

Satellite observations of aerosol properties: from climate to air quality

Climate Change 2016, Valencia, October 24-26, 2016

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Government sponsorship acknowledged.

Jet Propulsion Laboratory
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What are atmospheric aerosols?

Dust



Smoke



Pollution

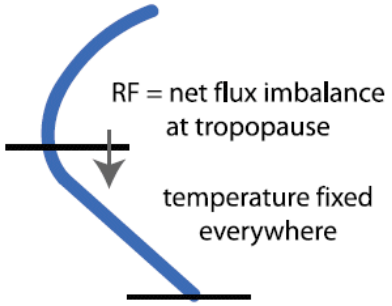


Volcanic aerosol

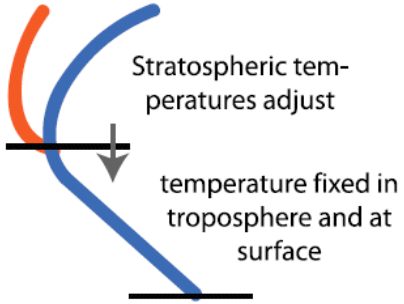


Aerosol DARF

Instantaneous RF



Stratospheric-adjusted RF



$$\Delta F = F_{net,perturbed}(TOA) - F_{net,clean}(TOA)$$

Climate GCM (official IPCC definition):

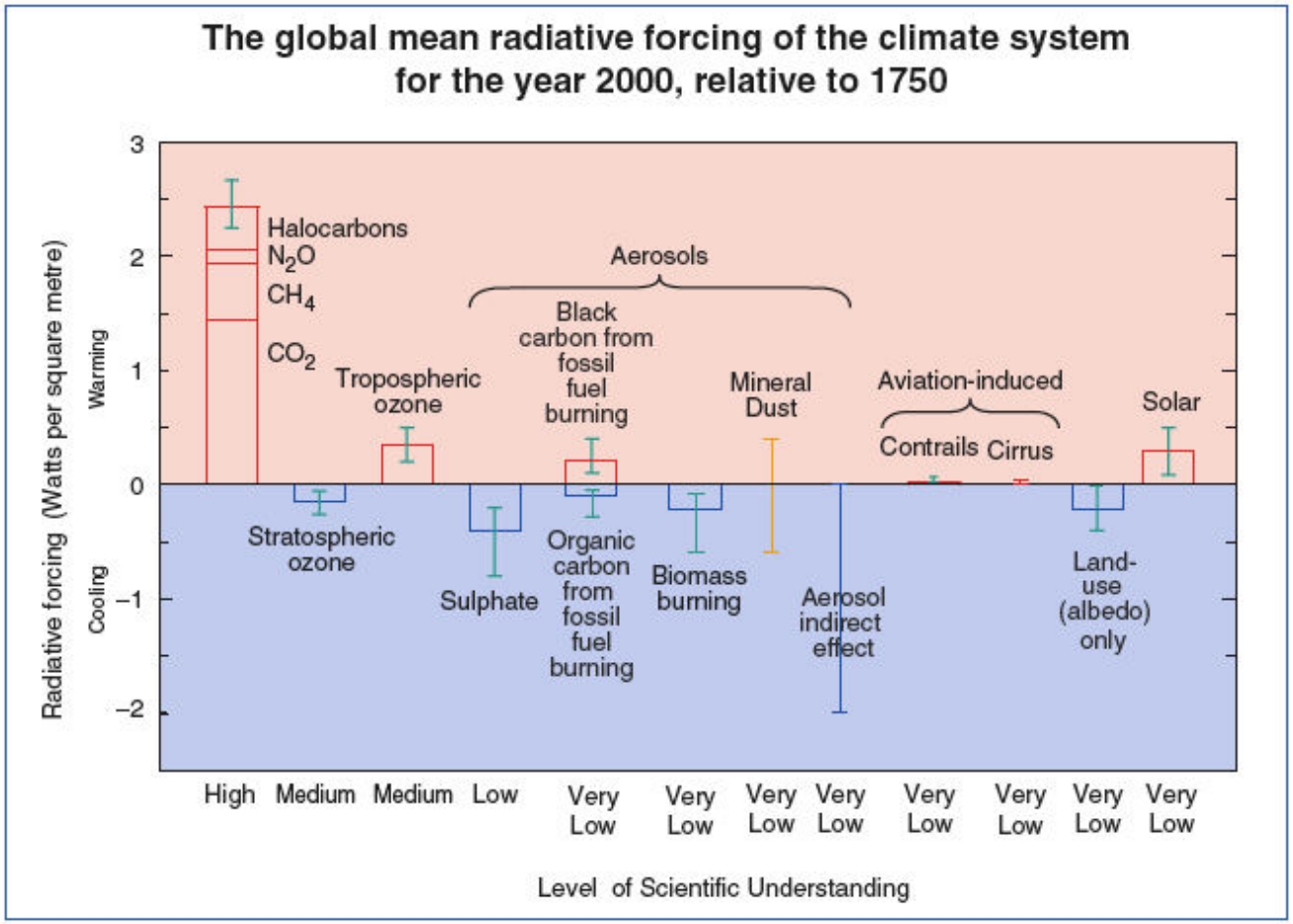
Radiative forcing is a change in net radiative flux at the tropopause after the stratosphere comes back into equilibrium.

Differences between GHG forcing and aerosol forcing:

- The two forcings have very different spatial and temporal distributions:
  - GHG operates day and night, whether clear or cloudy, and is at a maximum in the hottest, driest places on Earth.
  - Aerosol forcing occurs mainly by day (except dust), and is concentrated near aerosol sources and downwind from the sources.
- Two forcing are determined differently:
  - GHG forcing is well-posed problem in radiative transfer (because IR absorption is well quantified for all GHG gases).
  - Aerosol forcing remains an unresolved problem because of complex spatial and temporal distribution of aerosols, and their complex chemical composition

DARF – historical level of understanding

IPCC AR3, 2001 (Pre-EOS)

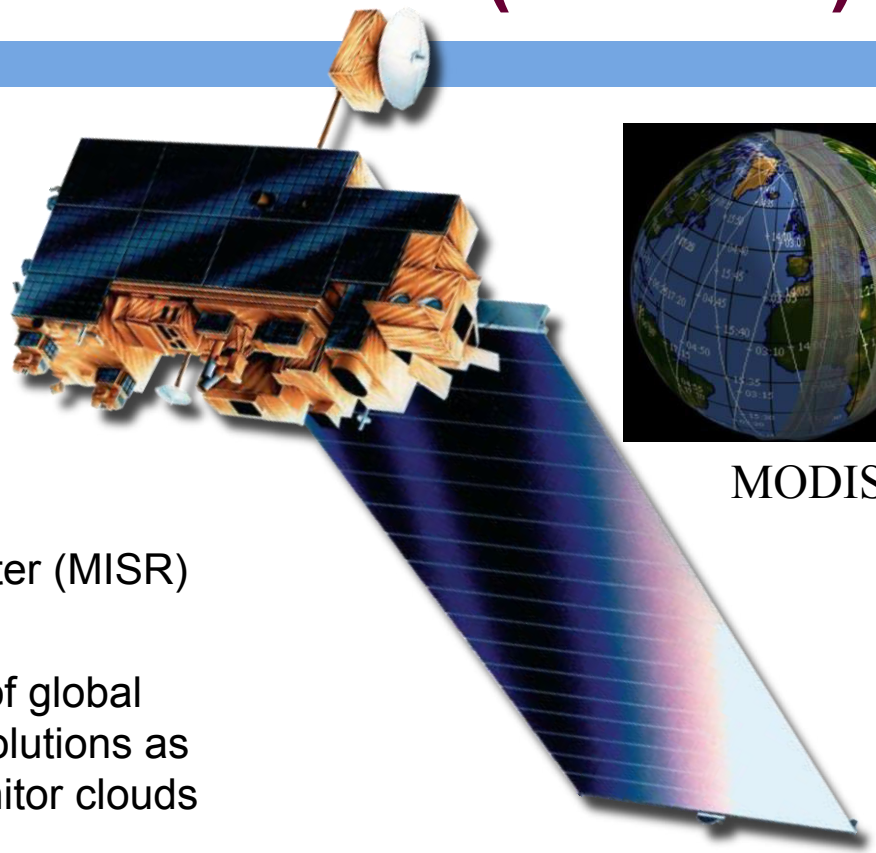


Aerosols contribute the largest uncertainty to the total Radiative Forcing (RF) estimate

NASA climate aerosol record (satellite)

