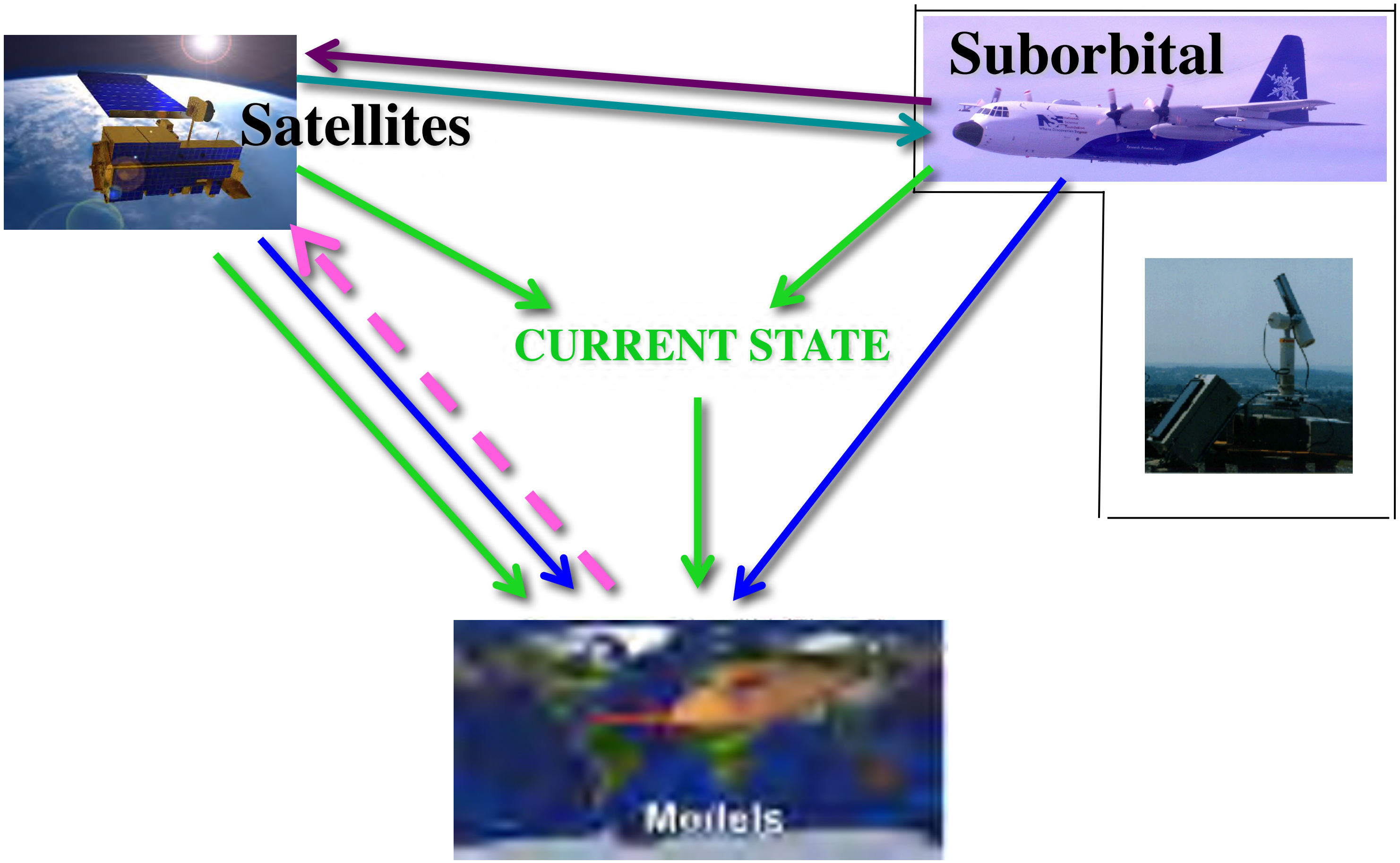
Aerosol Concentration, Size, Hygroscopicity, & MEE, Globally:
What do we need to know, and how can we know it?

Ralph Kahn *NASA Goddard Space Flight Center*



What We Need, Globally

- Aerosol ***AMOUNT*** (AOD – 2D)
- Aerosol ***VERTICAL DISTRIBUTION***
- Aerosol "***TYPE***"

-- ***Light Absorption*** *(direct forcing)*

-- ***Hygroscopicity*** *(interpreting AOD; indirect forcing)*

-- ***Composition***

(source attribution; μ–physical properties; mass flux)

-- ***Mass Extinction Efficiency (MEE)***

(measurement ←→ model translation)

What We Have...

