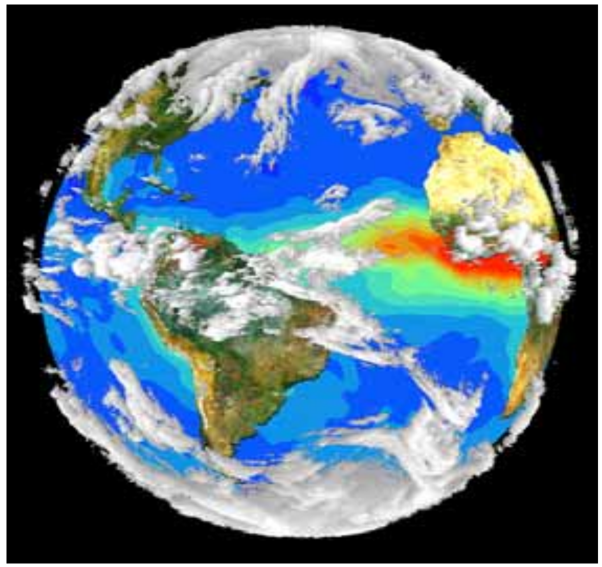
Multi-Sensory Data Integration for Air Quality Science, Management and Policy



Rudolf B. Husar
Washington University, St. Louis, USA

Atmospheric Composition Constellation Workshop
June 15-17, 2009, ESA, Frascati, Italy

Intended contributions to ACC Workshop

1. What values are added by satellites

2. Accuracy issues and barriers to use in air quality

3. Future…

Use of Satellites in Air Quality Management

As formulated by **Rich Scheffe**, Architect of EPA's new monitoring strategy

Satellite applications to AQ:

1. Building a conceptual picture.. e.g. visual evidence of long range transport
2. Characterizing emissions and model support
3. Surrogates for filling gaps in surface observations

However, opinions vary and confusion exists regarding the relevancy of satellites to surface observations

Surrogates for filling gaps in surface observations

As formulated by **Rich Scheffe**, EPA

- During well mixed conditions and pollutants in the BL, satellites can add to ‘gap filling’
- The appeal of filling in surface measurements with satellite data should be tempered by the limited applicability of satellite data to the surface.

Impediments to satellite use in air quality

As formulated by **Rich Scheffe**

- Satellites complement surface/aircraft data and valuable for emission and model improvements, but there are basic incommensurabilities:
  - Temporal: 1 or 2/day; cloud-free daytime only. Poor for diurnal dynamics
  - Vertical: Satellite column is good for mass balance but not for where people are; difficulty of separating stratospheric, tropospheric and BL components

Remote Sensing of Particulate Pollution from Space:
Have we reached the promised land?

2009 AWMA Review by **Ray Hoff**, UMBC, **Sundar Christopher**, UAH

Satellite measurements are important to event detection, transport and model prediction an emission estimation

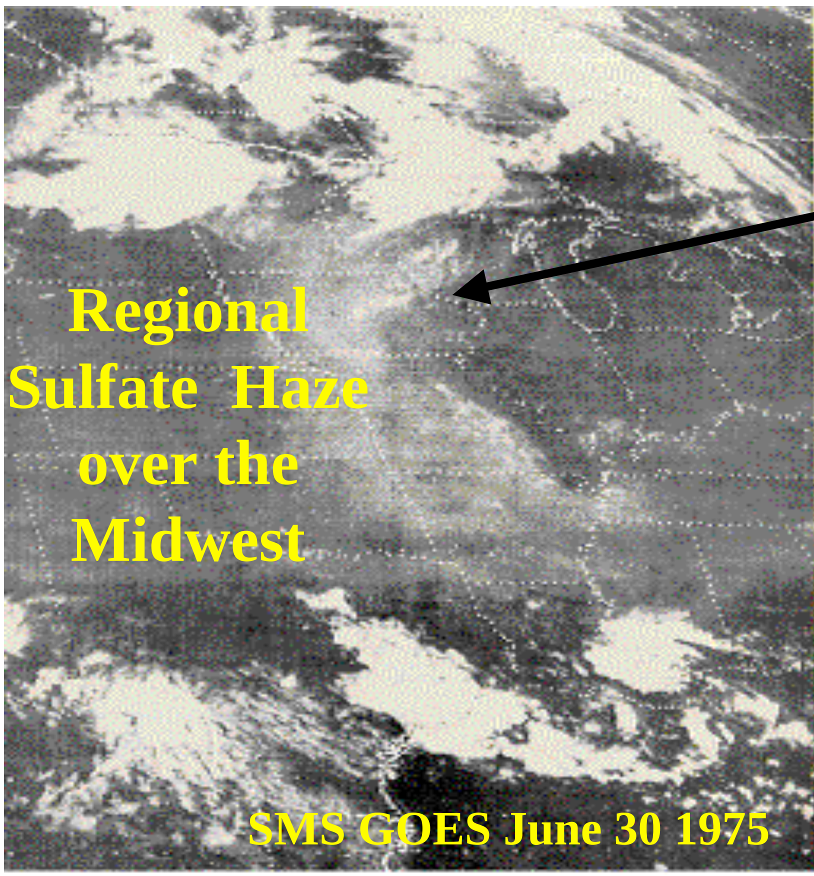
Regulatory compliance is not aided by the current precision of the AOD measurements

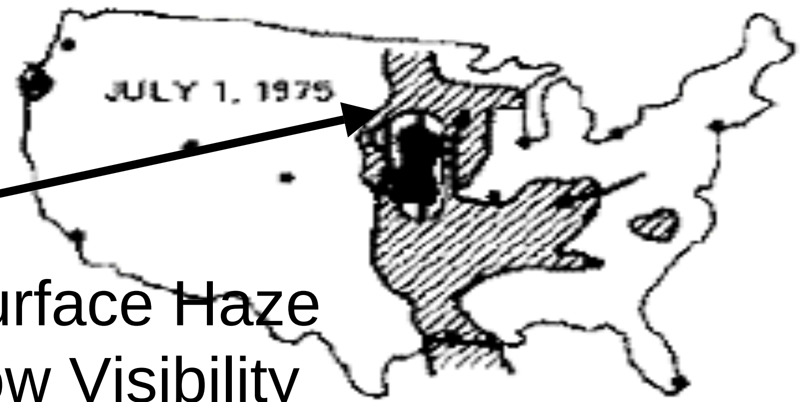
Ground-based measurements, models and satellite measurements should be viewed as an [integrated, reconciled] system, each components of which is necessary to better understand air quality.

Building a conceptual picture..
Visual evidence of long range transport

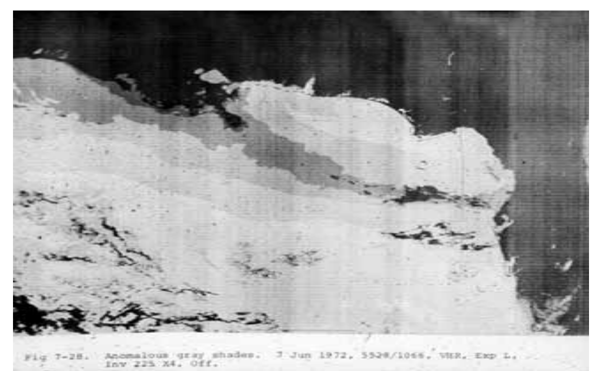
Satellite Detection of Regional Haze, 1976

Lyons W.A., Husar R.B. *Mon. Weather Rev.* **1976**



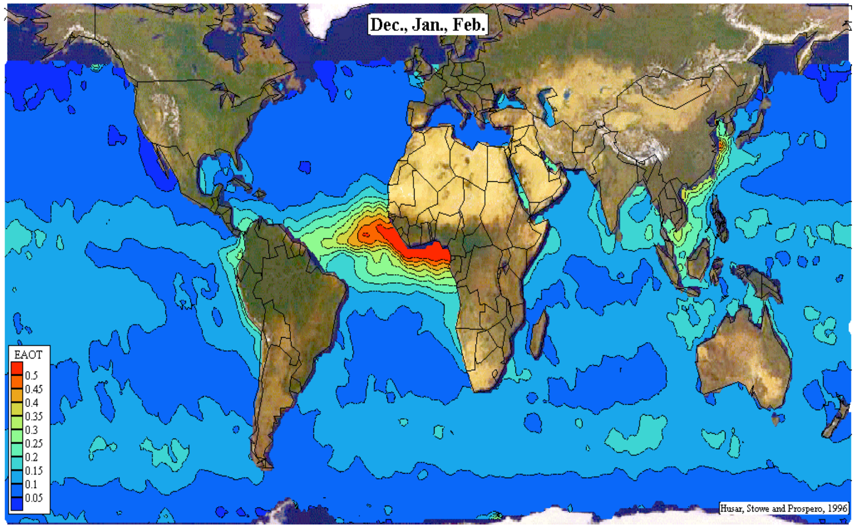


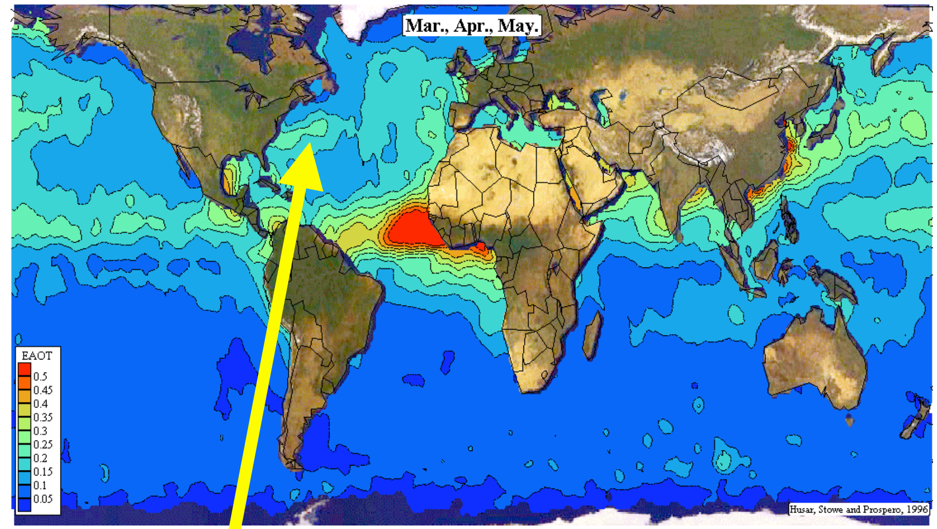
Surface Haze
Low Visibility



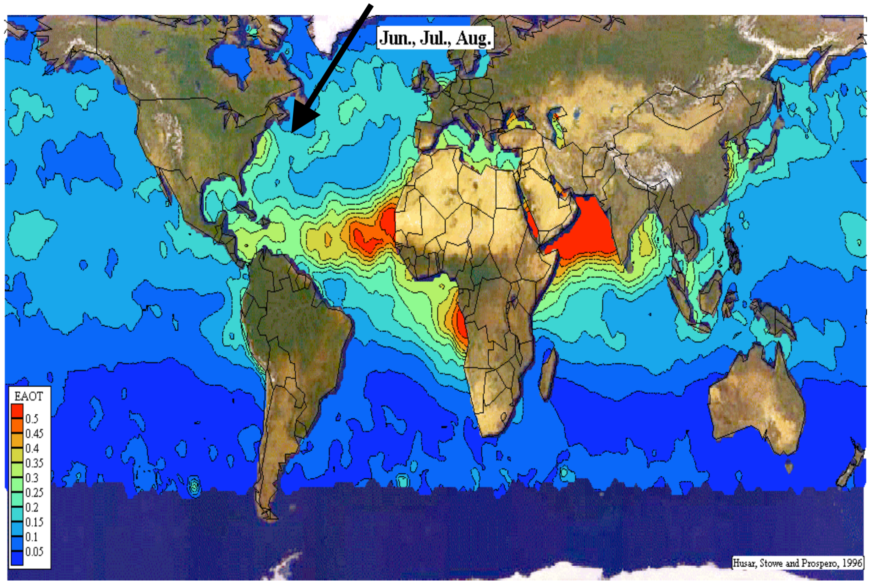
1972: “Anomalous Gray Shades”

