbon Management

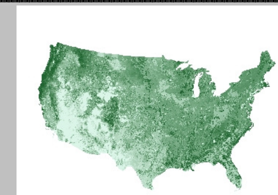
Carbon Management Decision Support

NASA / NGA SRTM Elevation

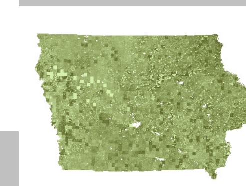




NASA MODIS Products



Leaf Biomass



Cropland NPP

CASA CQUEST

Decision Support Tool for Carbon Accounting

Inputs include continental-scale land cover, NDVI, FPAR, elevation, soils, and climate data …

User Defined Profile

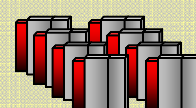
- Region of Interest
- Time Frame
- Biophysical
- Management
- Climate Scenario

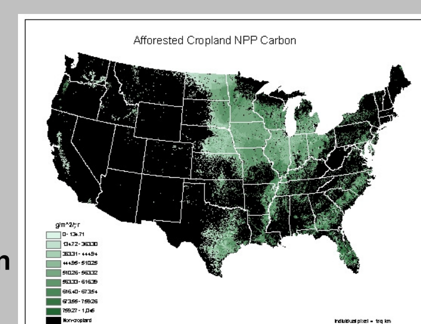
Output: landscape-to continental scale predictive maps of above and below ground distributions of sequestered carbon for different climate scenarios

http://geo.arc.nasa.gov/website/cquestwebsite

USFS Forest Inventory and Analysis Data

Yale/UW Landscape Management System





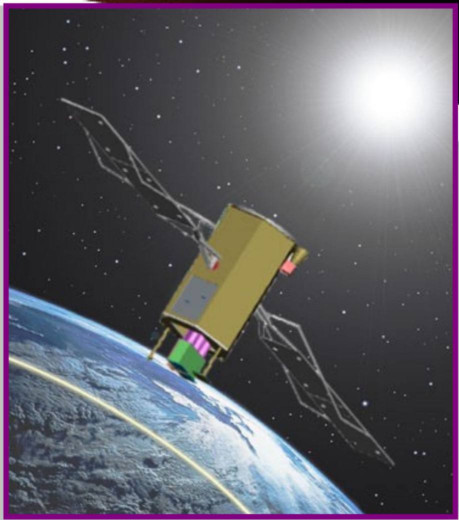
Cropland Afforestation Prediction

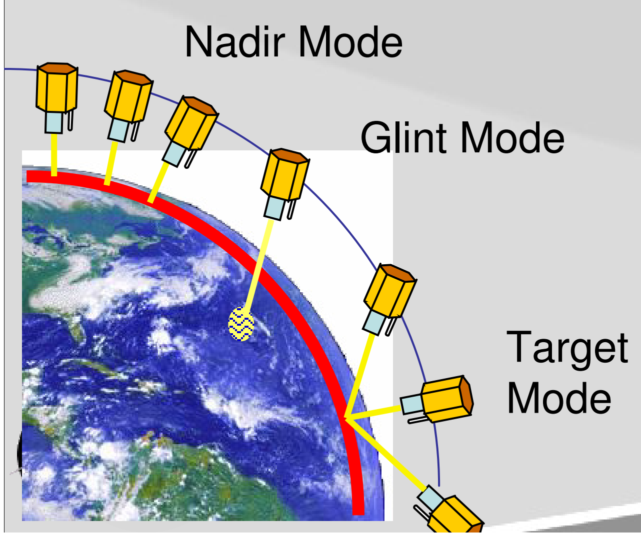
Multi-scale Validation Information

Orbiting Carbon Observatory (OCO)

<u>Science & Applications</u>

- Space-based measurements of atmospheric CO_2
- Column average dry mole fraction
- Characterize carbon sources and sinks on regional scales and quantify their variability.
- OCO measurements are needed to:
  - Identify and bound CO_2 sources and sinks
  - Aid in understanding the global carbon budget
  - Study carbon management activities
  - Aid in verifying C emissions/sequestration reports