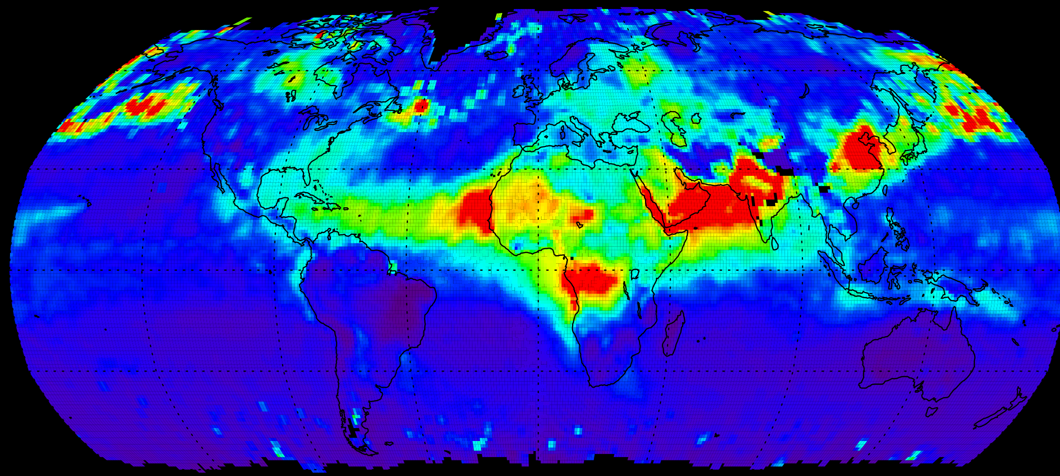
AeroCom Experiment "A" Values

Quantity	Mean	Median	Range	Stddev /mean*
Sources (Tg yr^{-1})				
Sulfate	179	186	98-232	22%
Black carbon	11.9	11.3	7.8-19.4	23%
Organic matter	96.6	96.0	53-138	26%
Dust	1840	1640	672-4040	49%
Sea salt	16600	6280	2180-121000	199%
Removal rate (day^{-1})				
Sulfate	0.25	0.24	0.19-0.39	18%
Black carbon	0.15	0.15	0.066-0.19	21%
Organic matter	0.16	0.16	0.09-0.23	24%
Dust	0.31	0.25	0.14-0.79	62%
Sea salt	5.07	2.50	0.95-35.0	188%
Lifetime (day)				
Sulfate	4.12	4.13	2.6-5.4	18%
Black carbon	7.12	6.54	5.3-15	33%
Organic matter	6.54	6.16	4.3-11	27%
Dust	4.14	4.04	1.3-7.0	43%
Sea salt	0.48	0.41	0.03-1.1	58%
Mass loading (Tg)				
Sulfate	1.99	1.98	0.92-2.70	25%
Black carbon	0.24	0.21	0.046-0.51	42%
Organic matter	1.70	1.76	0.46-2.56	27%
Dust	19.2	20.5	4.5-29.5	40%
Sea salt	7.52	6.37	2.5-13.2	54%
MEE at 550 nm (m^2 g^{-1})				
Sulfate	11.3	9.5	4.2-28.3	56%
Black carbon	9.4	9.2	5.3-18.9	36%
Organic matter	5.7	5.7	3.7-9.1	26%
Dust	0.99	0.95	0.46-2.05	45%
Sea salt	3.0	3.1	0.97-7.5	55%
AOD at 550 nm				
Sulfate	0.035	0.034	0.015-0.051	33%
Black carbon	0.004	0.004	0.002-0.009	46%
Organic matter	0.018	0.019	0.006-0.030	36%
Dust	0.032	0.033	0.012-0.054	44%
Sea salt	0.033	0.030	0.02-0.067	42%
Total AOT at 550 nm	0.124	0.127	0.065-0.151	18%

* Stddev/mean was used as the term "diversity" in Textor et al., 2006.

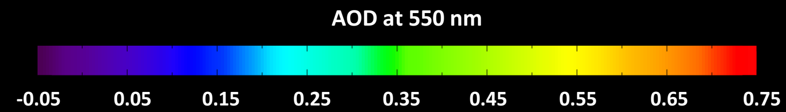
MEE Ranges
***Factors* of 3 – 6**
or more!