Terra

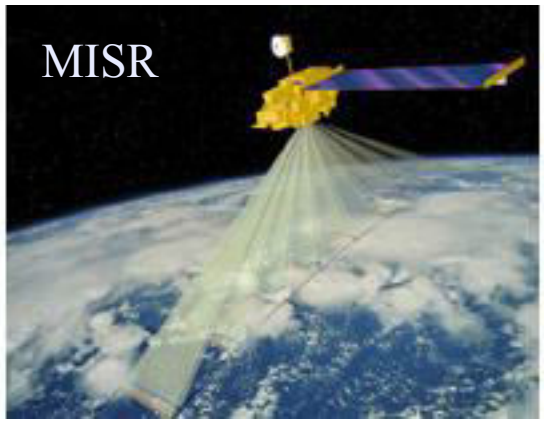
- Launched in December 1999
- Carries five instruments
- **Aerosol instruments:**
  - Moderate-Resolution Imaging Spectroradiometer (MODIS)
  - Multi-angle Imaging SpectroRadiometer (MISR)



MODIS

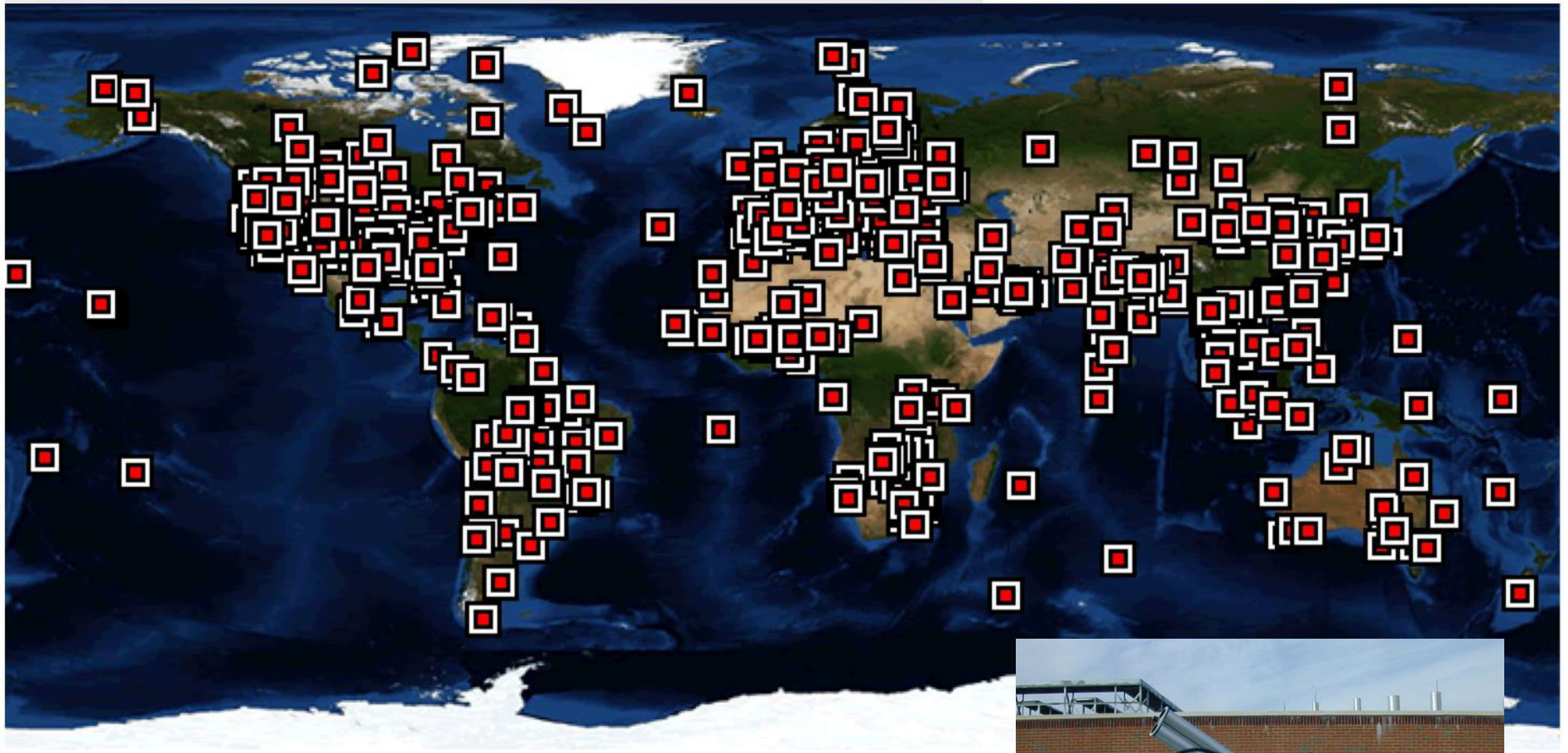
- **MODIS** provides a comprehensive series of global observations every two days at spatial resolutions as fine as 250 meters. It provides data to monitor clouds and aerosols.

- **MISR** measures the amount of sunlight scattered in different directions. Earth's surface is successively imaged by nine cameras over a period of seven minutes. Because of its different viewing angles, MISR can differentiate between various types of clouds, particles, and surfaces.



NASA aerosol ground-based monitoring

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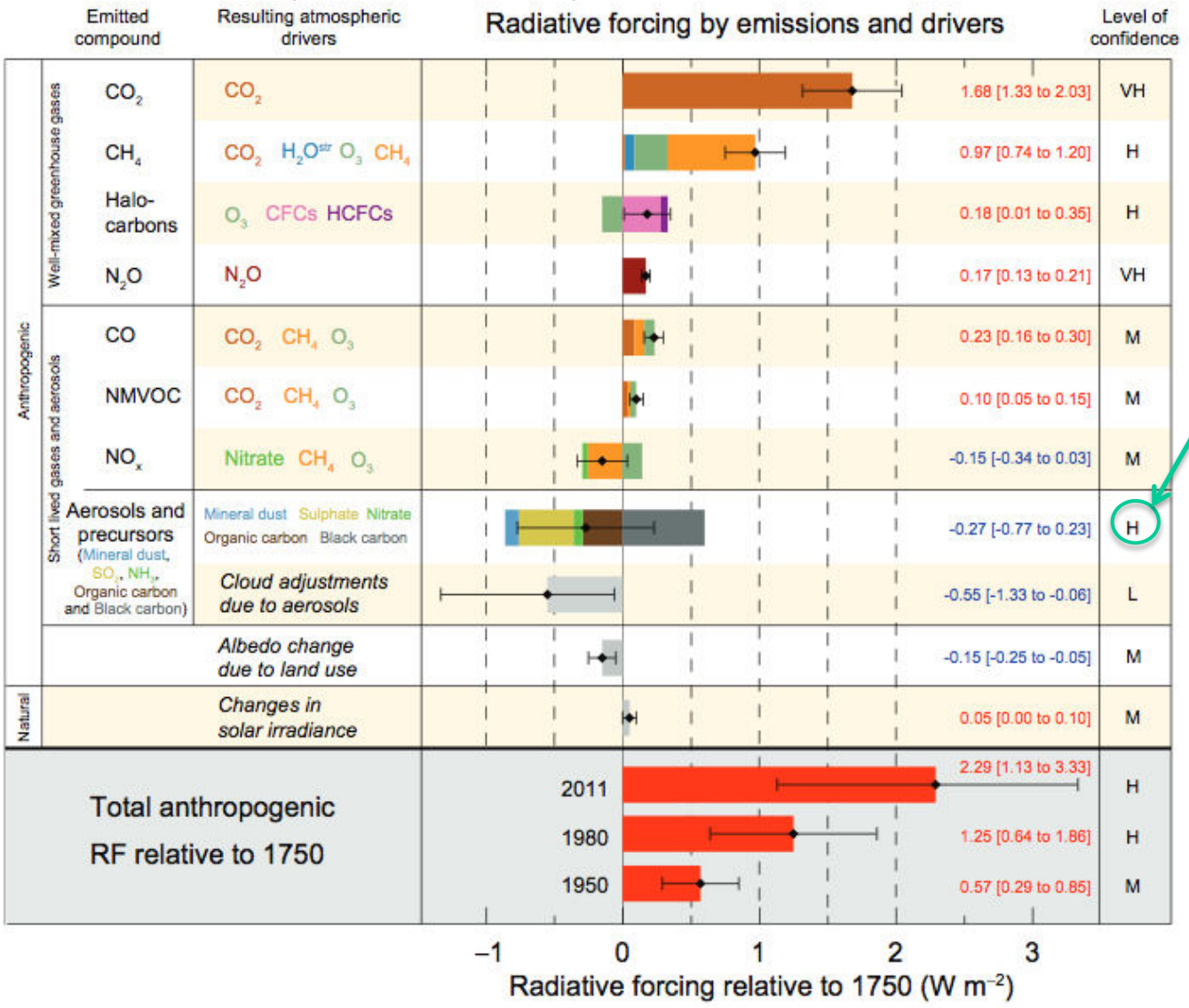
Globally: ~70-75% of MISR AOD retrievals fall within 0.05 or 20% AERONET AOD

Globally: MODIS C6 AOD fall within (-0.02–10% ocean),(+0.04+10% land)

Current assessment of climate forcing

–0.35 (–0.85 to +0.15) W/m2.

