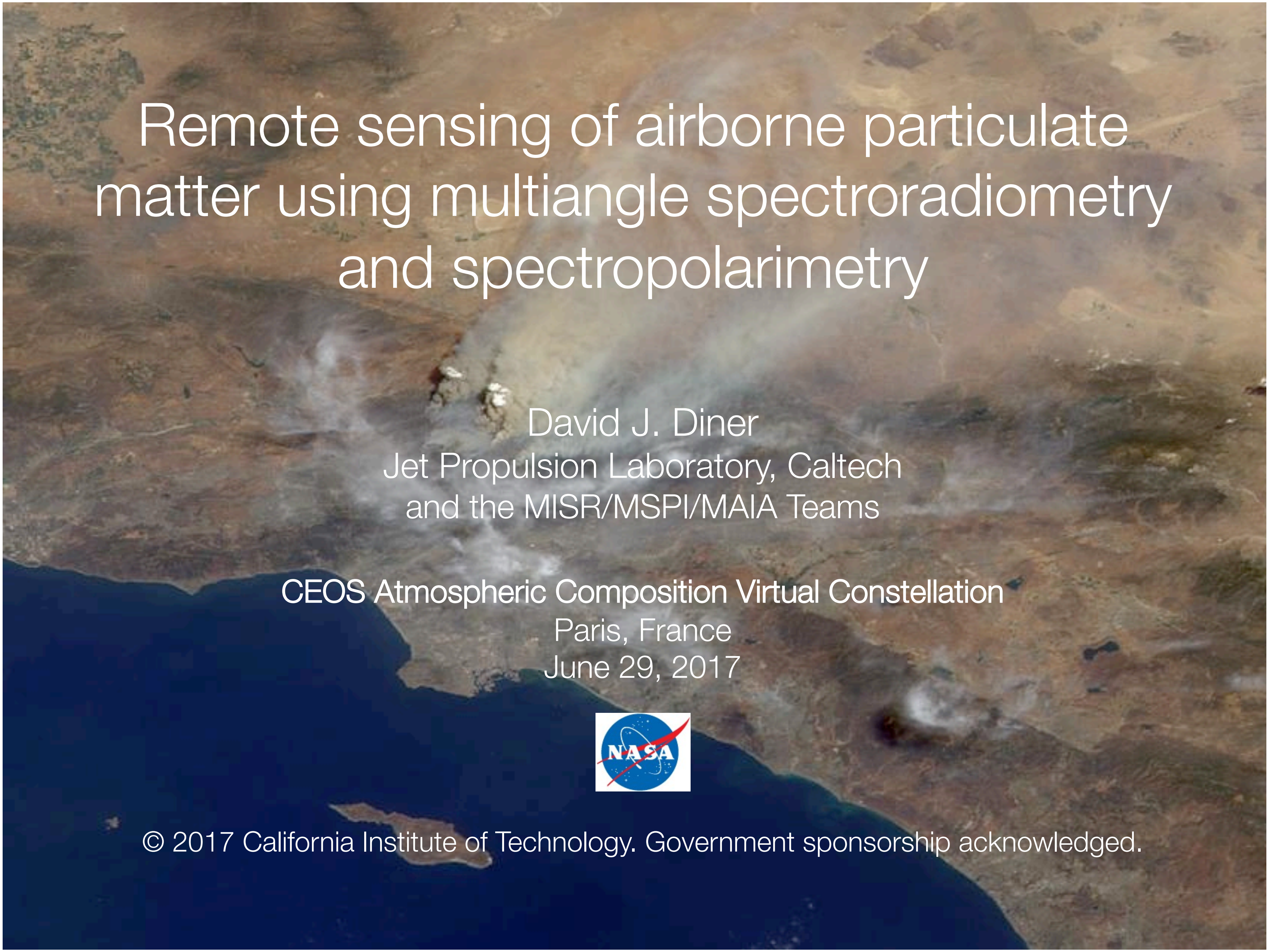

Remote sensing of airborne particulate matter using multiangle spectroradiometry and spectropolarimetry

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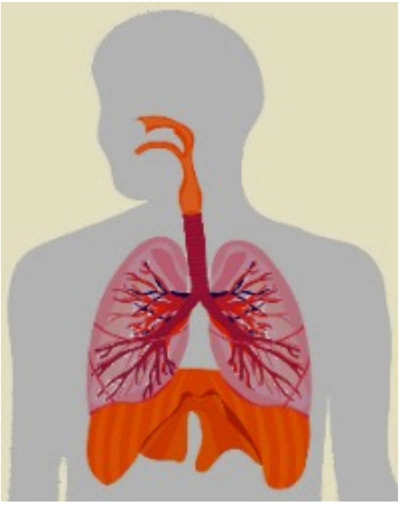
and the MISR/MSPI/MAIA Teams

CEOS Atmospheric Composition Virtual Constellation
Paris, France
June 29, 2017

Particulate matter (PM) impacts on human health



Airborne PM is a well-known cause of cardiovascular and respiratory diseases.

Coarse particles (PM_{10}-$PM_{2.5}$) irritate our respiratory systems.

Fine particles ($PM_{2.5}$) penetrate deep into our lungs. Toxins can migrate to other organs.

- Heart attacks
- Stroke
- Lung disease, lung cancer
- Aggravated asthma
- Low birth weight and preterm delivery

Importance of particle type

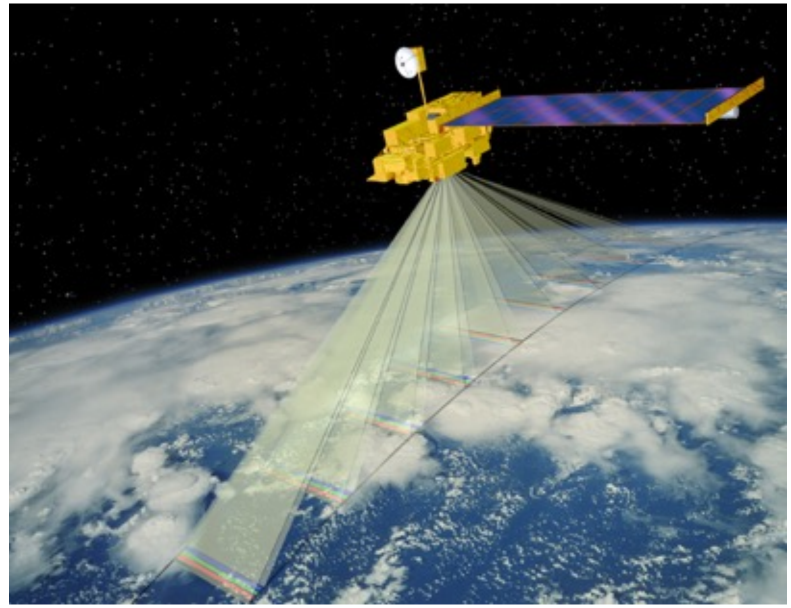



- Although PM is implicated in many adverse health impacts, the relative toxicity of specific **PM types** is not well understood
- PM “type” refers to the fractional proportions of PM_{10}, $PM_{2.5}$, and $PM_{2.5}$ components (sulfate, nitrate, organic carbon, black carbon, dust)
- According to the US EPA (2013)
  - [T]he evidence is not yet sufficient to allow differentiation of those constituents or sources that may be more closely related to specific health outcomes.
  - The use of central fixed-site monitors to represent population exposure is a key factor limiting our knowledge as to which PM types pose the greatest health risks.