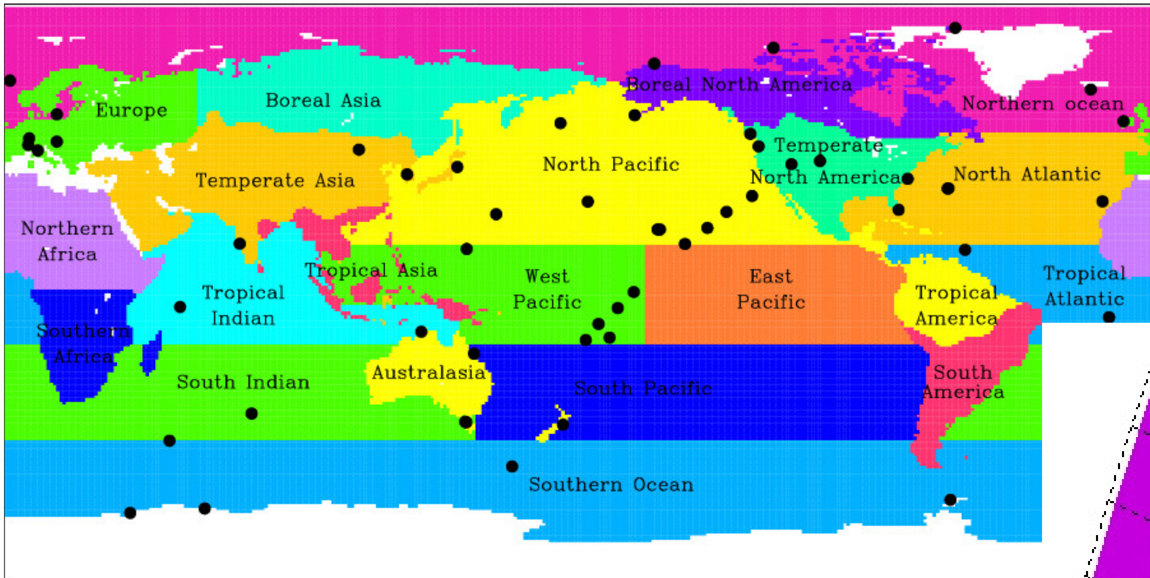


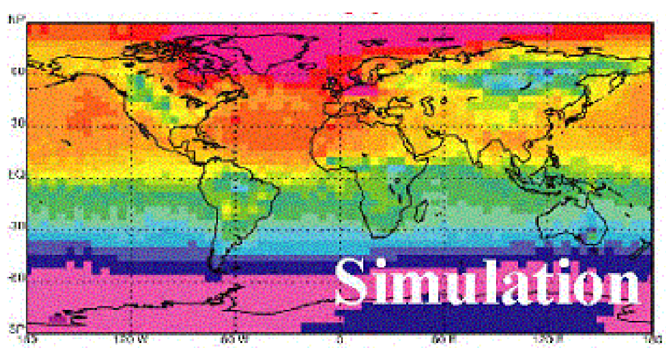
<u>OCO Features</u>

- High Resolution, 3-channel grating spectrometer
- Launch date: 2008
- Operational life: 2 years

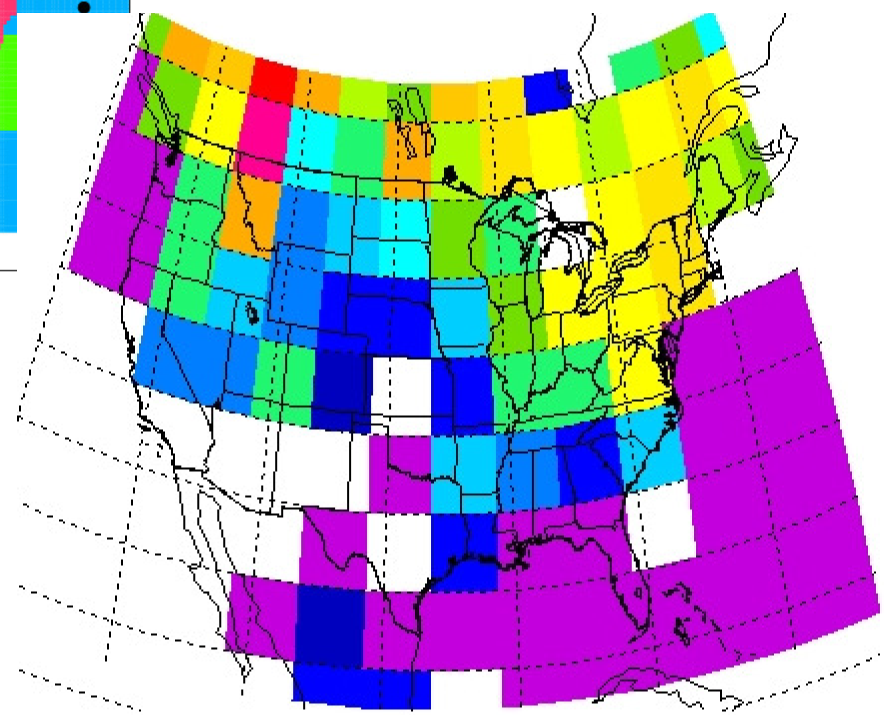
OCO: Measuring CO_2 From Space

Current in-situ network: Continental scales





Monthly global source/sink estimates at regional to sub-regional scales



OCO will make global, space-based observations of atmospheric CO_2 with the precision, resolution, and coverage needed to monitor sources and sinks.

Data & Information:

Availability, Priorities, Opportunities

Group on Earth Observations

Group on Earth Observations:

Ministerial-level leadership for coordination of Earth observing systems

10-year implementation plan

Began August 2003

Integrate scientific capacity of organizations and observing systems to support nine societal benefit areas:

- Natural & Human Induced Disasters
- Water Resources Ecosystems
- Sustainable Agriculture & Desertification
- Energy Resources
- Climate Variability & Change
- Weather Information, Forecasting
- Human Health & Well-Being
- Oceans