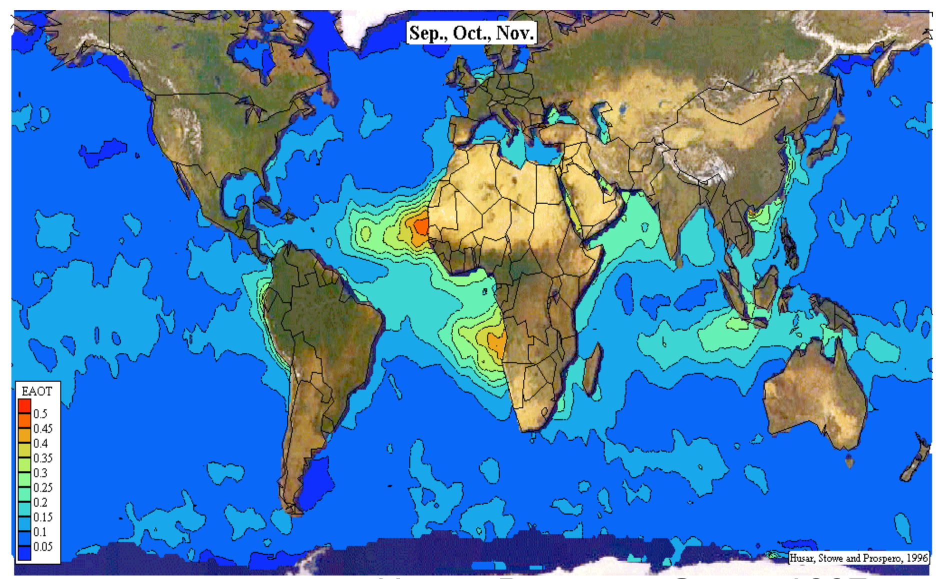
AVHRR satellite optical depth climatology over the oceans, 1988-90





Surprise: Small Sulfate Plume, Spring, Summer Only

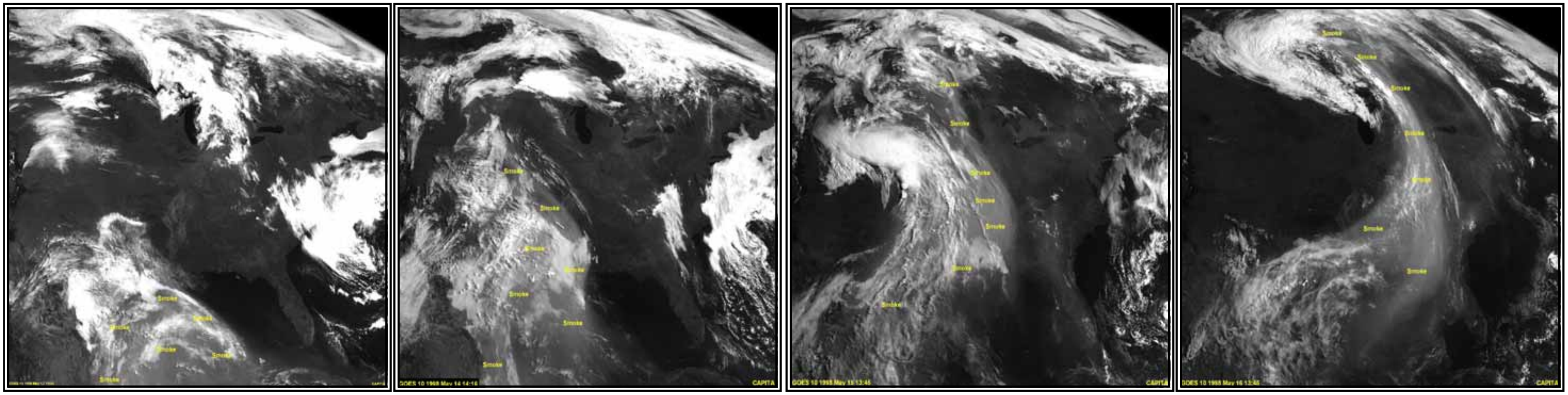




Husar, Prospero, Stove, 1997

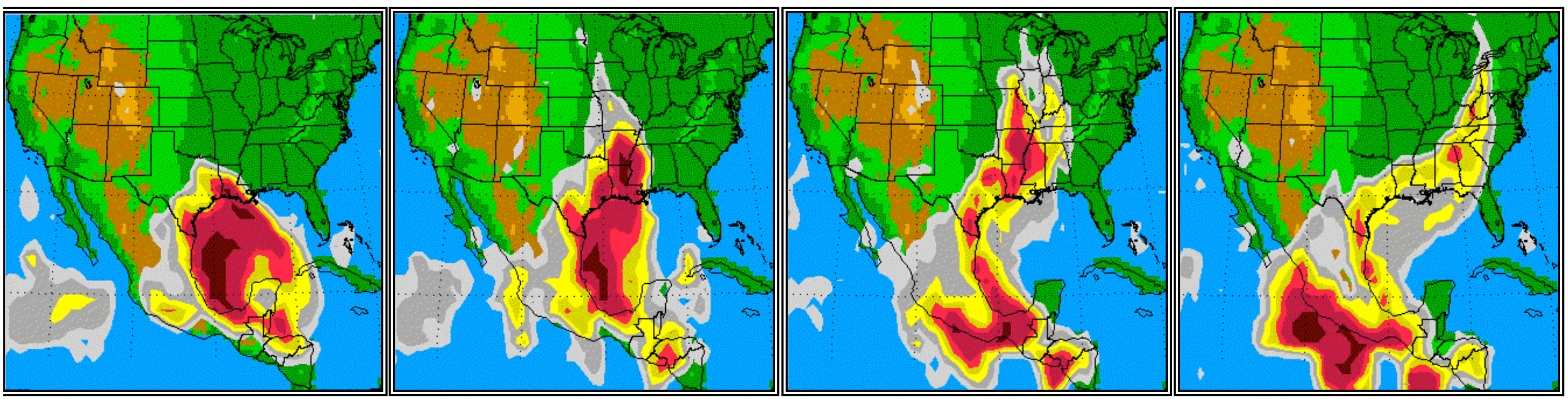
Smoke passes over Eastern North America

GOES 8 Visible Imagery



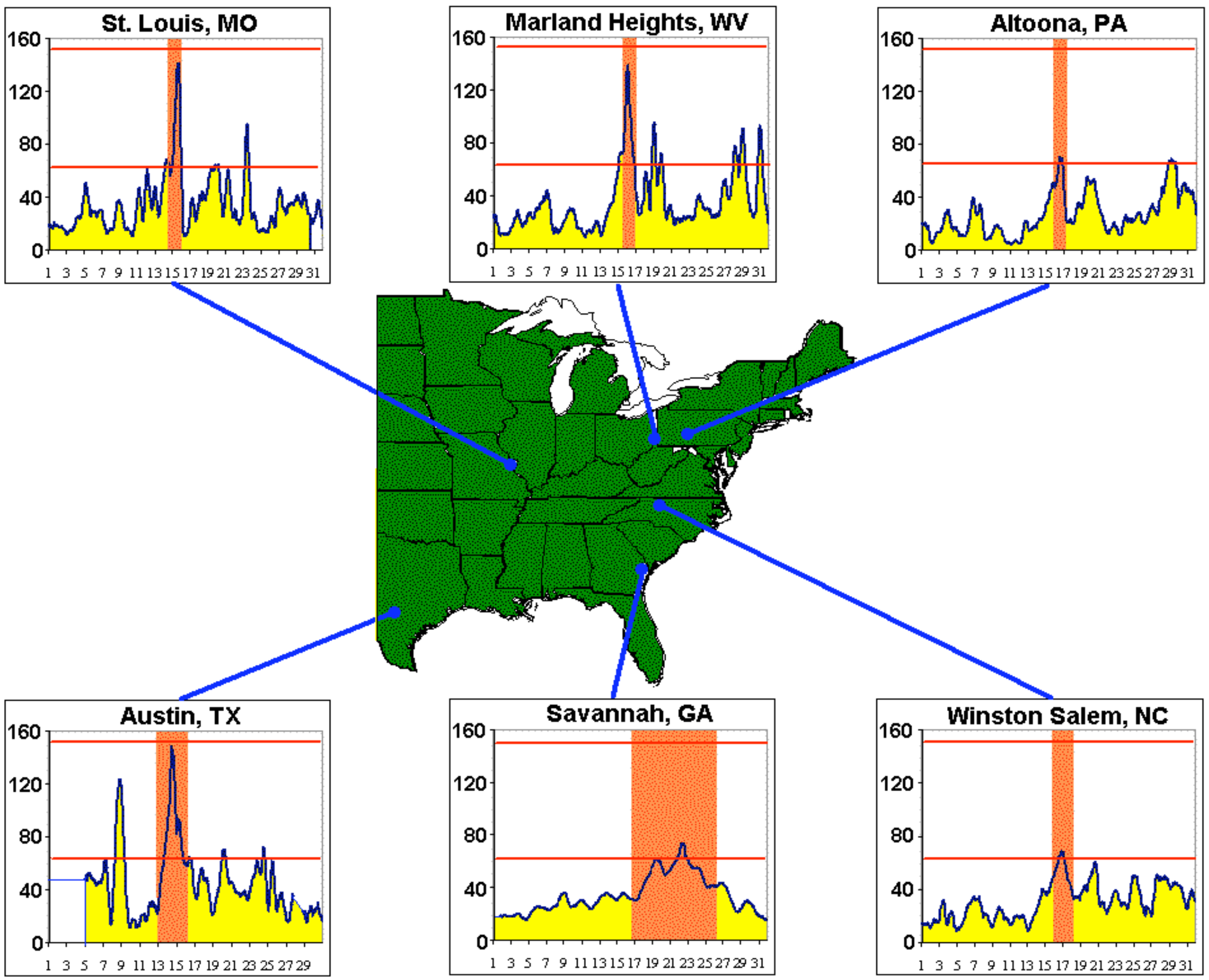
May 12 May 14 May 15 May 16

[TOMS Aerosol Index]



PM10 concentration over the Eastern U.S. during the smoke event

The smoke drifted into the US and Canada and caused exceedances of the PM standard, health alerts, and impairment of air traffic due to thick haze.



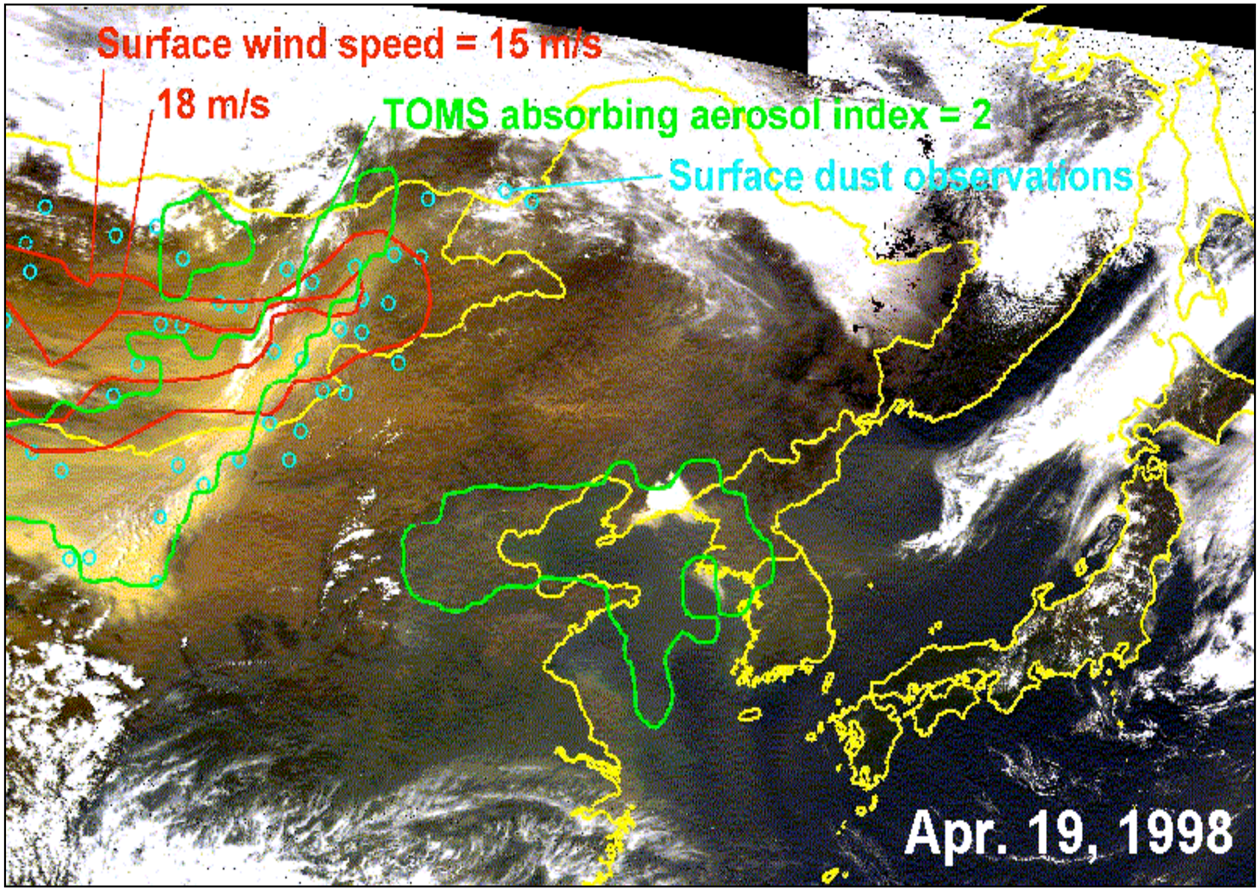
1998 Asian Dust Storm

The underlying color image is the surface reflectance derived from SeaWiFS.