Multi-angle Imaging SpectroRadiometer (MISR)

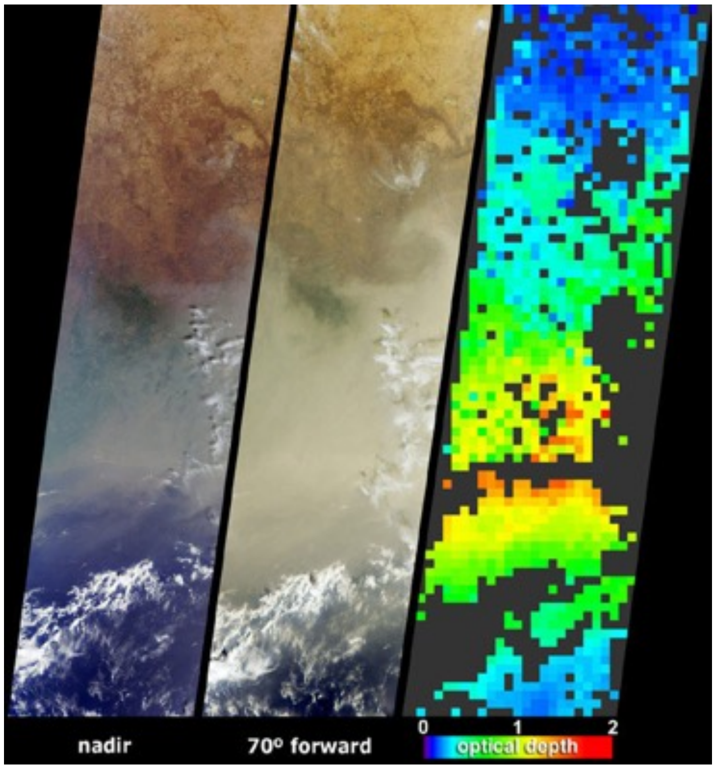
- 9 view angles between ±70º
- 275 m sampling
- Four spectral bands:

446, 558, 672, 866 nm

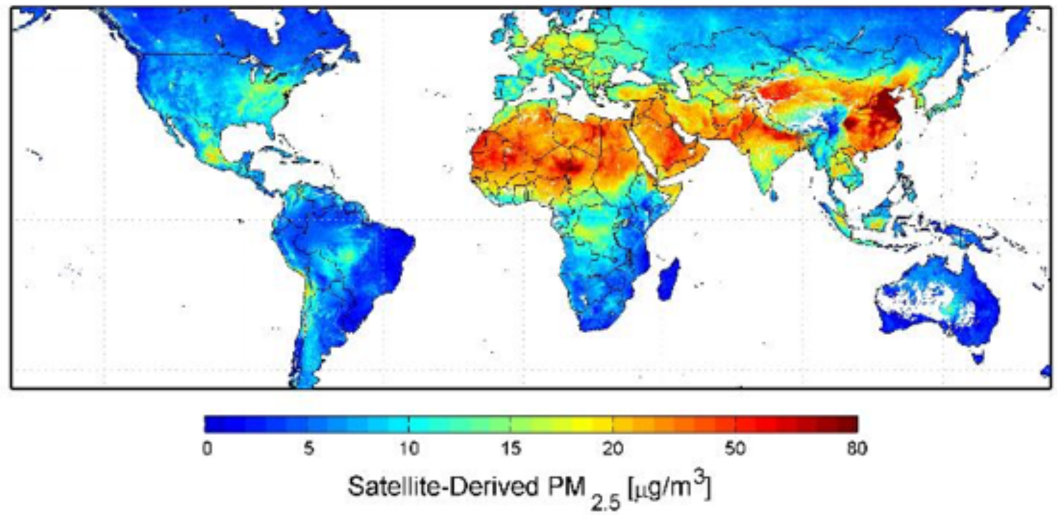


Terra launch, Dec. 1999

Oblique-angle sensitivity to aerosols over many surface types



MISR imagery and AOD over Western Africa



van Donkelaar et al. (2010, 2015)

$PM_{2.5}$ maps derived from MODIS and MISR are used in many health studies, e.g.,

- Global Burden of Disease (*Brauer et al., 2012*)
- Relative risk of death from circulatory system diseases (*Jerrett et al., 2017*)
- Associations between $PM_{2.5}$ and low birth weights (*Fleischer et al., 2014*)
- Increased breast cancer mortality risk from $PM_{2.5}$ exposure (*Tagliabue et al., 2016*)

Relating AOD to PM concentration

$$[PM] \approx \left[\frac{4\rho r_{eff}}{3Q_{ext}H} \right] AOD$$

- These factors are highly variable
- Difficult to obtain reliable accuracies from first principles

Gupta and Christopher (2009)

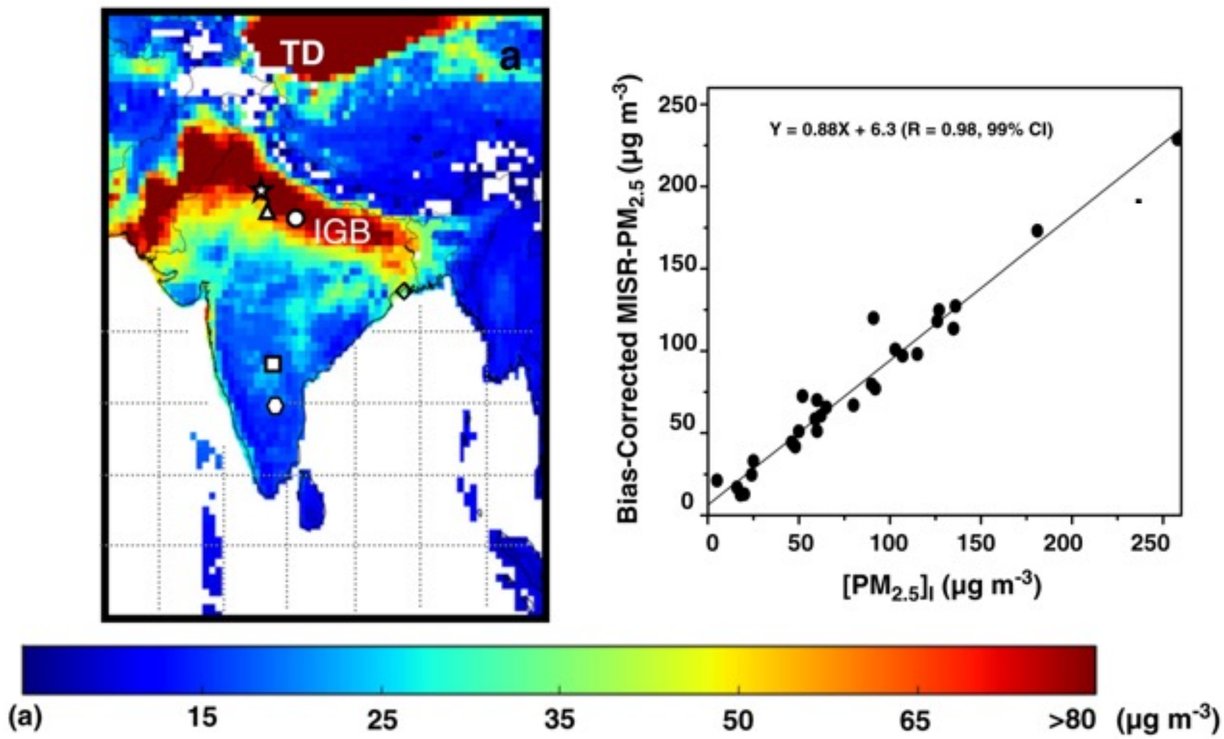
- ρ = particle density
- r_{eff} = effective particle radius (ratio of 3rd to 2nd moment of size distribution)
- Q_{ext} = extinction efficiency (ratio of optical to geometric cross section of the particles) under ambient conditions
- H = height of the aerosol layer

Mapping of $PM_{2.5}$ over India with MISR

Empirical regressions work better, e.g., $PM_{2.5} = A \times \eta \times AOD + B$