CCSP 2009 Table 3.2

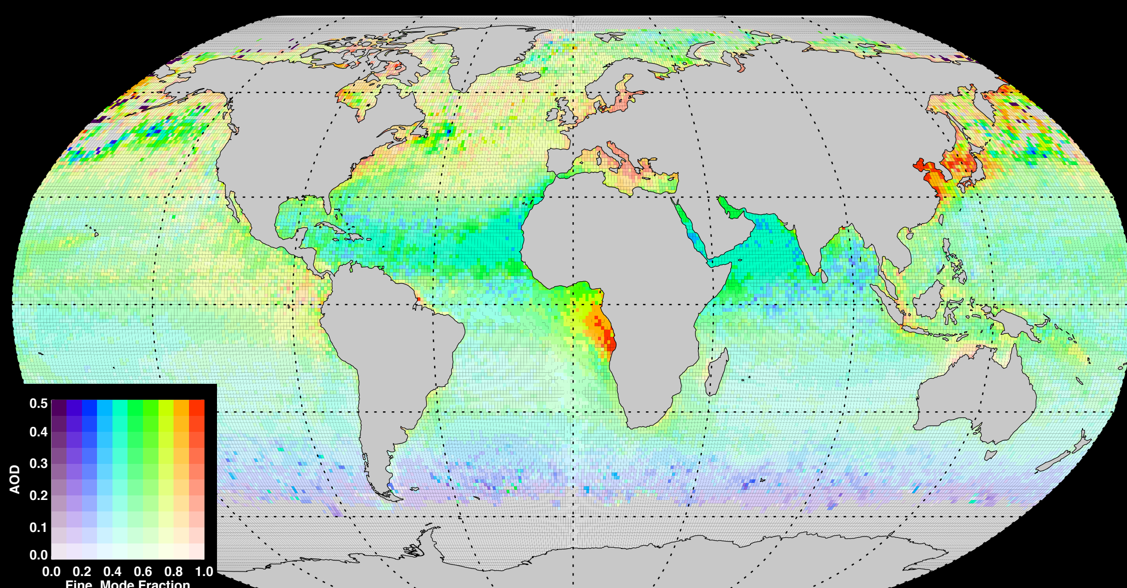


Mid-Visible
AOD
"Dark Target" + "Deep Blue"

MODIS
July 2010
Monthly Average



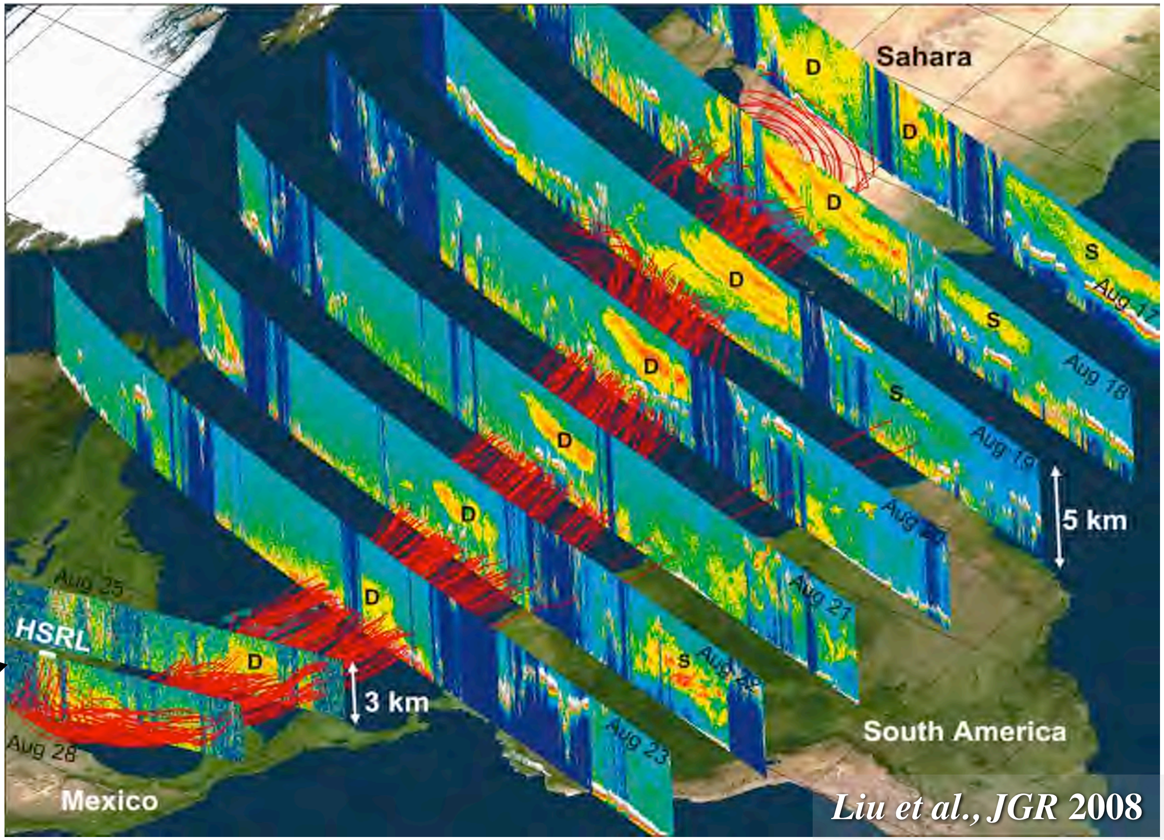
- Water & some Land
- Globe ~ Every 2 days
- ~ 10:30 AM & 1:30 PM