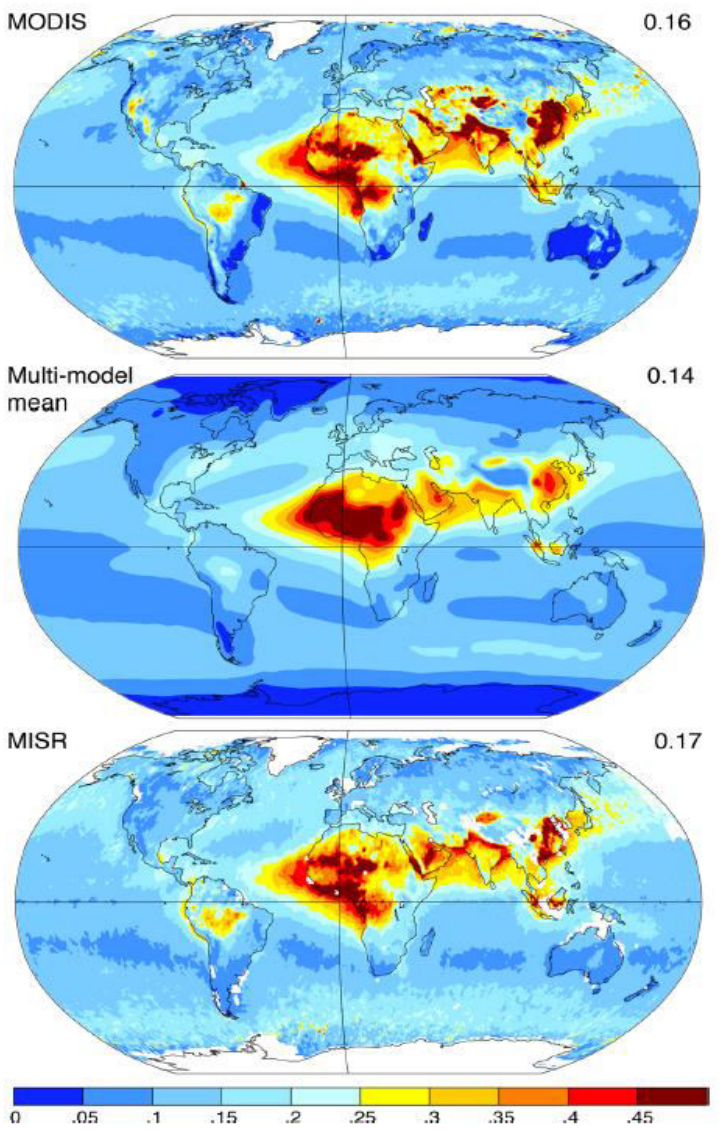
IPCC AR5, 2013

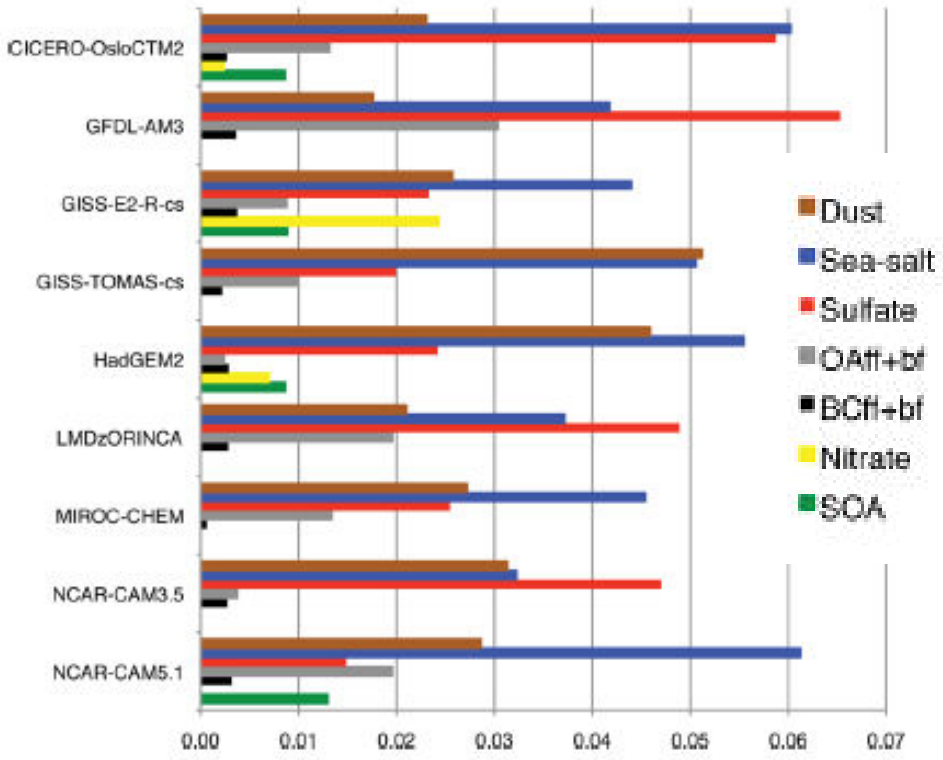


Global average when compared to other uncertainties in the models

"There is high confidence that aerosols have offset a substantial portion of global mean forcing from well-mixed greenhouse gases. **They continue to contribute the largest uncertainty to the total RF estimate."**

What about aerosol types?





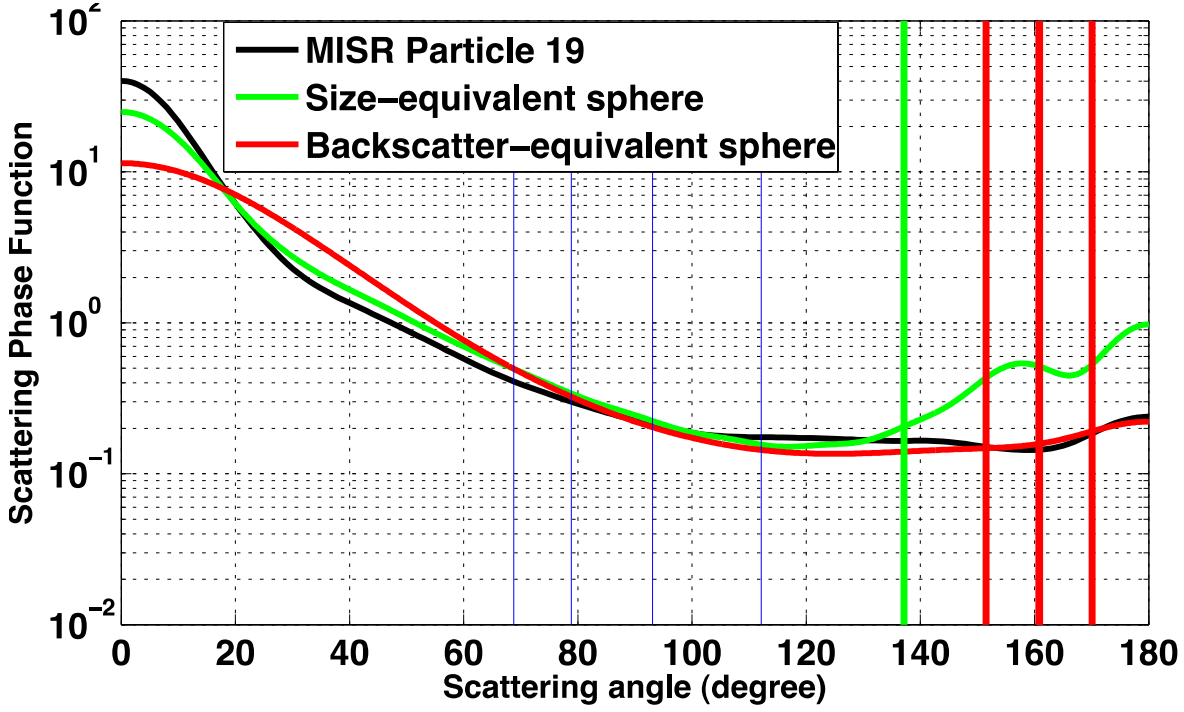
- Chemistry climate models (CCMs) reproduce present day total aerosol optical depth (AOD) relatively well
- However, contributions from individual aerosol components (speciated AOD) are quite different