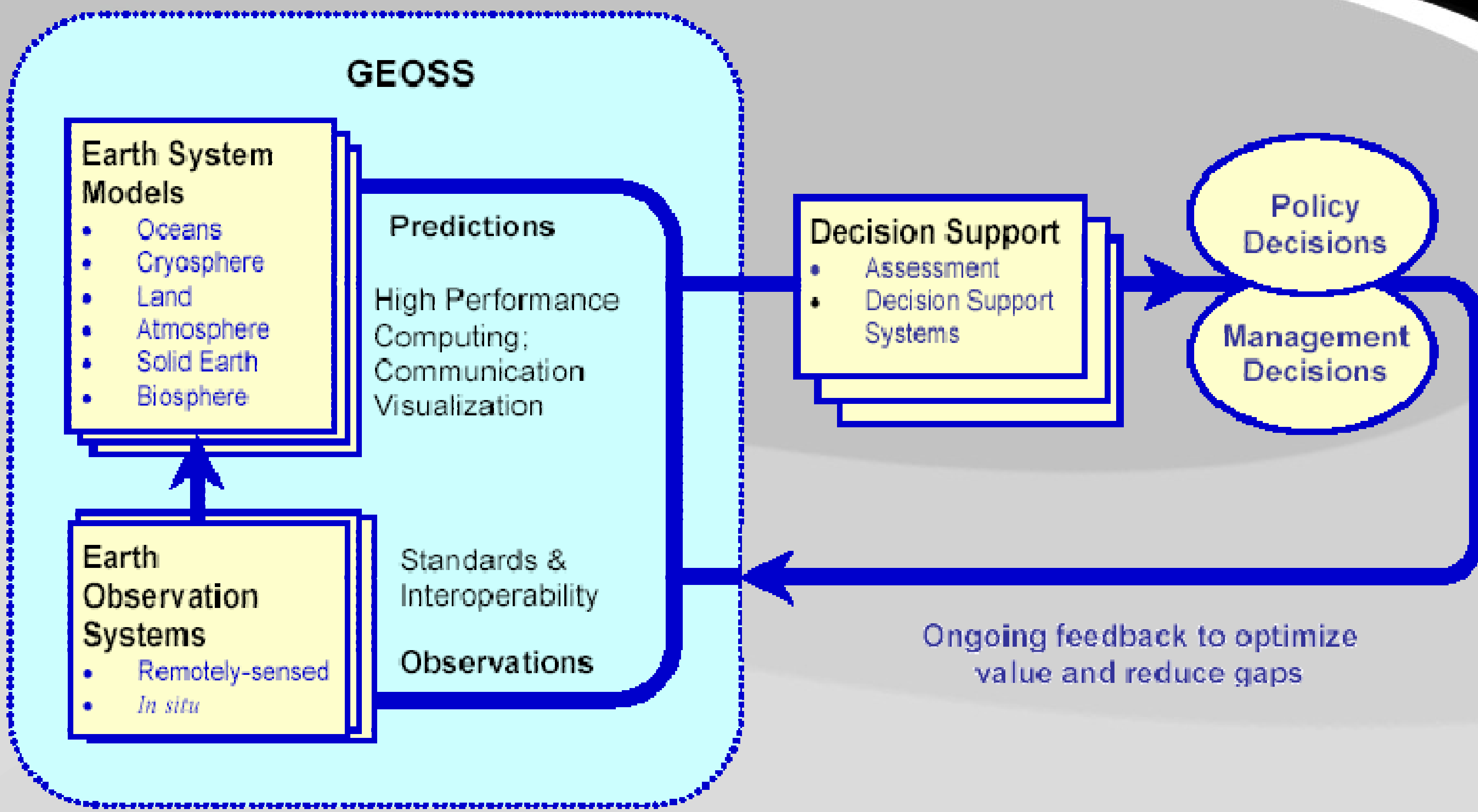
Earth Observation Summit III
Feb. 2005

GEO involves:
65 nations

35+ international Organizations

GEO Secretariat at WMO in Geneva

GEO & “System of Systems” Architecture



GEO-NETCast

What?

GEO-NETCast is a near real-time data dissemination system

Environmental *in situ*, airborne, and space-based observations, products, and services in standard formats

Built on existing dissemination systems with data collection hubs around the globe

Use of standard, multicast, dissemination protocols (e.g., Digital Video Broadcast – DVB) to encapsulate products of any format

Sample Data Products

Radiation fluxes

Land surface type, albedo, temperature

Cloud Analysis and Cloud Mask

Ocean surface wind speed

Chlorophyll concentration

Normalized Differential Vegetation Index

Volcanic ash imagery and advisories

Fire and smoke analysis

Snow cover, depth, and water content

Sources of Information

Sensor Site

Moderate Resolution Imaging Spectroradiometer (MODIS)	http://modis-atmos.gsfc.nasa.gov/ http://rapidfire.sci.gsfc.nasa.gov/ http://eosdb.ssec.wisc.edu/modisdirect/

Data Sites

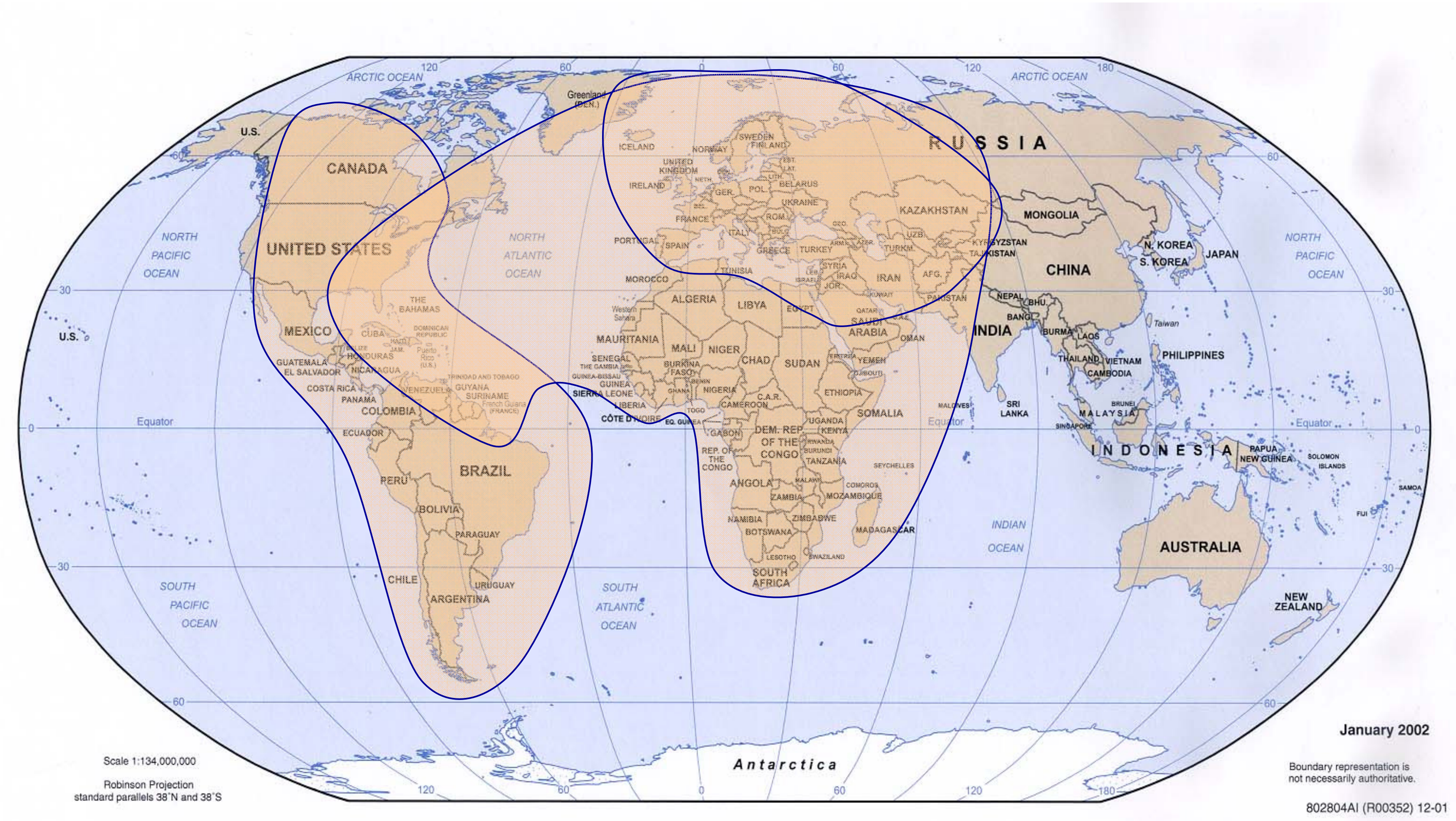
NASA Goddard Space Flight Center DAAC	http://daac.gsfc.nasa.gov/
NASA Langley Atmospheric Sciences Data Center	http://eosweb.larc.nasa.gov/
NASA Level 1 and Atmosphere Archive and Distribution Center	https://ladsweb.nascom.nasa.gov:8300/

