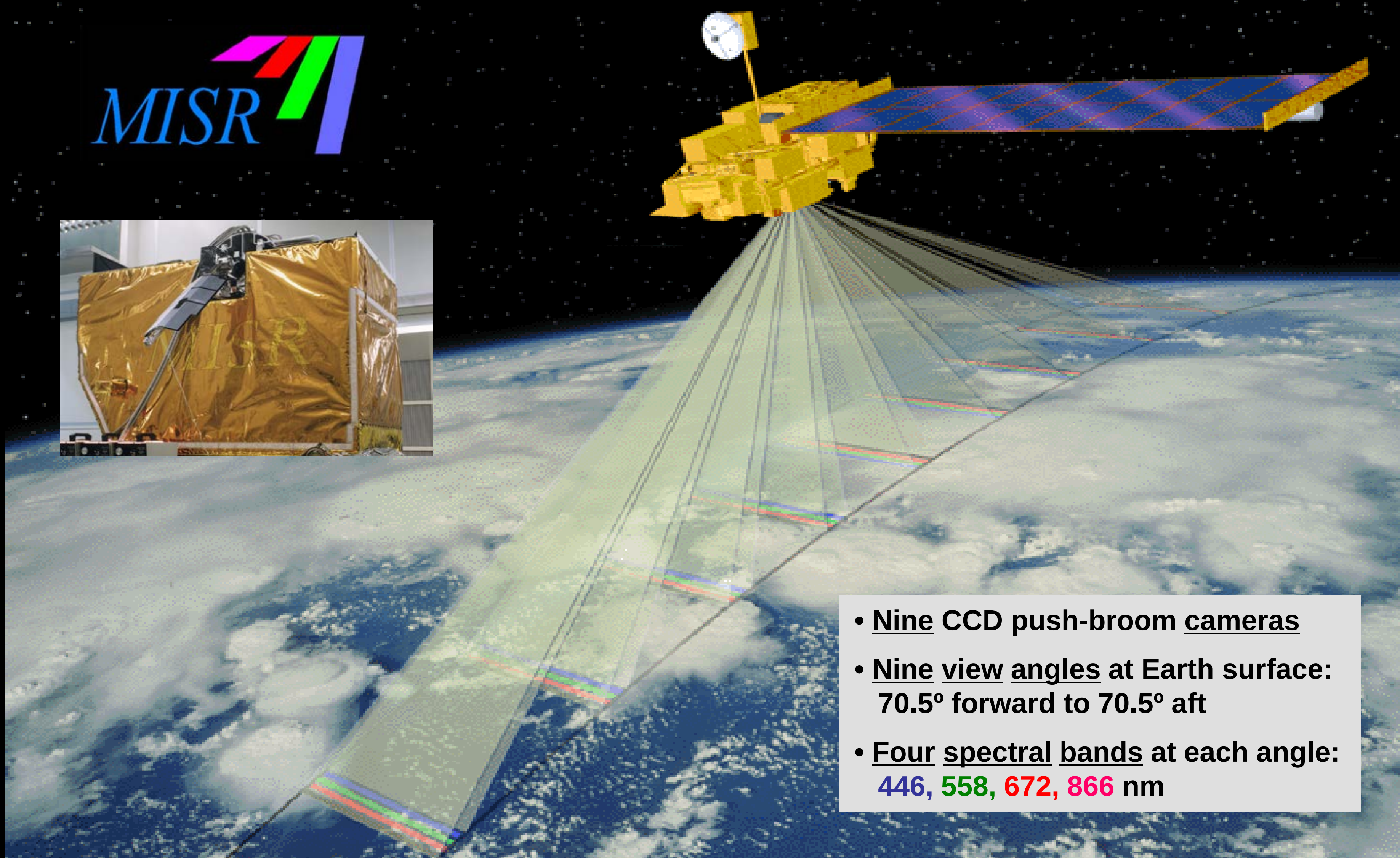
Particle Shape, Size, and Composition from Satellites

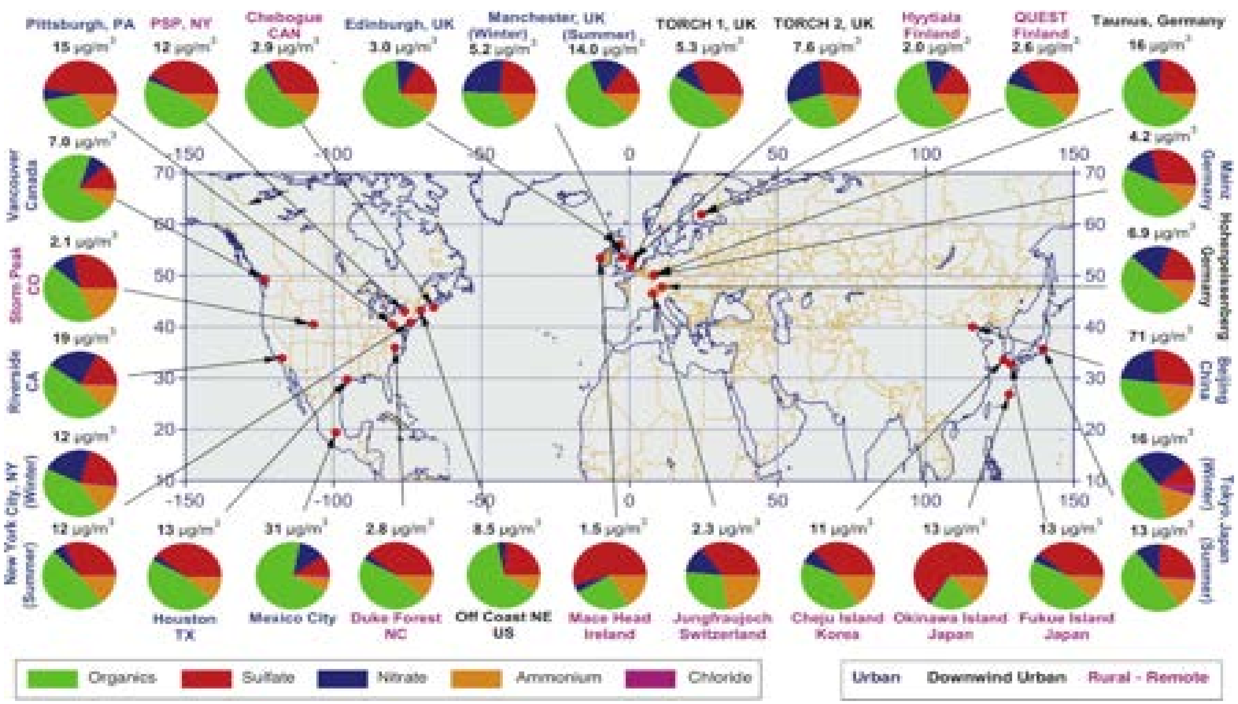
Ralph Kahn

NASA Goddard Space Flight Center



- Nine CCD push-broom cameras
- Nine view angles at Earth surface: 70.5º forward to 70.5º aft
- Four spectral bands at each angle: 446, 558, 672, 866 nm

