Use of Satellite Data for Air Pollution Research

Regional Planning Organization's

Discussion Group

26 June 2002

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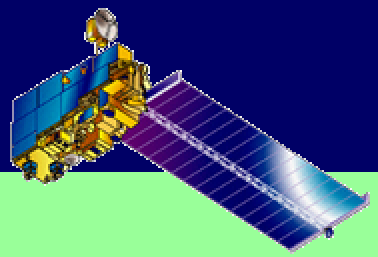
Use of Satellite Data for Air Pollution Research

- Overview of NASA Earth Science Enterprise (ESE) Applications Program
- Overview of Satellite Remote Sensing Instruments
- Current State of the Measurements
- Potential Applications in Air Quality
- Potential Future measurements

Earth Science in the Nation's Service

Extend the use of Earth science knowledge, data, and technology to support our partners' decision systems and management responsibilities.



Federal Agencies

Local Governments

Universities

NASA Centers

Scientists

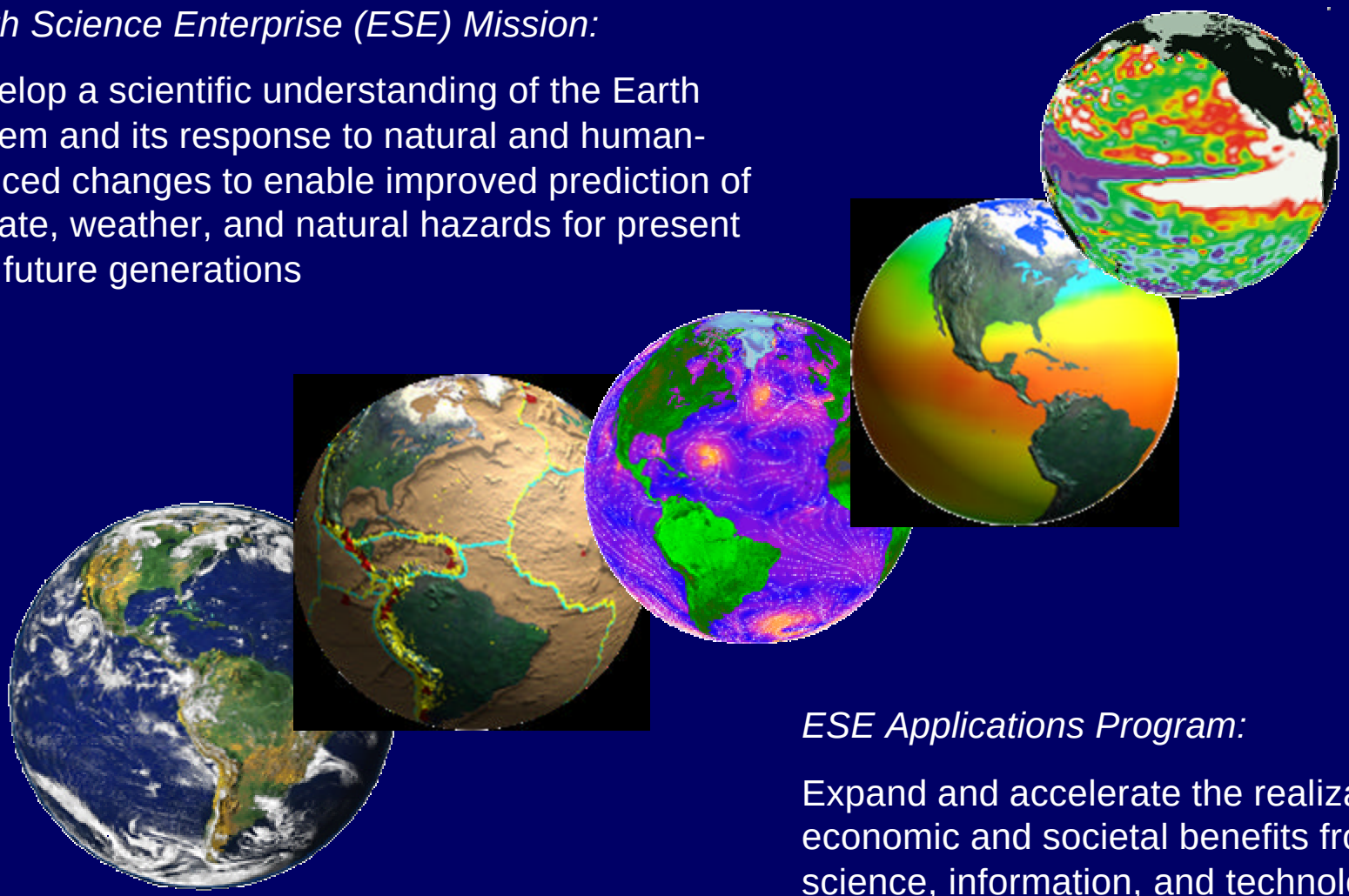
State Governments

International Partners

NASA's Earth Science Enterprise

Earth Science Enterprise (ESE) Mission:

Develop a scientific understanding of the Earth system and its response to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations



ESE Applications Program:

Expand and accelerate the realization of economic and societal benefits from Earth science, information, and technology.

Decision Support Cycle

NASA ESE Contributions:

ESE Partners' Prediction Models

Decision Support Systems

Data Distribution/ Management

EOS Data Information System

Standards-based Products

ESE/EOS Information Products

Data Sources/ Measurements
- Public
- Private
- International

Earth Observing System

Decision Support: Serving Our Nation

Applying NASA's system engineering approach and ESE results to support decision-making tools, predictions, and analysis for policy and management decisions.

Science Models

GTEC, MOM3, GISS GCM, CCSM, HadCM3, ROMS, …

Data

Measurements

SeaWinds, MOBY, Terra, MAMS, Aqua, AVIRIS, Aura, …

Predictions

High Performance Computing, Communication, & Visualization

Observations

Decision Support Systems

HAZUS, AWIN, NREL, CMAQ, …

Owned and operated by Partners

Value & benefits to citizens and society

Policy Decisions

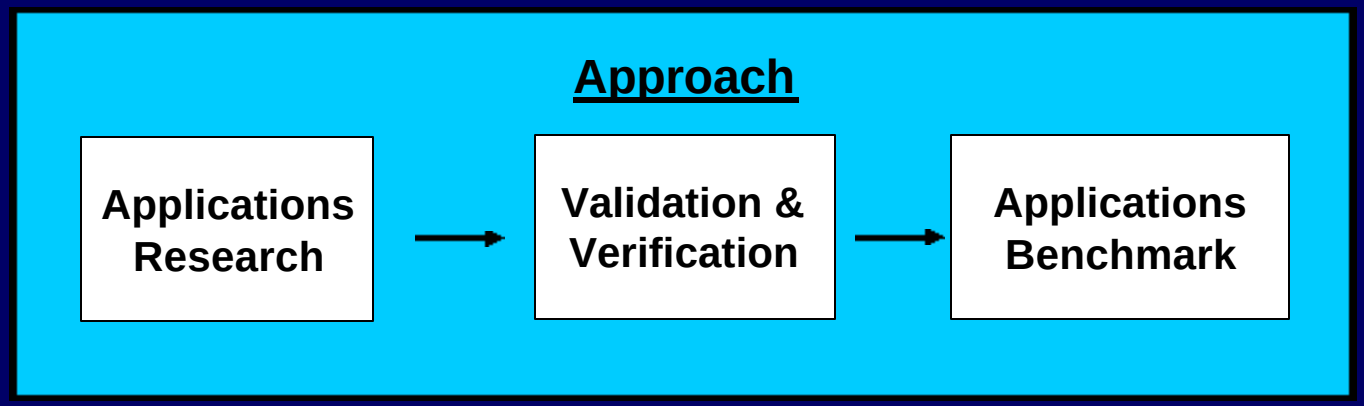
Management Decisions

Inputs *Outputs* *Outcomes* *Impacts*

National Application Themes

- Energy Forecasting
- Carbon Management
- Agricultural Competitiveness
- Aviation Safety
- Community Growth
- Homeland Security
- Public Health
- Disaster Management/Preparedness
- Coastal Management
- Invasive Species Management
- Water Management
- Air Quality

National Applications: Approach



Applications Research

- Extend scientific findings to requirements of operational environments
- Identify designs for information and data products to (enable use by automated systems)

Verification and Validation Reports

- Benchmark approach and results of technology & operational technique
- Identify improvements for information products

Applications Benchmark

- Document prototypes, guidelines, and procedures for potential operational implementation

Air Quality Management:
Clean Air Standards and Air Quality Forecasts

DRAFT

Earth System Modeling Framework Forecasts by 2012:
Robust emissions control planning and management. Routine warnings of elevated pollution episodes. Accurate 3-day air quality forecasts.