- Fine/Coarse Ratio Over Water + AOD
- Sensitivity to PM10

MODIS Team, NASA Goddard Space Flight Center

Aerosol Sources, Processing, Transports, Sinks: Lidar + Model



Ariborne HSRL

Space-based CALIPSO

August 2007 Saharan dust "D" and smoke "S" event
mapped by CALIPSO 532 nm backscatter, with superposed model back trajectories and airborne HSRL observations

Piecing together the bigger picture. Consistency requires –

- An understanding of the ***mechanisms*** governing aerosol evolution
- Adequately constrained ***initial & boundary*** conditions

Multi-angle Imaging SpectroRadiometer

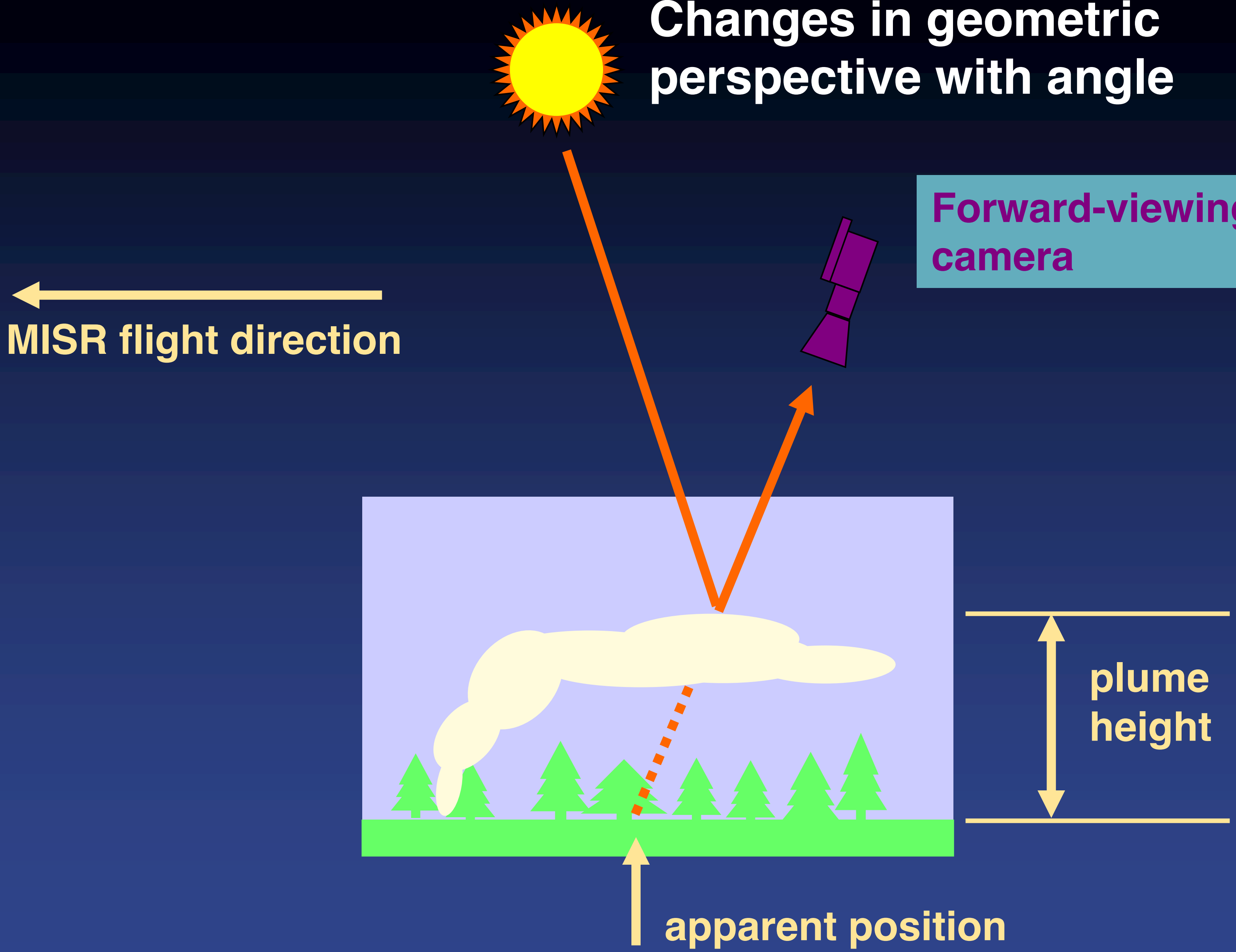
MISR

http://www-misr.jpl.nasa.gov

http://eosweb.larc.nasa.gov

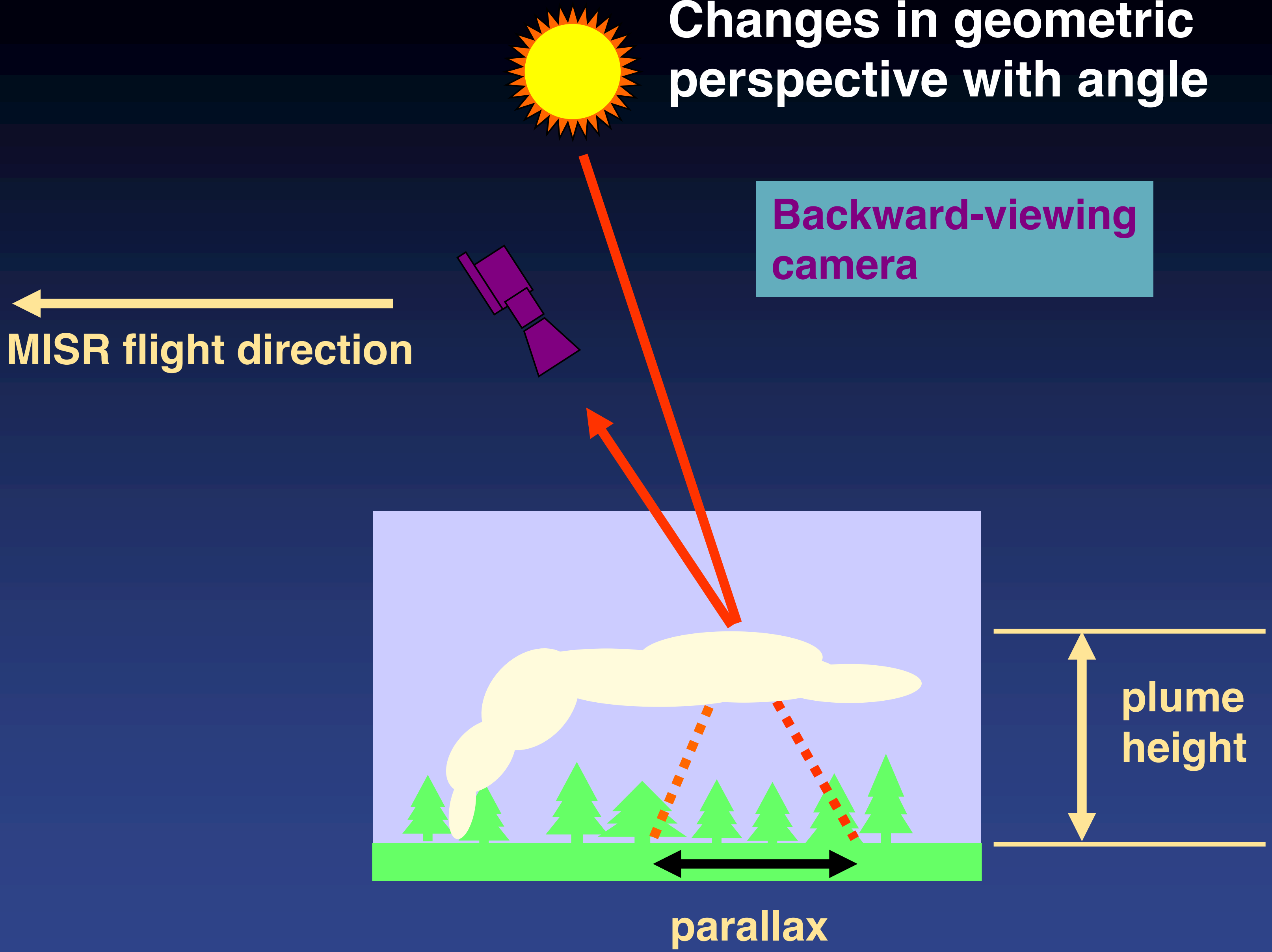
- Nine CCD push-broom cameras
- Nine view angles at Earth surface: 70.5° forward to 70.5° aft
- Four spectral bands at each angle: 446, 558, 672, 866 nm
- Studies *Aerosols*, *Clouds*, & *Surface*