Regional-scale Air Quality Assessment

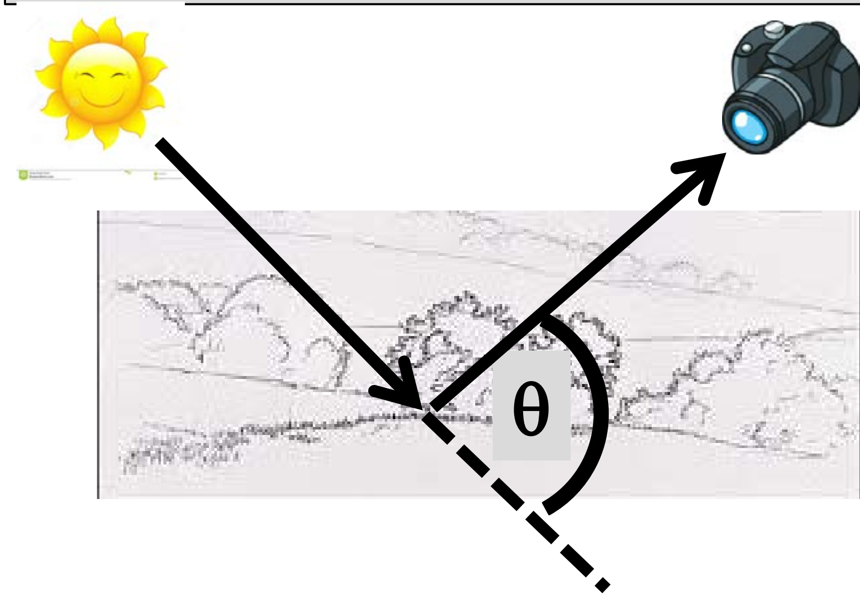


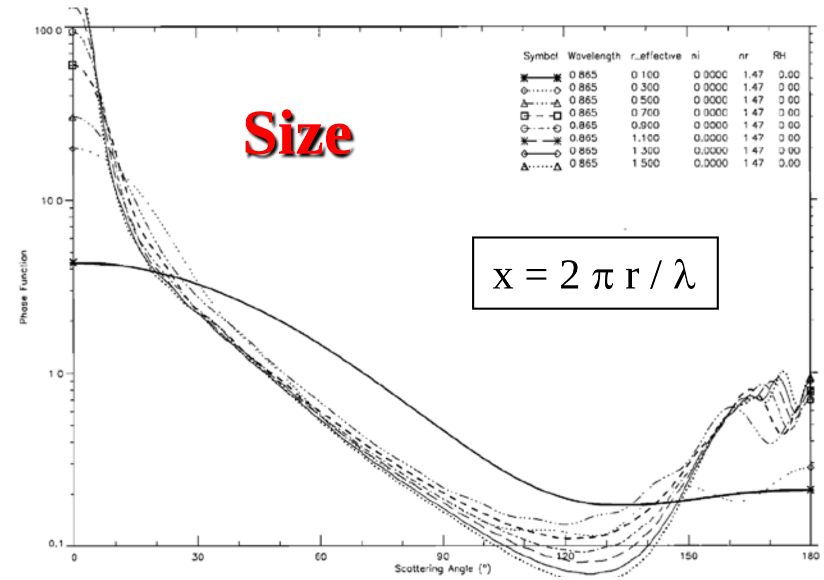
Zhang et al., GRL. 2007

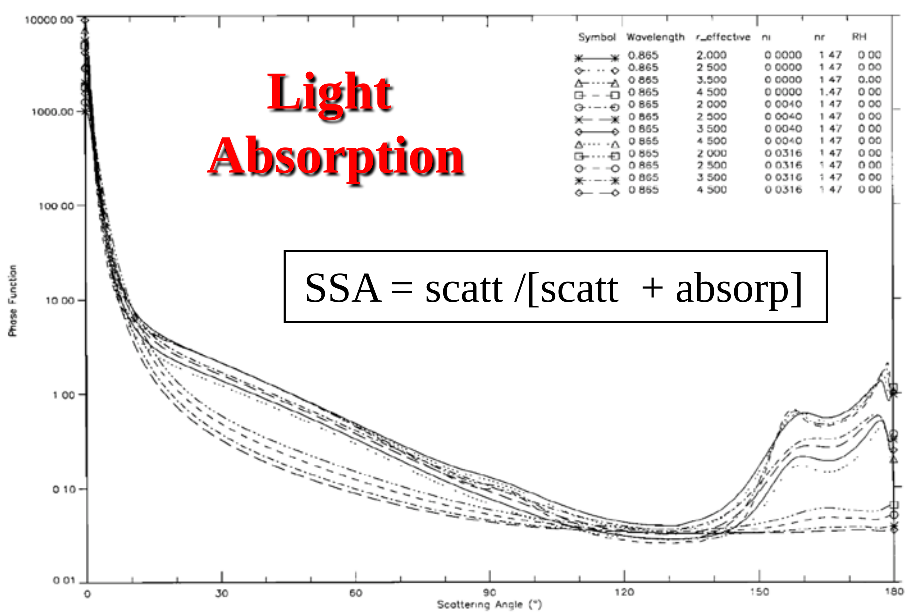
Surface-based mass-spec aerosol composition measurements

- **Need to isolate *Near-surface Aerosol Component* *(local v. transp; PBL ht.)***
- **Need sufficient *Spatial-Temporal Coverage* to capture *Severe Events***
- **Detailed *Chemical Speciation* often required *(+MEE, Hygroscopicity)***
- ***High Spatial Resolution* often required** (e.g., in Urban areas)

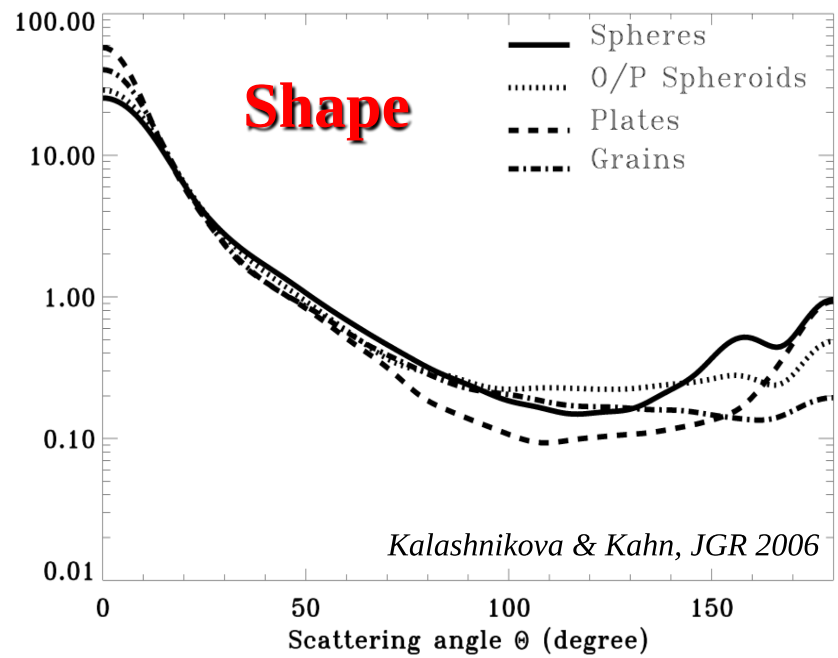
Single-scattering Phase Functions for **Different Particle Properties**





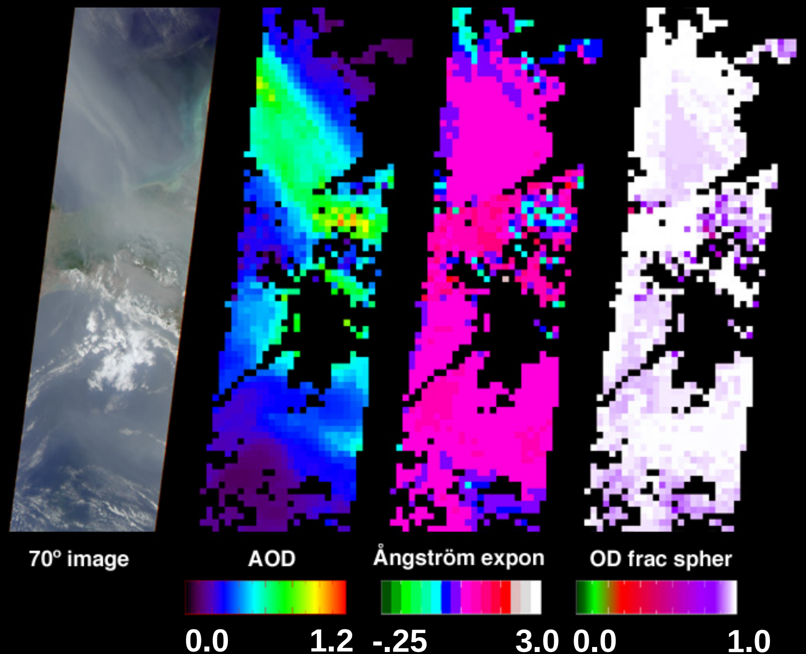


Kahn et al., JGR 1998



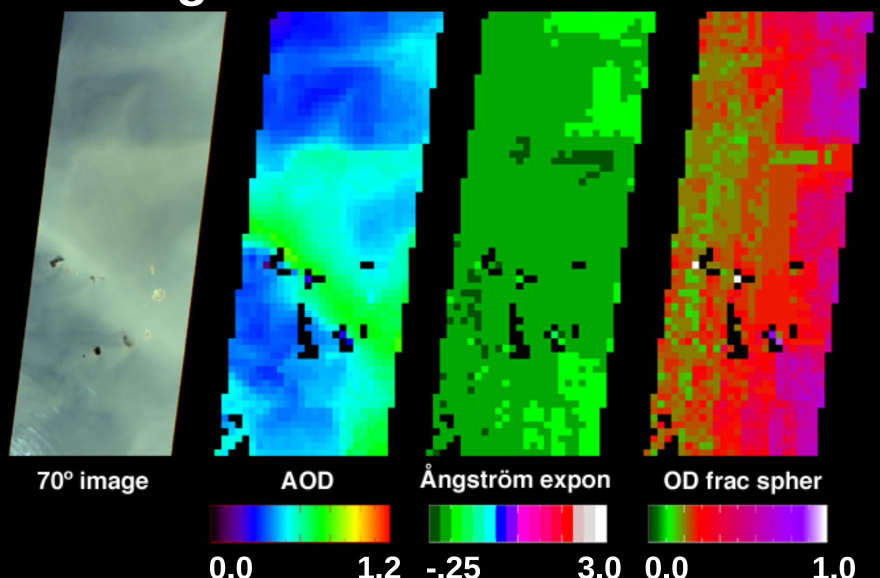
Smoke from Mexico -- 02 May 2002

Aerosol:
Amount
Size
Shape



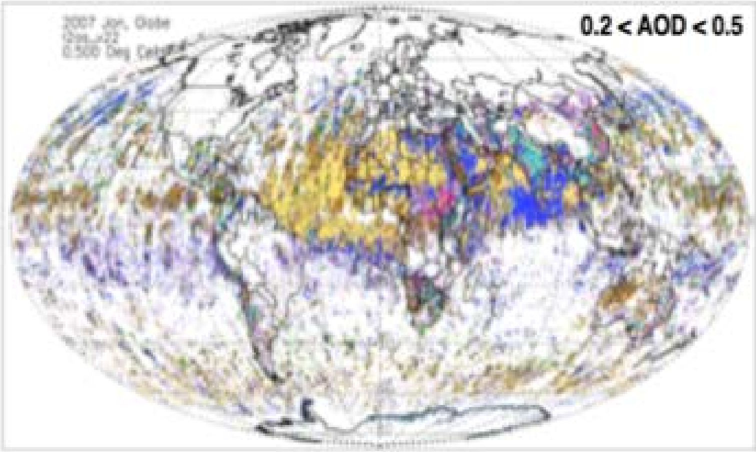
Medium
Spherical
Smoke
Particles

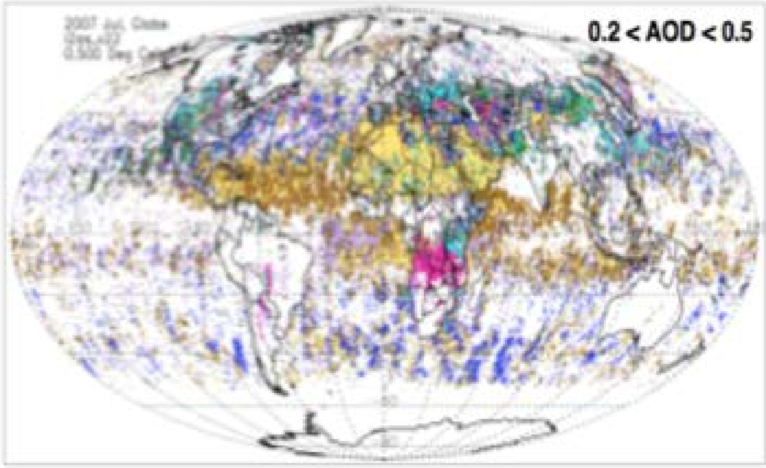
Dust blowing off the Sahara Desert -- 6 February 2004