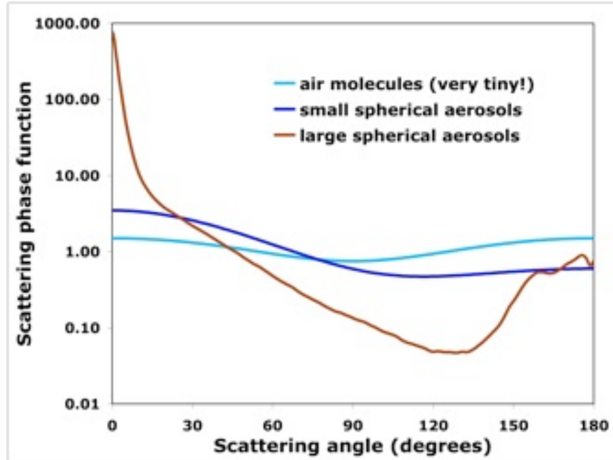
η is calculated from GOES-Chem and is a function of aerosol size, type, diurnal variation, vertical distribution, and relative humidity

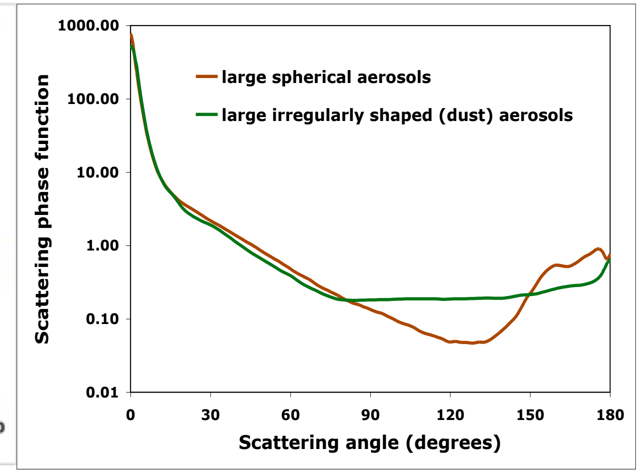
A, B = correction factors are derived from surface $PM_{2.5}$ measurements

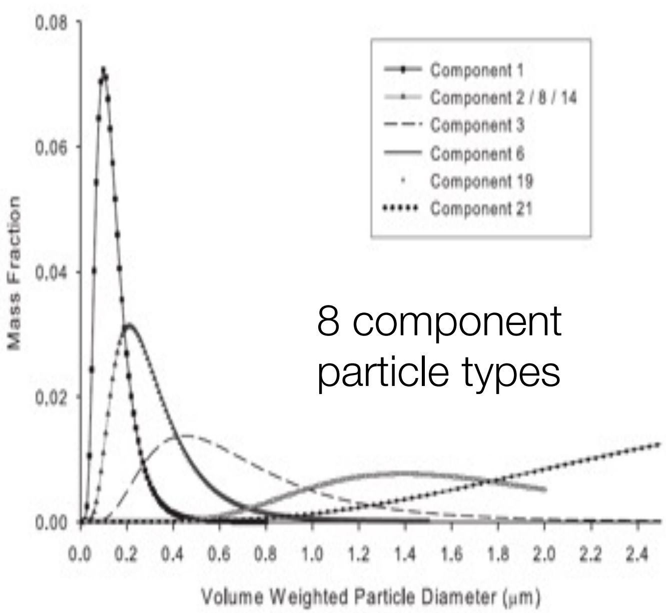


Dey et al. (2012)
Liu et al. (2004, 2007)
van Donkelaar et al. (2006, 2010)

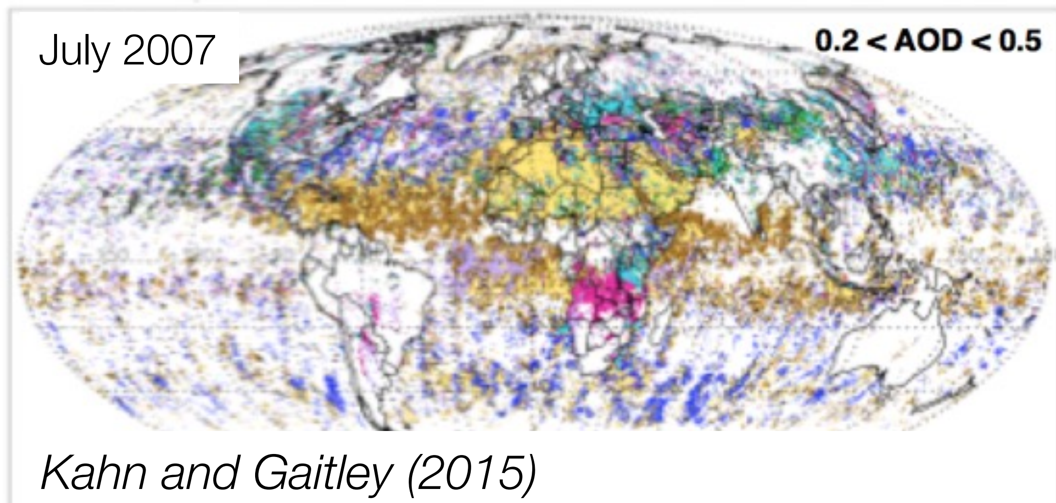
Multiangular sensitivity to particle size and shape







8 component particle types



Kahn and Gaitley (2015)

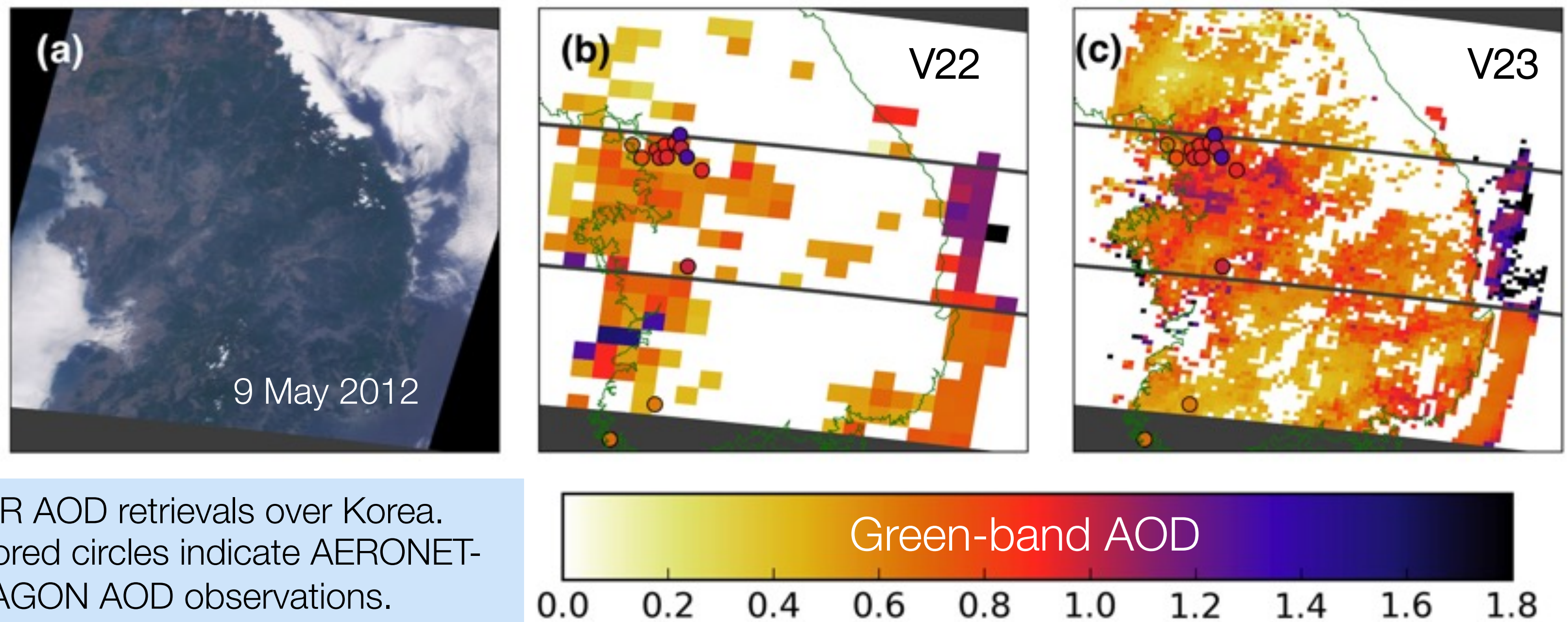
1-10 | 11-20 | 21-30 | 31-40 | 41-50 | 51-62 | 63-70 | 71-74 — Mixture Group

Spherical, non-absorbing

Non-spherical

Spherical, absorbing

New MISR global 4.4 km resolution AOD product to be released Fall 2017



MISR AOD retrievals over Korea. Colored circles indicate AERONET-DRAGON AOD observations.