The TOMS absorbing aerosol index (level 2.0) is superimposed as green contours.

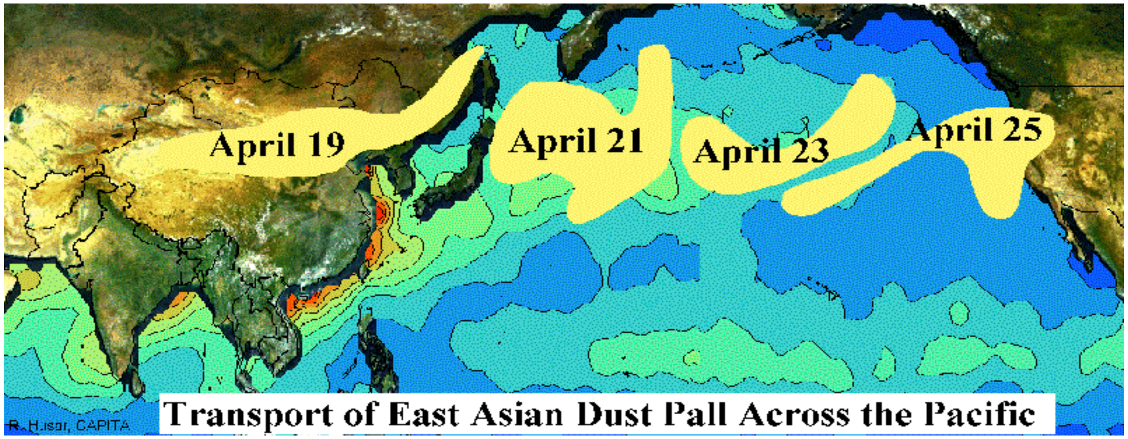
The red contours represent the surface wind speed from the NRL surface observation data base.

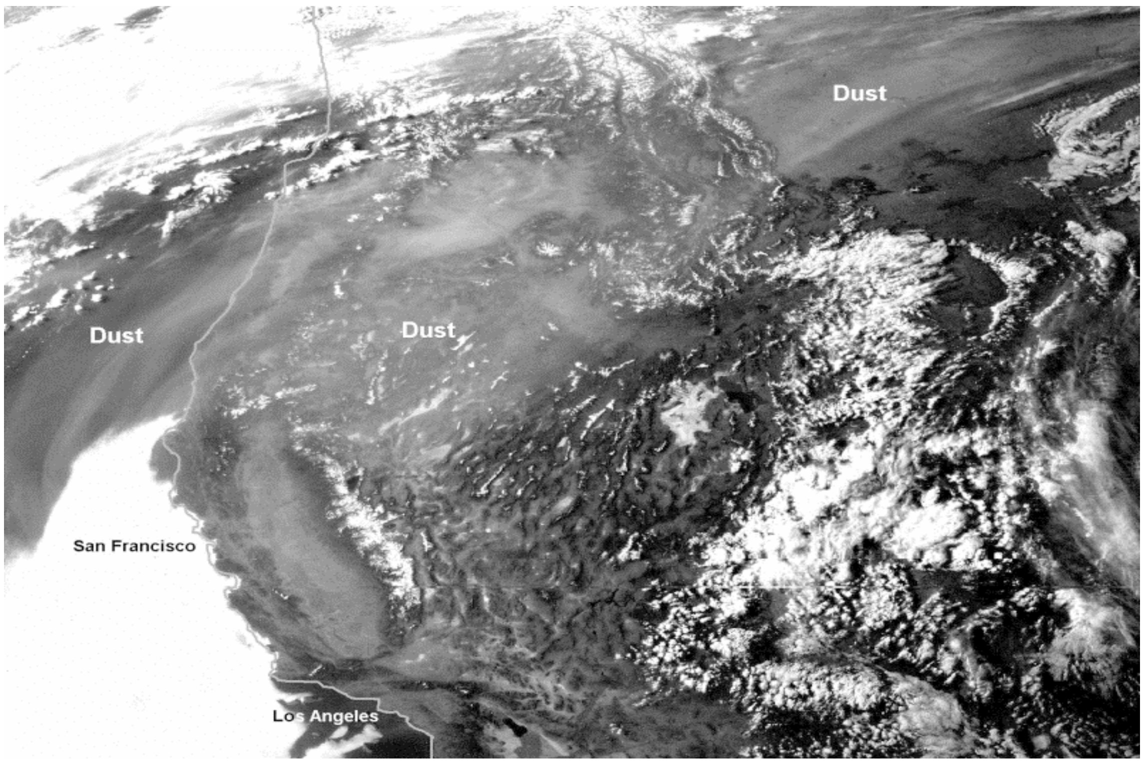
The blue circles are also from the NRL database and indicate locations where dust was observed.



The high wind speeds generated the large dust front seen in the SeaWiFS, TOMS, and surface observation data.

Asian Dust Cloud over N. America

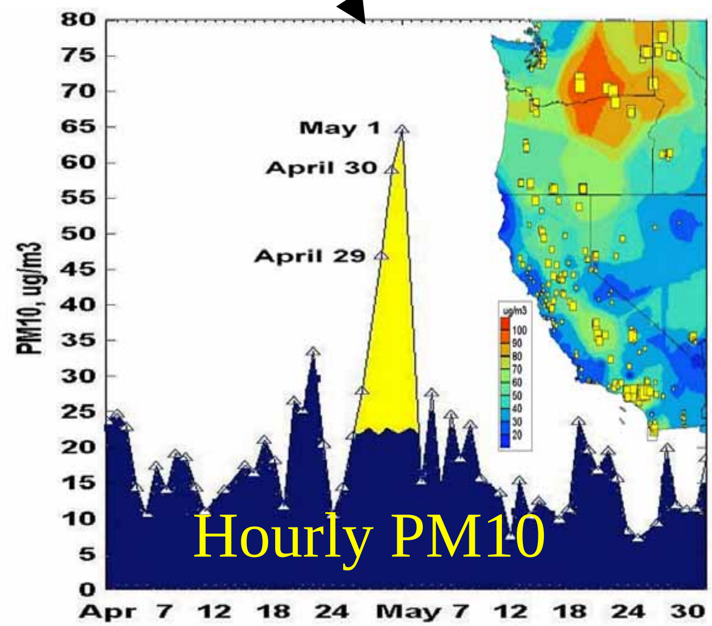




In Washington State, PM10 concentrations exceeded 100 μg/m^3

100 μg/m^3

Asian Dust



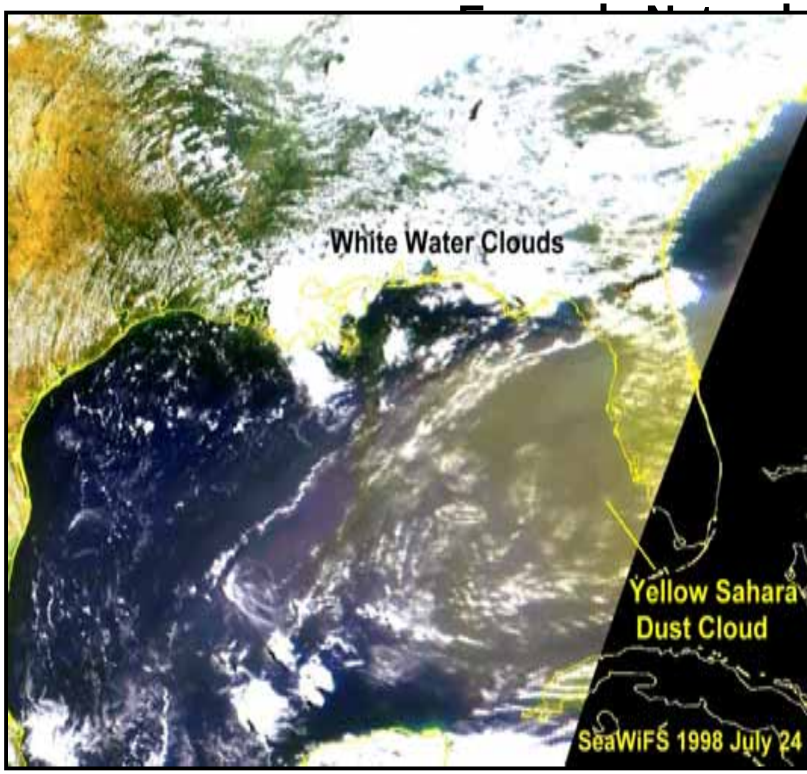
On April 27, the dust cloud arrived in North America.

Regional average PM10 concentrations increased to 65 μg/m^3

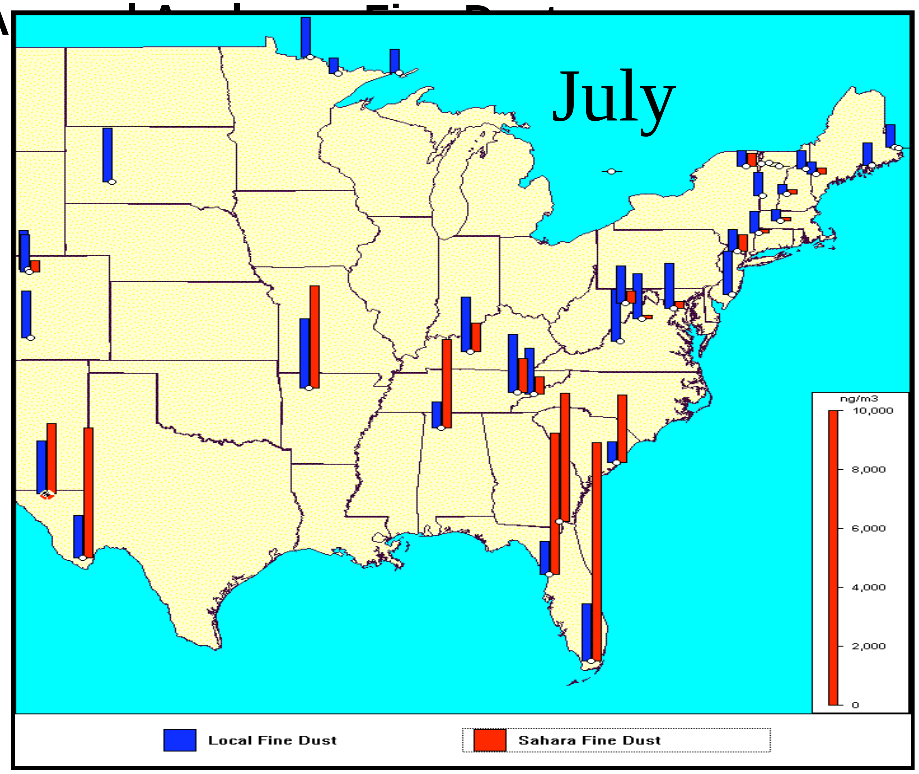
Task 2: Quantitative Estimation of Regional Natural Contributions

Approach:

- Study each natural aerosol type in detail (dust, smoke, biogenic, sea salt)
- Use ALL available aerosol observations (surface and satellite) and model results
- Establish source strength/variability and spatio-temporal pattern at relevant scales (e.g.natural aerosol statistics)
-



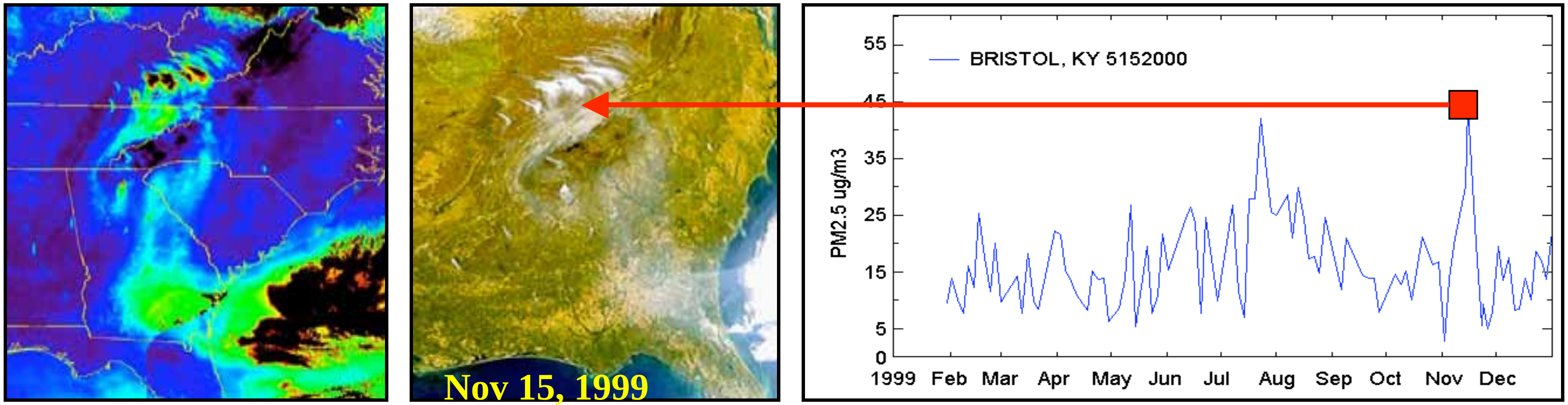
SeaWiFS satellite image of Sahara dust approaching the continent (July 24,1998).



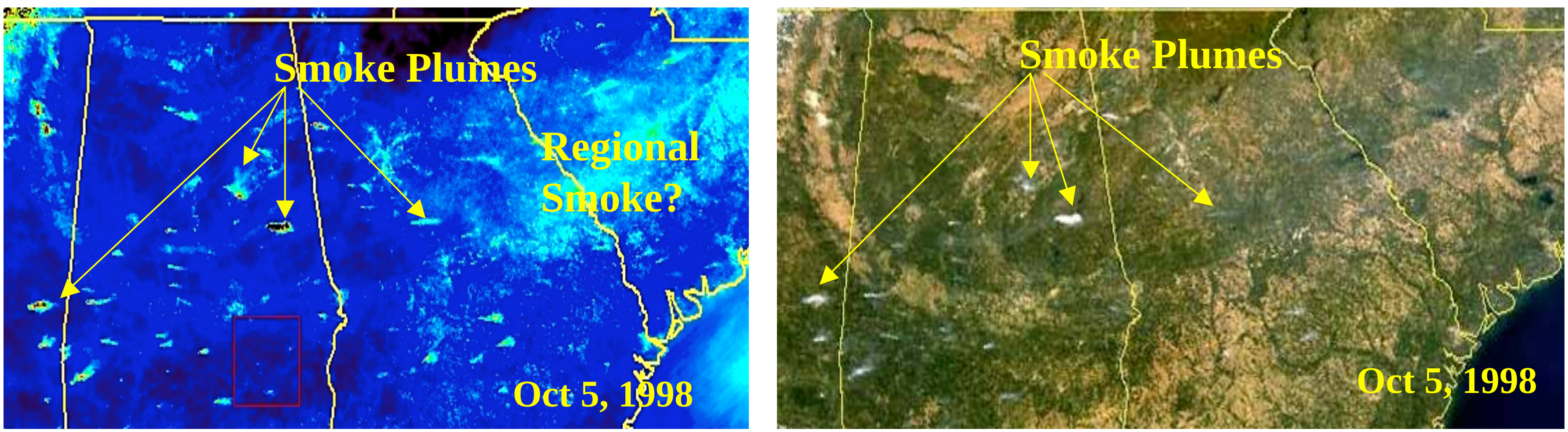
In July, in the Southeast, Sahara dust contributes 4-8 μg.m^{3}, about 2-4 times the local fine dust.

For more detail see: Local and Global Dust Over N. America

Task 2: Spatial Analysis of ‘Natural’ Aerosols: Biomass Smoke



PM2.5 conc., smoke pattern and SeaWiFS image of plumes originating from Kentucky, Nov 15, 1999.



Satellite data show numerous small fires in the Southeast

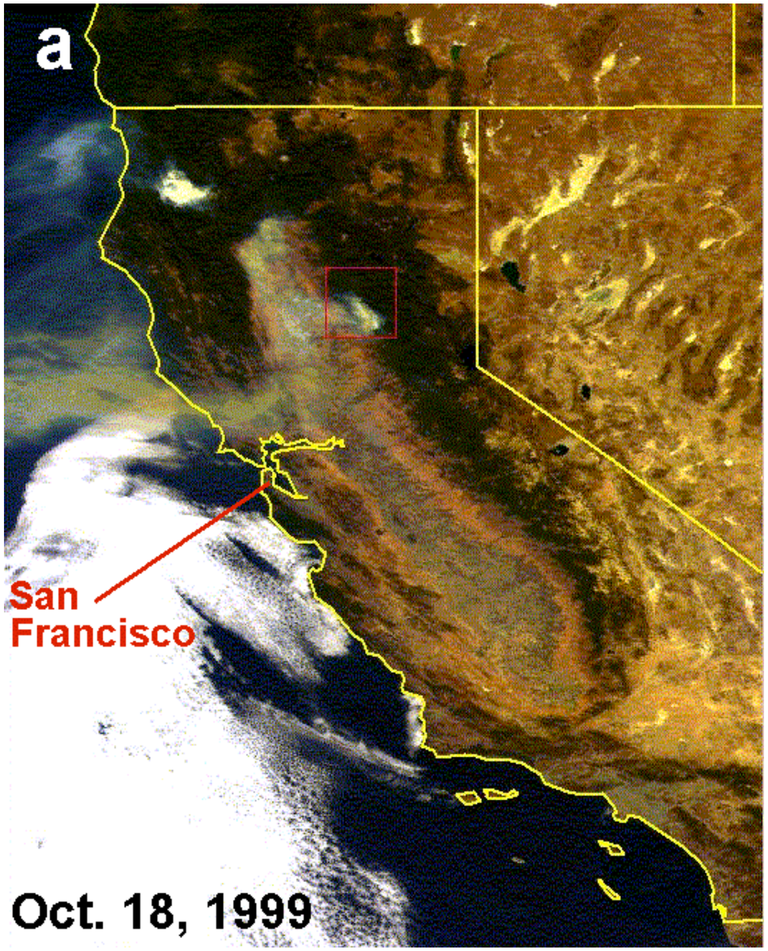
The type of these fires is not known. Prescribed/agricultural burning? Wild fires?

Issue: How does one space-time aggregate such a highly variable emission?

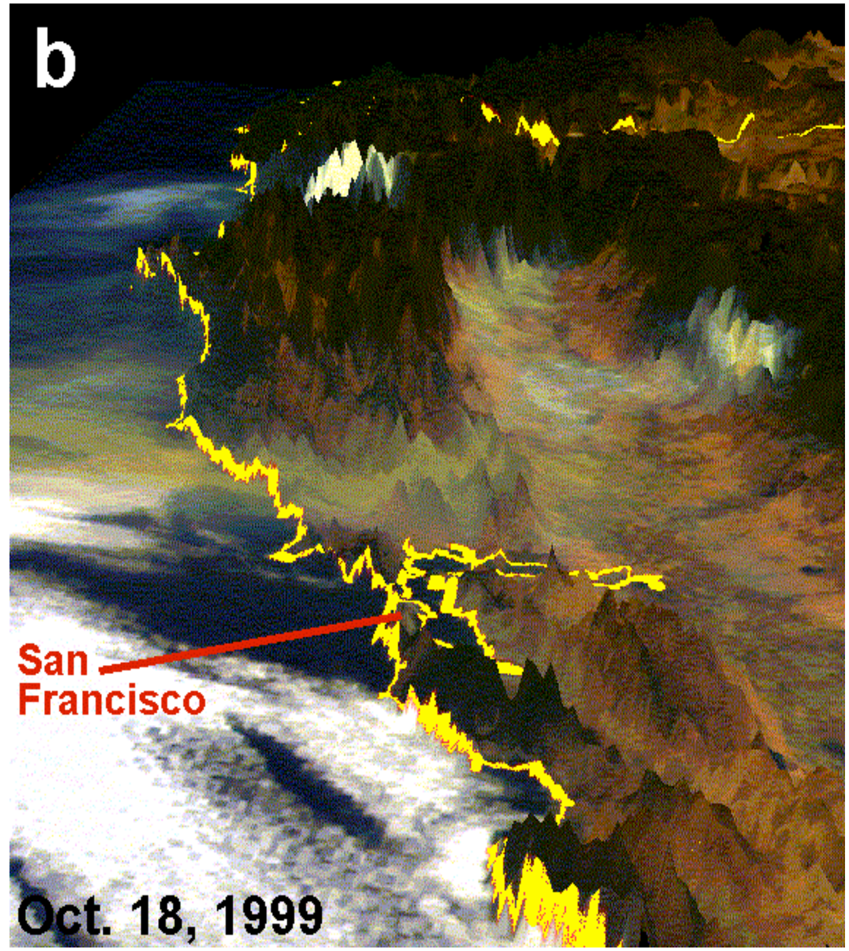
More details here here

1999 California Fires

S. Falke



Fires on the eastern side of the San Joaquin Valley generate smoke dispersed to the west that is transported over the Pacific just north of San Francisco

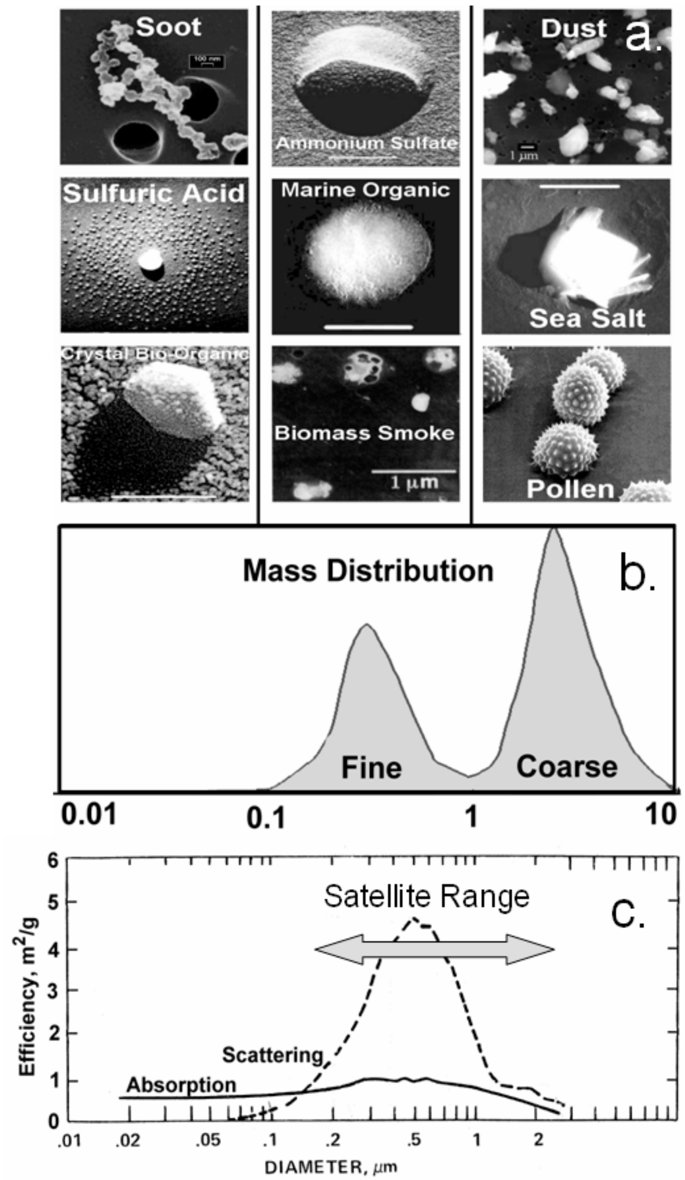


Smoke is dispersed at low elevations and is directed north-south by high elevation on western ridge of Valley