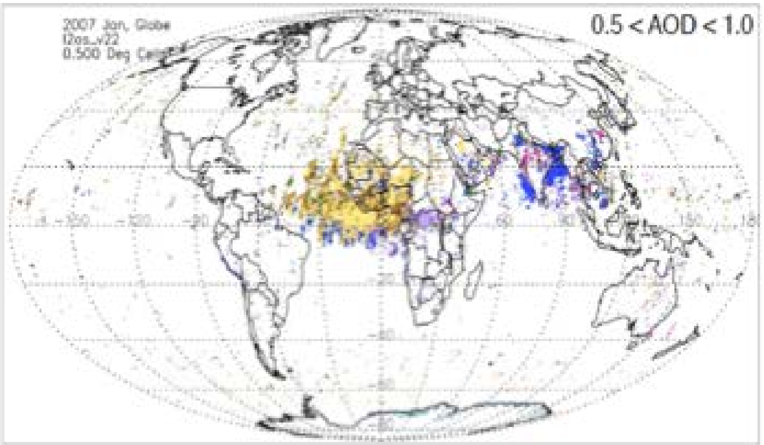
Large
Non-Spherical
Dust
Particles

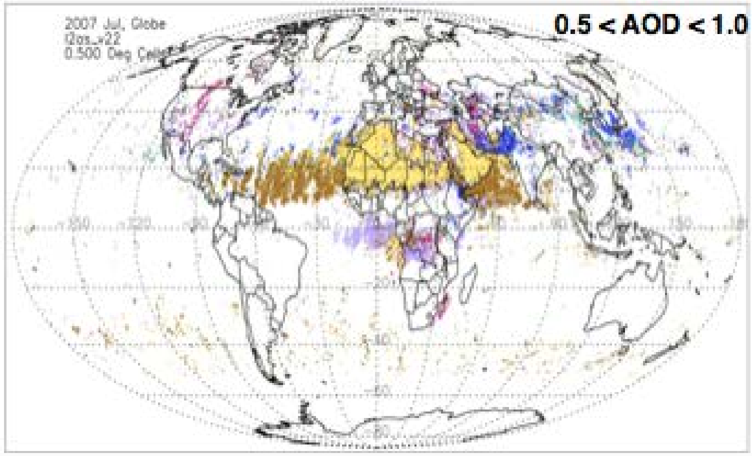
MISR Aerosol Type Discrimination





January 2007 | **July 2007**





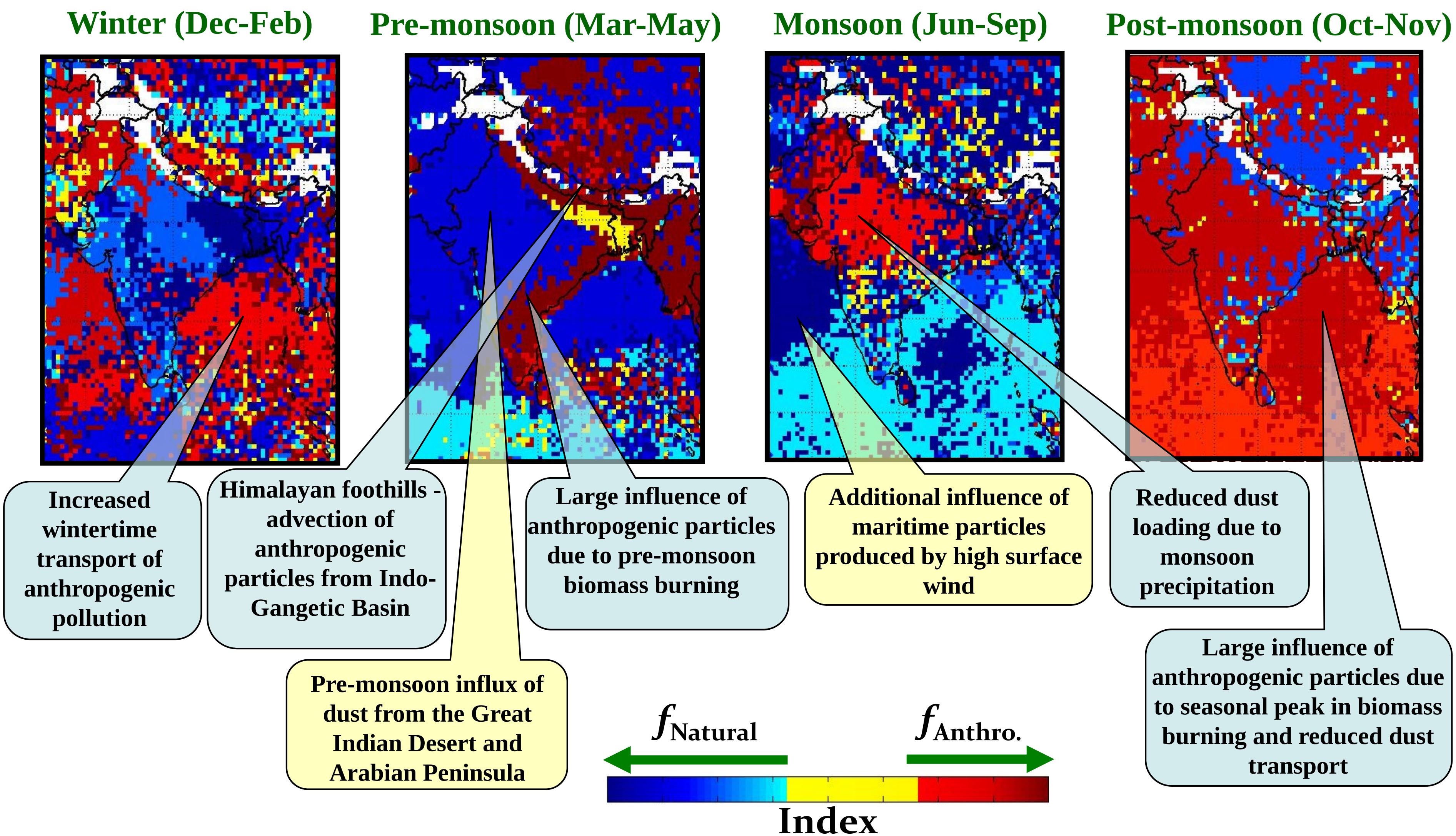
Spherical, non-absorbing

Non-spherical

Spherical, absorbing

Kahn & Gaitley JGR 2015

Characterizing seasonal changes in anthropogenic and natural aerosols w.r.t. preceding season over the Indian Subcontinent



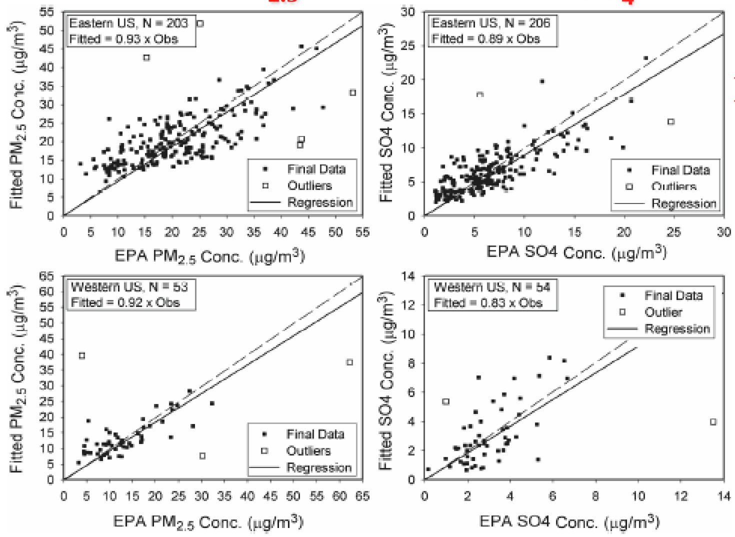
Index uses MISR-retrieved ***particle shape and size*** constraints to separate natural from anthorpogenic aerosol

***Dey & Di Girolamo* JGR 2010**

MISR - GEOS-Chem Regression Model To Map **Near-surface Aerosol Pollution**

$PM_{2.5}$ **SO_4**

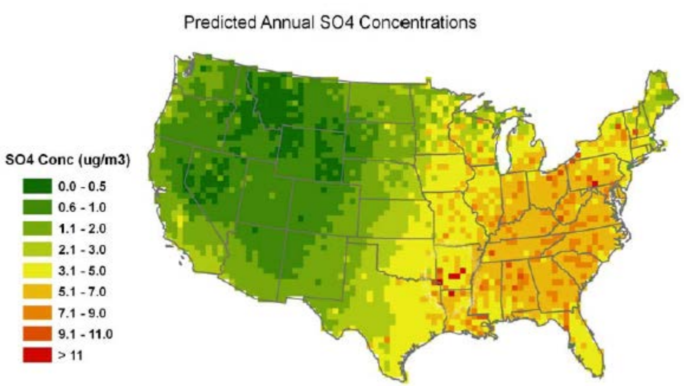
***MISR*-Constrained Model**

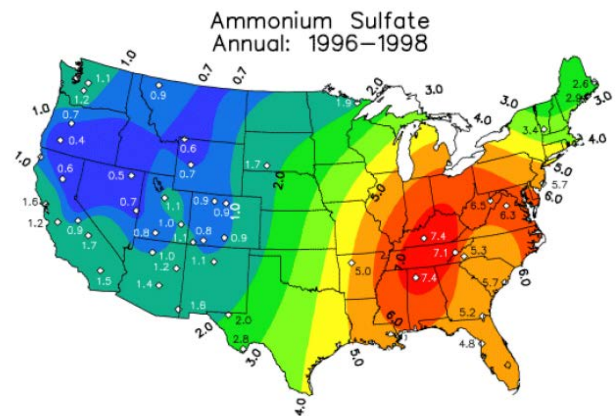


Eastern US

Western US

EPA *Surface* Measurements





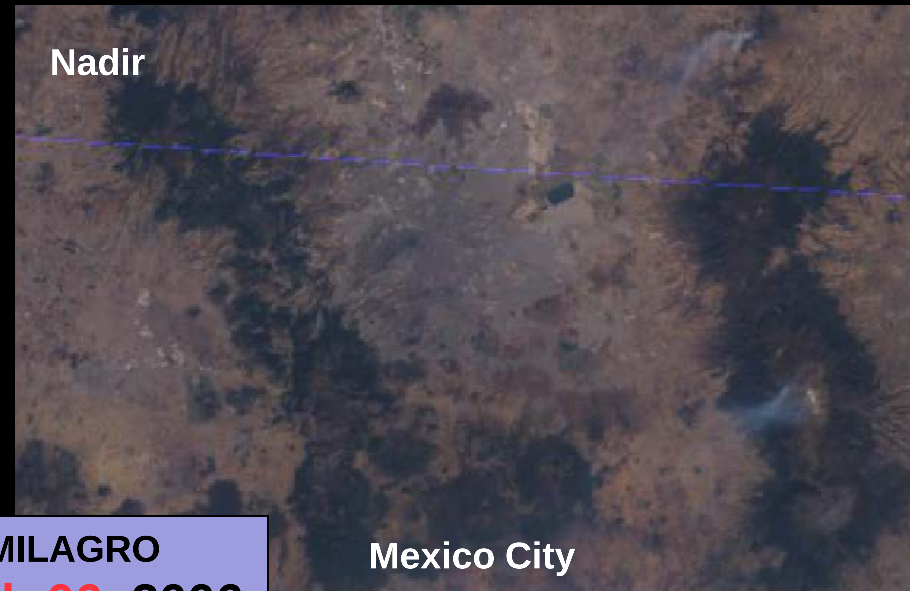
MISR / GEOS-CHEM ***Retrieval*** ***Surface*** network (IMPROVE) measurements