Shindell et al. **[2013]**

MISR aerosol type detection

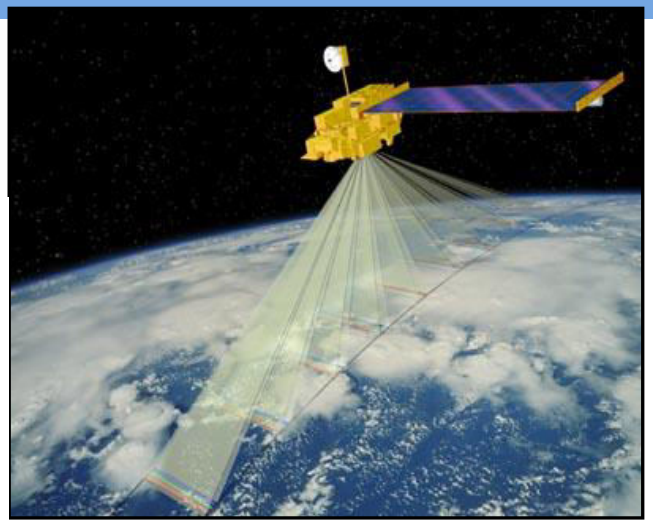
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Launched in December 1999 on NASA's Terra satellite
Operational from late February 2000 to present



MISR retrieves particle size and shape classes through their effect on the scattering of light

Kahn et al., 2001; Kalashnikova et al., 2005, 2013



Nine view angles at Earth surface: 70.5° forward to 70.5° backward

Nine 14-bit pushbroom cameras

275 m - 1.1 km sampling

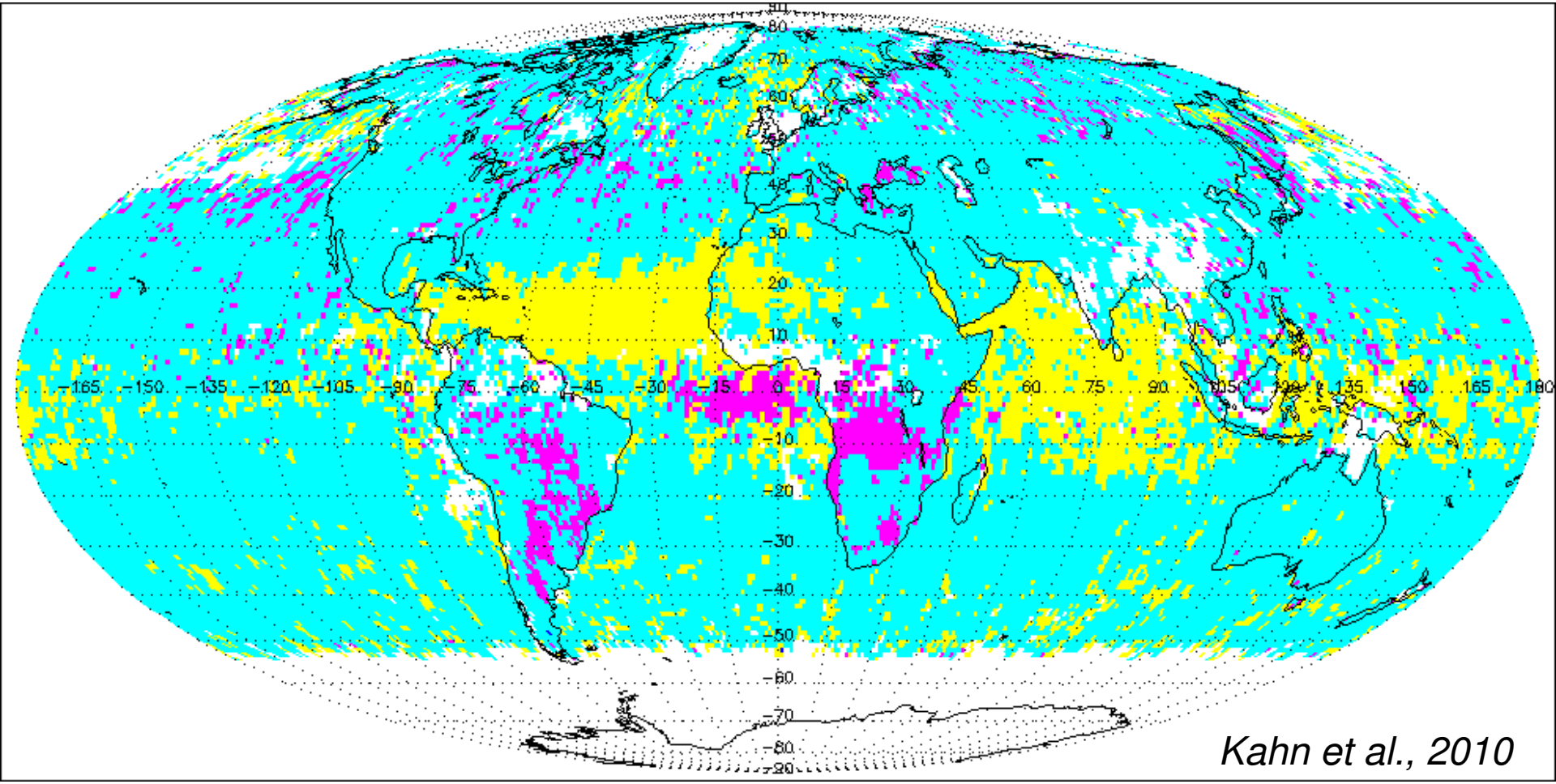
Four spectral bands at each angle: 446, 558, 672, 866 nm

400-km swath: 9-day coverage at equator, 2-day at poles

7 minutes to observe each scene at all nine angles

MISR separates aerosol types globally

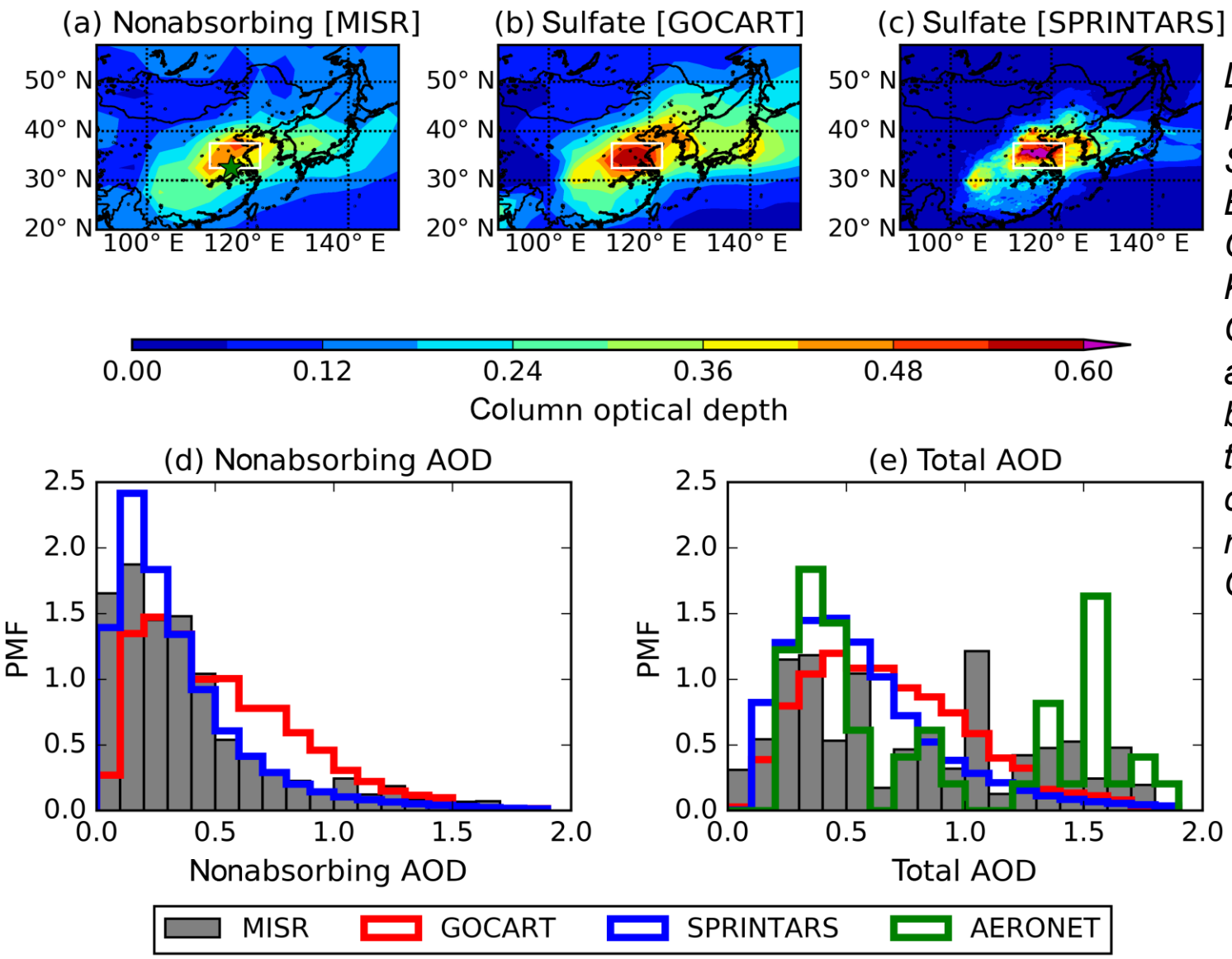
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Key