Barrier to the use of satellite data products in AQ

- Slow progress in satellite aerosol characterization.
  - Massive underestimation of the inversion retrieval problem
- Providers are pushing the aerosol products
  - Users need to be convinced, educated and enabled
- User support is support is inadequate
  - GEOSS-like IT infrastructure can provide easy data access

Satellite Aerosol Retrieval: A Mirage..for 30+ Years
Massive underestimation of the aerosol sensing problem



Scientific Challenges:

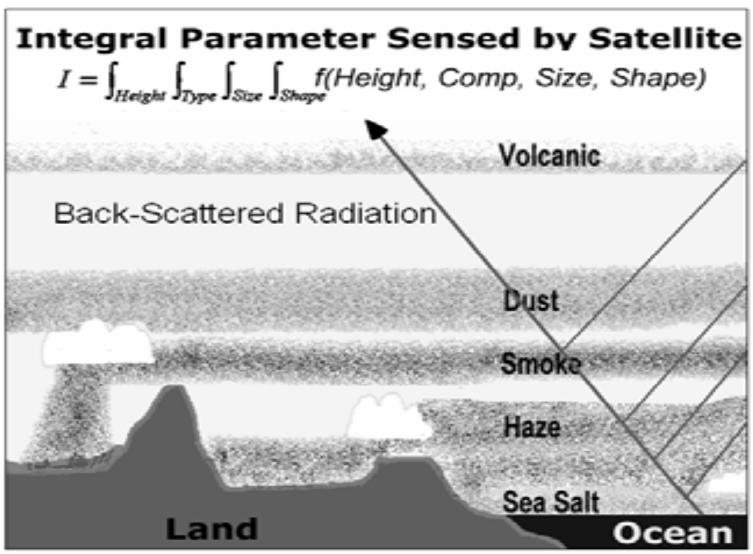
Six Dimensions, Dynamic Complexity

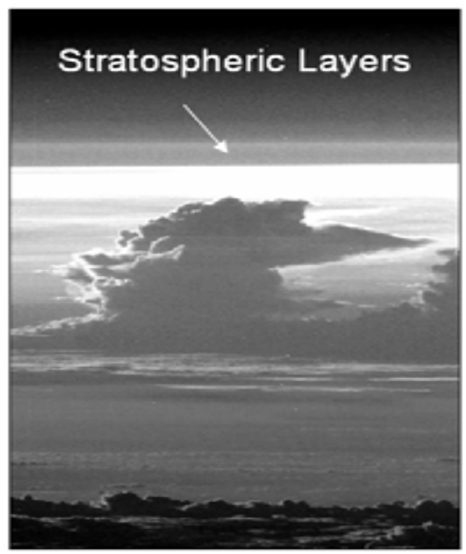
Dimension		Data Sources
Spatial dims	X, Y	Satellites, networks
Height	Z	Lidar, soundings
Time	T	Monitoring
Particle size	D	Size-sampling
Chemical Comp.	C	Speciated analysis
Particle Shape	F	Microscopy
Ext/Int Mixture	M	Microscopy

Aerosol Remote Sensing Paradox:
Easiest to Detect, Most Difficult to Characterize

- PM characterization requires many different instruments and analysis tools.
- *Each sensor/network covers only a fraction of the 8-D PM data space*.
- Most of the 8D PM pattern is extrapolated from sparse measured data

Satellites, integrate over height, size, composition, shape…dimensions
These data need de-convolution of the integral measures
Retrieval is a notoriously ill-defined mathematical problem



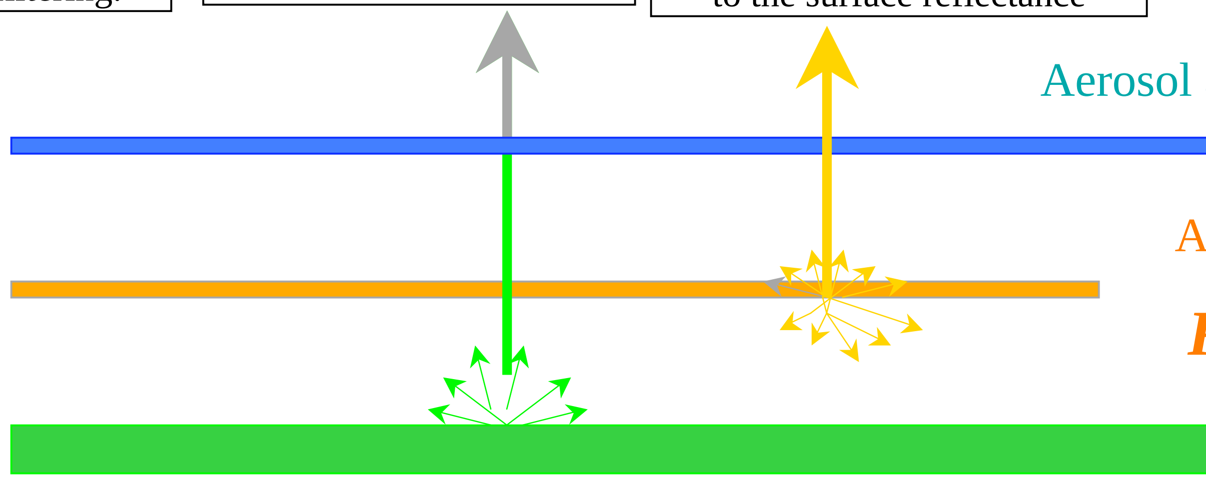


Co-Retrieval of Surface and Aerosol Properties
Apparent Surface Reflectance, R

- The surface reflectance R_0 objects viewed from space is modified by aerosol scattering and absorption.
- The **apparent reflectance, R,** is: $R = (R_0 + R_a)\, T_a$

Apparent Reflectance	**Surface Reflectance**	**Aerosol Reflectance**	**Aer. Transmittance**
R may be smaller or larger then R_0, depending on aerosol reflectance and filtering.	The surface reflectance R_0 is an inherent characteristic of the surface	Aerosol scattering acts as reflectance, R_a adding '**airlight**' to the surface reflectance	Both R_0 and R_a are attenuated by aerosol extinction T_a which act as a filter

Aerosol as Filter: $T_a = e^{-\tau}$

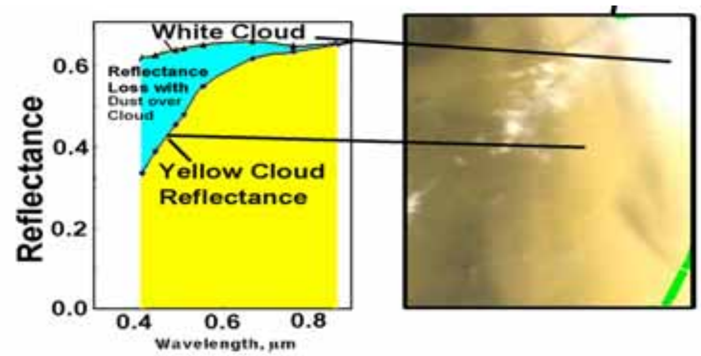


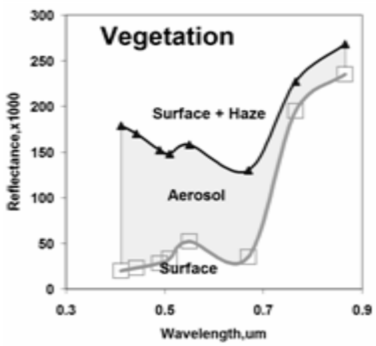
Aerosol as Reflector:

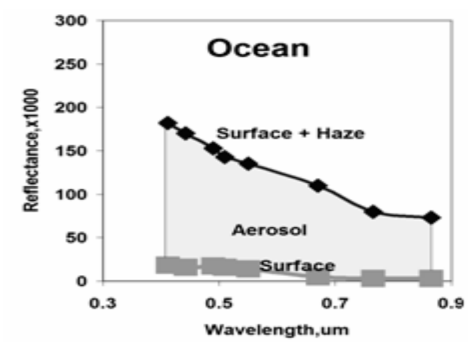
$$R_a = (e^{-\tau} - 1)\, P$$

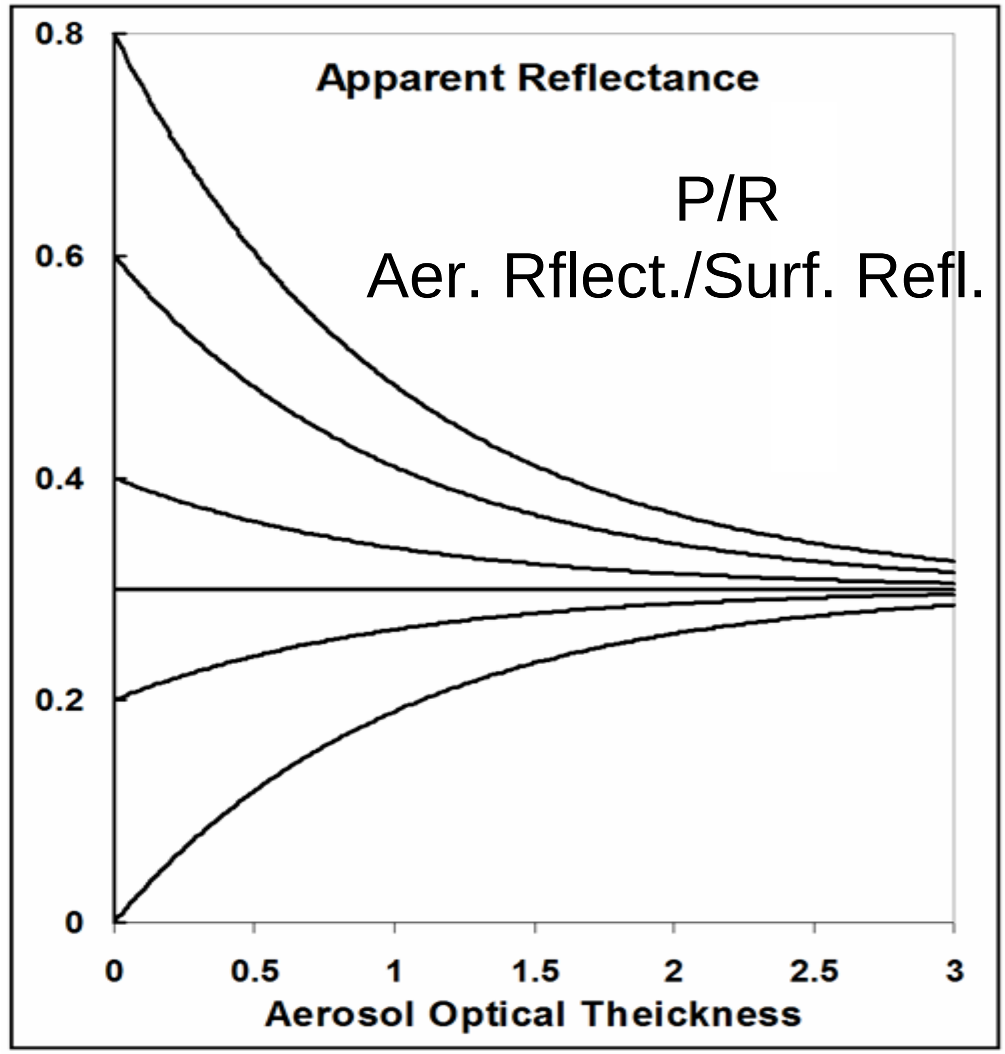
$$R = (R_0 + (e^{-\tau} - 1)\, P)\, e^{-\tau}$$