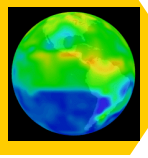
Prevent 15,000 premature deaths/year
Mitigate $5B- $10B/yr crop damage

Primary Partners:

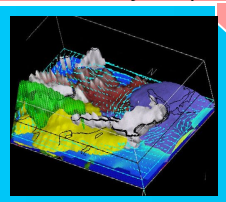
EPA NOAA

Socioeconomic Impact

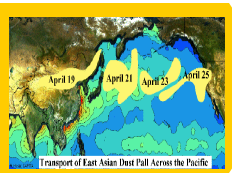
- •Simultaneous, high time & space resolved multi-pollutant (O3, CO, NOx, SO2, HCHO, aerosol) data enables sound decision making



Outcomes: Accurate (regional, multi-day) pollution forecasts. NAAQS planning and mitigation based on validated models.



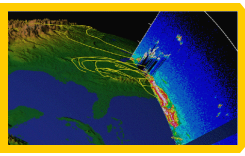
- • Couple chemistry & aerosol models
- • Assimilate satellite data for trace constituents



Outcomes: Reassess ozone and precursor transport across state boundaries. Implement air quality strategies & related development policy based on detailed data and models.

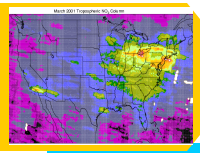
Impacts: Reduce asthma & lung related diseases. Improve visibility. Improve crop health & yields.

- • Monitor long range transport of mineral and pollution aerosol (CALIPSO)

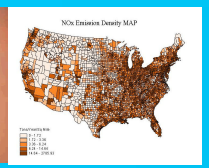


Outcomes: Determine source and destination of long range dust and pollutants. Route airplanes. More accurate forecasts of haze & pollution episodes. Warn hospitals & farmers.

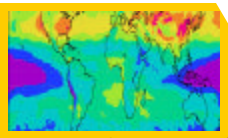
- •Ozone, SO_2 & NO_2 profiles & regional transport (Build on TOMS & GOME)
- •Continental inflow/outflow



Outcomes: Quantify contributions of physical & chemical processes to pollutant concentrations. Extend ozone forecasting to regional transport for urban to rural areas.



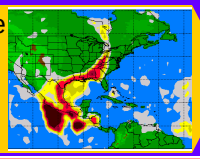
- • Improve boundary conditions (ozone residual)
- •Validate measurements



Outcomes: Assess effects of emissions control options. Evaluate development options and emissions strategies to set policies and construct attainable State (air quality) Implementation Plans.

Impacts: Reduce impaired lung function and use of medications. Reduce hospital admissions and lost work/school days.

- •Large scale transport of aerosols (TOMS aerosol index)



Outcomes: Evaluate exceptional events for effect on NAAQS violations; provide exceptions for attainment.

CMAQ / Forecasts:
State/regional planning.
Same-day air quality predictions.

Current trajectory:

Steady improvement in documenting the chemical content of the lower atmosphere,

Steady improvement in the physical accuracy of modeled processes for pollution episode warnings.

Improved capabilities to air quality management tools to assess, plan and implement emissions control strategies & improve air quality forecasts.

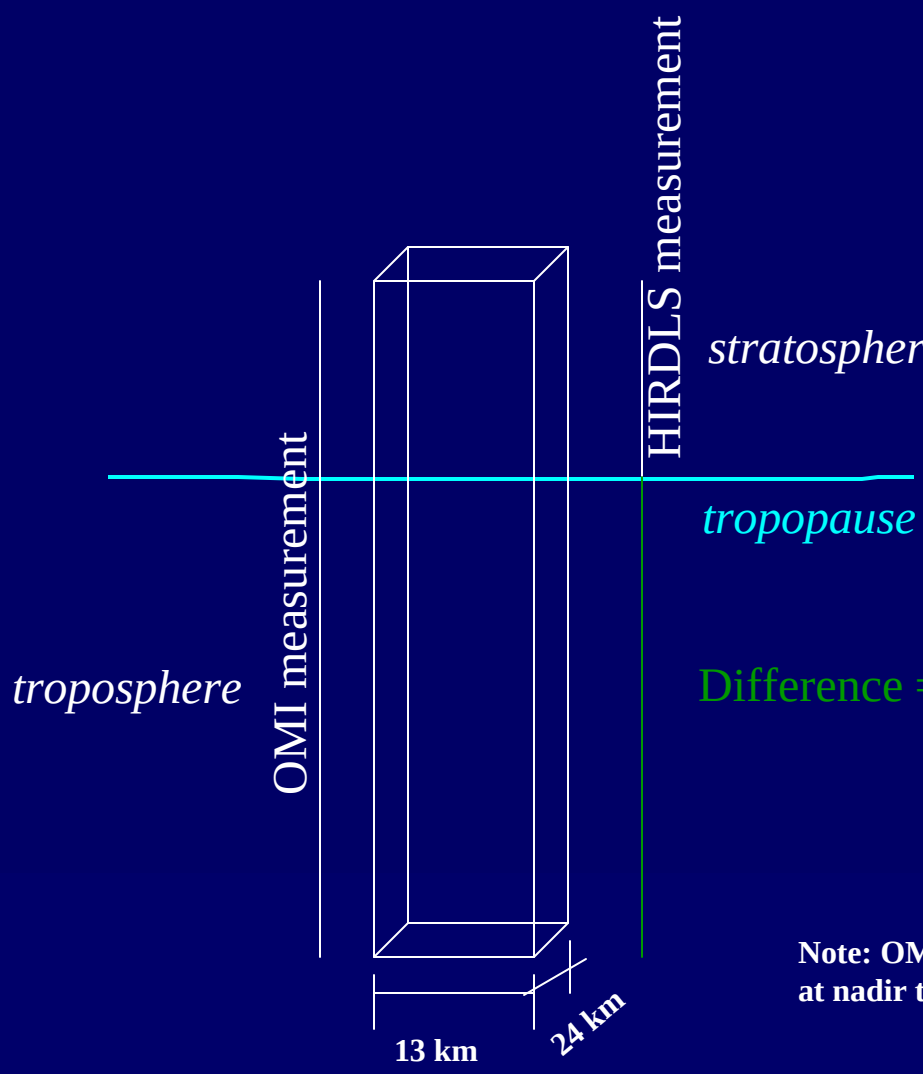
TOMS TERRA SAGE III AQUA AURA Cloud Sat CALIPSO NPOESS