- Spherical Non-Absorbing
- Spherical Absorbing
- Non-Spherical

Climatology of AOD by components from MISR

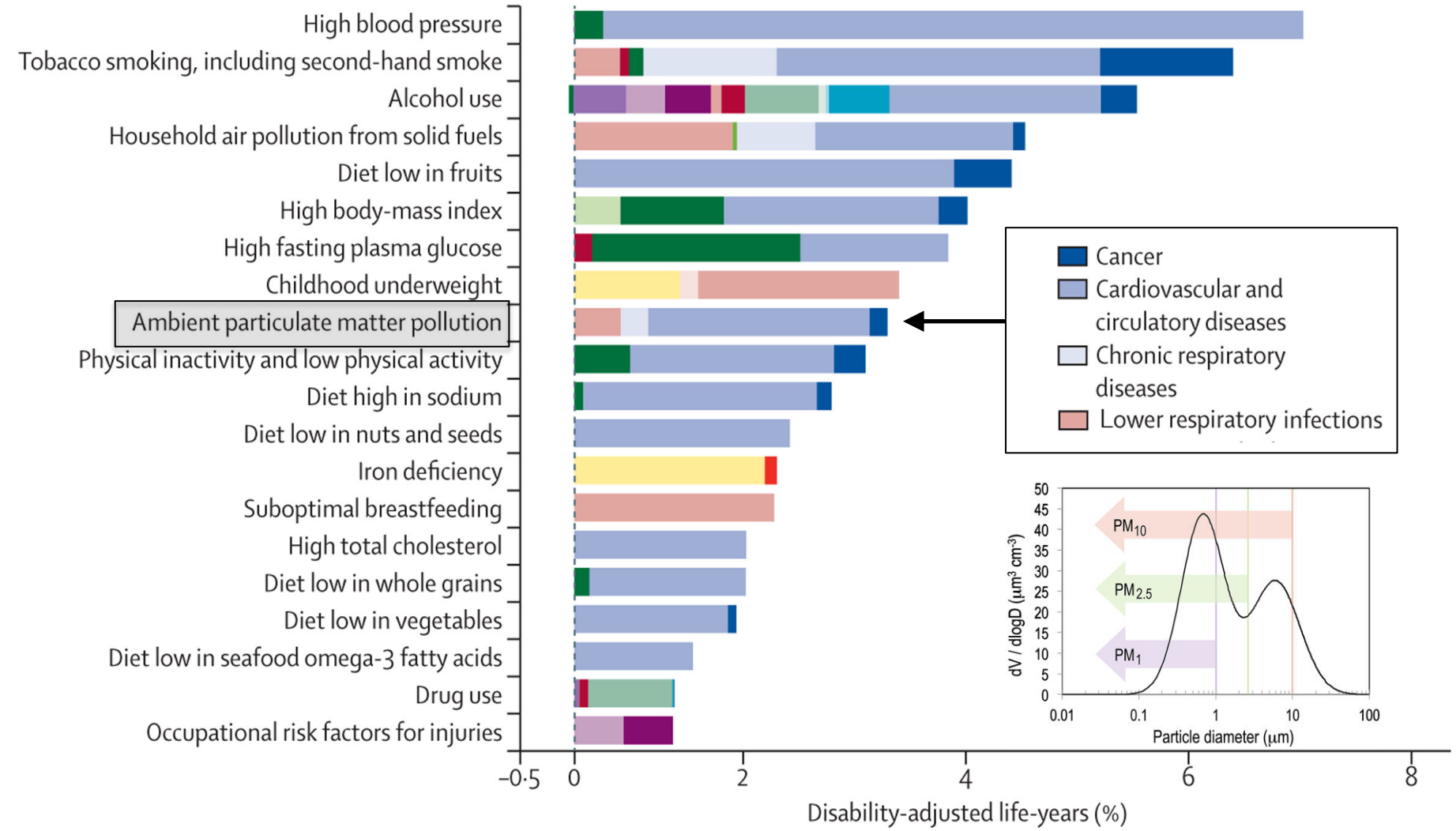


Lee, H., Kalashnikova, O., Suzuki, K., Braverman, A., Garay, M. J., and Kahn, R. A.: Climatology of the aerosol optical depth by components from the MISR and chemistry transport models, Atmos. Chem. Phys. 2016.

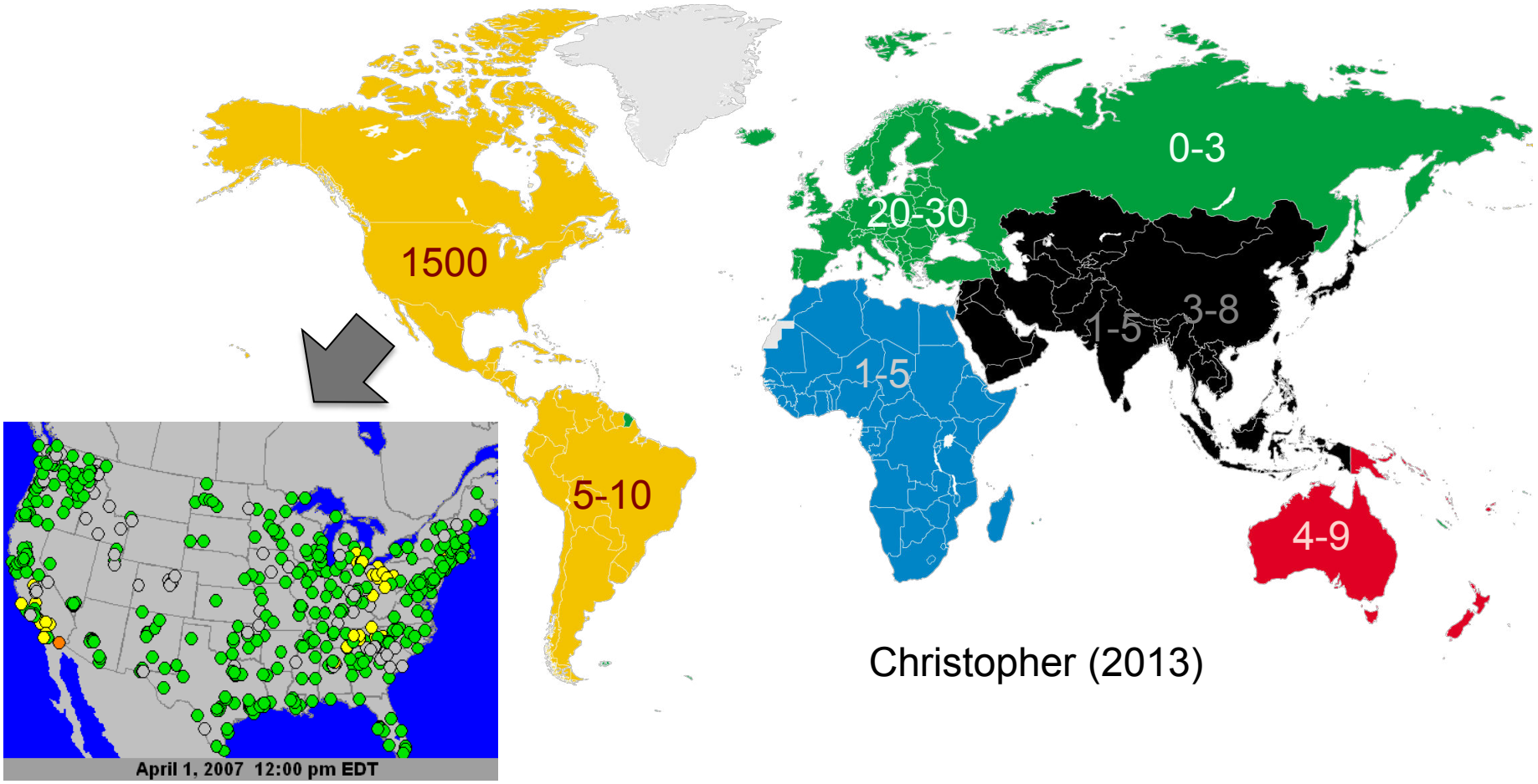
Aerosols: outstanding climate questions

- How are natural and anthropogenic aerosols and their impact on the radiation budget at the top, within, and at the bottom of the atmosphere changing in response to a warming climate, and how to these changes feed back to the climate system?
- **What regions are most susceptible to aerosol phenomena, how are different aerosol types affecting regional brightening or dimming** and what impacts are regional pollution controls and emissions changes having?
- **What are the connections between forcing in one region and impact in another and what are the underlying transport mechanisms of different aerosol types?**
- What are the meteorological processes that control the distribution, transport, and deposition of aerosols?