Changes in geometric perspective with angle



Diner 2003

Changes in geometric perspective with angle



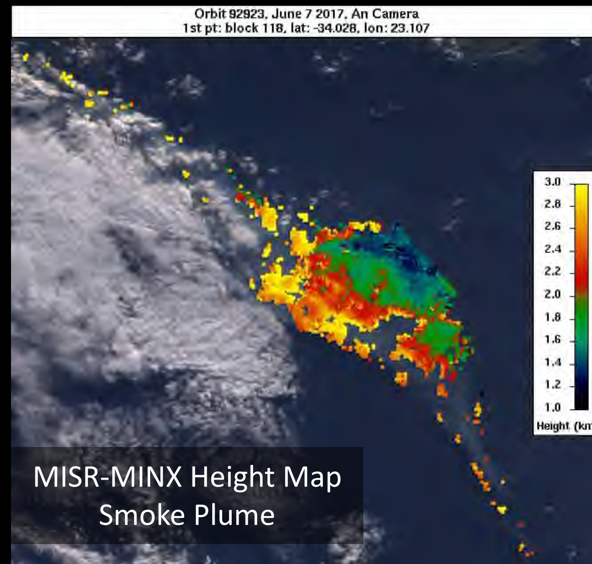
Diner 2003

Wildfire Outbreak in Knysna, South Africa

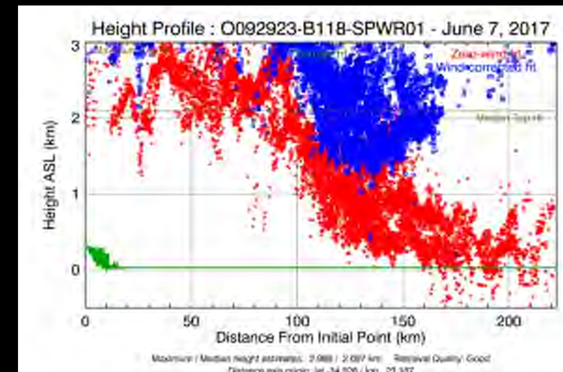
MISR Active Aerosol Plume-Height (AAP) Project 7 June 2017

Wildfire outbreaks can generate a significant amount of atmospheric aerosols that can have ***regional to global impacts*** on Earth's energy balance and surface temperature. To determine the influence of wildfires, ***accurate plume heights*** are needed, but are ***difficult to obtain in areas of significant cloud cover***. Stereo images from NASA's Multi-Angle Imaging Spectroradiometer (***MISR***) make it possible to retrieve plume heights using parallax by constraining the smoke plume layer height. When the retrieval height is significantly below the Lifting Condensation Level (LCL), the effects of cloud contamination are often reduced.

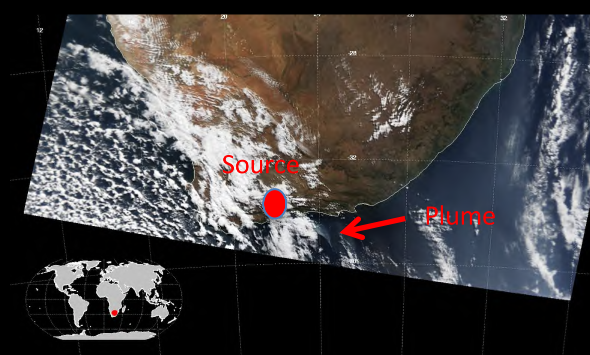
The ***Knysna Wildfire*** began the evening of June 6, 2017 and by June 07, consisted of 26 fires. These fires were fanned towards residential areas by strong winds from a cyclone to the west. The towns of Belvidere, Breonton-on-Sea, and Rheenendal were evacuated after news that a family of three passed away in the fire on June 6. The smoke observed by MISR on June 7 was injected at 3+ km. At this height, the aerosols can escape the boundary layer and enter the middle Troposphere, causing enhanced regional cooling and increased long-range aerosol transport.



MISR-MINX Height Map
Smoke Plume



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



MODIS image – 7 June 2017

Aerial photograph from June 7
(SA Red Cross Air Mercy Services)

CJ Vernon / U. Maryland
R. Kahn / NASA GSFC

Why We Care About *Aerosol Air Mass Type*

Some applications of satellite-mapped aerosol type, especially when ***combined with*** otherwise-constrained, detailed particle properties:

- ***Source Attribution***

- Mapping 3-D ***Aerosol Absorption*** that mediates impacts on ***atmospheric stability structure*** and can affect ***convection***, ***cloud evolution***, and ***larger-scale atmospheric circulation***