2000 2002 2004 2006 2008 2010 2012

Instrument	Name	Resolution	AQ Parameter	platform
Current and past instruments for tropospheric studies				
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric ChartographY	Daily ~100 km	O_3, NO_2, H_20, BrO, OCLO, SO_2, HCHO, clouds and aerosols	ESA's ENVISAT-1 (2001)
GOME	Global Ozone Monitoring Experiment	Weekly ~100 km	O_3, NO_2, H_20, BrO, OCLO, SO_2, HCHO, clouds and aerosols	ESA-ERS2 (1995----)
MODIS	Moderate Resolution Imaging Spectroradiometer	Daily 10 km	Aerosol optical thickness, aerosol type (sulfate, biomass burning) over land	NASA Aqua (2002) Terra (1999)
MISR	Multi-angle Imaging SpectroRadiometer	Weekly 17.6 km	Aerosol properties (angular radiance dependence)	NASA Terra (1999)
MOPITT	Measurement of Pollution in the Troposphere	Weekly ~100 km	Total column of CO, CH_4 + CO profiles	NASA Terra (1999)
SBUV	Solar Backscatter Ultra-violet Ozone Experiment	Daily ~100 km	O_3	Nimbus-7 (1979-90)
SBUV-2	Solar Backscatter Ultraviolet Ozone Experiment 2	Daily ~100km	O_3	NOAA-9 (1985-present) NOAA -11 (1989-95) NOAA-14(1995---)
TOMS	Total Ozone Monitoring Spectrometer	Daily ~100 km	O_3 aerosol optical depth	Nimbus 7 (1979-92) Meteor (1992-94) ADEOS (1996-97) Earth Probe (1996--)

Instrument	Name	Resolution	AQ Parameter	platform
Future instruments for tropospheric studies scheduled to be launched				
OMI	Ozone Monitoring Instrument	Daily 36 x 48 km	O_3, $S0_2$, $N0_2$	EOS Aura (2003)
TES	Total Emission Spectrometer	Weekly ~100 km	0_3, NO_y, CO H_2O, SO_2, HNO_3	EOS-Aura (2003)
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations		Aerosol density and radiative properties	NASA CALIPSO (2004)
New instrument for tropospheric study to be proposed				
GeoTRACE	Geostationary Observatory for Tropospheric Air Chemistry	Hourly 5x5 km	0_3, NO_y, CO, SO_2, HCHO	Future mission

In general, tropospheric column density is determined using coincident measurements



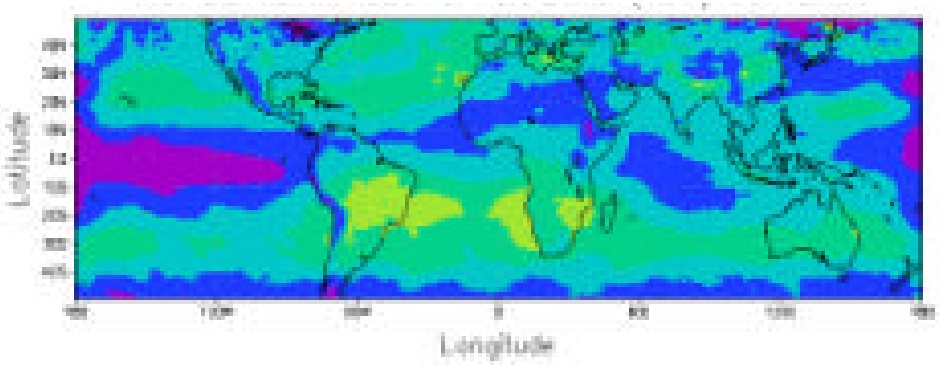
Difference = "tropospheric residual"

Note: OMI horizontal resolution varies from 13 km x 24 km at nadir to about ~100 km at the extreme off-nadir.

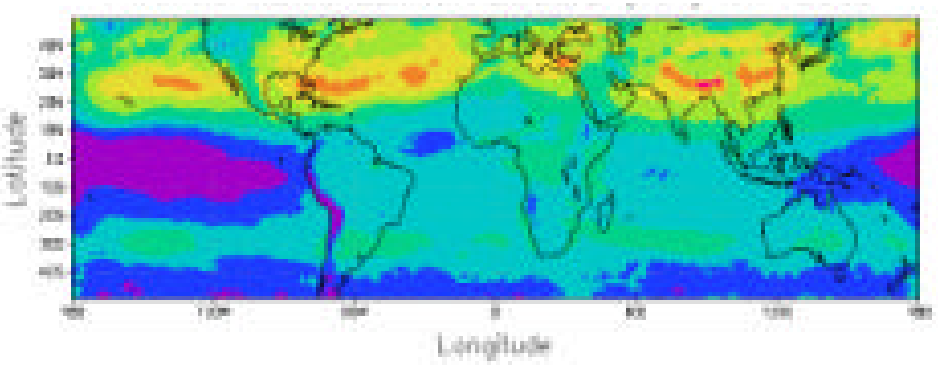
Source: Fishman, J., Chandra, S., Ziemke, J., *Draft OMI-ATBD, Chapter 5: Tropospheric O_3 Residual*, May 2002

2000 Seasonal Tropospheric Ozone Residual (TOR)
(Dec 99 – Nov 00)

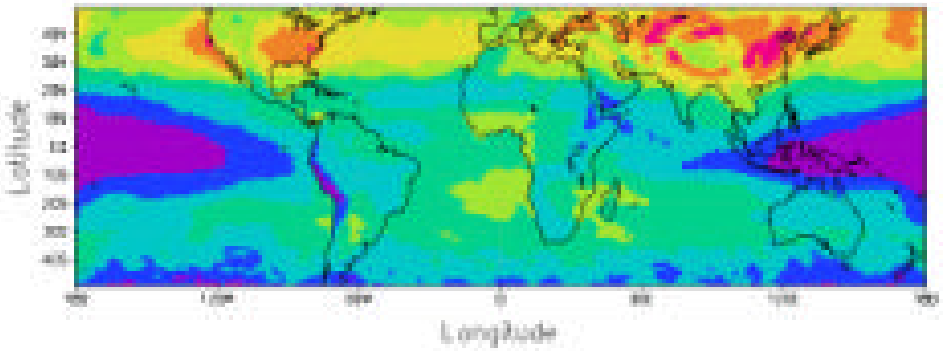
TROPOSPHERIC OZONE RESIDUAL (TOR) DJF 2000



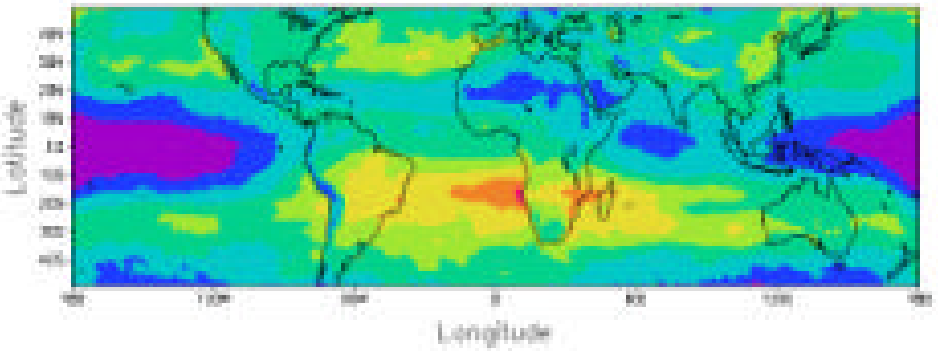
TROPOSPHERIC OZONE RESIDUAL (TOR) MAM 2000



TROPOSPHERIC OZONE RESIDUAL (TOR) JJA 2000



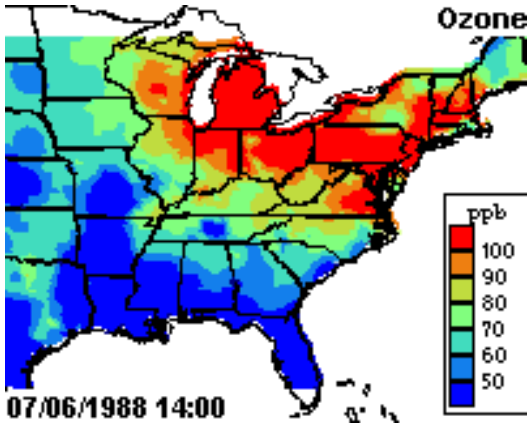
TROPOSPHERIC OZONE RESIDUAL (TOR) SON 2000