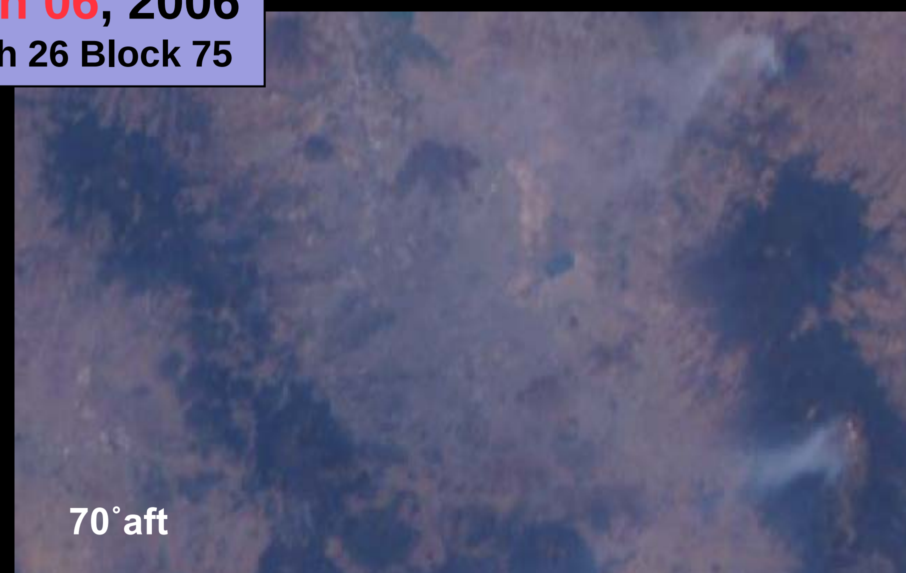
- Using MISR ***Particle Shape*** as well as AOT to constrain model --> much better result
- Can add column ***Size*** and ***SSA*** information when MISR retrieval is more robust

Y. Liu et al, JAWMA 2007

Mapping AOD & Aerosol Air-Mass-Type in Urban Regions

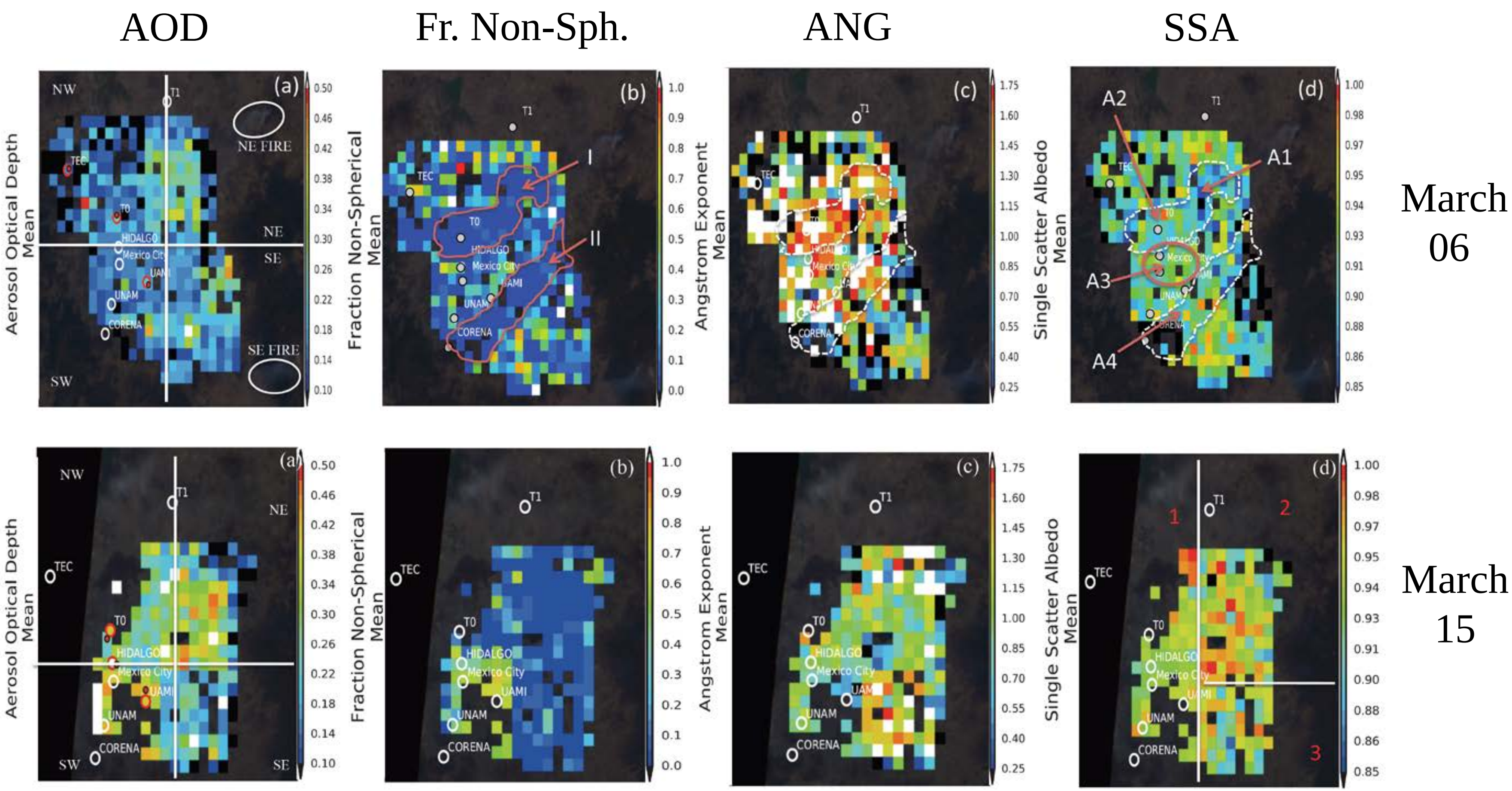
INTEX-B/MILAGRO
MISR March 06, 2006
Orb 33062 Path 26 Block 75





Patadia et al.

Urban Pollution AOD & Aerosol Air Mass Type Mapping
INTEX-B, 06 & 15 March 2006



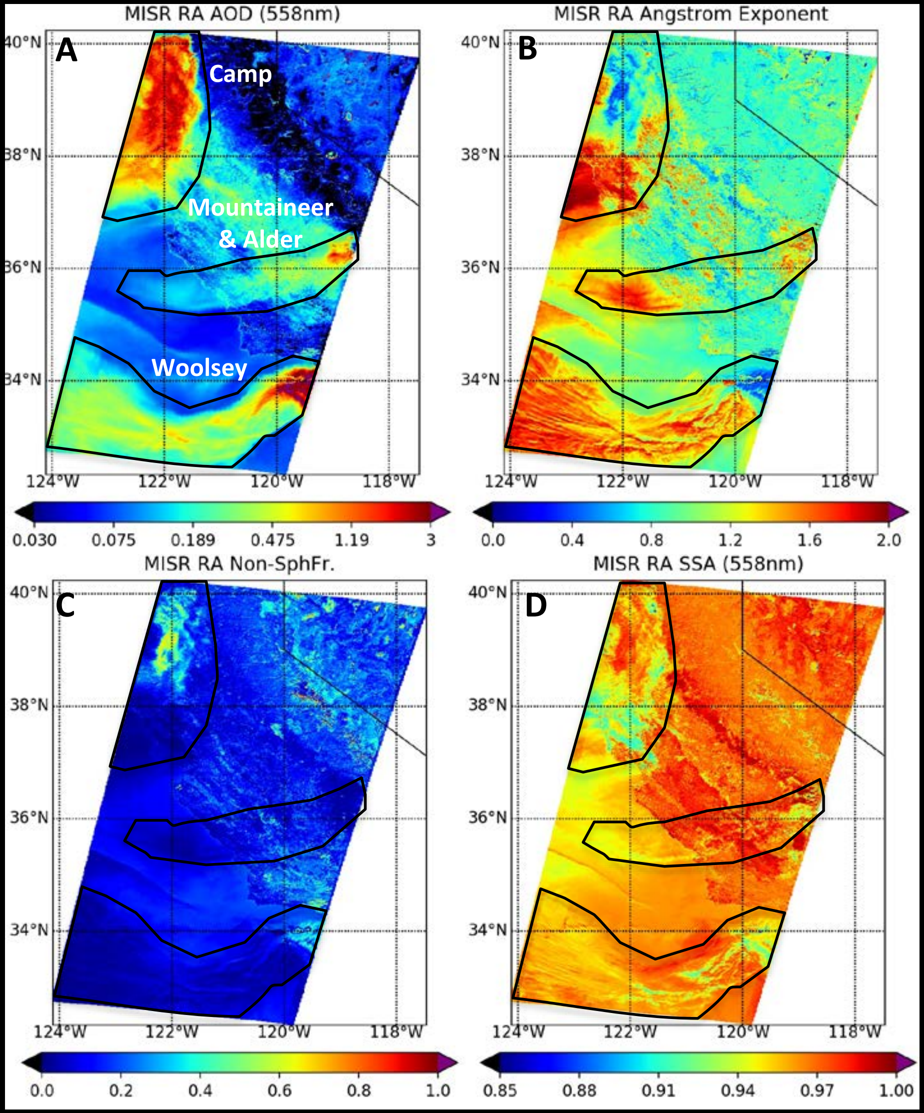
Aerosol Air Masses: ***Dust*** (non-spherical), ***Smoke*** (spherical, spectrally steep absorbing), and ***Pollution*** particles (spherical, spectrally flat absorbing) dominate specific regions

Patadia et al., ACP 2013

California fire plumes – *Smoke Particle Properties*

MISR Active Aerosol Plume-Height (AAP) Project *9 November 2018*

MISR Research Algorithm (RA) – Aerosol Amount and Type Retrievals



The MISR Research Aerosol (RA) retrieval algorithm produces (A) aerosol amount (optical depth – AOD), (B) an aerosol size constraint (Angstrom Exponent) (C) fraction of non-spherical particles, and (D) particle light-absorption (SSA).