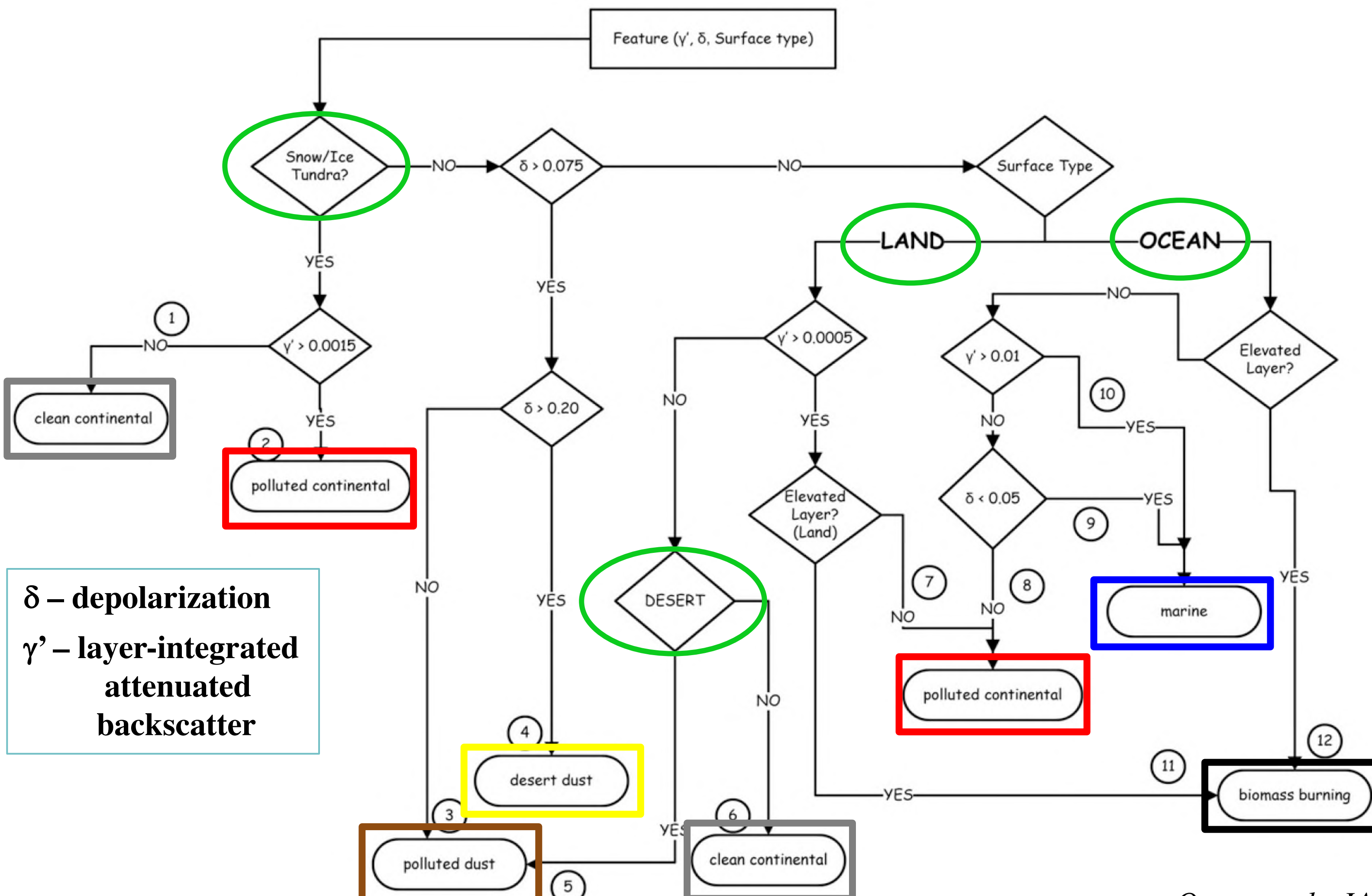
- Mapping ***Particle Hygroscopicity*** required to account for humidity-dependent ***particle optical property changes*** as well as ***particle activation conditions*** that initiate cloud formation

- Deducing ***Mass Extinction Efficiency*** (MEE) distributions, required to ***constrain & validate air quality***, ***aerosol-transport***, and ***climate model*** aerosol mass with remote-sensing-derived particle ***optical*** properties.

Aerosol Air Mass Type derived from remote sensing can provide ***2-D and 3-D mapping required*** for many of these applications.