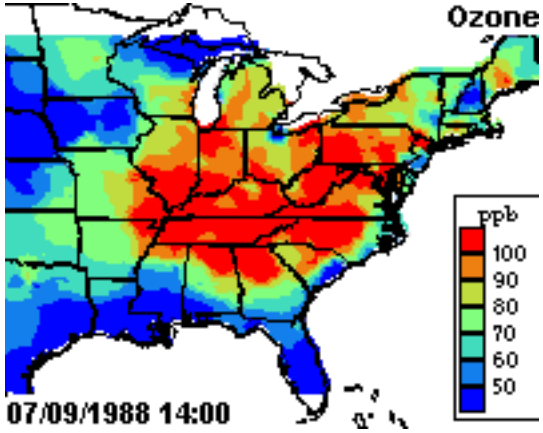
Source: (Fishman and Balok, NASA/LaRC)

Satellite Data Captures Northern Pollution Invading Southern States

July 6: Major Northern Pollution Event Established



July 9: Pollution Episode Develops In South

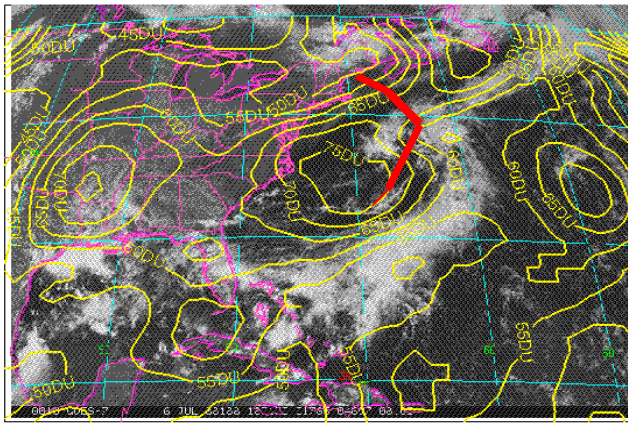


Fishman and Balok [1999, *JGR*, 104, pp. 30,319]

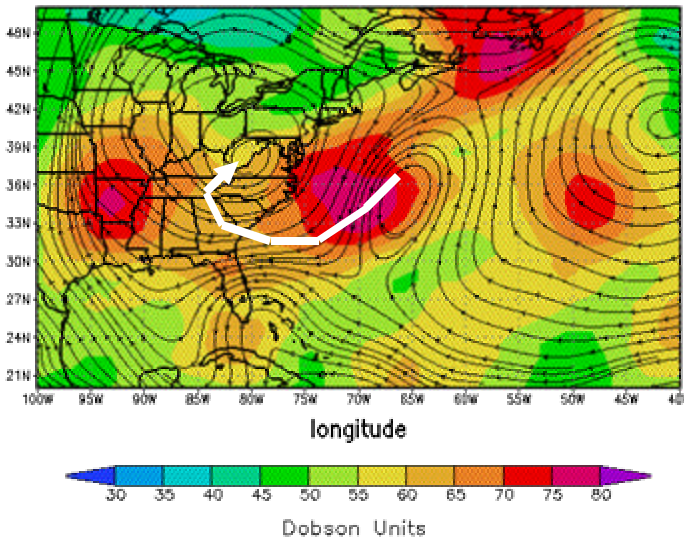
Backward trajectory calculations show air from North contributing to ozone pool

Forward trajectories show eastward transport from ozone maximum off the coast of North Carolina into the South 3 days later

Ozone Builds Off Coast Behind Stationary Front

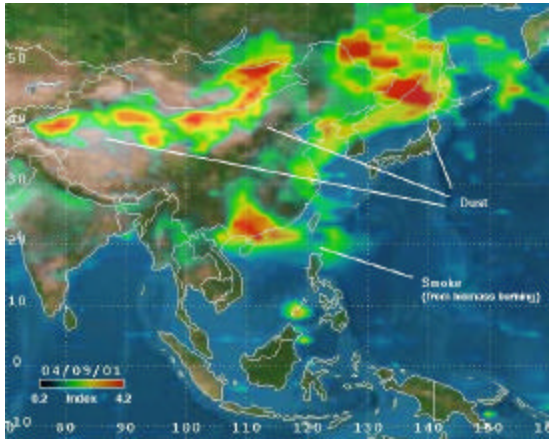


Meteorology Conducive to Widespread Stagnation



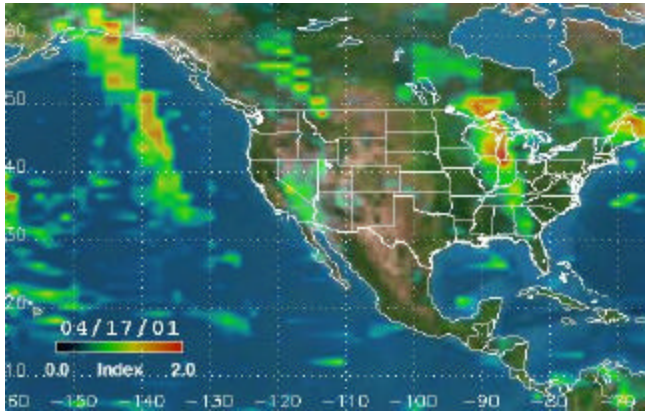
Earth Probe TOMS captures April 2001 China dust storm

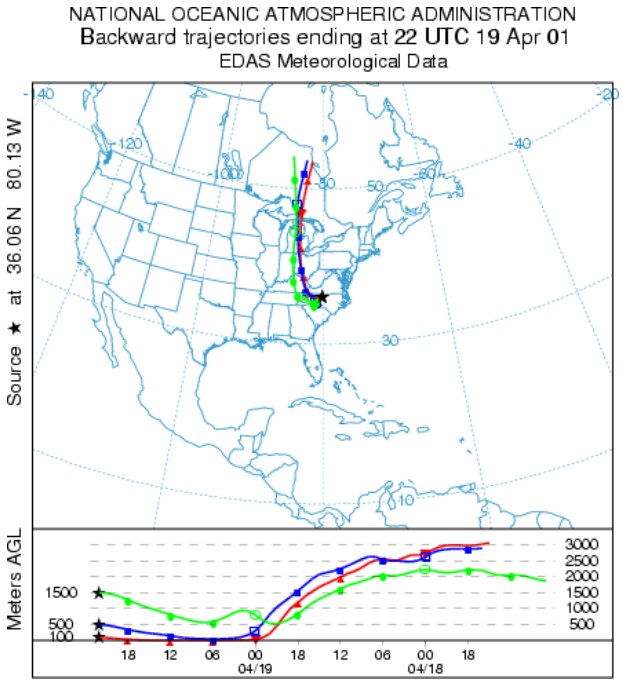
April 7-9: Major dust storm originates over Gobi Desert



Analysis of TOMS AI with 700 mb heights indicates upper level transport of dust across the US

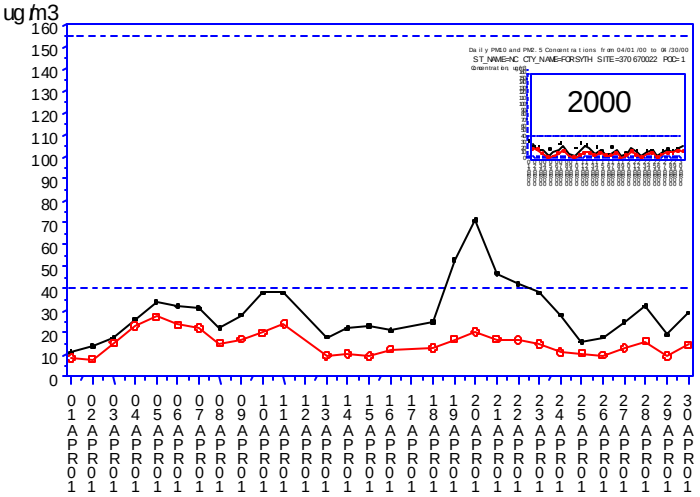
April 11-20: Remnants of dust storm move across the US