Near the Camp fire *source region* the particles tend to be *large* (low Angstrom Exponent) and *non-spherical particles*, probably from burning in the town of Paradise. Aerosols are smaller and more spherical downwind, probably as the plume mixes with *smoke from burning forest*.

The Alder and Mountaineers plume-height analysis, which relies on pixel-level contrast elements in the imagery, tracked the plume for only 50 km. However, the MISR RA, more sensitive to thin aerosol layers, observes the plume *extending to the Pacific ocean*. This result highlights the *possible influence of plumes* even when *particle concentrations render them sub-visible*.

The southernmost Woolsey fire displays similarities to the Camp fire with *near source regions containing larger particles*. This area also contained a significant fraction *of non-spherical particles (~40%)*, though at a *lower concentration than the Camp fire (70%)*. The shift in particles from large, non-spherical to small, spherical characteristics suggests that the bigger particles are settling to the surface, and it corresponds to the decrease in plume altitude.

V. Flower, R. Kahn, J. Limbacher / NASA GSFC

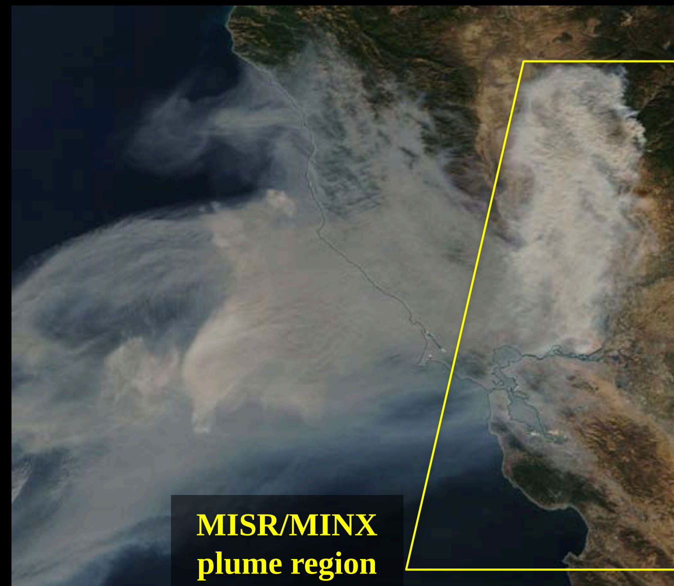
MISR Plume Heights – The California Camp Fire

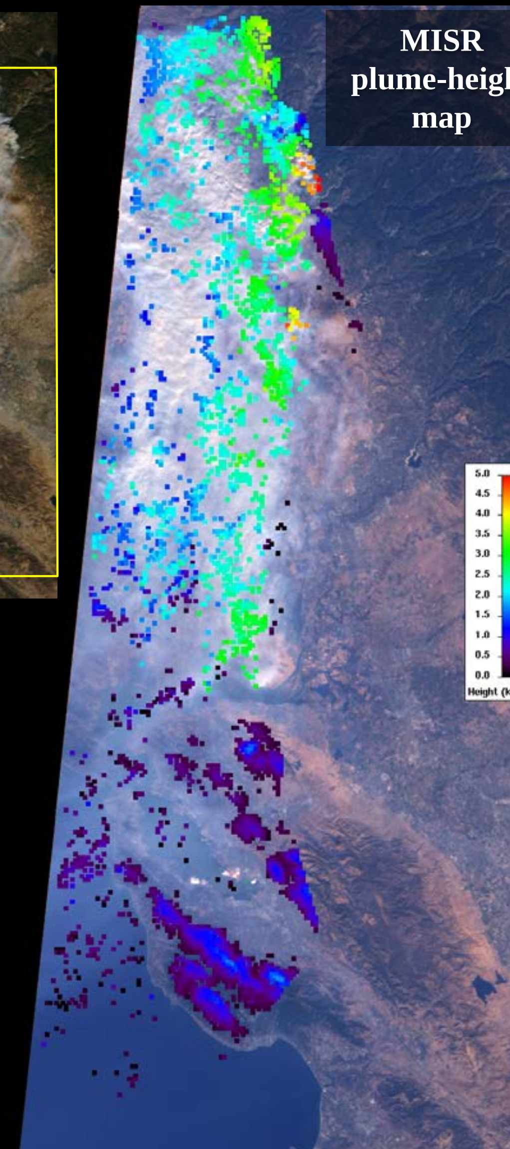
MISR Active Aerosol Plume-Height (AAP) Project 9 November 2018

CAMP FIRE

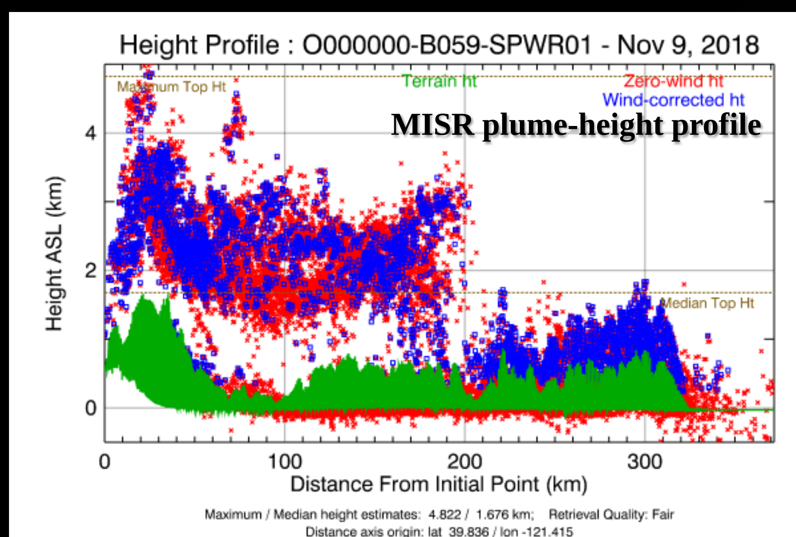
Origin: November 8, 2018
~39.81N, -121.44W

The Camp fire was the northernmost California fire MISR imaged on Nov. 9, and it was the deadliest fire in state history. It ***lofted smoke 2-3 km*** above the terrain, and some was ***transported over 300 km*** downwind. It is likely that the fires were sufficiently energetic to inject the smoke above ***the stable near-surface atmospheric boundary layer*** into the free troposphere. The plume descended to ***~1 km*** as it moved south and west and approached the ocean.





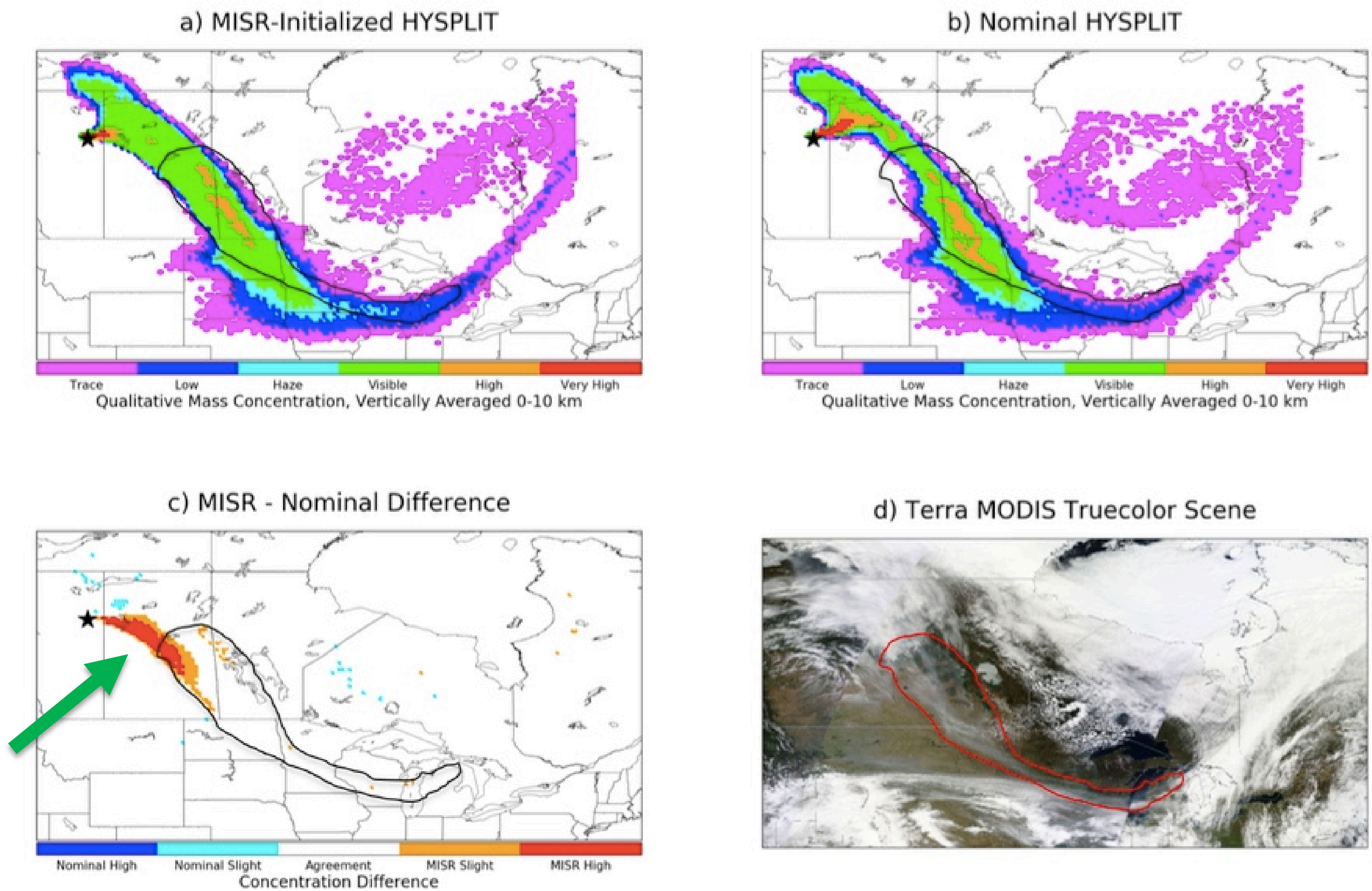
Red = zero-wind height
Blue = wind-corrected height
Green = surface elevation



V. Flower, R. Kahn, J. Limbacher / NASA GSFC

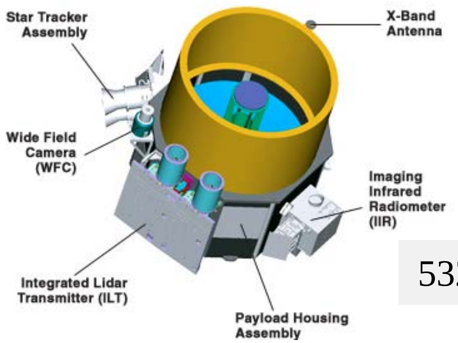
Ft. McMurray Wildfire, Alberta Canada

May 07, 2016 (Day 2) NOAA HySPLIT Model



When the injection height is above the PBL in regions with significant wind shear, MINX-initiated simulations better represent satellite observations.