Imagery Sites

U.S. Air Quality (“Smog Blog”)	http://alg.umbc.edu/usaq/
NASA Earth Observatory	http://earthobservatory.nasa.gov/
NASA Visible Earth	http://visibleearth.nasa.gov/
NOAA Operational Significant Event Imagery	http://www.osei.noaa.gov/
US Interagency Air Quality Forecasting Support	http://idea.ssec.wisc.edu/

Group on Earth Observations

EUMETCast Coverage

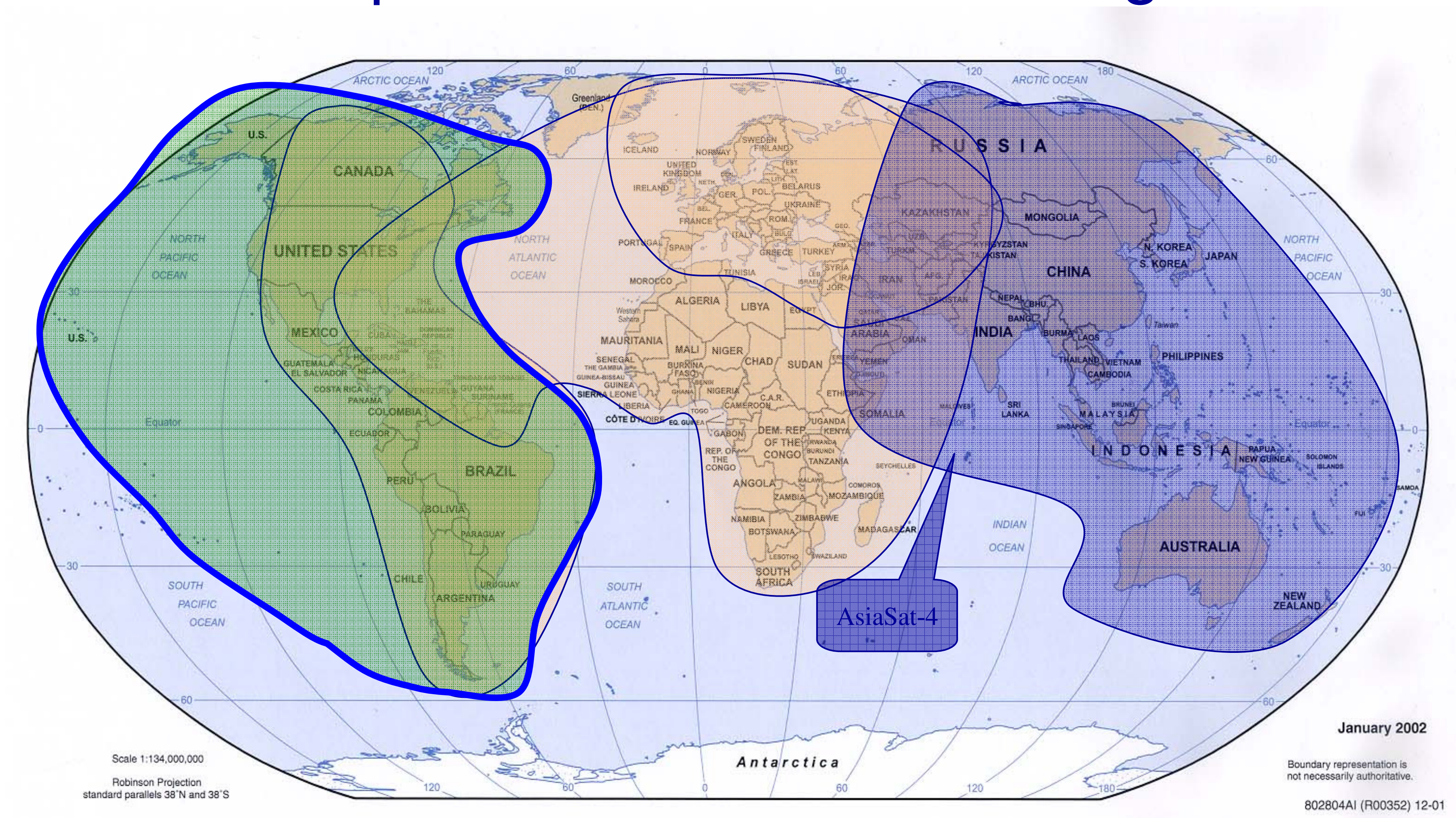


Typical Receiver Station Configuration

- Dedicated personal computer (~ $1000)
- Satellite antenna dish (1-3 m) (~ $300-1200)
- DTH receiver card or box (~ $200)