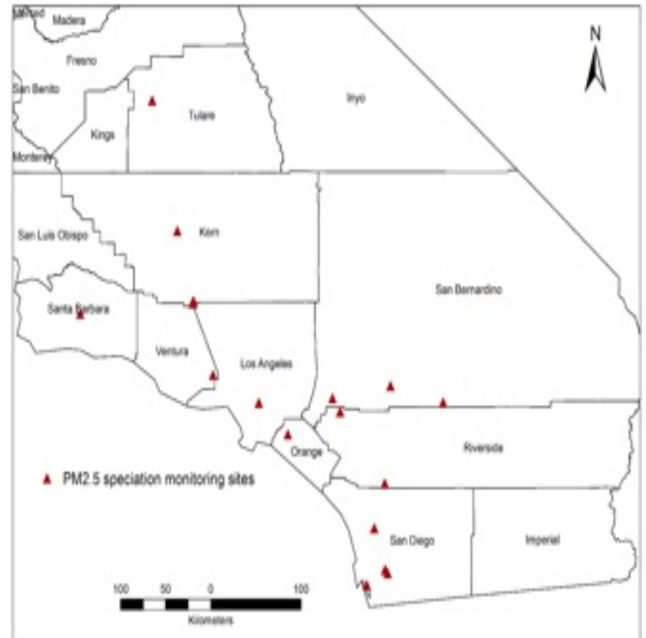
- High-resolution aerosol data is important for urban-scale air-quality and health impact assessments.
- Compared to the current MISR V22 aerosol product, the new V23 product will:
  - improve the spatial resolution from 17.6 km to 4.4 km
  - increase spatial coverage and enhance the ability to resolve aerosol spatial gradients
  - increase accuracy at high and low AODs compared to AERONET sunphotometer data

Garay et al. (2017)

Use of MISR fractional 4.4-km AODs for speciated $PM_{2.5}$ retrieval in California

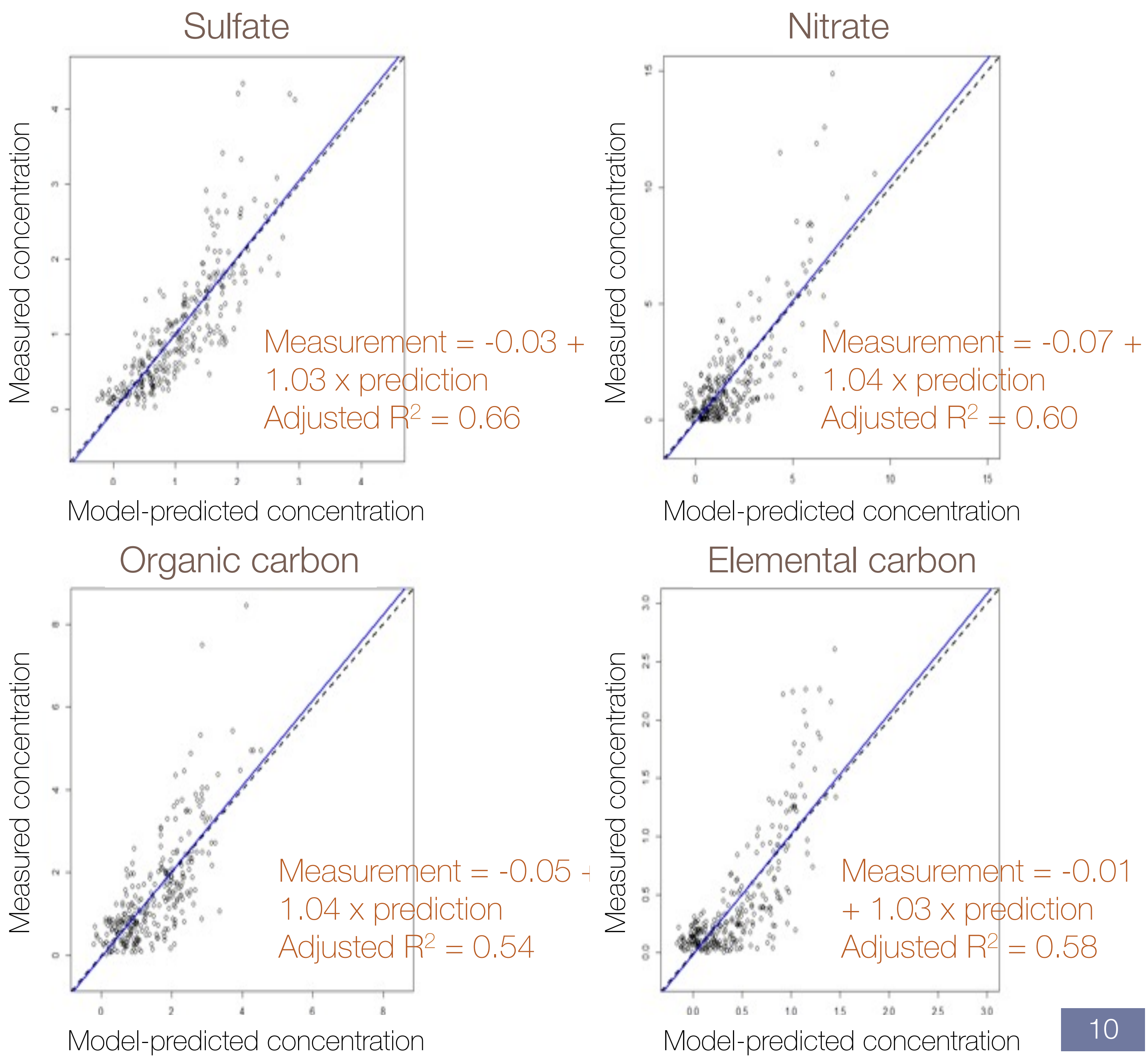
$$\text{PM2.5 speciation} = \sum_{i=1}^{8} f_i(MISR\ fractional\ AOD_i) + f_k(\text{predictor}_k) + f_{x,y}(\text{x,y}) + f_t(\text{t})$$

Meng et al. (2017)