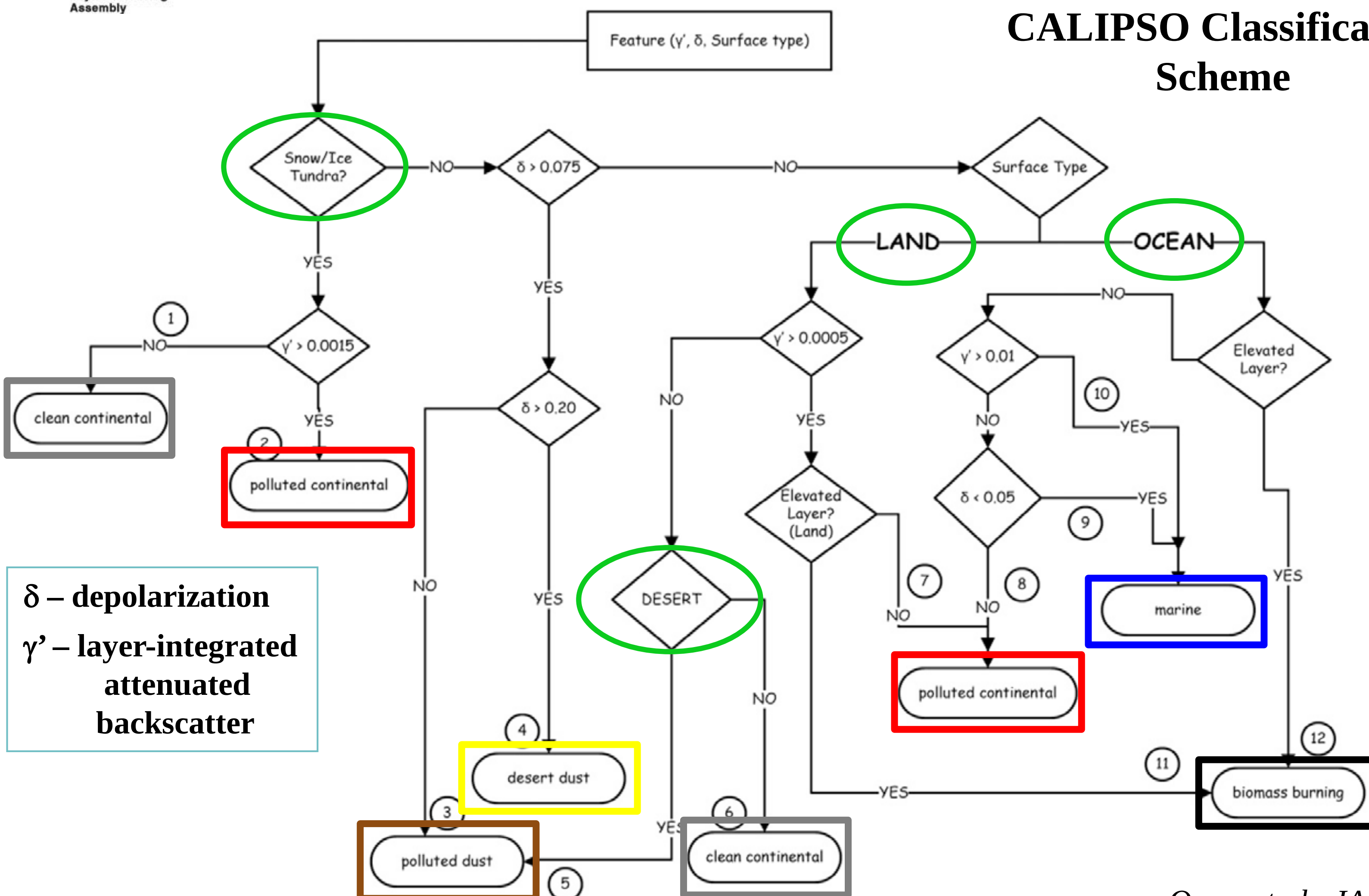
Vernon, Bolt, Canty & Kahn; AMT 2018



CALIPSO 6-Type Interpretive Aerosol Classification Scheme

532 and 1064 nm channels; ~100m horizontal resolution

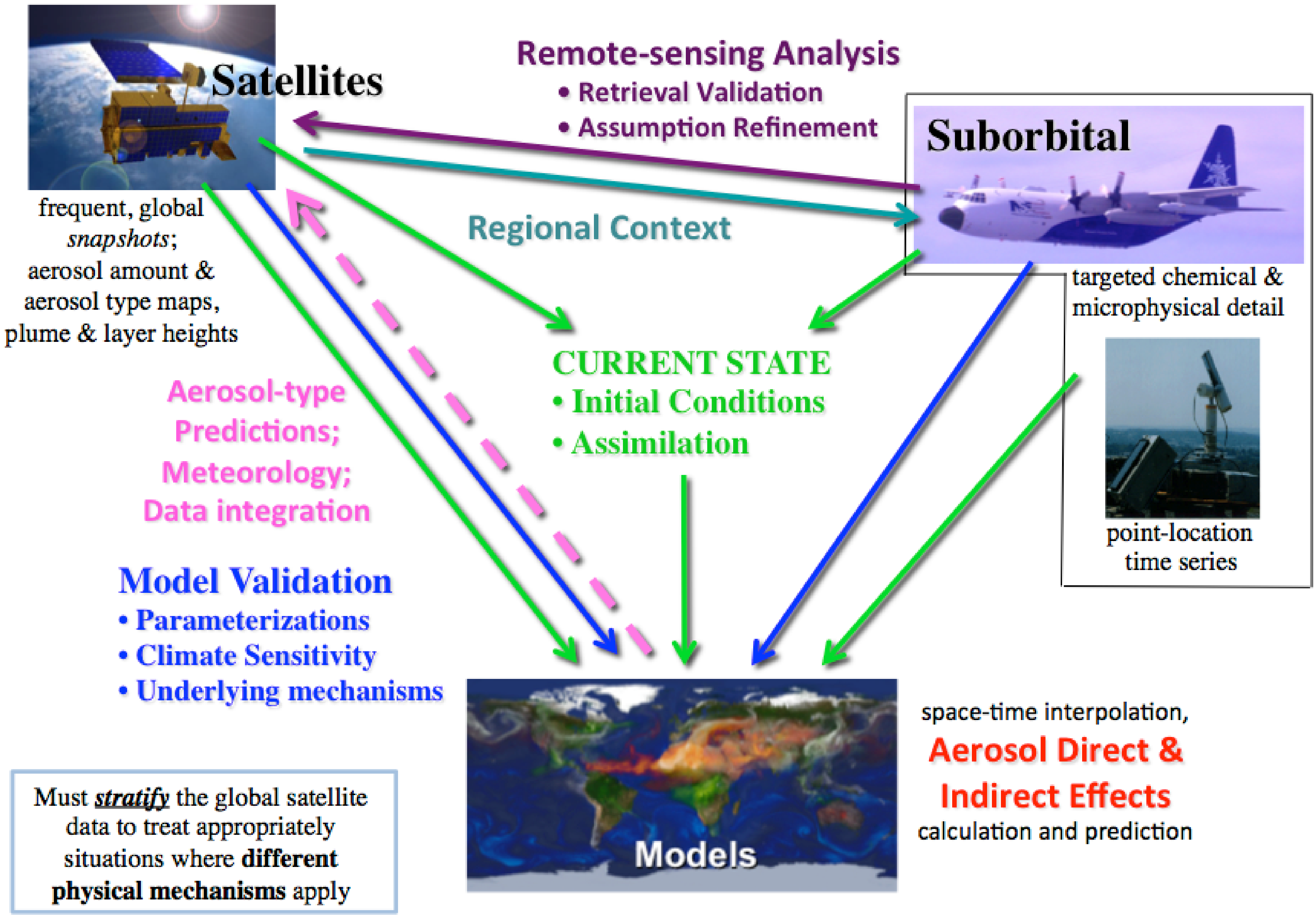
CALIPSO Classification Scheme



δ – depolarization

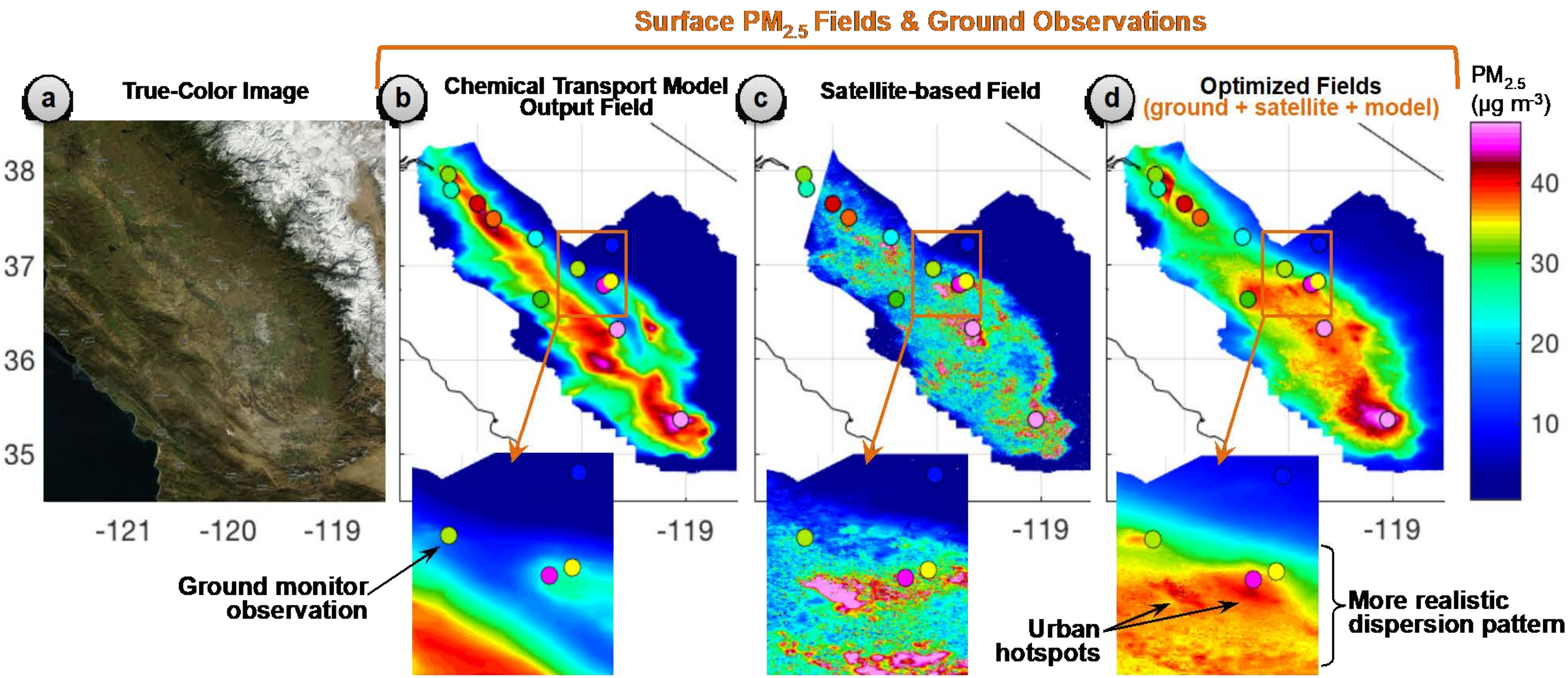
γ' – layer-integrated attenuated backscatter