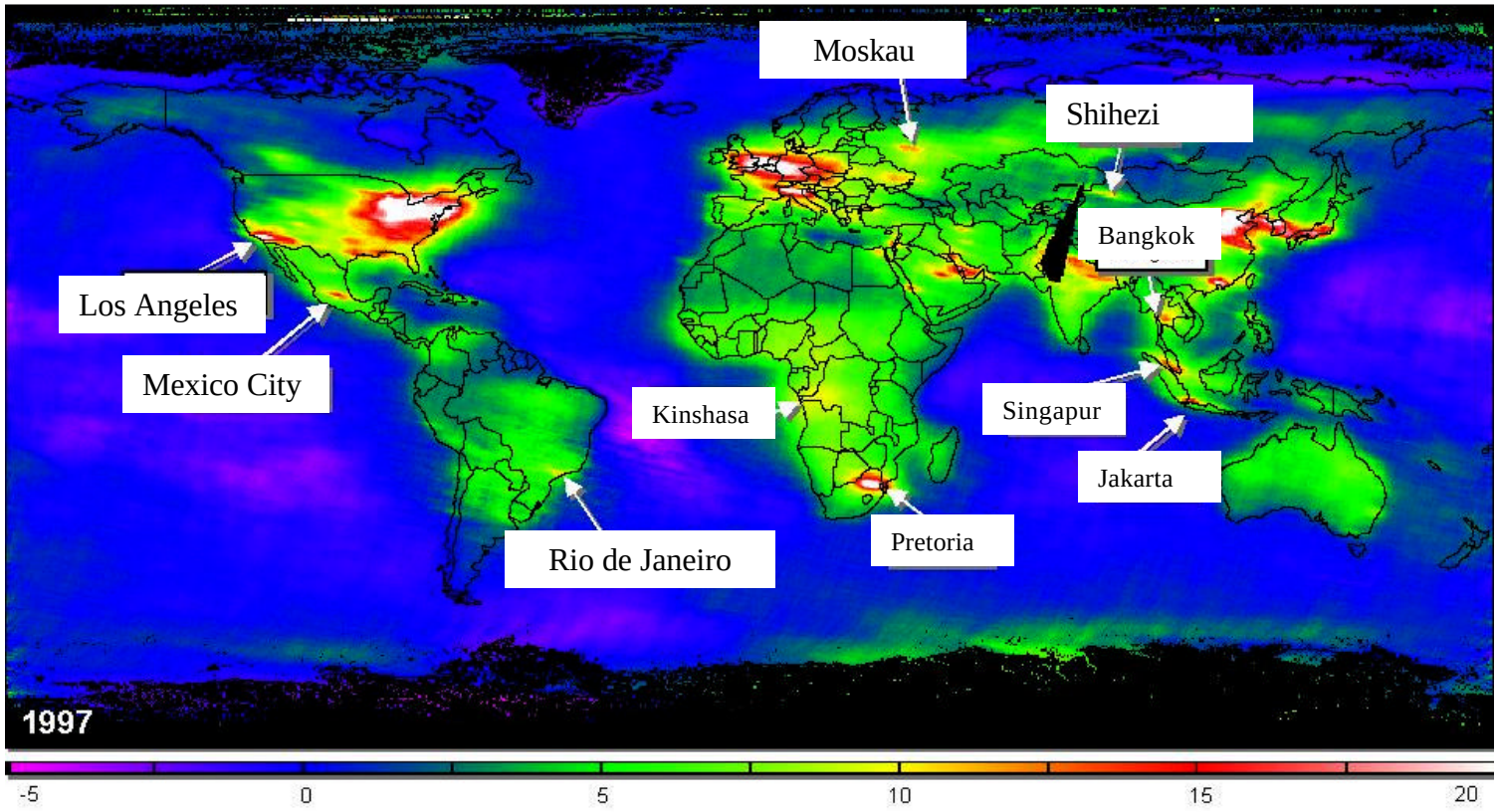
Backward trajectory indicates dust plume seen across Great Lakes on April 17 probable source of elevated PM10 in NC on April 20

Time series of PM10 and PM2.5 Forsyth County, NC April 2001



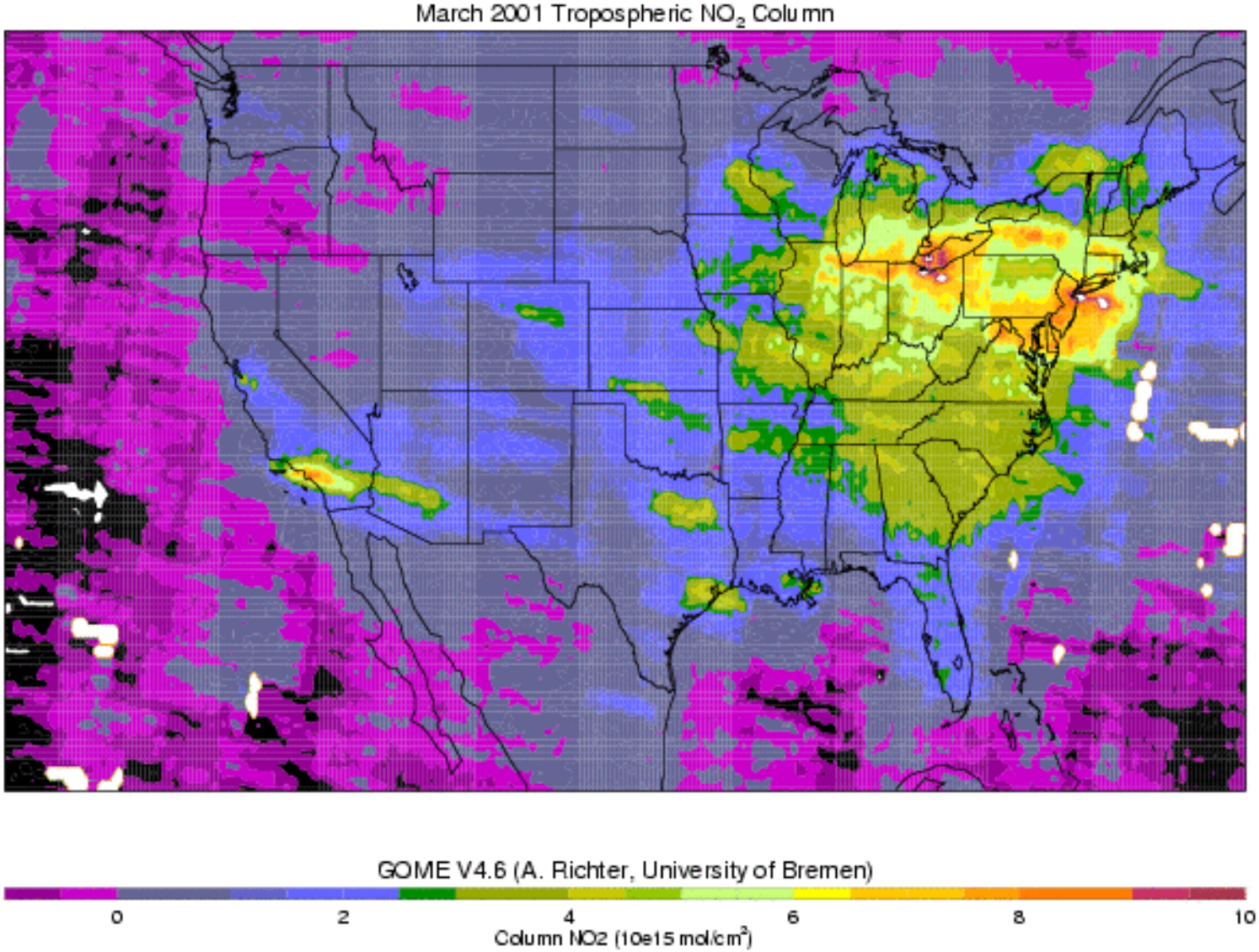
Source: Mintz and Szykman, USEPA/OAQPS, 2002