Data analysis and processing should be done on separate computer(s)

Proposed Additional Coverage



Americas: US/NOAA

Asia: China

Science for Society:

Convention on Long-range Transboundary Air Pollution

Convention on Long Range Transboundary Air Pollution (LRTAP)

1979 Agreement;
49 countries signed and ratified

Primarily Europe, Canada, USA, and Former Soviet Republics

Asia, Middle East, northern Africa, and central America are not currently included in LRTAP

Southern Hemisphere not included (different pollution issues – less industrial, more biomass burning)

Protocols:

- Sulfur (1985, 1994)
- Nitrogen Oxides (1988)
- Volatile Organic Compounds (1991)
- Persistent Organic Pollutants (1988)
- Heavy Metals (1998)
- Acidification, Eutrophication, and Ground-level Ozone (1999)

Typically, protocols set specific emission targets for pollutants and/or designate actions

LRTAP sets out fundamental principles to reduce air pollution, cooperate on research and monitoring, and information exchange

UN Economic Commission for Europe (UNECE) provides the Secretariat

Calls on parties to reduce transboundary air pollution using the best policies and strategies and best available technology which is economically feasible.

LRTAP Task Force: Hemispheric Transport of Air Pollutants

Dec. 2004: New Task Force on Hemispheric Transport of Air Pollutants

Intercontinental transport in Northern Hemisphere

Involves Northern Hemisphere countries who are not signatories to LRTAP

2005 – 2009: Assessment of the scientific evidence concerning hemispheric transport for use in international policy discussions and reviews of LRTAP protocols

Hemispheric approach will likely require information over oceans and regions with minimal ground-based monitors

Air Pollutants of Interest:

- Fine particles / PM
- Acidifying substances
- Persistent organic pollutants
- Ozone and precursors
- Mercury

http://www.htap.org/

HTAP Assessment Activities

Four Types of Experiments:

1. Sensitivity studies
   - North America, Europe, North Asia, South Asia
2. Tracer studies
3. Mixed activities
   - Climate change and variability issues
   - Short/long-term effects
   - Studies addressing disagreements from first two experiments
4. Source-receptor relationships

June 2005: Initial meeting

Jan. 2006: Model evaluation and intercomparison methodology
http://aqm.jrc.it/HTAP