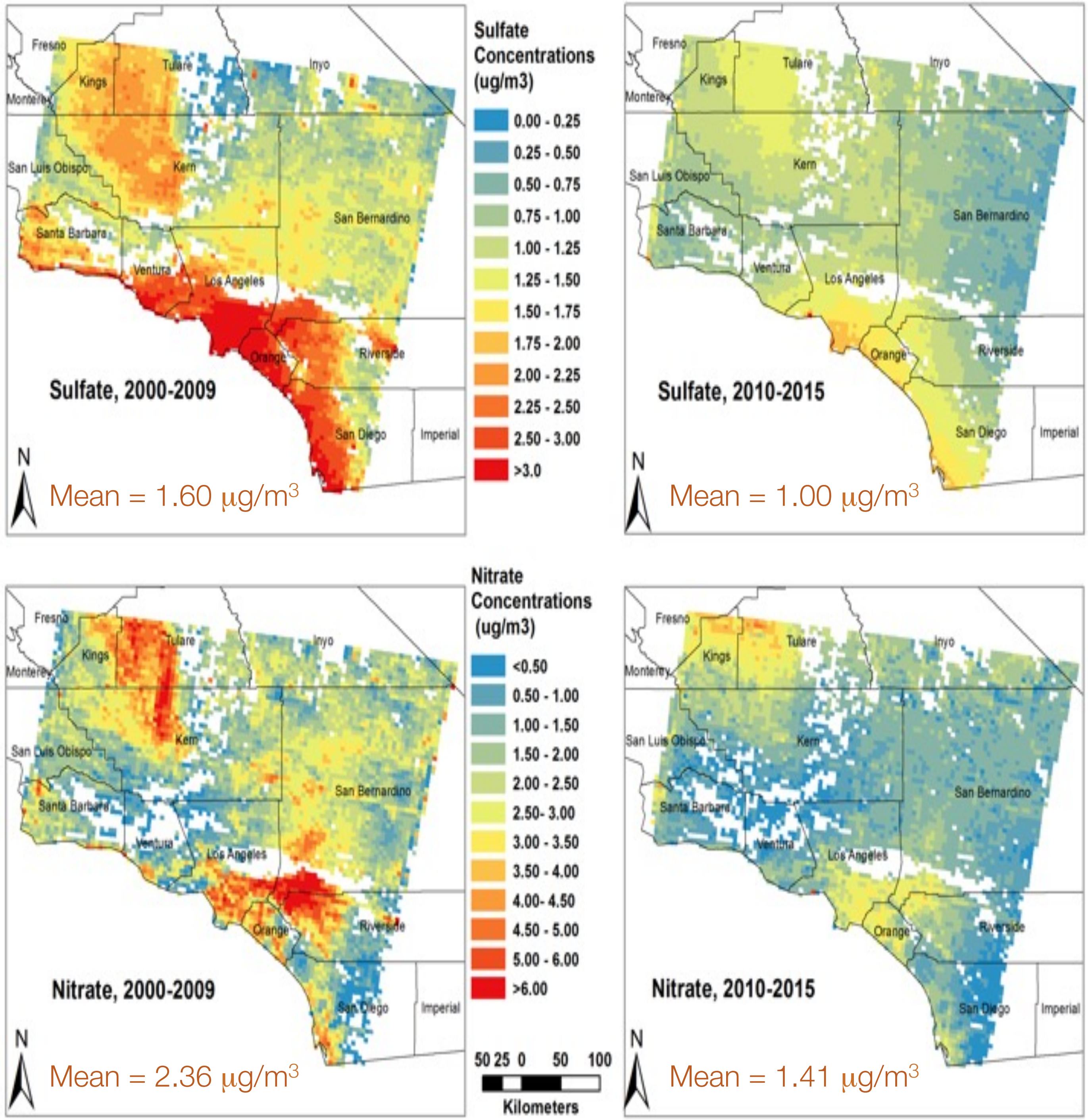
- f_i (MISR fractional AOD_i) is smooth term of MISR fractional AOD_i
- f_k ($predictor_k$) is the smooth term of predictor variables k, including elevation, PBLH, NDVI and road length
- $f_{x,y}$ (x,y) is a 2-D smooth spatial function of sites' coordinates
- f_t (t) is a nonlinear term of DOY or the YEAR varying smoothly in time

Daily speciated $PM_{2.5}$, 2010-2015



Meng et al. (2017)

Averaged annual means of predicted sulfate and nitrate $PM_{2.5}$ concentrations



Meng et al. (2017)

JPL Airborne Multiangle SpectroPolarimetric Imager (AirMSPI)

• Gimbaled camera with selectable view angles between ±67°

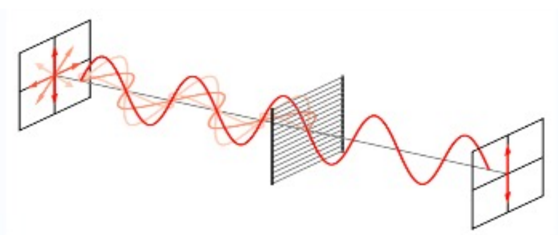
• Uses electro-optical measurement approach to provide accurate polarimetric imaging without moving parts

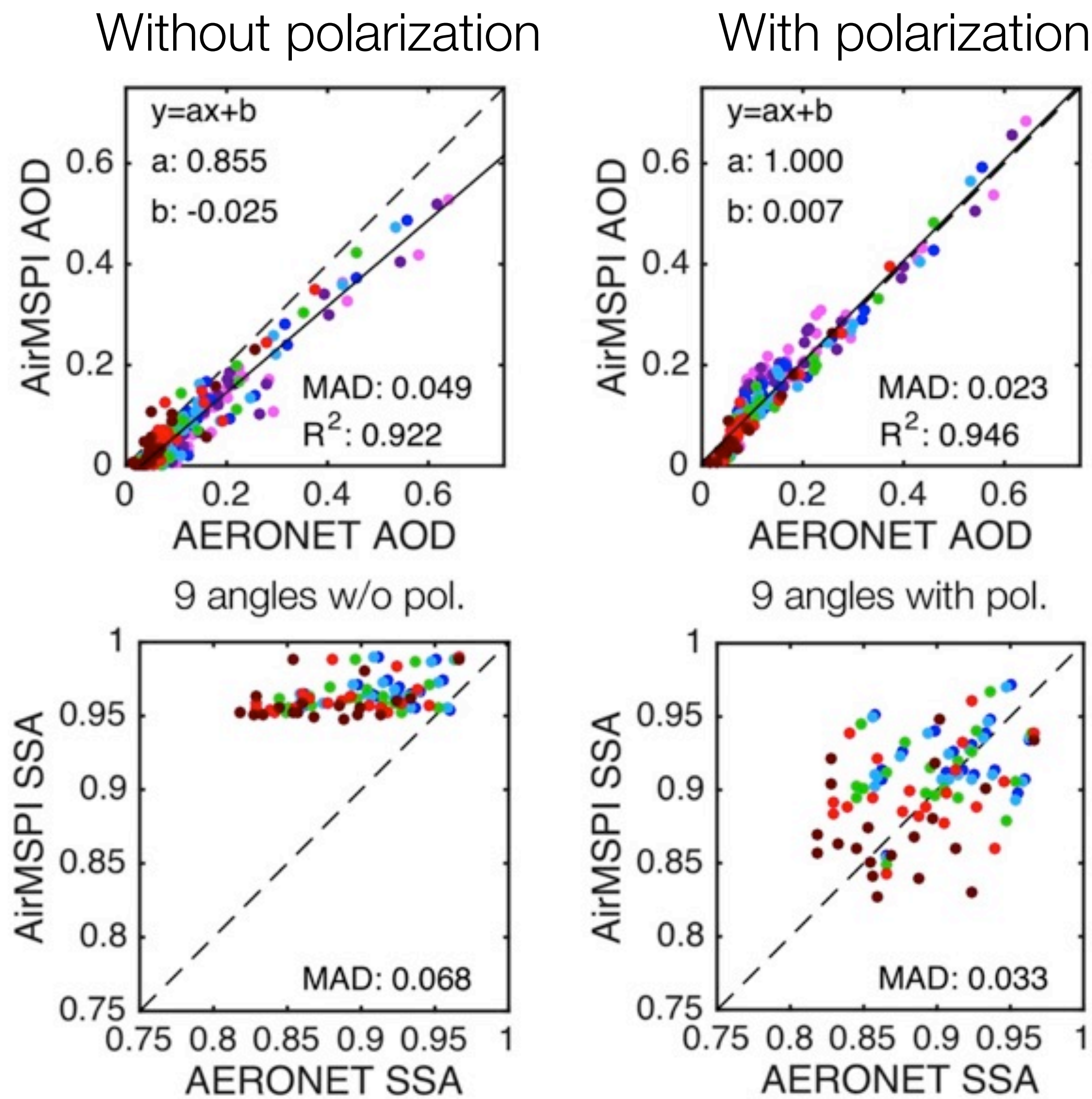
• 10 m sampling

• 355, 380, 445, 470*, 555, 660*, 865*, 935 nm (*polarized)