Global Burden of Disease Study 2010



Surface $PM_{2.5}$ mass monitors are sparse



Christopher (2013)

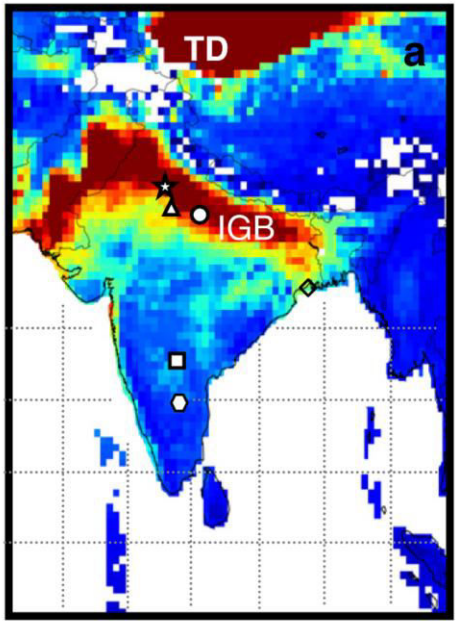
Satellite remote sensing of aerosol amount (aerosol optical depth) may provide a useful proxy for locations without monitors both in the US and globally

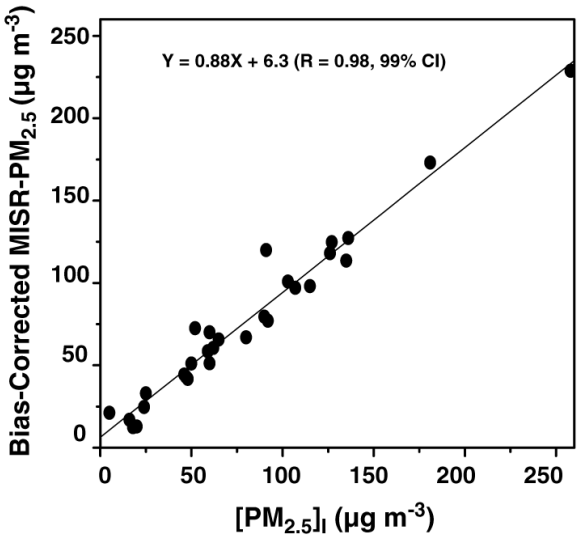
Linear conversion of AOD to $PM_{2.5}$

$$PM_{2.5} = A \times \eta \times AOD + B$$

- η is calculated from the GOES-Chem 3-D Chemical Transport Model and is a function of aerosol size, type, diurnal variation, vertical distribution, and relative humidity