October 2006: Emissions Inventory and Projections Workshop

January 2007: Integrated Observations Workshop

March 2007: Interim assessment on O3 and PM

2007 & 2008: Additional workshops

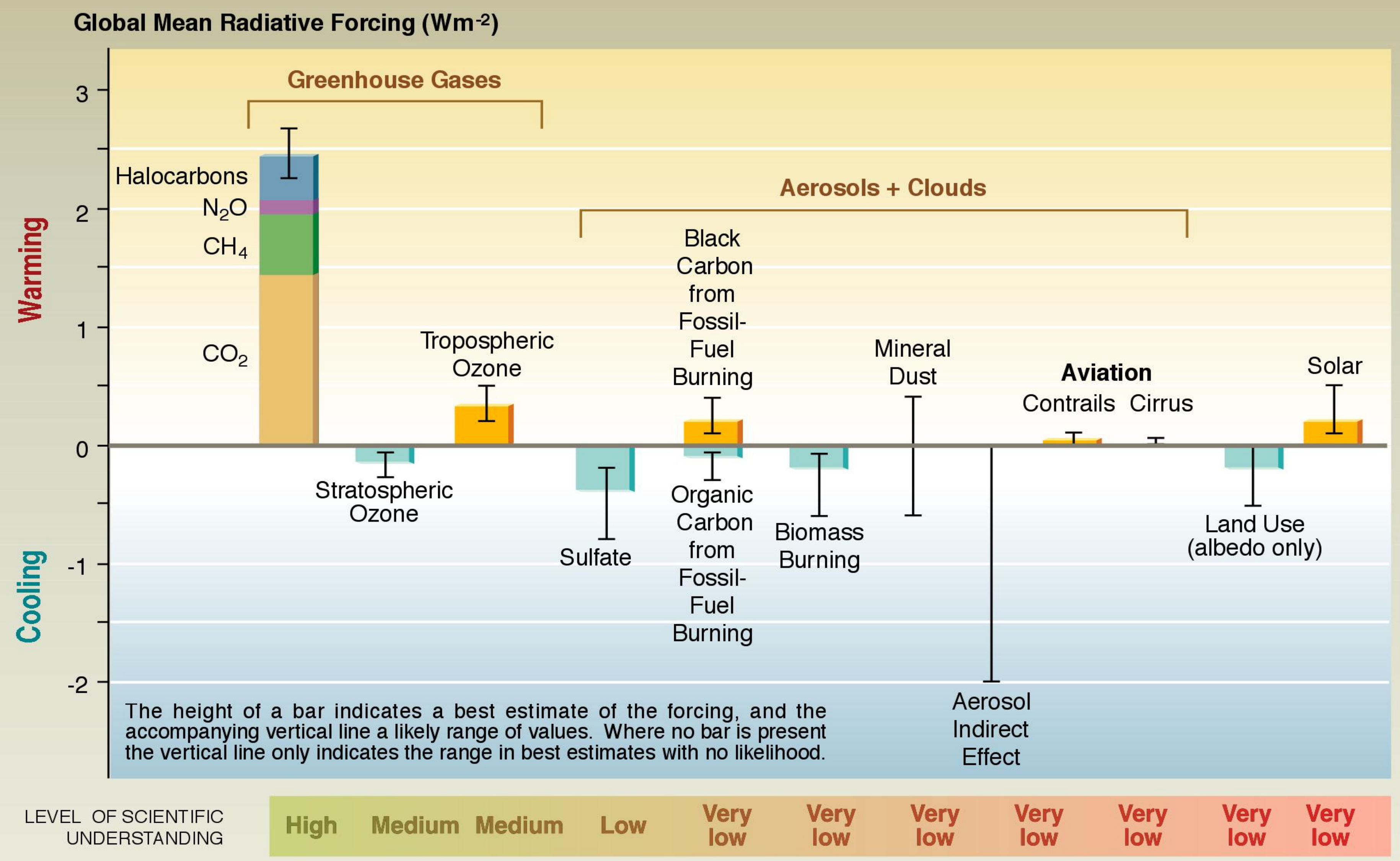
2009: Assessment adds Hg and POPs

An energy policy is also an environmental policy is also an economic policy.

- William Rosenberg

Back-up Slides

Pre-industrial to present-day contributions to radiative forcing: 1750 to 2000



CO_2 Storage

Options

Enhanced oil recovery

Depleted oil and gas reservoirs.

Deep saline reservoirs.

Deep unmineable coal seams.

Coal-bed methane recovery.

Deep ocean storage not a suitable option.

Risks

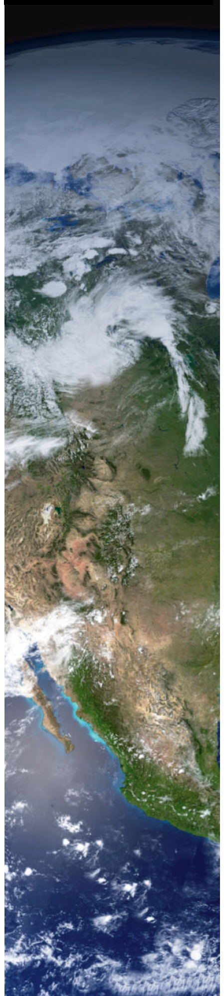
Leaks that cause local concentrations to exceed 2% can be harmful or fatal around 10%.

Leaks into fresh water aquifers could mobilize toxic metals, sulfate or chloride. Trace gases (H2S, SO2 or NO2) could make this more likely.

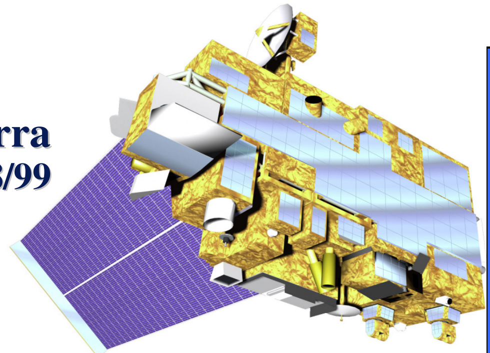
Slow leaks could affect the climate for hundreds of years.

Current evidence suggests that these risks would be minimal with well understood reservoirs, identification of abandoned wells and monitoring.