Flying since 2010 on the NASA ER-2 aircraft (20 km flight altitude)
PODEX, SEAC4RS, CalWater-2, RADEX, ImPACT-PM, ORACLES

Inclusion of polarization reduces retrieval scatter and bias

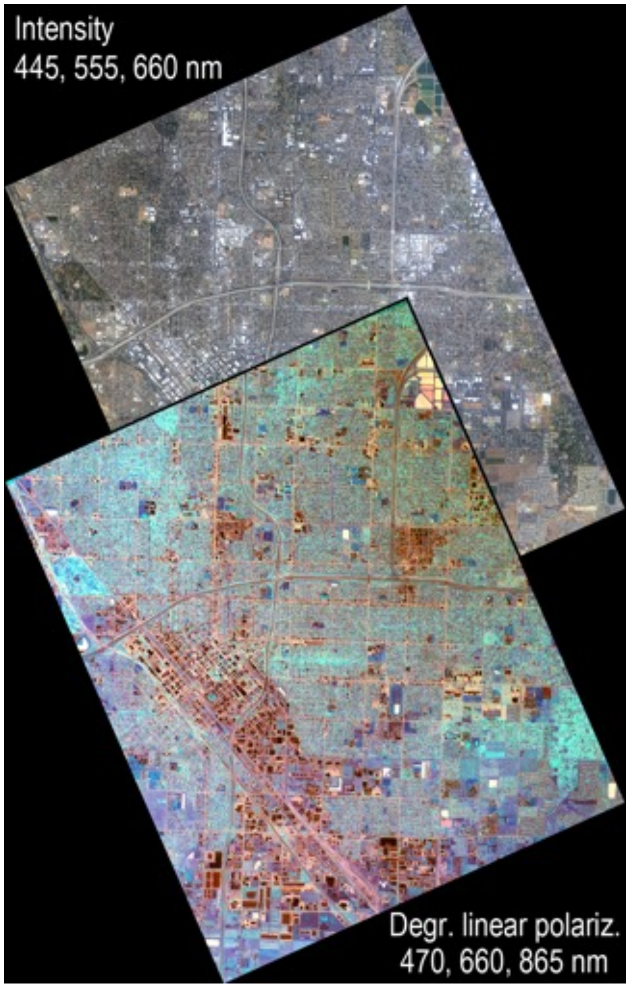


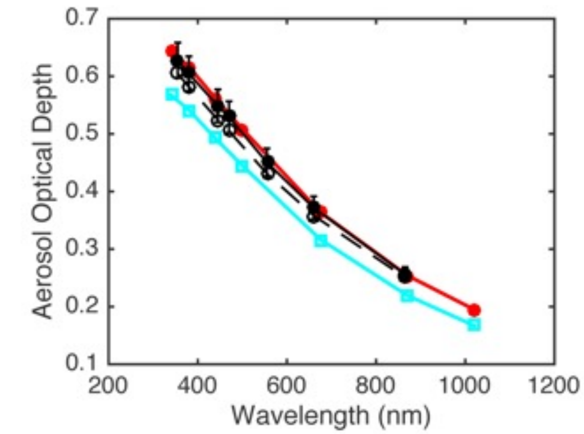


MAD = mean absolute difference

Xu et al. (2017)

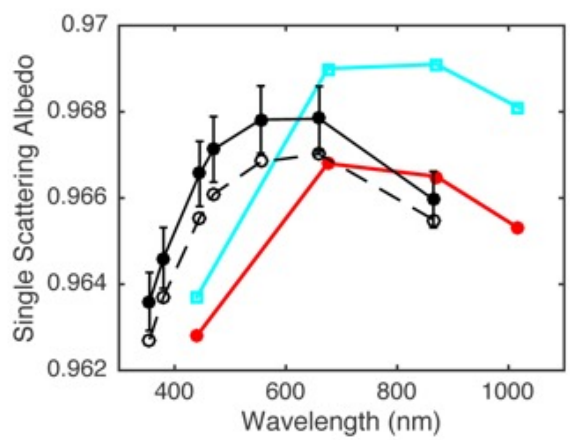
AirMSPI sensitivity to aerosol particle properties

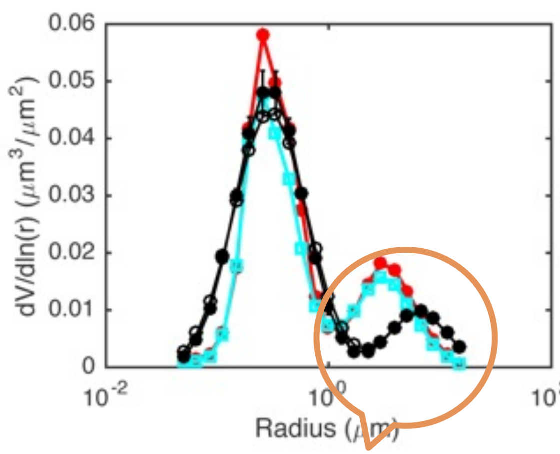




Xu et al. (2017)