Omar et al., JAOT 2009



Adapted from: Kahn, Survy. Geophys. 2012

Physical Approach to Constraining Air-Quality Model w/Satellite-Derived Aerosol Type



Science Question: How can we use aerosol data from satellites and ground monitors to improve regional air quality (AQ) model predictions of airborne fine particles?

Impact: Satellite aerosol-attribute products provide regional context and decrease error and uncertainty in surface AQ characterization.

Friberg et al., ACP 2018

MISR Research Algorithm Retrieved Aerosol Properties Mapped to Model Species-Specific Aerosol Components

Properties Provides:

- **Regional AOD Snapshots**
- ***Size (S, M, L)***
- ***Spherical vs. Non-Spherical***
- ***Absorbing vs. Non-Absorbing***

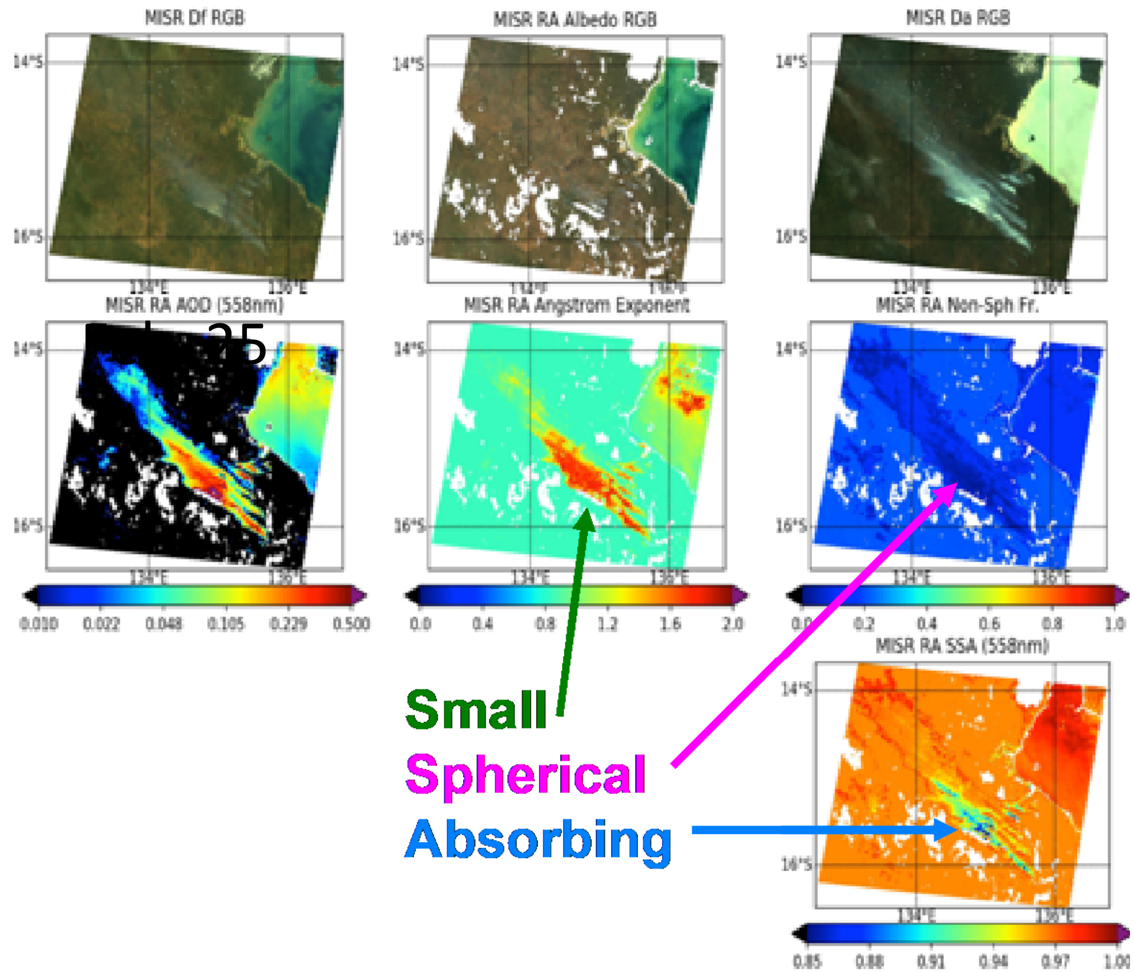
Hydrated Species Partitioning by Microphysical Properties

	Spherical	*Non-Spherical*
Scattering	II, SS, OM, LAC	Dust
Absorbing	OM, LAC	Dust

$$RM[\mu g/m^3] = C_{II} + C_{OM} + C_{SS} + C_{LAC} + C_{Dust}$$

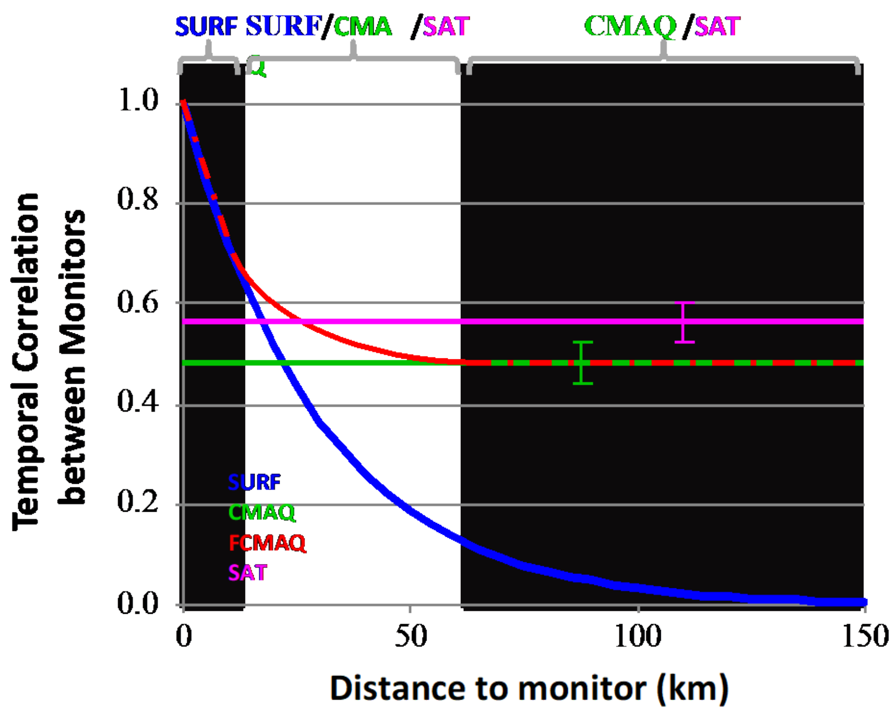
C_{II} = Inorganic Ions [μg/m³]
C_{SS} = Sea Salt [μg/m³]
C_{OM} = Organic Matter [μg/m³]
C_{LAC} = Light Absorbing Carbon[μg/m³]
C_{Dust} = Dust [μg/m³]

Biomass-Burning Northern Australia: 6/6/2012



Friberg et al., ACP 2018

Data Fusion Method Measurement Weighting Functions: Surface Stations Near-Source + Satellite Downwind/Regional



! ! " #$! ,! ≈ ! ! " ## ! ! ! ,! /!

! ! " #$ ≈ ! / ! ! ! ∑ ! " ## (! ! " #$! ! (!), ! ! " #$! ! (!))

! ! " # $ % ! ,! = { ! ! ,! ! ! ! ,! + (! − ! ! ,!)! ! ! ! > ! ! ; ! ! ! ! =< ! ! }

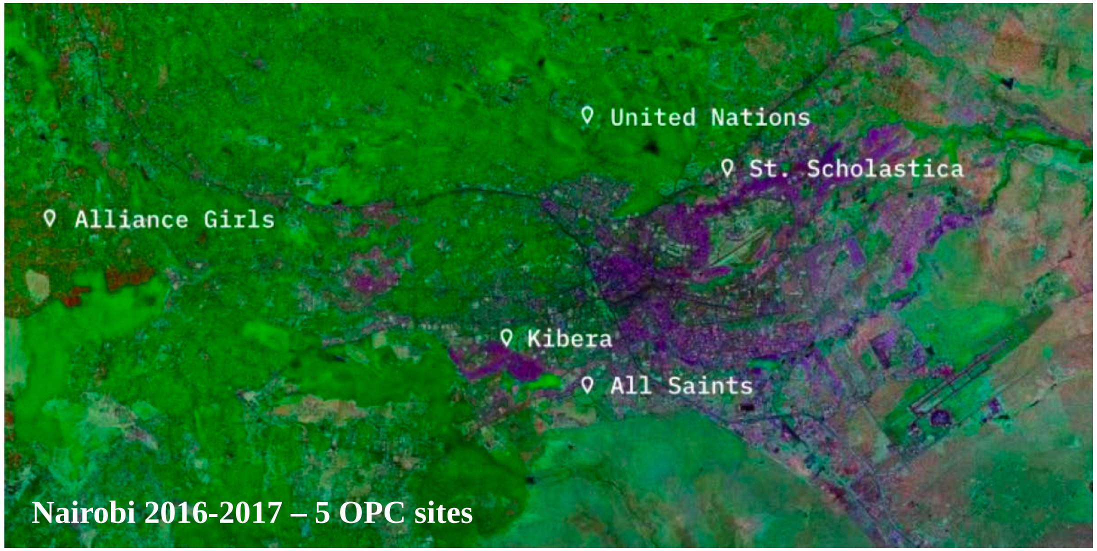
! ! ,! = ! ! " #$! ,! (! − ! ! " #$) / ! ! " #$! ,! (! − ! ! " #$) + ! ! " #$ (! − ! ! " #$! ,!)