Satellite / Sensor Characteristics

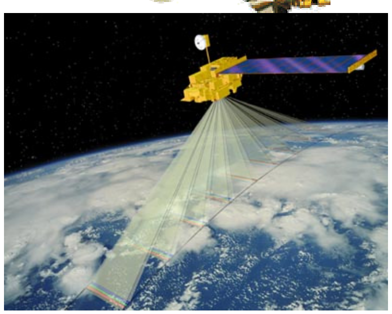


Terra and Aqua



Terra
12/18/99

Aqua
5/4/02

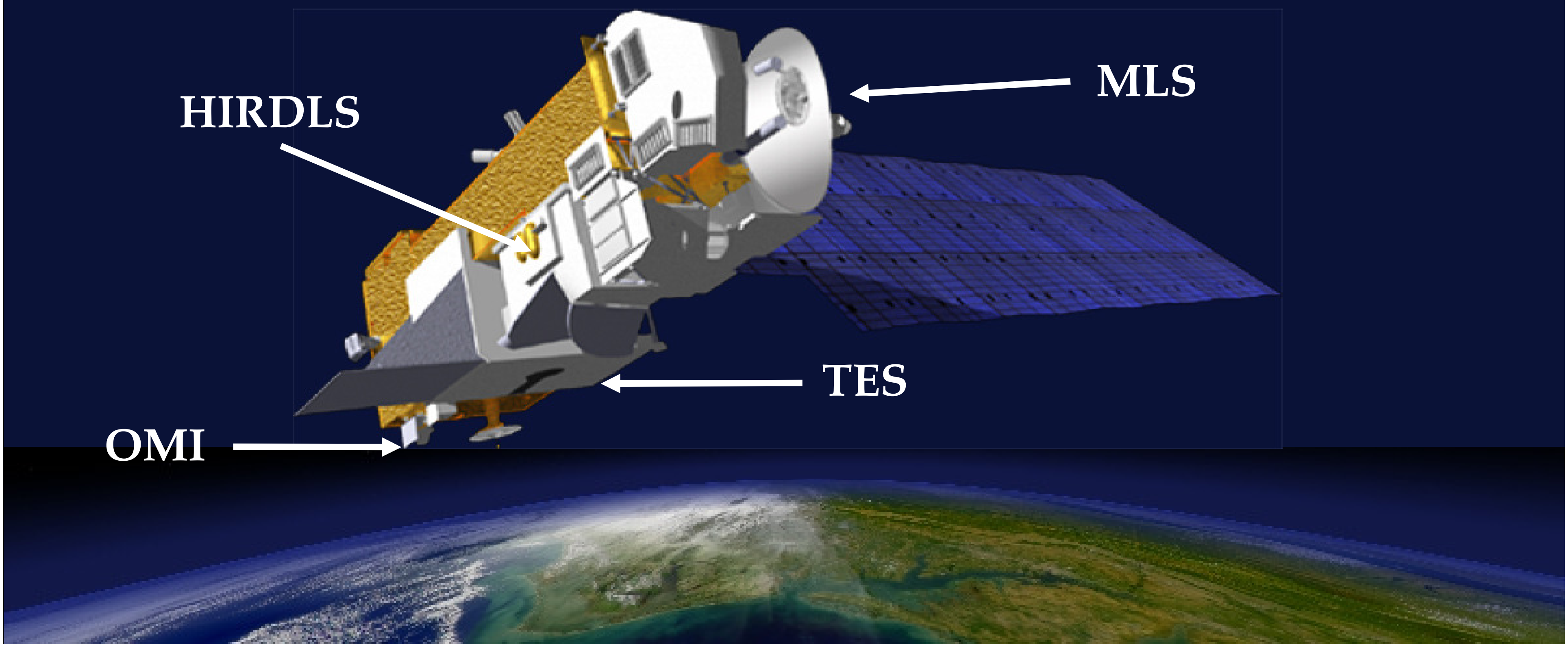


MISR

- NASA, Terra & Aqua
  - launched 1999, 2002
  - 705 km polar orbits, descending (10:30 a.m.) & ascending (1:30 p.m.)
- MODIS Sensor Characteristics
  - 36 spectral bands ranging from 0.41 to 14.385 µm
  - 2330 km swath width
  - Spatial resolutions: (250-1000m)
- MISR Sensor Characteristics
  - 4 spectral (0.446-0.867um)
  - 9 cameras
- CERES Sensor characteristics
  - Total shortwave <5 µm
  - Total longwave > 5 µm

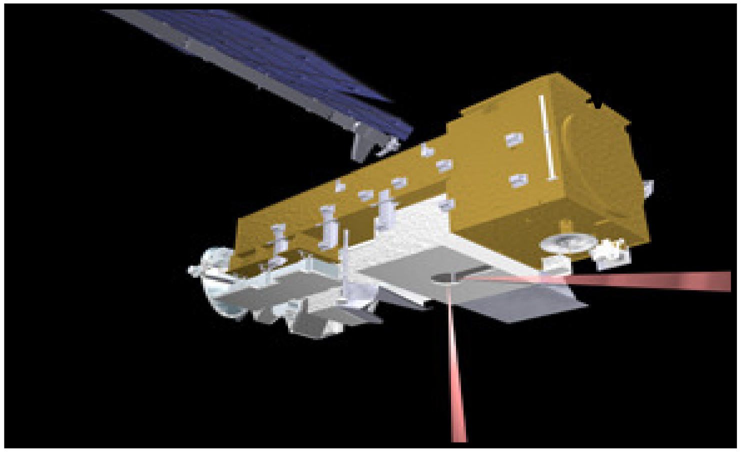
EOS Aura

- Third of the big EOS platforms (Terra and Aqua are the other two)
- Orbit: Polar: 705 km, sun-synchronous, 98º inclination, ascending 1:45 PM equator crossing time. AURA follows AQUA in the same orbit by 15 minutes.
- Launched VAFB, July 15, 2004
- Six Year Spacecraft Life
- Main science objectives: stratospheric ozone recovery; air quality



TES

- Tropospheric Emission Spectrometer
  - PI: R. Beer, JPL
  - Nadir and limb Fourier transform emission spectrometer
    - Limb mode, 2.3 km vert. res., vertical coverage 0-34 km
    - Nadir mode, 5.3x8.5 km
    - Spectral Coverage 3.3 - 15.4 µm
  - Tropospheric and stratospheric T, O_3, H_2O, CH_4, CO, HNO_3, NO_2
  - Aerosols, Temperature
  - Research Products (mostly limb)
    - H_2O_2, HDO, ethane, acetylene, formic acid, acetone, ethylene, nitric oxide, ammonia, HCN, SO_2, H_2S, SF_6, OCS, CFC's, HCl, CCl_4, $ClONO_2$