Fresno, CA 6 Jan 2012, 20:23 UTC

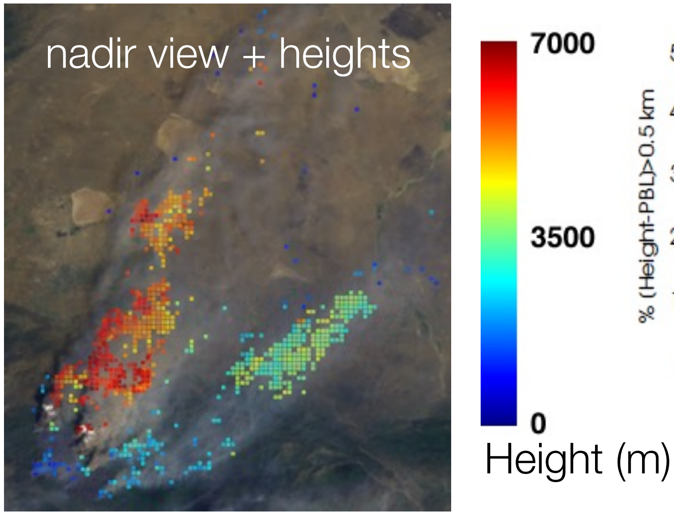


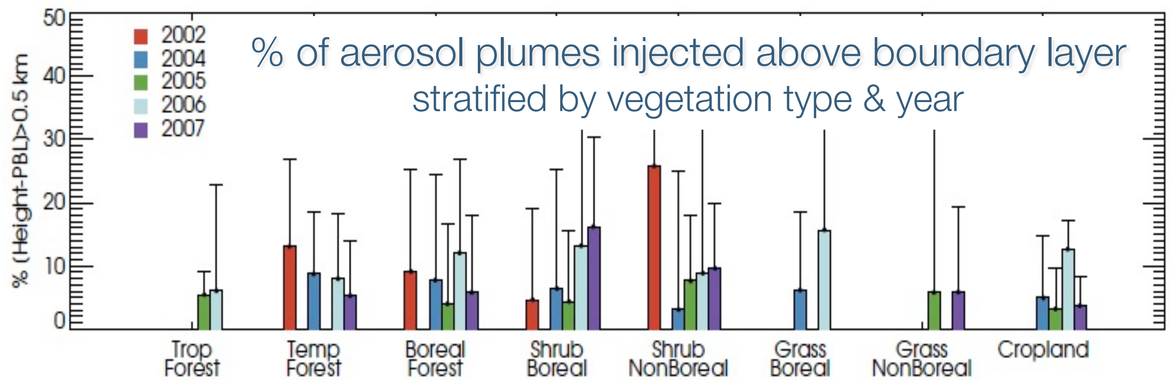


Limited sensitivity to coarse mode with UV/VNIR observations only

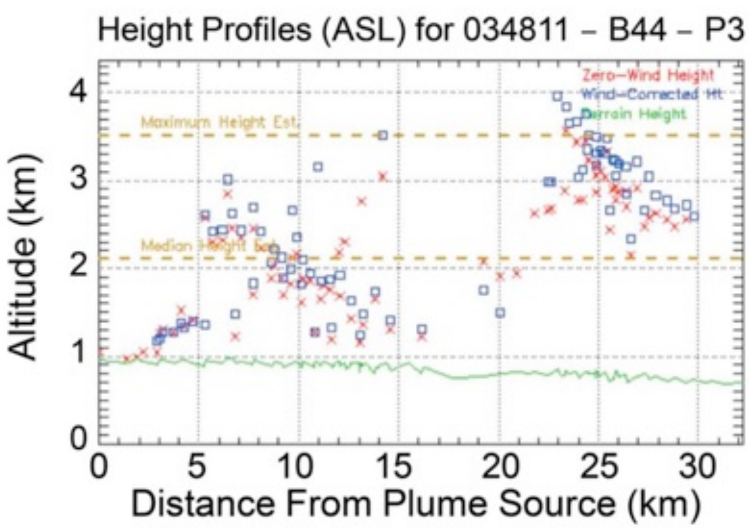
Data: https://eosweb.larc.nasa.gov/project/airmspi/preliminary-airmspi-datasets

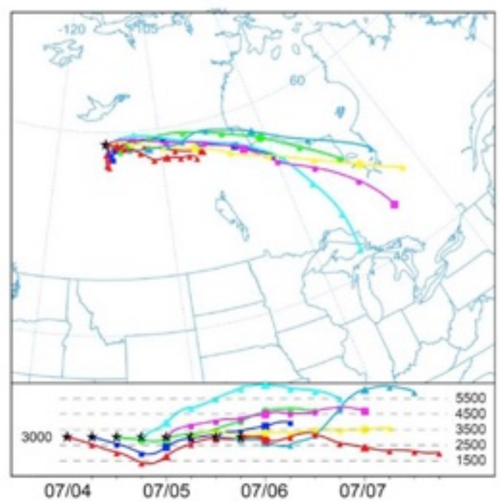
MISR stereoscopic sensitivity to aerosol plume height





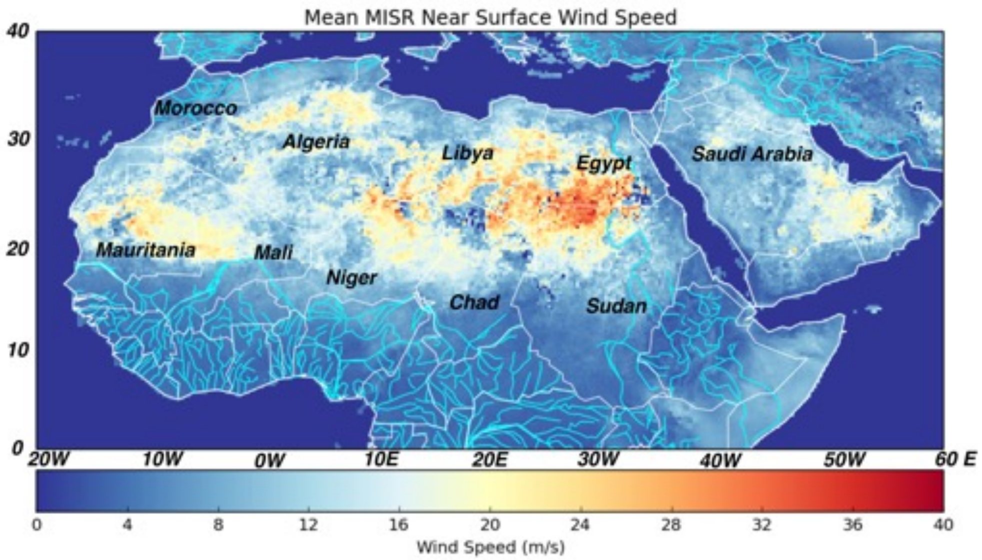
Kahn et al. (2008), Val Martin et al. (2010)

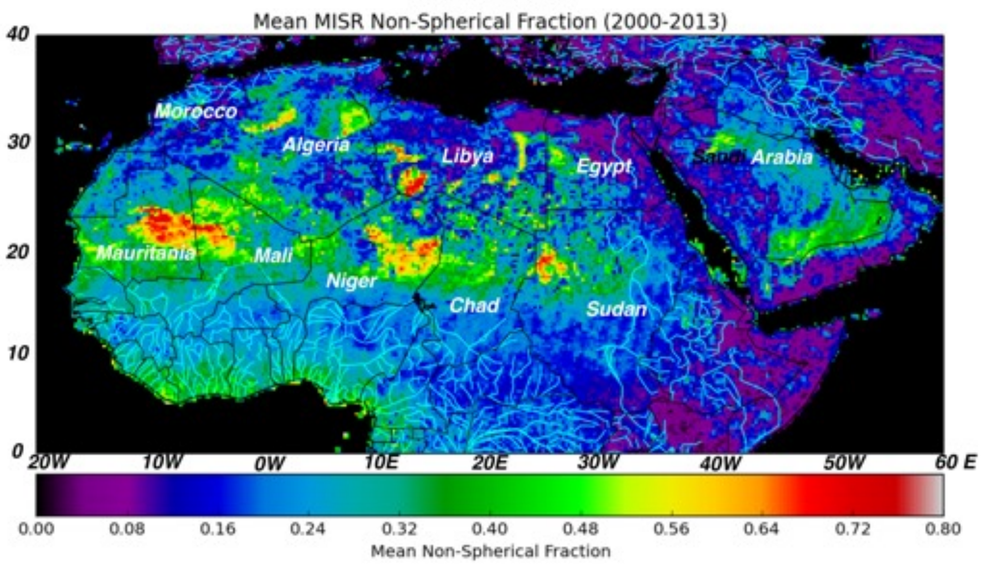




Miller et al. (2011)

Stereoscopic and time-lapse sensitivity to plume-tracked winds





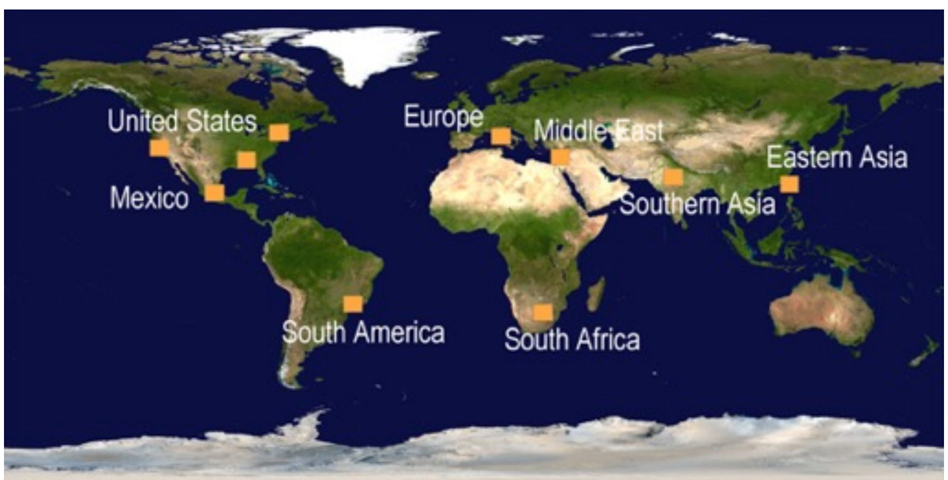
- Middle East and African dust storms have significant environmental and societal impacts.
- Northwesterly Shamal winds are responsible for major dust events.
- MISR’s near-surface wind and aerosol nonspherical fraction data products enable development of a Shamal climatology and seasonal dust prediction capability.