Measured TOA Appurtenant Reflectance





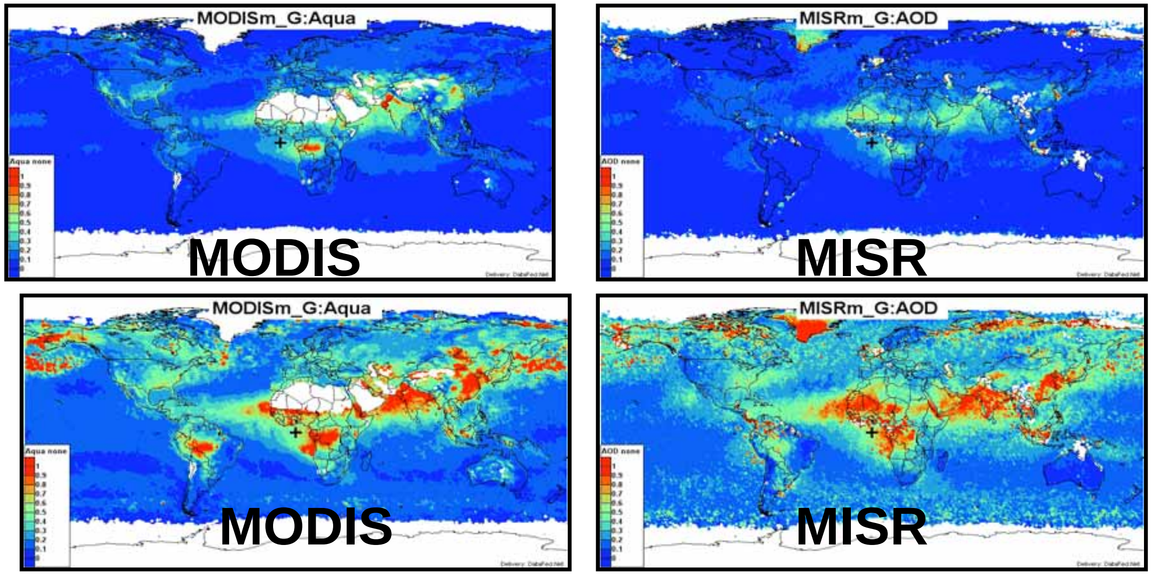




MODIS-MISR AOT Aggregated, Jun, Jul, Aug

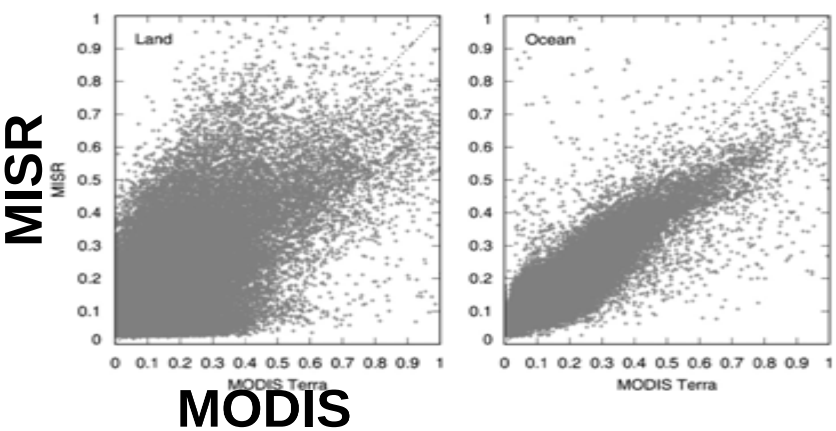
10 Percentile

90 Percentile



AOT & Angstrom Pixel Level, Jun, Jul, Aug

Liu & Mishchenko, 2008



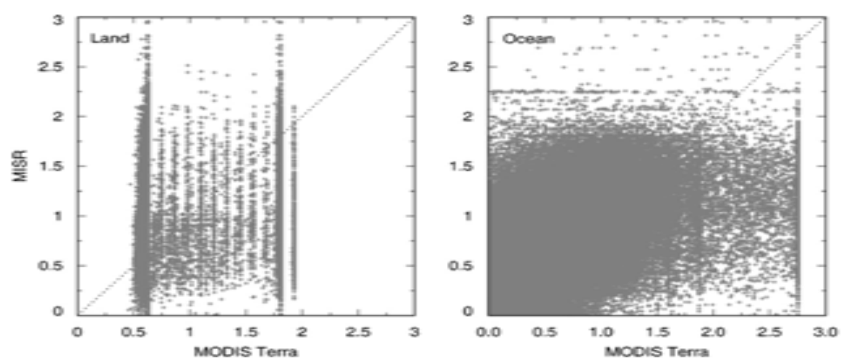
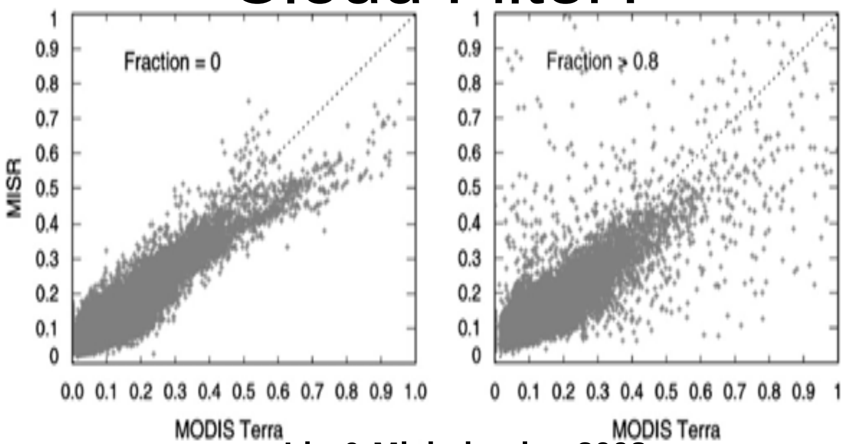


Fig. 3. MISR vs. MODIS-Terra AEs. The straight dotted lines depict the one-to-one perfect agreement.

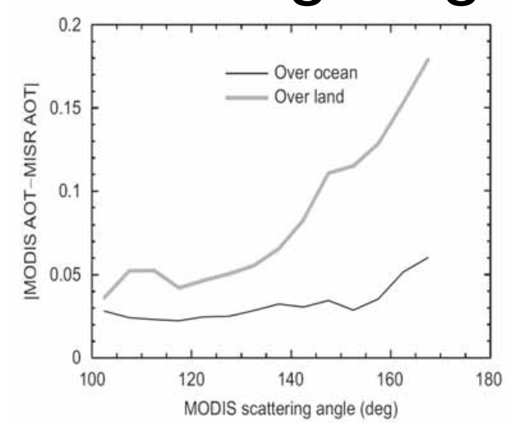
Systematic Deviations

Cloud Filter?