Average Tropospheric NO_2 Column Density During 1997, GOME

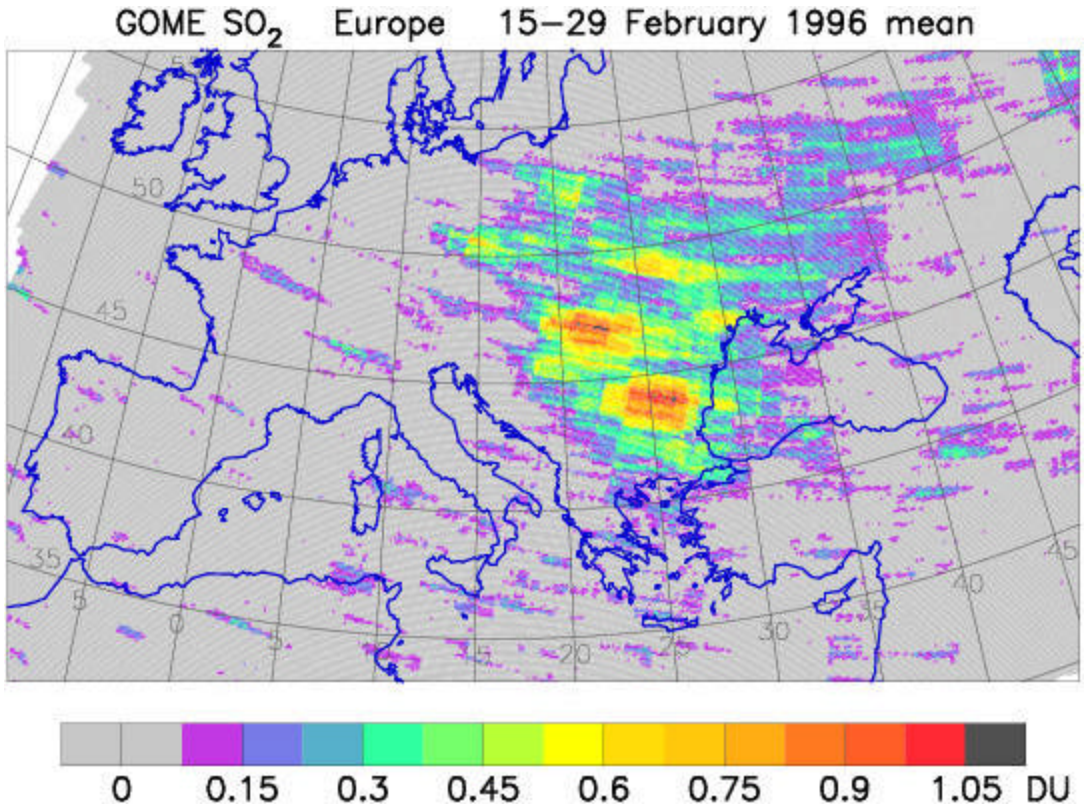


Vertical NO_2 Column Density [10^{14} molec/cm2]

Leue et al. [2001, *JGR*, 106, pp. 5,501]

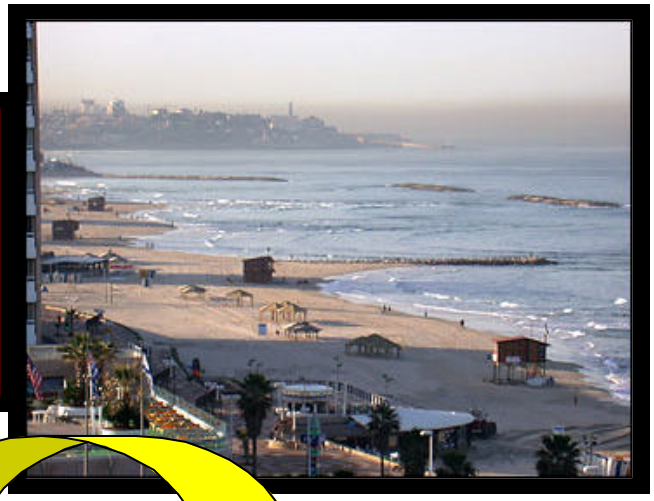

March 2001 Tropospheric NO_2 Column
GOME V4.6 (A. Richter, University of Bremen)
0
2
4
6
8
10
Column NO2 (10e15 mol/cm^2)