A, B = correction factors are derived from surface $PM_{2.5}$ samples

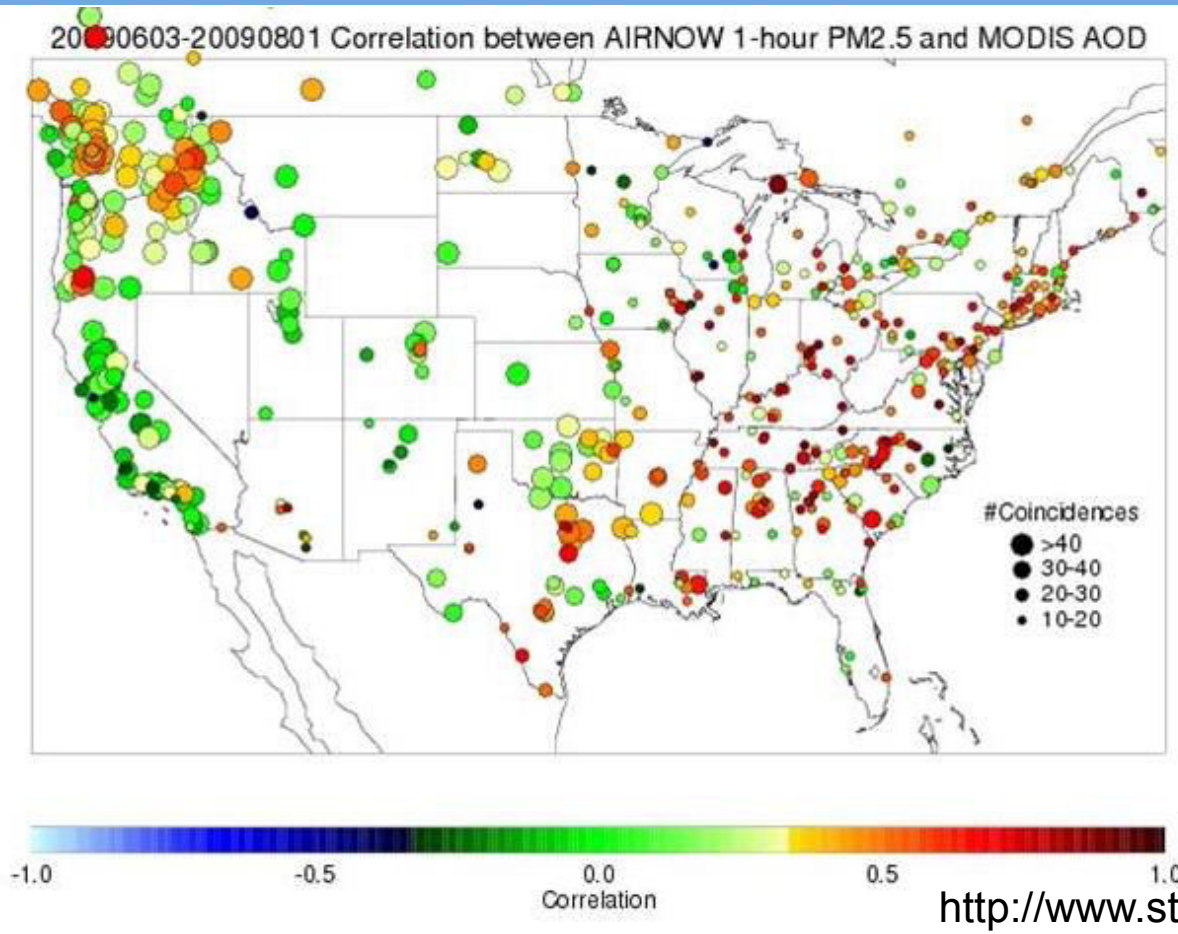






Dey et al. (2012); Liu et al., 2004, 2007; van Donkelaar et al., 2006, 2010

US West Coast challenge

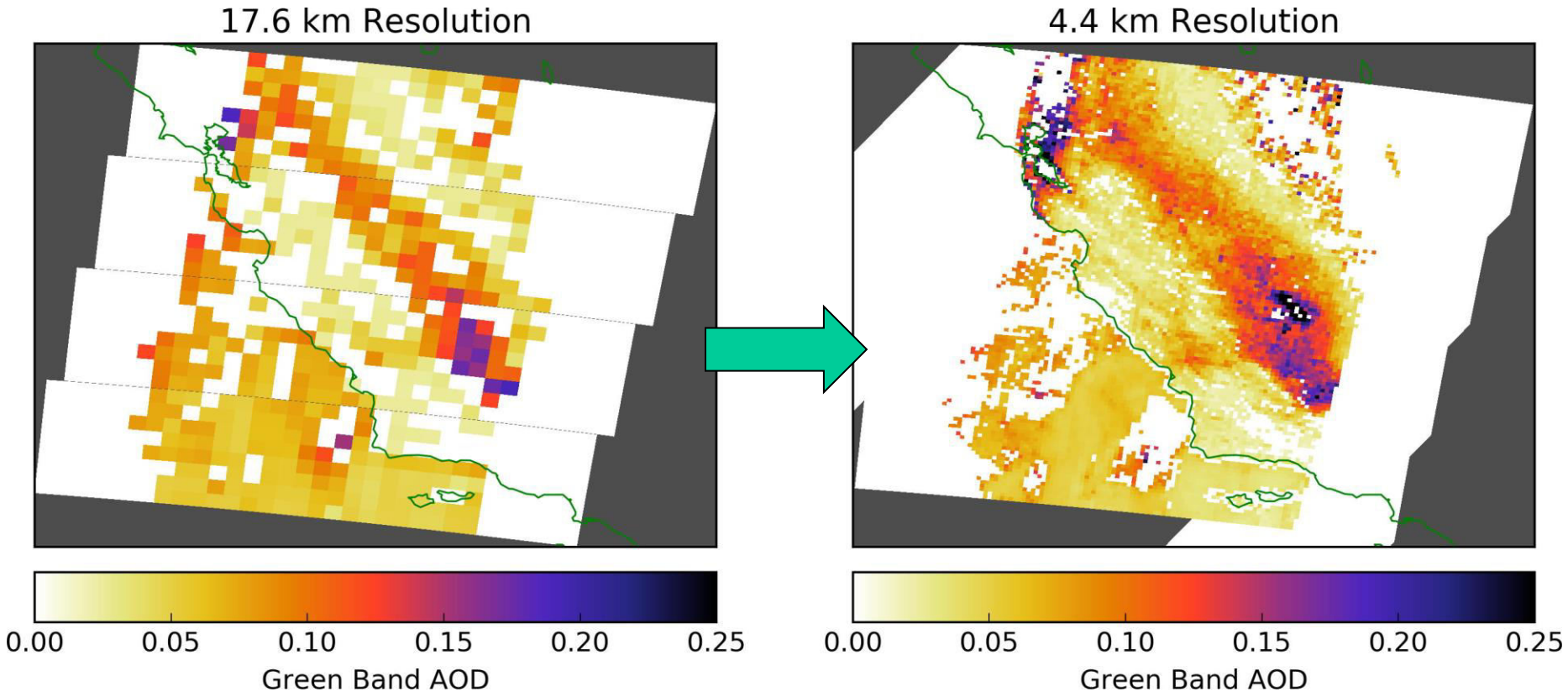




http://www.star.nesdis.noaa.gov/smcd/spb/aq/

- The US West Coast is a particular challenge for establishing the connection between AOD and $PM_{2.5}$
- Human exposure and health applications require neighborhood resolution (~ 1 km) to resolve spatial gradients of pollution

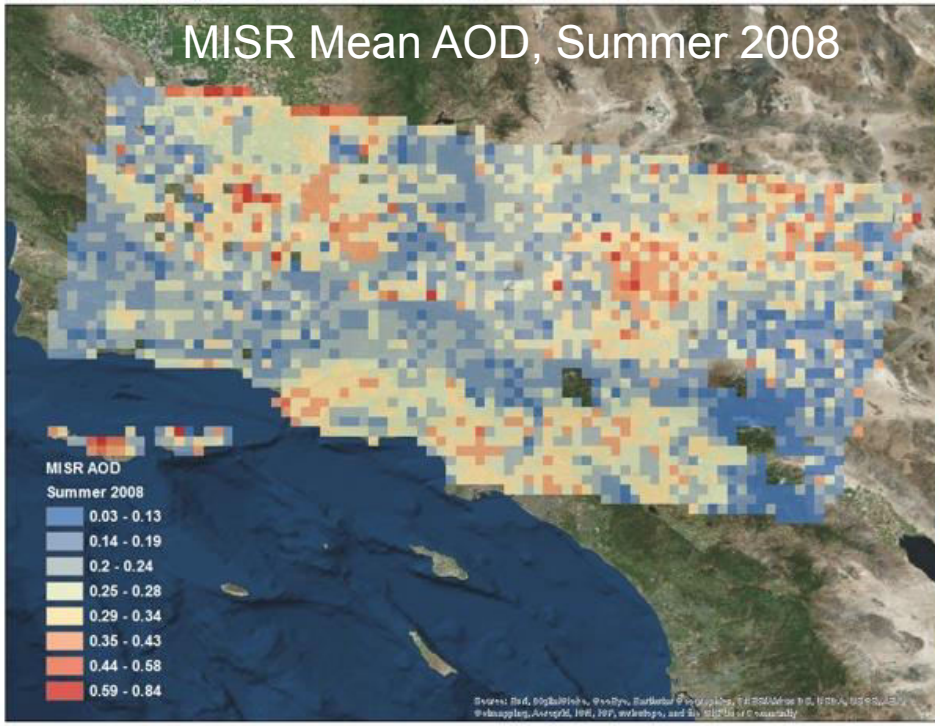
From climate to air quality (spatial resolution)