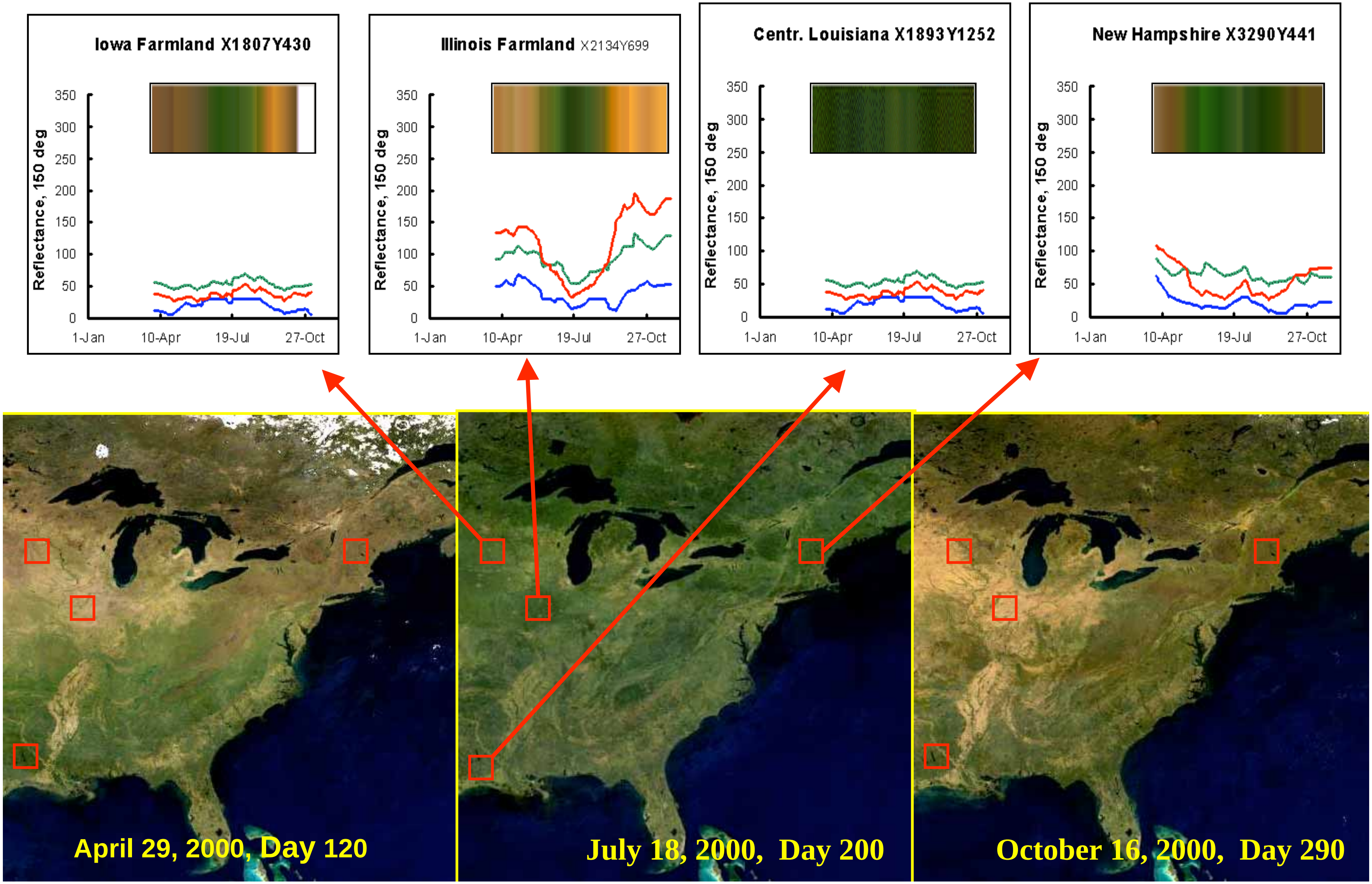
Liu & Mishchenko, 2008

Scattering Angle



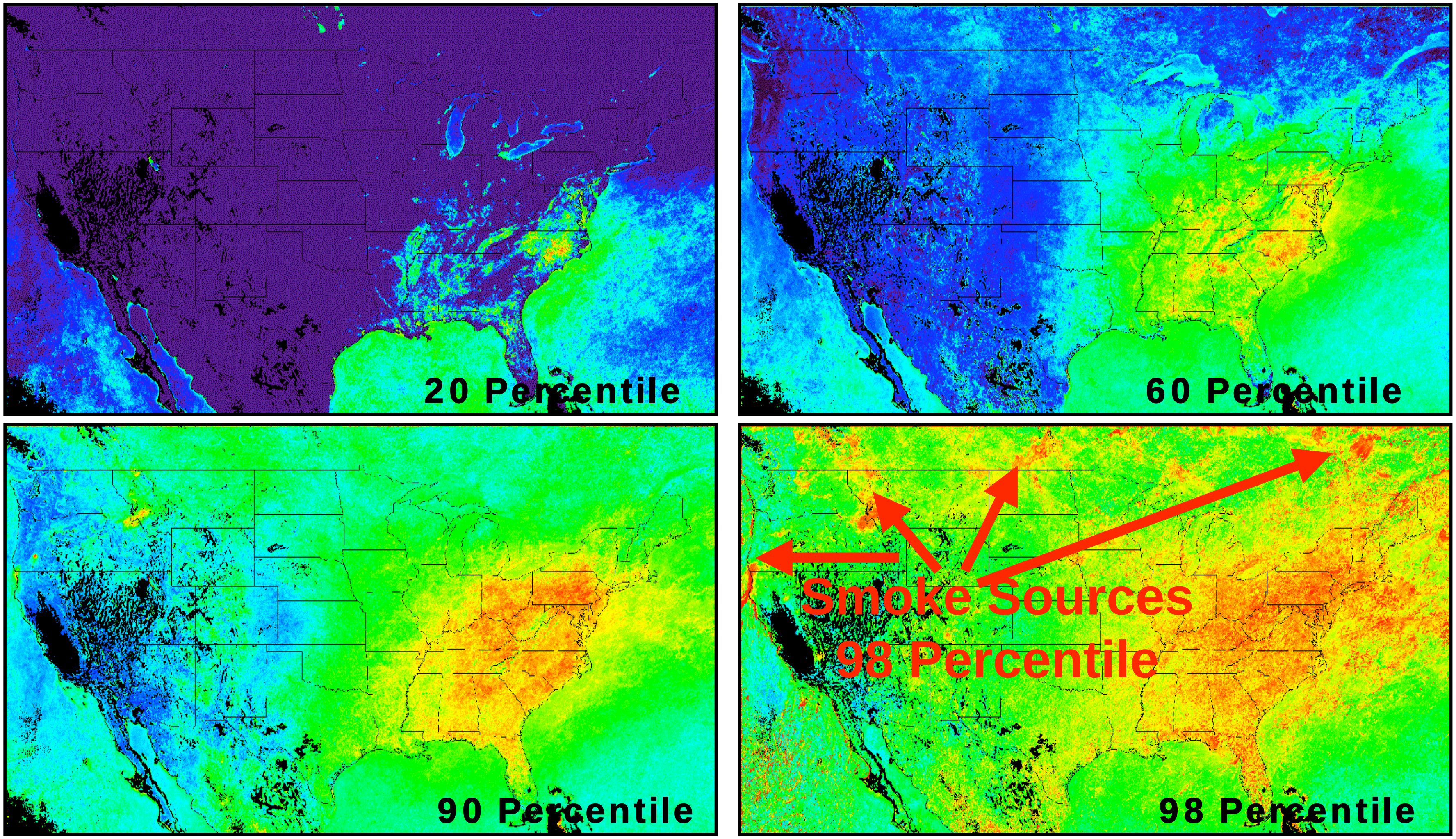
Liu & Mishchenko, 2008

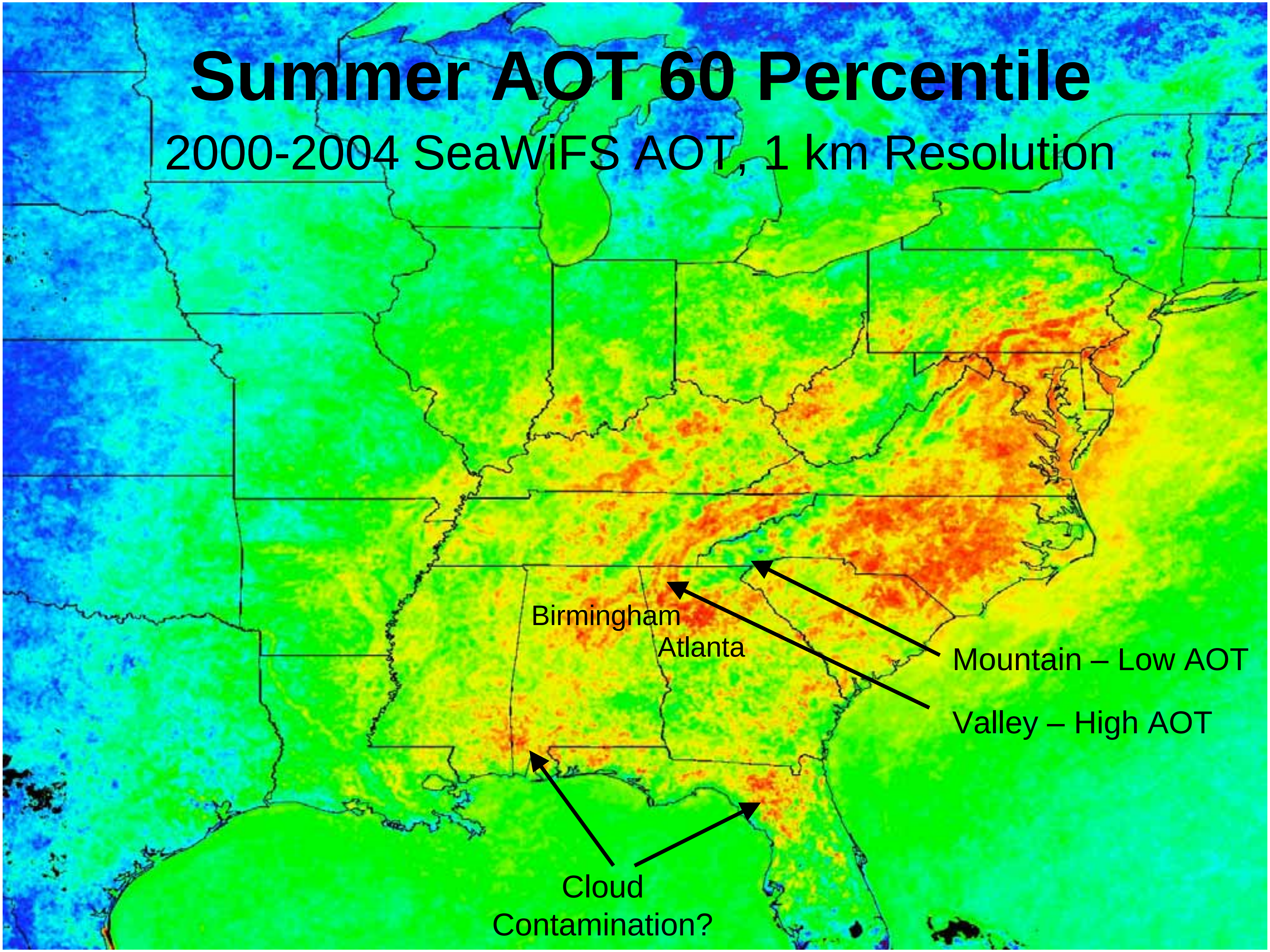
Co-Retrieval:
Seasonal Surface Reflectance, Eastern US



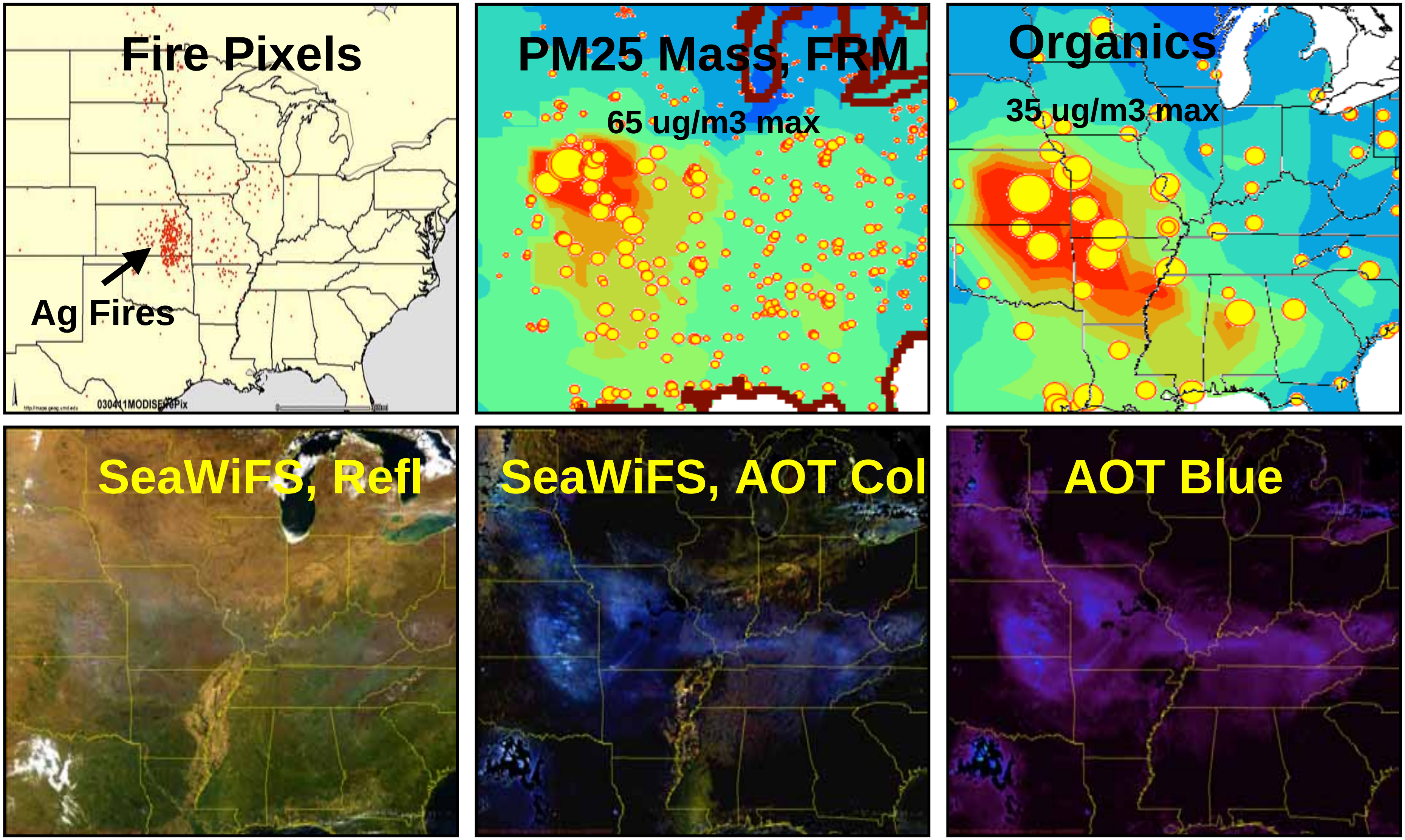
Satellite Aerosol Optical Thickness Climatology