Yu et al. (2015, 2016)

Multi-Angle Imager for Aerosols (MAIA)

- MAIA was selected in March 2016 as part of NASA's Earth Venture Instrument program
- The satellite instrument will target major urban areas to assess the impacts of different types of airborne PM on human health
- TBD satellite and launch into sun-synchronous orbit, 600-850 km altitude, ~2021

birth outcomes (restricted intrauterine growth, preterm delivery, low birth weight)
acute illness events (e.g., asthma flare-ups), premature deaths
chronic cardiovascular and respiratory disease

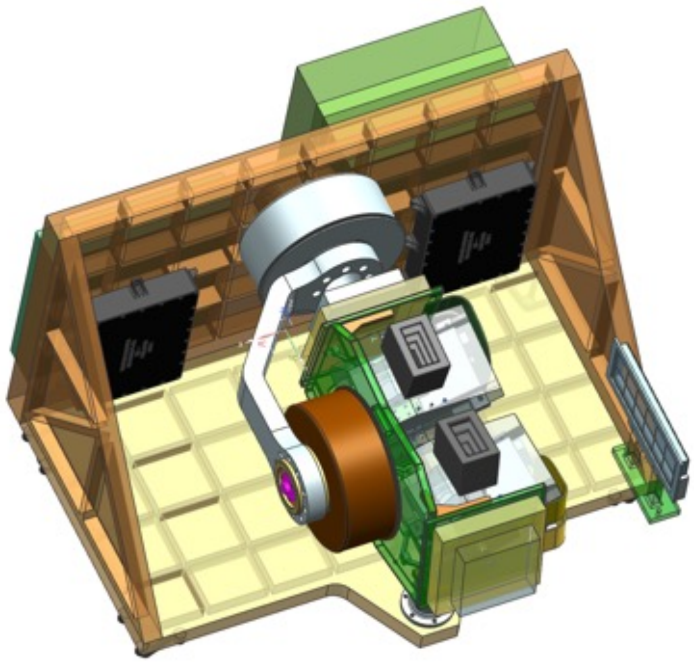


- Candidate Primary Target Areas
- Other target areas to be observed for air quality and climate science

Liu and Diner (2017)

MAIA instrument

- Contains a pair of spectroradiometric/polarimetric cameras on a 2-axis gimbal to image the selected target areas



Along-track multi-angle viewing to ±67°

Cross-track axis enables viewing targets off the sub-S/C track

Target dimensions ≥ 300 km cross-track x 150 km along-track

Nadir footprint ~200 m

PM data products to be generated in ground processing at 1 km resolution

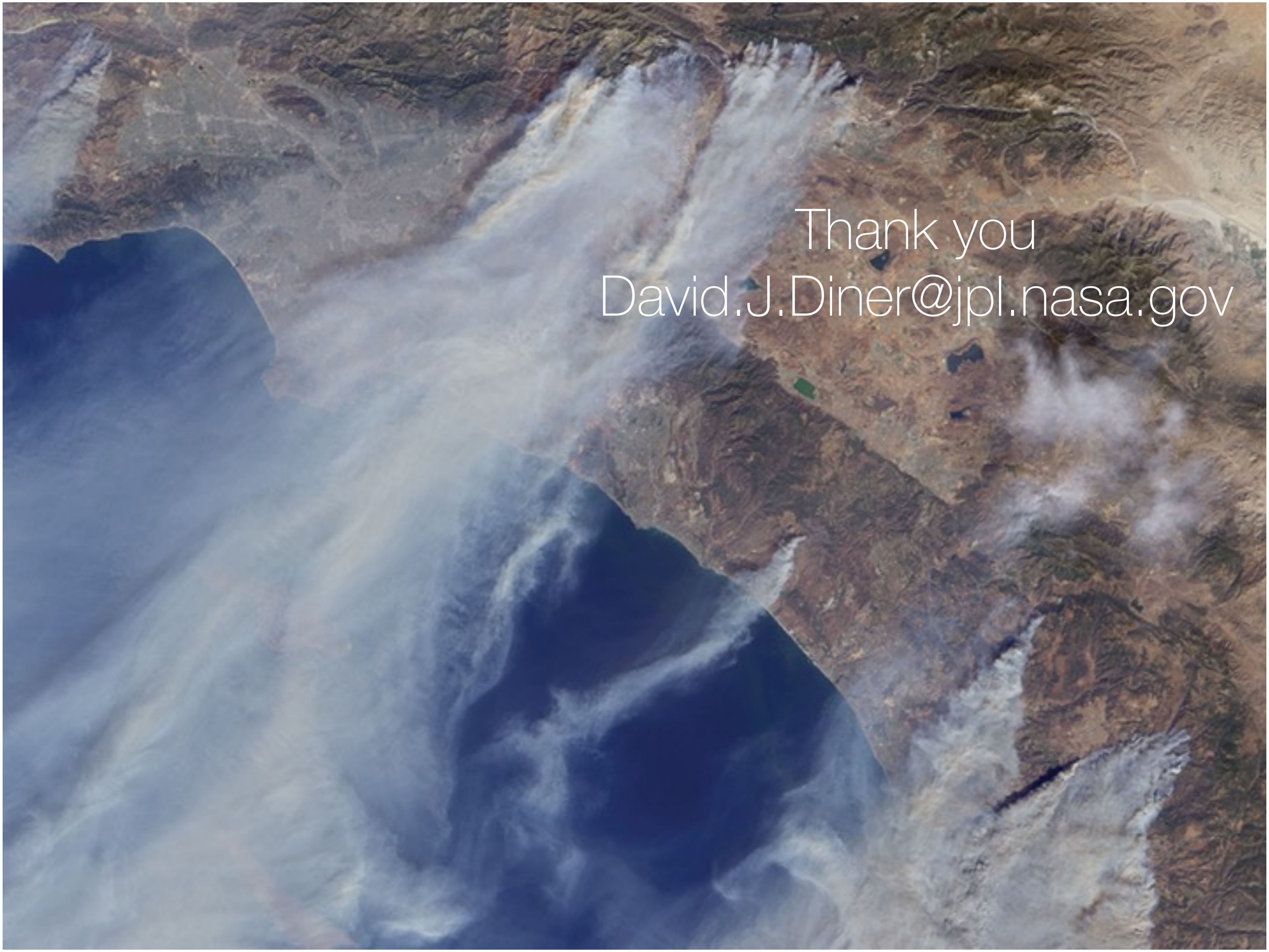
	UV	Visible						Near-IR		Shortwave IR			
Band (nm)	365	385	415	445	550	645	749	762.5	867	945	1035	1610	1880	2125

polarimetric (bands 445, 645, 1035) | absorbing particles | fine particles | coarse particles

(MISR, MODIS, TOMS, POLDER + airborne heritage)

Concluding remarks

- Benefits of multiangle imaging:
  - Oblique views enhance the aerosol signal relative to many types of surface background, including urban areas and deserts
  - Sampling of the particle phase functions provides sensitivity to particle size and shape—enhanced by inclusion of polarimetry
  - Stereoscopy maps aerosol plume injection heights
  - Time-lapse between views allows tracking atmospheric winds
- MISR and AirMSPI data illustrate these capabilities
- Regression of satellite AOD with surface PM and other environmental variables is effective for mapping airborne particulate concentrations
- MAIA will integrate UV/VNIR/SWIR and polarimetric observations to map PM types in major cities around the world
  - Epidemiologists on the MAIA science team will use the resulting data products to conduct health impact investigations



Thank you

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