Initial SO2 Measurements from GOME capture Anthropogenic Emissions over Europe



Source: A. Richter, University of Bremen

Regional Air Quality Modeling System (RAQMS) Chemical Assimilation/Prediction

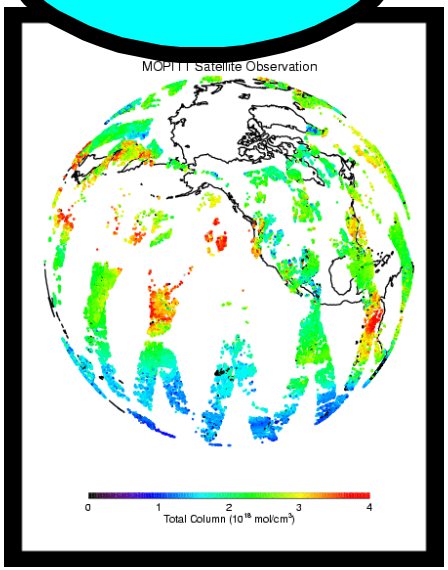


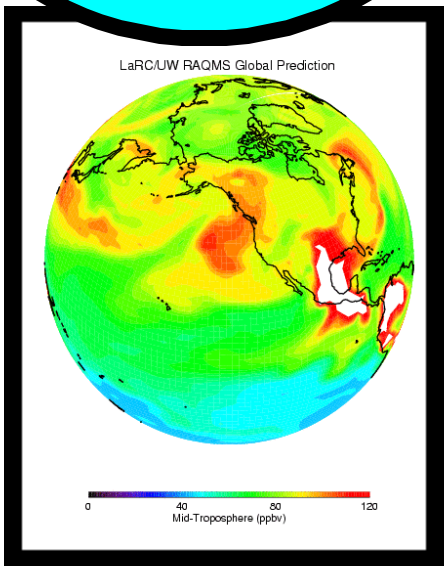
ESE Satellite Products

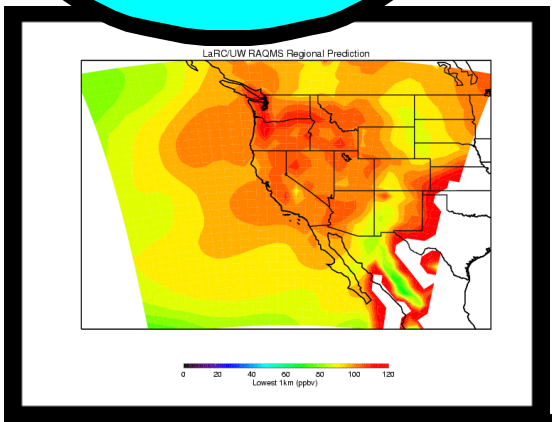
Global Assimilation

Regional Prediction

Public Impact

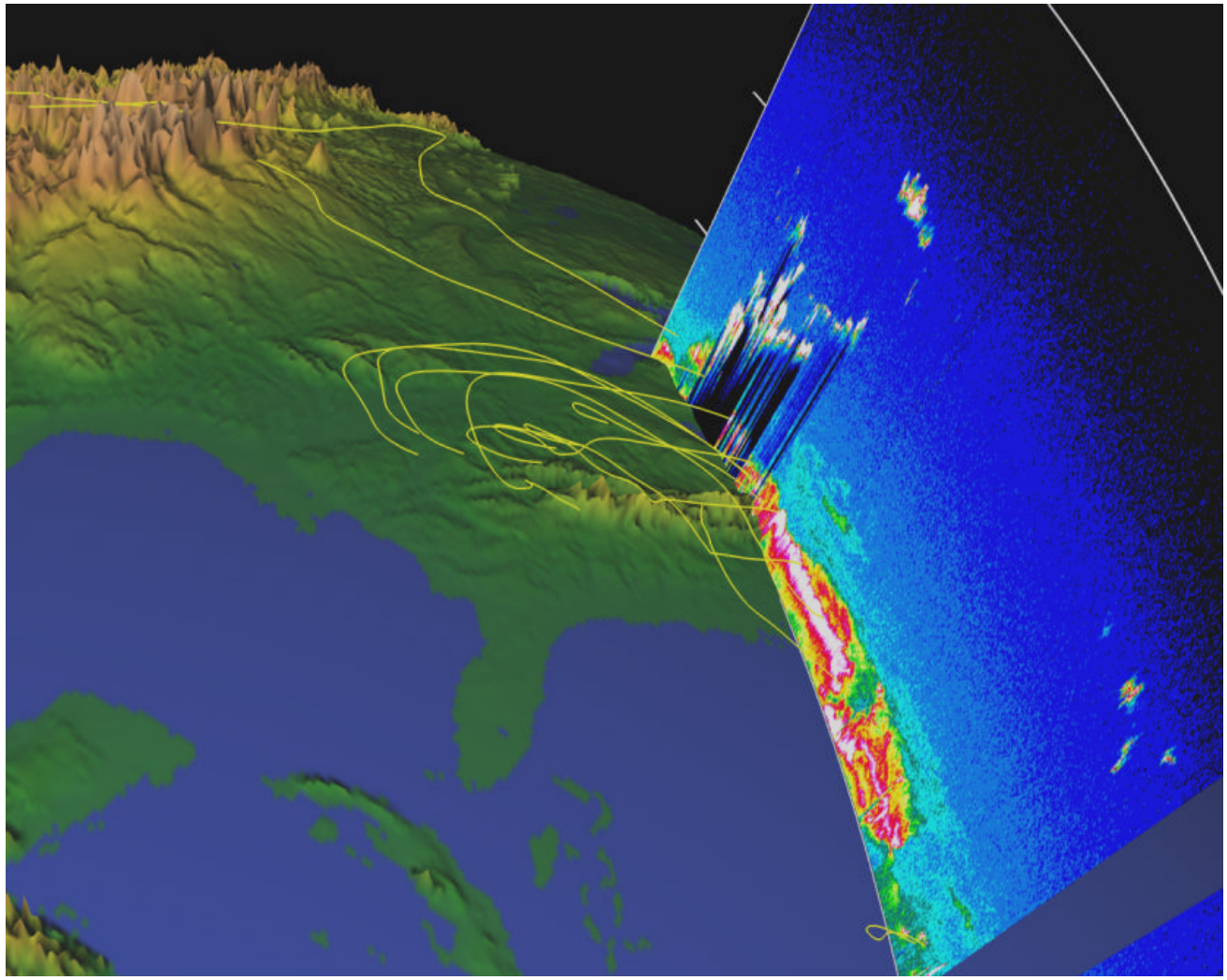






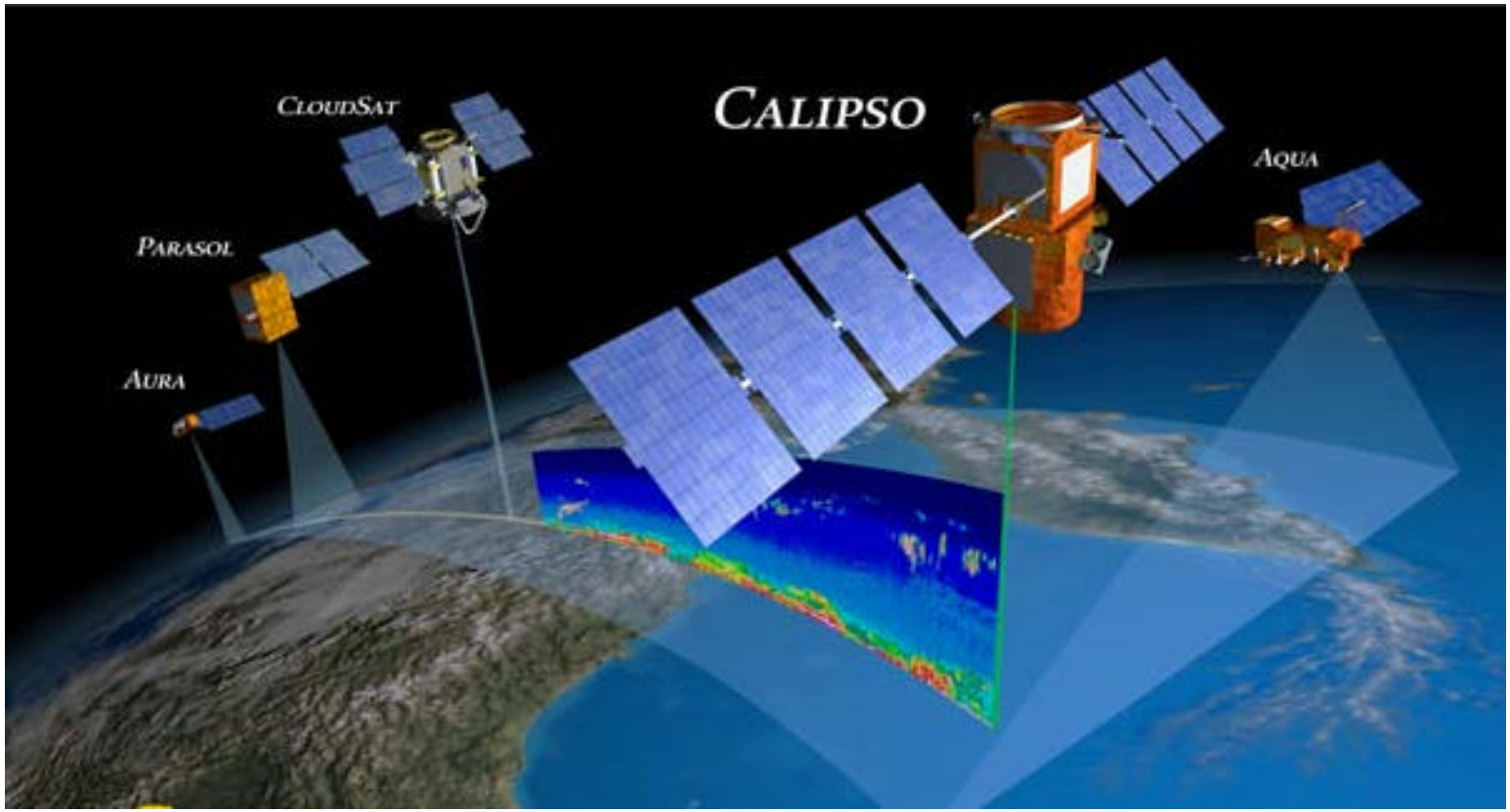
RAQMS can help validate and extend capabilities of air quality models

LITE Data represents future CALIPSO measurements of Clouds and Aerosol across the Eastern USA