! ! " # $ % ! ,! = ! ! " #$ %! ! " #$! [! ! ,! { ! ! " #$! ! ,! / ! ! " #$! ! ,! } ! " #$ + (! − ! ! ,!) { ! ! " #$! ,! / ! ! " #$! }]

Daily Optimized Fused Fields	Estimated 2 mo. Mean Fields	Daily Interpolated SURF Ratio Fields	Weighting Factor	Daily Adjusted CMAQ Results Ratio Fields

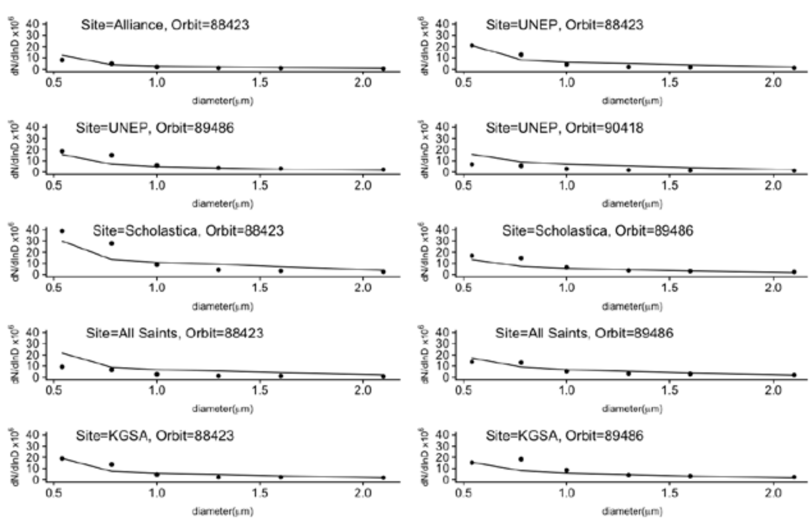
Friberg et al., ACP 2018

Constraining Low-Cost Surface-based Optical Particle Counters (OPCs) with Satellite-retrieved Particle Size

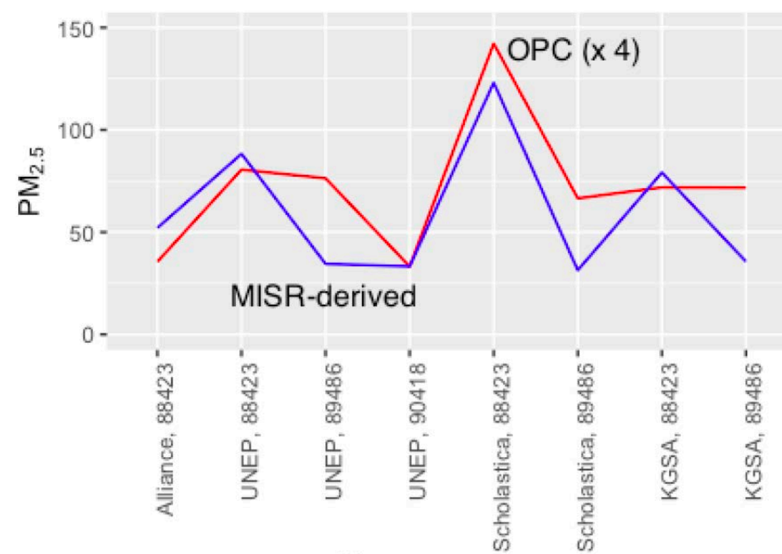


Nairobi 2016-2017 – 5 OPC sites

- OPCs offer size-resolved ***surface particle concentration***, but only ***for d > 0.54 μm***
- MISR Research Algorithm – ***total-column*** size sensitivity down to ***d ~ 0.1 μm*** in 3-5 bins
- MISR offers uniform regional coverage, but needs ***AOD >~ 0.15*** to retrieve sizes



OPC size distributions for 10 events (dots) + MISR (lines)



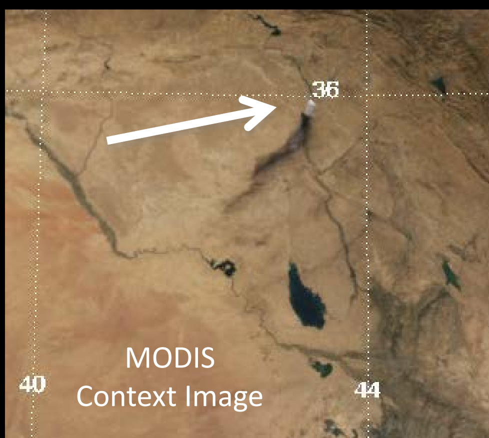
OPC and MISR scaled PM2.5

de Souza et al. AMT 2020 (in review)

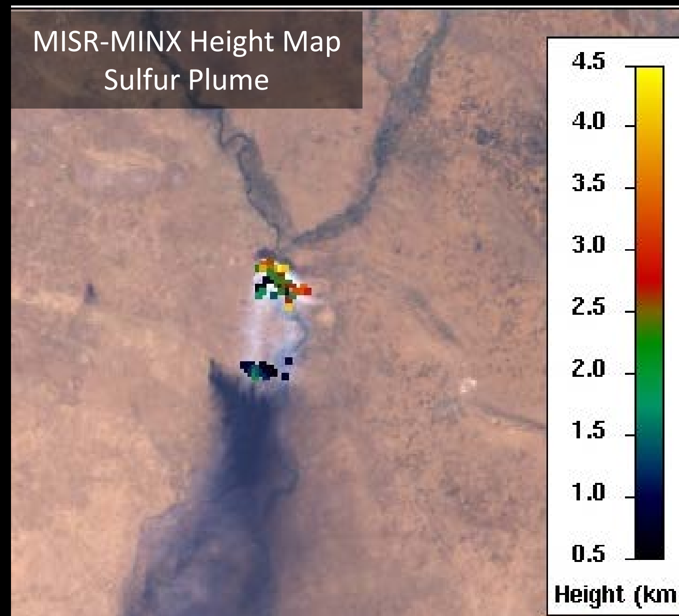
Iraq's Mishraq Sulfur Plant and Oil Well Smoke Plume Heights

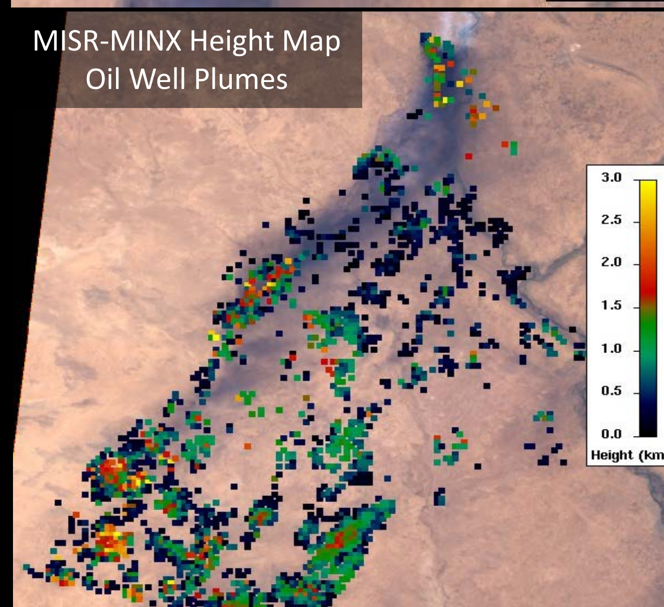
MISR Active Aerosol Plume-Height (AAP) Project 21 October 2016

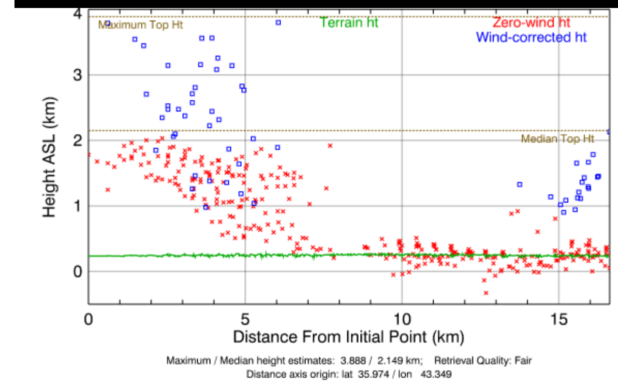
The ***height*** at which smoke is injected into the atmosphere affects ***how long*** it will stay aloft, ***how far*** it will travel, and ***how much of an impact*** it will have on air quality downwind, and regional climate. In ***northern Iraq***, at least two people have lost their lives, up to 1000 hospitalized, and 200 families evacuated from their homes due to sulfur & smoke pollution.



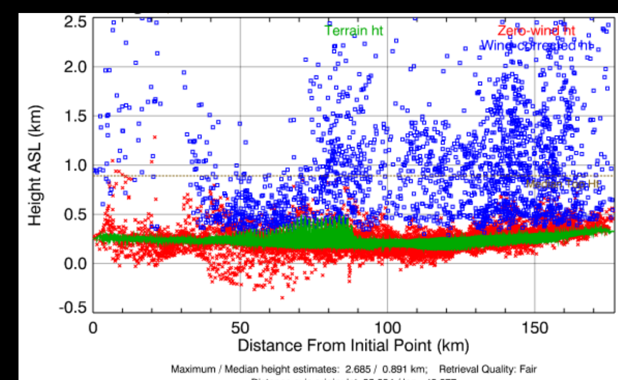
Parallax, the change in apparent plume position relative to the surface, as observed from the NASA Earth Observing System's Multi-angle Imaging Spectroradiometer (***MISR***) instrument, makes it possible to map the height of ***smoke***, ***dust***, and ***volcanic plumes*** near-source, where plume features are visible in the multi-angle views.







Zero-wind & Wind-Corrected
MISR Height Profiles
Downwind from Near-source



***R. Kahn*, T. Kucsera** / NASA GSFC
T. Canty, R. Bolt, CJ Vernon / U. Maryland