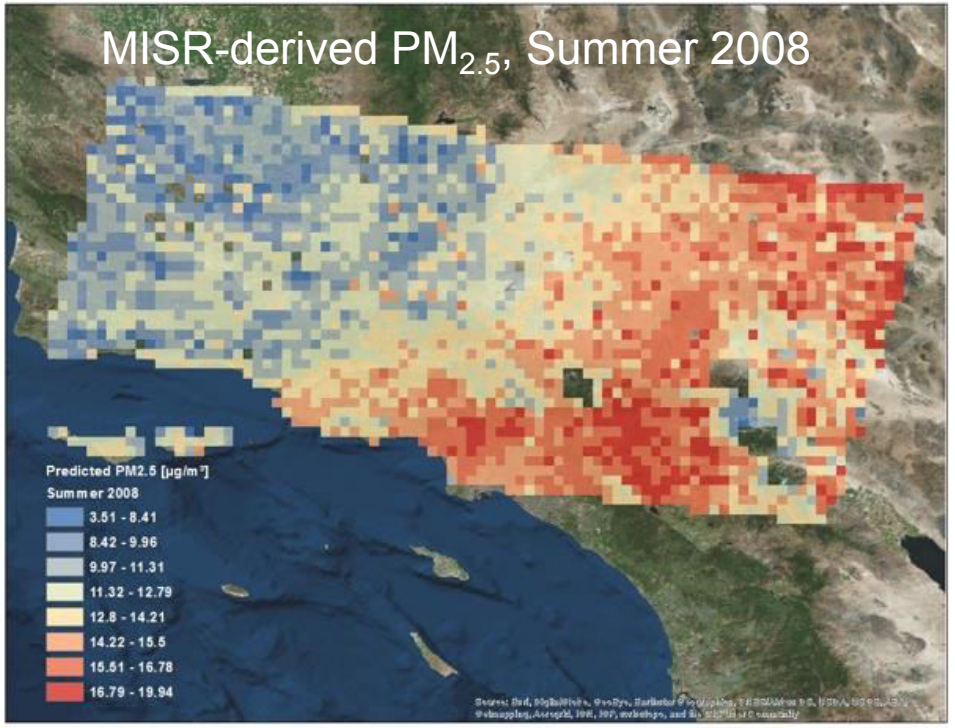


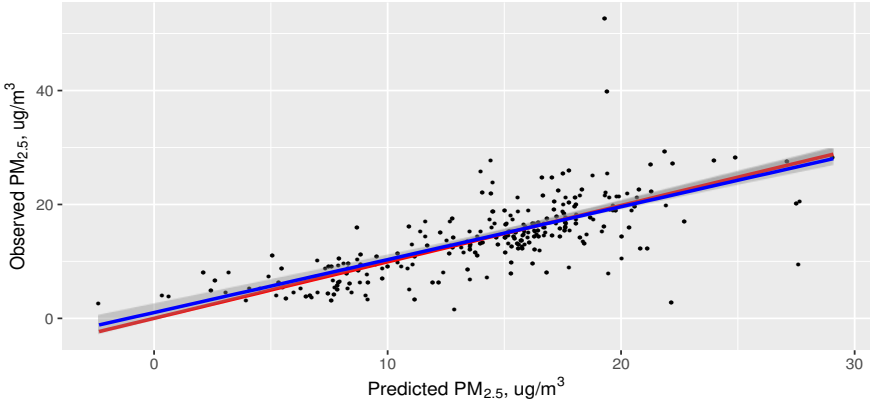
2016-02-05

MISR-derived 4km resolution speciated PM in the greater Los Angeles area

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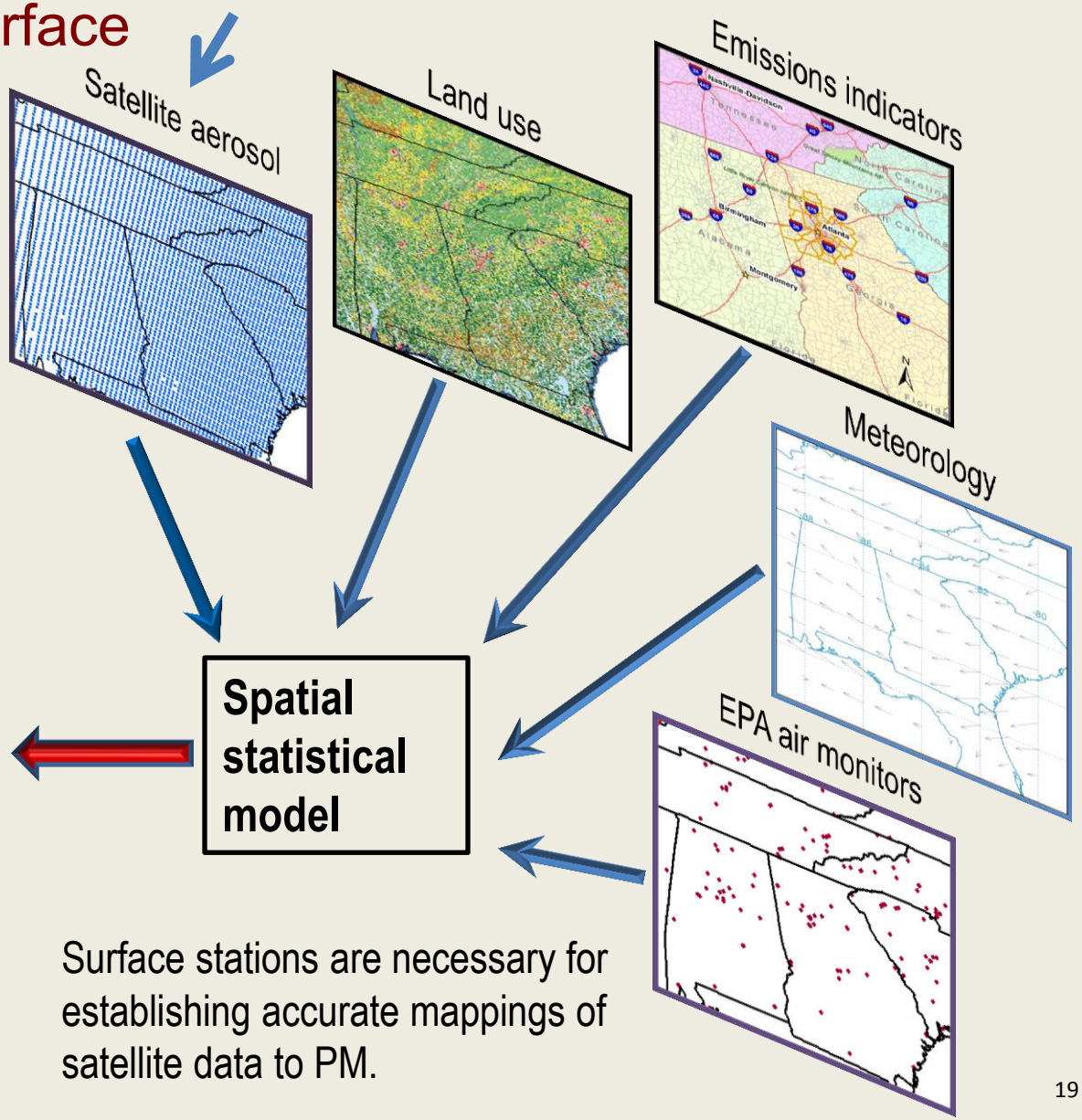


MISR AOD 4.4 km product combined with surface air pollution and meteorological measurements over Southern California were used to build spatio-temporal statistical models to reliably 'convert' AOD to PM concentrations of various sizes and types in LA area.

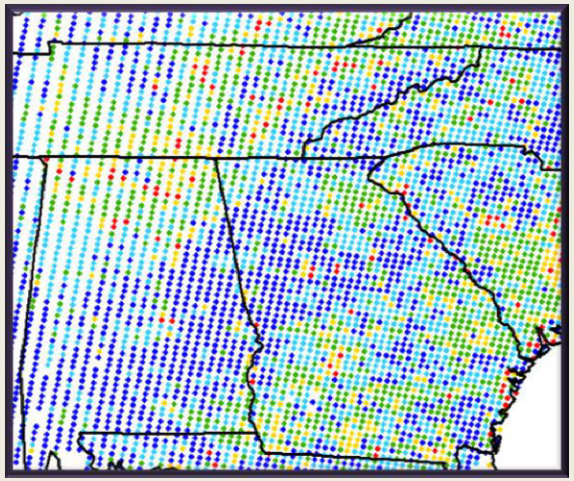
Franklin et al., RSE, in review.

An *integrated* approach, combining satellites, air quality models, and surface monitors is essential

Chemical transport model provides aerosol vertical profiles to get the boundary layer fraction of total AOD.



Satellite data, meteorology, land use, emissions indicators (e.g., population, traffic information), and EPA measurements are used as inputs to develop a statistical model to predict $PM_{2.5}$ concentration.



Predicted $PM_{2.5}$

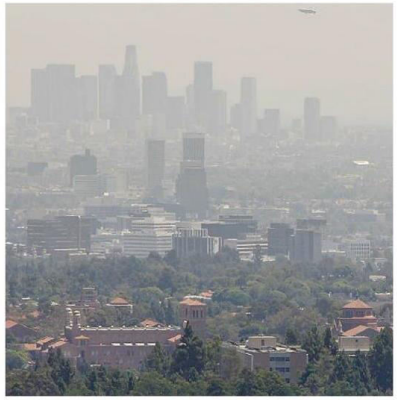
Liu (2013)

Surface stations are necessary for establishing accurate mappings of satellite data to PM.

From climate to air quality (MAIA)

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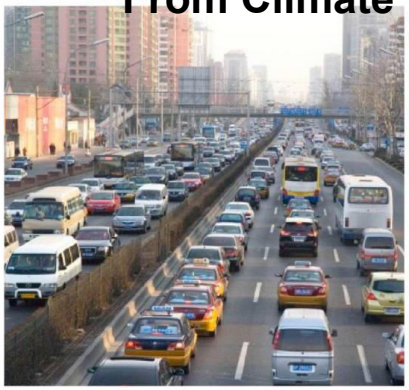
Earth Venture NASA mission: to be launched 2020-2022






MAIA

Spectropolarimetric Measurements from the Multi-Angle Imager for Aerosols: From Climate to Air Quality


MAIA Science Objective

PI: David Diner



MAIA

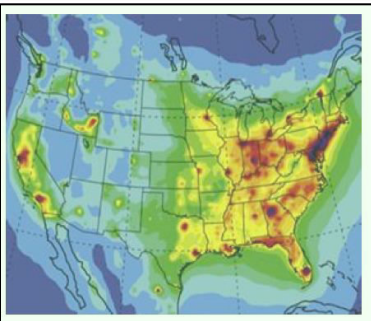


- **MAIA's primary science objective is to associate *specific types* of airborne particulate matter (PM) with adverse health outcomes**
- Observations of major cities on five continents will provide large sample sizes to conduct statistically robust epidemiological studies
- Secondary targets will also be observed to enable other types of aerosol and cloud investigations

MAIA Science Implementation

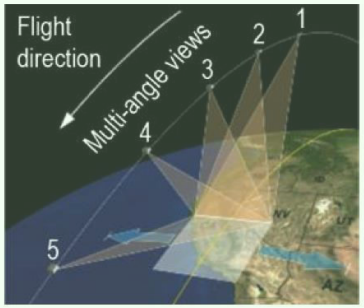
How are we measuring and what will we do with the data?

MAIA's spaceborne observations of PM concentrations in major cities around the globe wield enormous statistical power for associating PM exposure and disease.



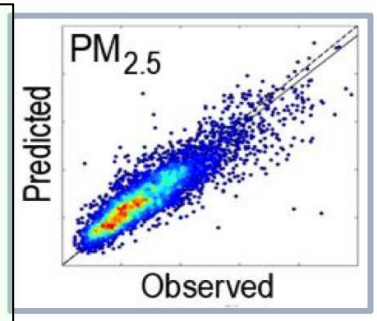
A state-of-the-art chemical transport model (CTM) provides initial estimates of the abundances of different aerosol types, along with their vertical distributions.

+



The MAIA instrument uses the proven power of multi-angle and multispectral radiometry and polarimetry to eliminate CTM biases and retrieve fractional aerosol optical depths of different particle types.

+



Geostatistical models (GSMs) derived from collocated surface and MAIA measurements relate these fractional aerosol optical depths to near-surface concentrations of major PM constituents.

+



Geocoded birth, death, and hospital records and established epidemiological methodologies are used to associate PM exposure with adverse health outcomes.

=



The MAIA investigation addresses NASA's EVI-3 goal of using observations from space and inter-disciplinary Earth science research to benefit society.

Model-constrained retrievals

Questions?

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