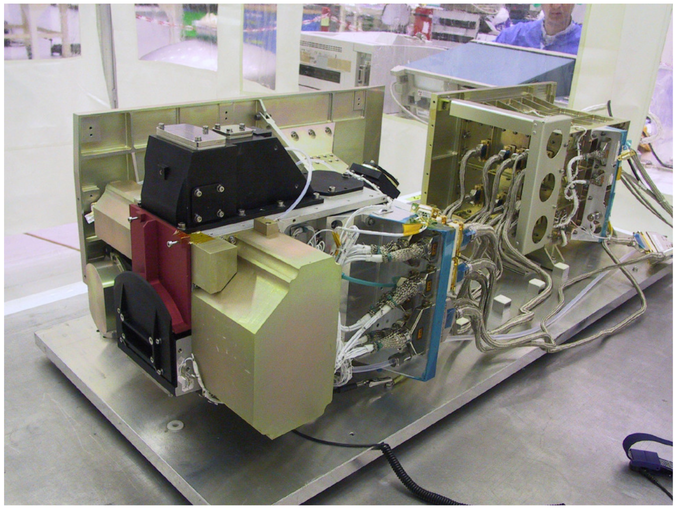


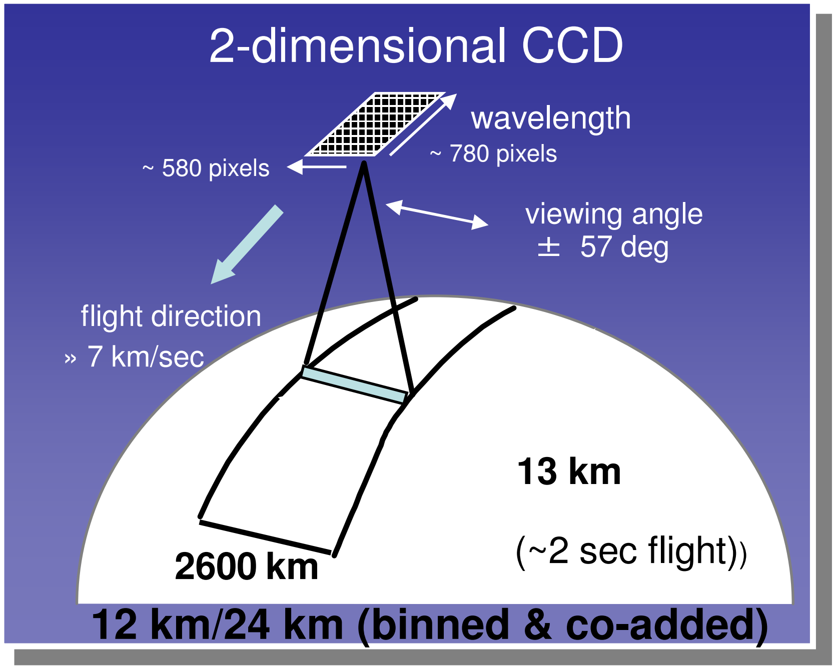
OMI

Ozone Monitoring Instrument

- Joint Dutch-Finish Instrument with Duch/Finish/U.S. Science Team
  - PI: P. Levelt, KNMI
  - Nadir solar backscatter spectrometer
    - 280-500 nm
    - 13x24 km footprint
    - Swath width 2600 km
  - Radicals: Column O_3, NO_2, BrO, OClO
  - O_3 profile ~ 5 km resolution
  - Tracers: Column SO_2 , HCHO
  - Aerosols (smoke, dust and sulfates)
  - Cloud top press., cloud coverage
  - Surface UVB
  - Tropospheric ozone residual

  (when combined with MLS or HIRDLS)

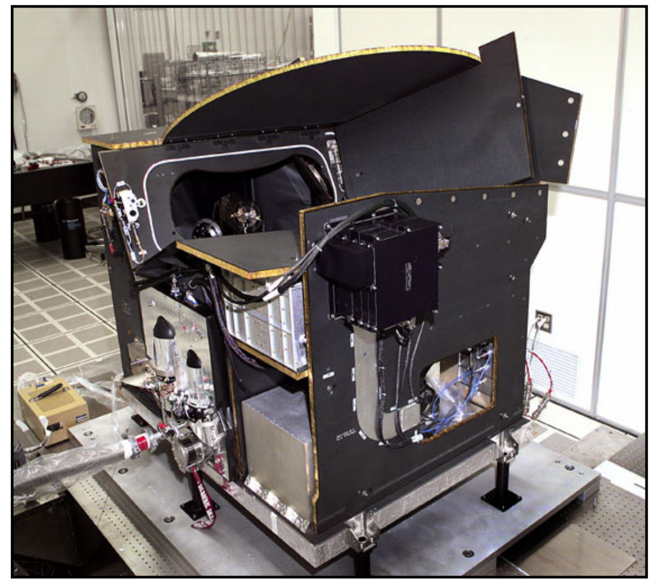




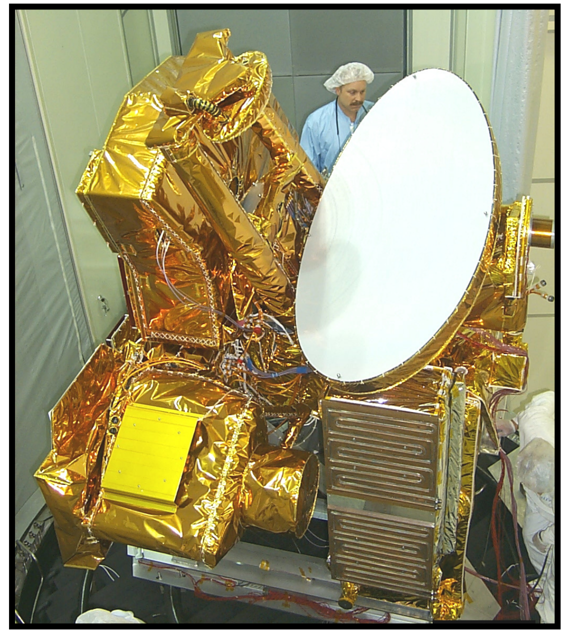
HIRDLS

High Resolution Dynamics Limb Sounder

- Joint UK-US instrument
  - Co-Pis: J. Gille, NCAR & U. of Col.; J. Barnett, Oxford
- Limb emission IR, high horizontal resolution scanner
  - 6.12 - 17.76 µm range
  - 1 km vertical, 500 km cross track
  - Swath 500-3,000 km wide, 6 positions
- Stratospheric radicals: O_3, NO_2
- Stratospheric Reservoirs: $ClONO_2$, HNO_3,N_2O_5
- Tracers: CFC-11, CFC-12, CH_4, H_2O, N_2O
- Temperature, Geopotential height
- Aerosols Extinction Coef. (4 channels)
- Upper tropospheric cirrus



MLS



Microwave Limb Sounder

- PI: J. Waters, JPL
- Microwave limb emission

118 GHz - 2.5 THz

  - Vertical resolution 1.5-3 km, 3x200 km horizontal

- Data Products
  - Stratospheric Radicals: O_3, OH, HO_2, ClO, HOCl, BrO.
  - Stratospheric Reservoirs: HCl, HNO_3.
  - Tracers: N_2O, H_2O, SO_2,CO, HCN

  Upper tropospheric O_3, H_2O, Cirrus ice, HCN, and CO.

  - Temperature and geopotential height.