SeaWiFS Satellite, Summer 2000 - 2003

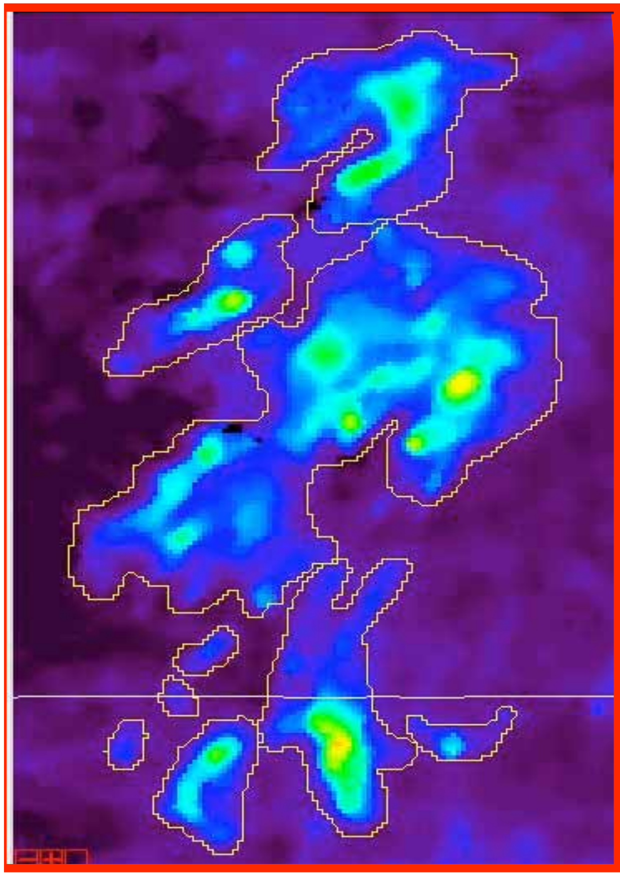


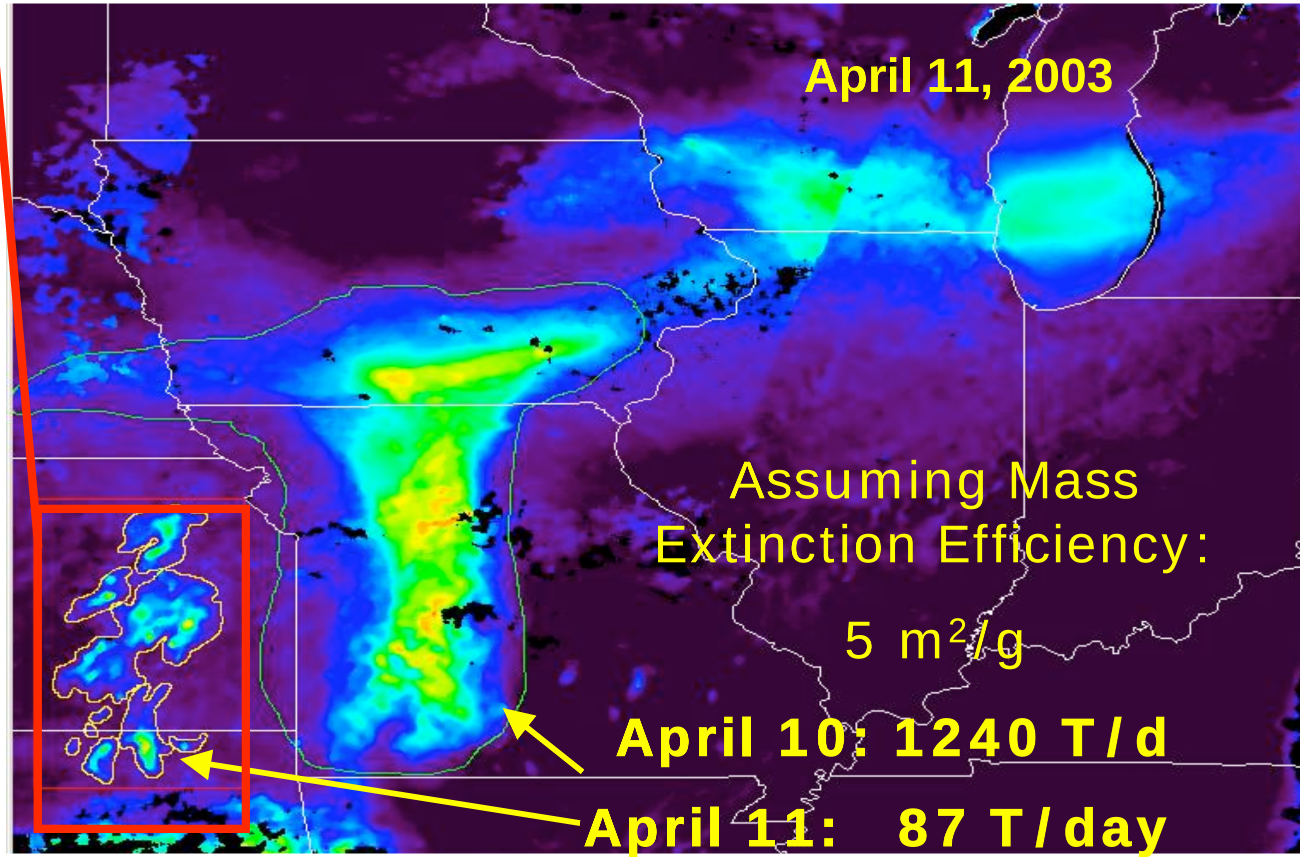

Summer AOT 60 Percentile
2000-2004 SeaWiFS AOT, 1 km Resolution
Birmingham
Atlanta
Mountain – Low AOT
Valley – High AOT
Cloud
Contamination?

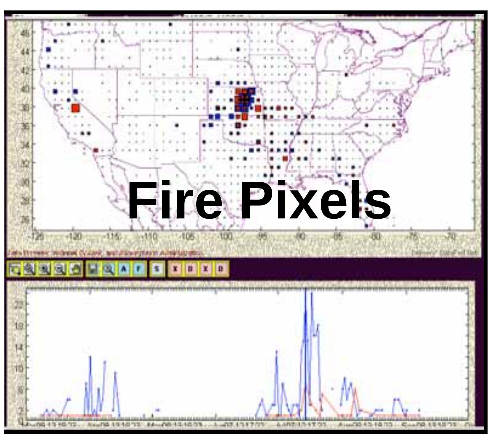
Kansas Agricultural Smoke, April 12, 2003

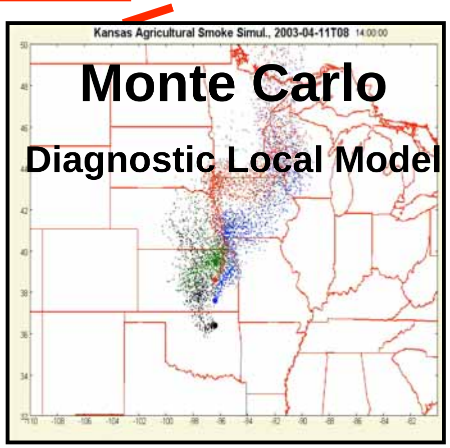


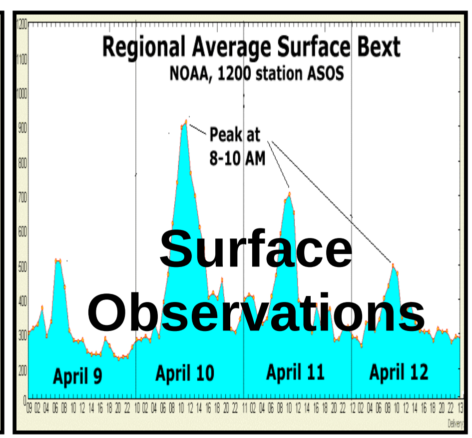
Kansas Smoke Emission Estimation

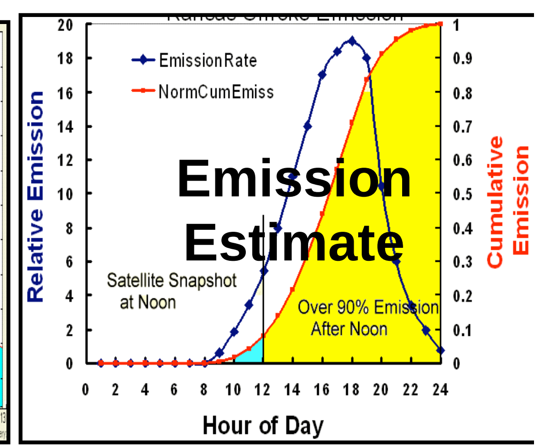




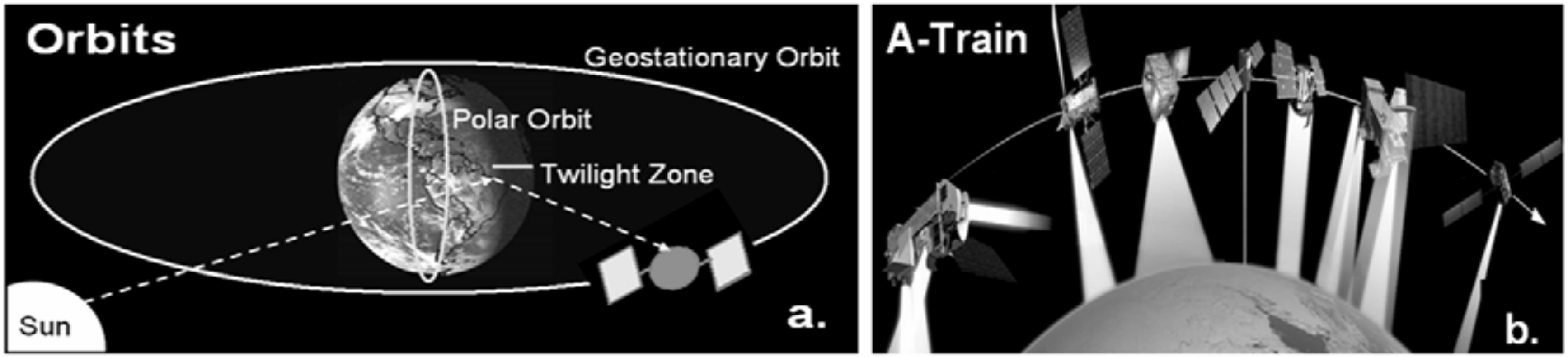






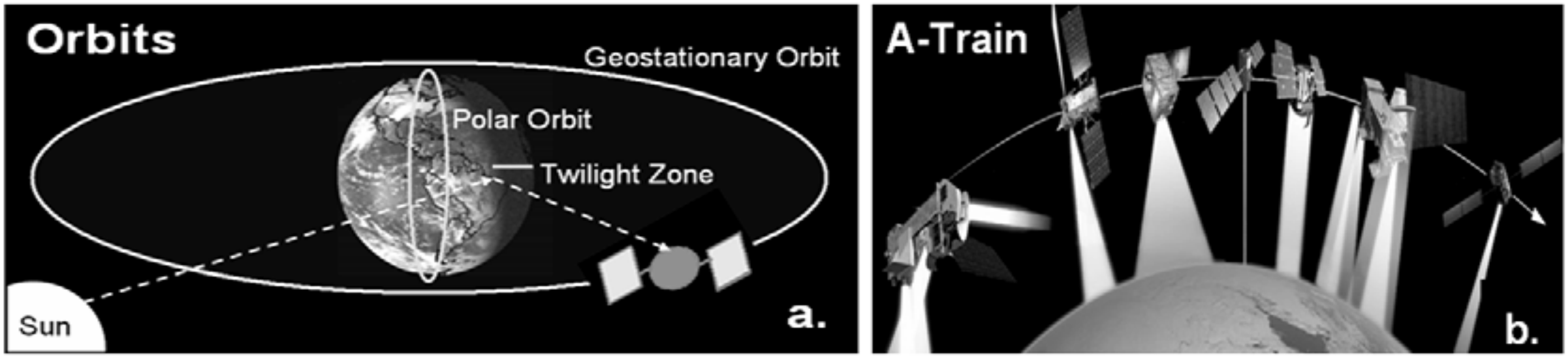


I believe…



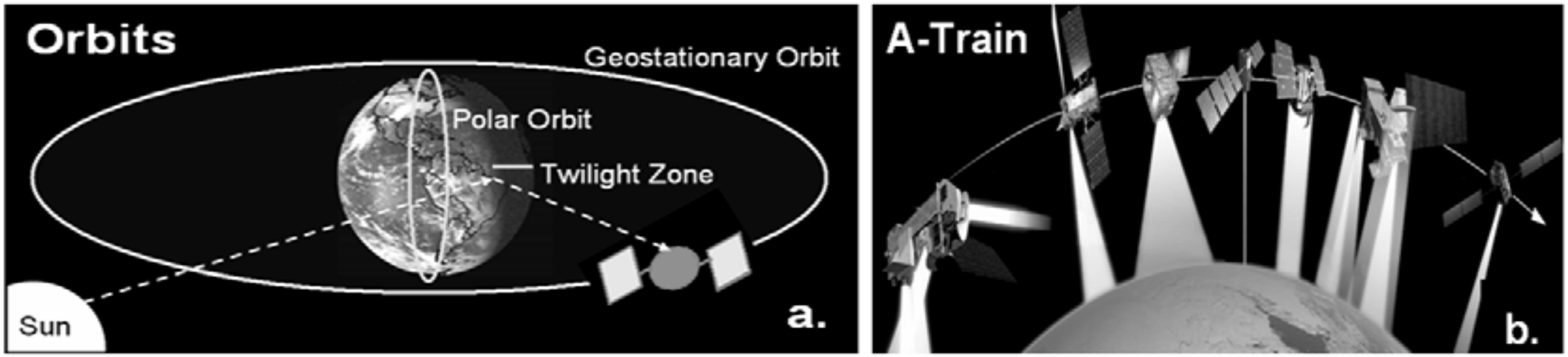
- ..that new conceptual and technical tools will soon integrate multisensory satellite, surface and aircraft data
  - spectral, angular, polarization scattering ..occulation measurements
  - sensors on geostationary and polar orbits…
  - fusion techniques on pixel, feature and object level

I believe…



- .. comparing and reconciling and fusing multi sensory data and models
  - will be the norm
  - and differences from the expected will be greeted as opportunities…

I believe…



- ..in a bright future for Atmospheric Constellation for air quality science and management through.
  - The Atmospheric Composition Portal
  - Meetings like this
  - Virtual Communities of Practice