NASA LaRC LITE data, September 1994

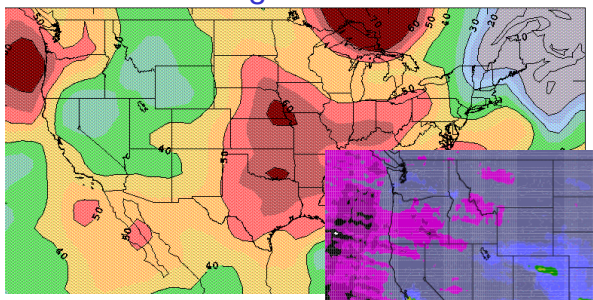
CALIPSO, Aqua and CloudSat will fly in formation to obtain coincident observations of aerosols



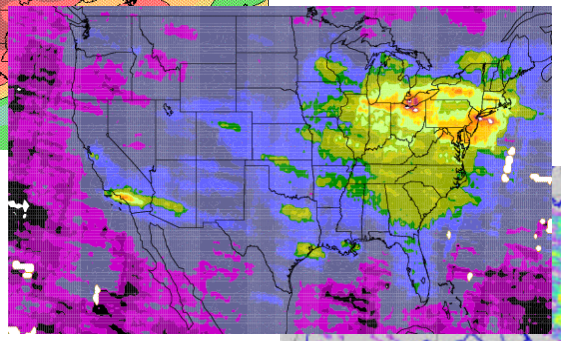
Source: CALIPSO http://www-essp3.larc.nasa.gov/picasso.html

OMI “Tropospheric Residual” Data and Products potentially available in 2004

O_3



NO



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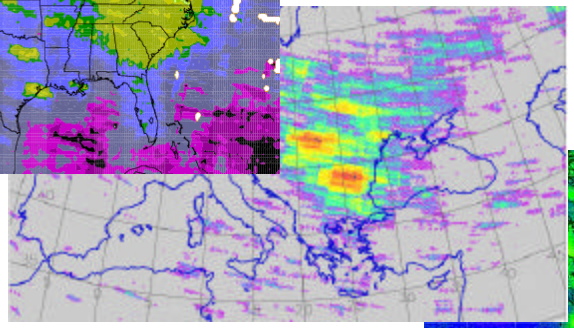
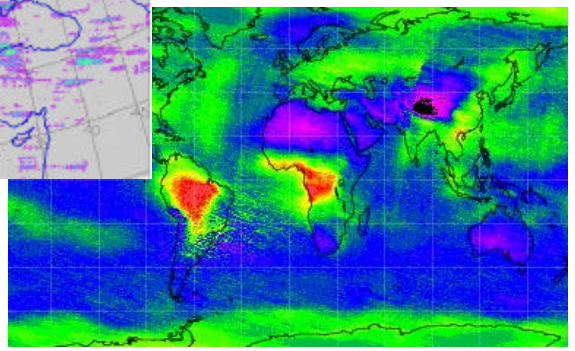


HCHO



Use of satellite data within the Air Quality Community

- EPA and NASA are working together on use of ESE data in Air Quality applications

- ➢ Current data products have coarse temporal and/or spatial resolution, but are becoming a valuable tool in large scale air quality assessments
- ➢ Near real-time data not routinely available, work underway for future near real-time products
- ➢ Current scientific data archive established for researchers – need input from air quality community on useful data and products

Use of satellite data within the Air Quality Community

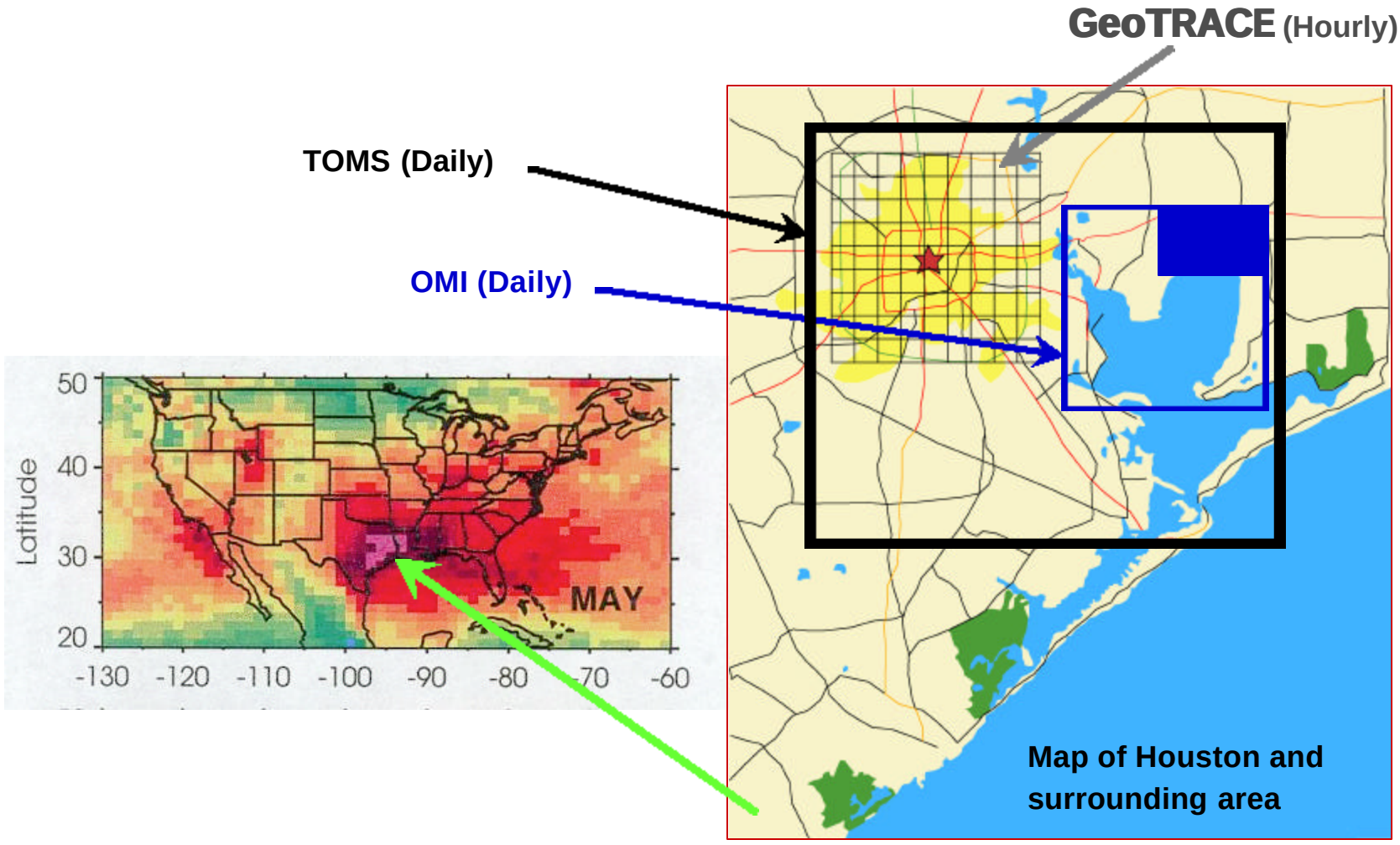
- Satellite data cover vast areas, and remote, non-urban regions

➢ Can provide boundary conditions for air quality models

➢ Can help assess continental and regional transport

➢ Can verify and improve emission inventories

Comparison of Pixel Sizes and Measurement Frequency for Different Satellites



GeoTRACE *is a mission concept to investigate the effects of urban and regional emissions, weather, and chemistry on the global pollutants: carbon monoxide, ozone, and aerosols.*

From the unique perspective of geostationary orbit, **GeoTRACE** provides measurements that

- are **time resolved** (hourly).
- measure key tropospheric **trace constituents** (O_3, CO, NO_2, SO_2, aerosol optical index, and others).
- have **excellent spatial** resolution (5 km x 5 km).
- occur **simultaneously** over continental or larger regions (domain is continental to full Earth disk).