Progress Toward a Global Aerosol Type Climatology

CALIPSO Classification Scheme

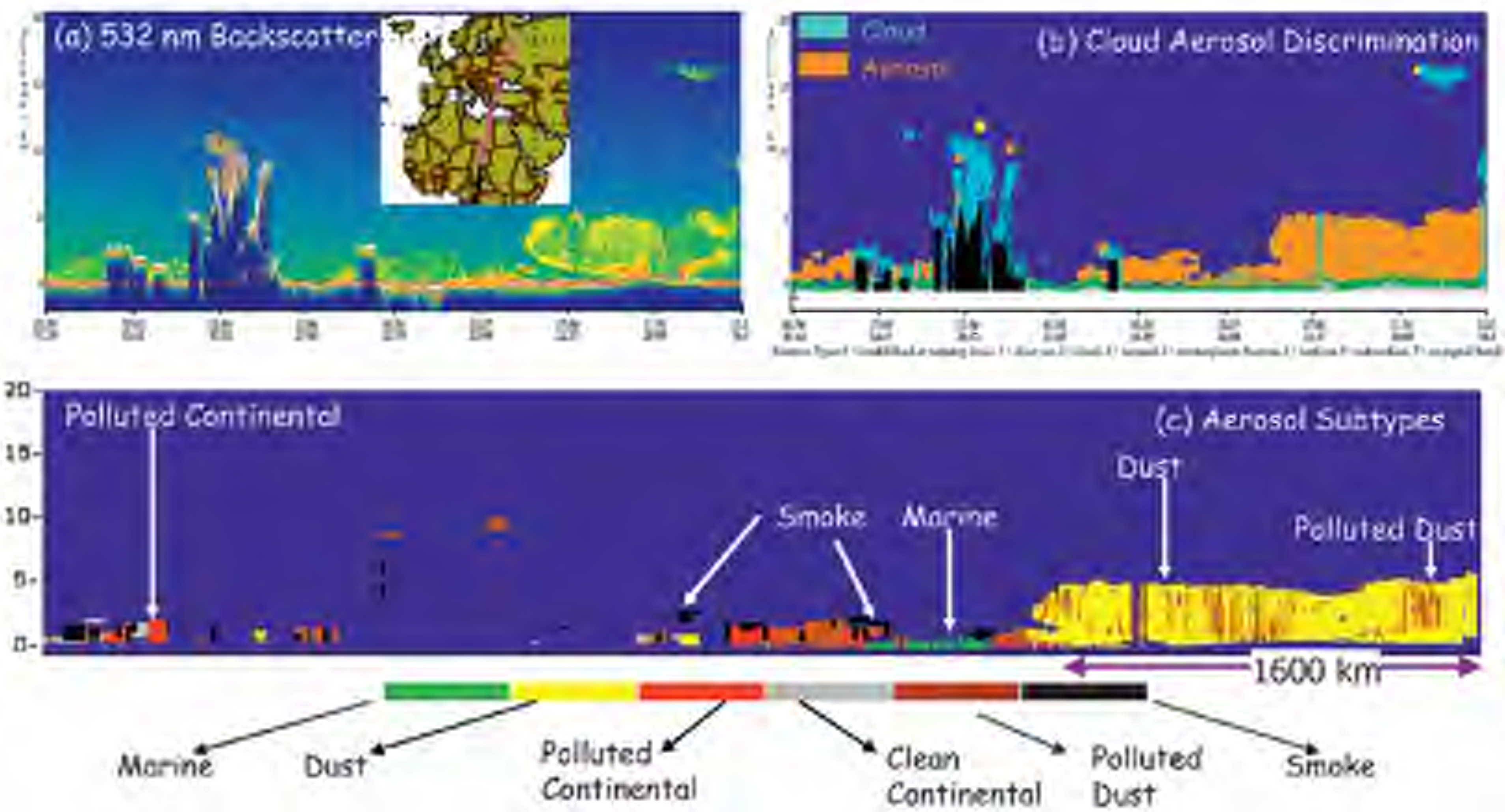


δ – depolarization

γ' – layer-integrated attenuated backscatter

Omar et al., JAOT 2009

CALIPSO 6-Grouping Aerosol Type Classification

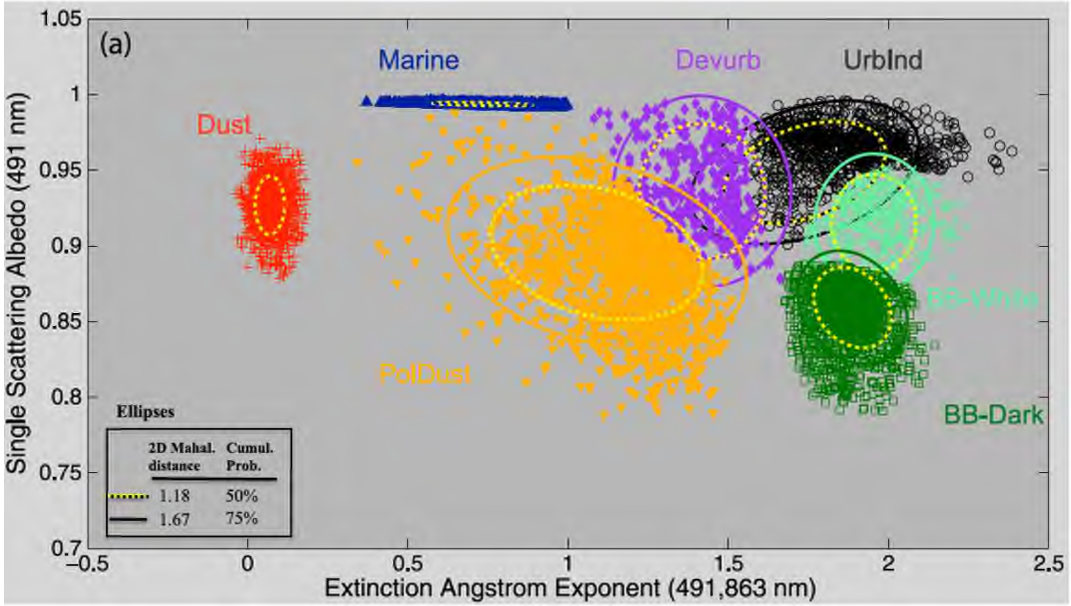


Omar et al., JAOT 2009

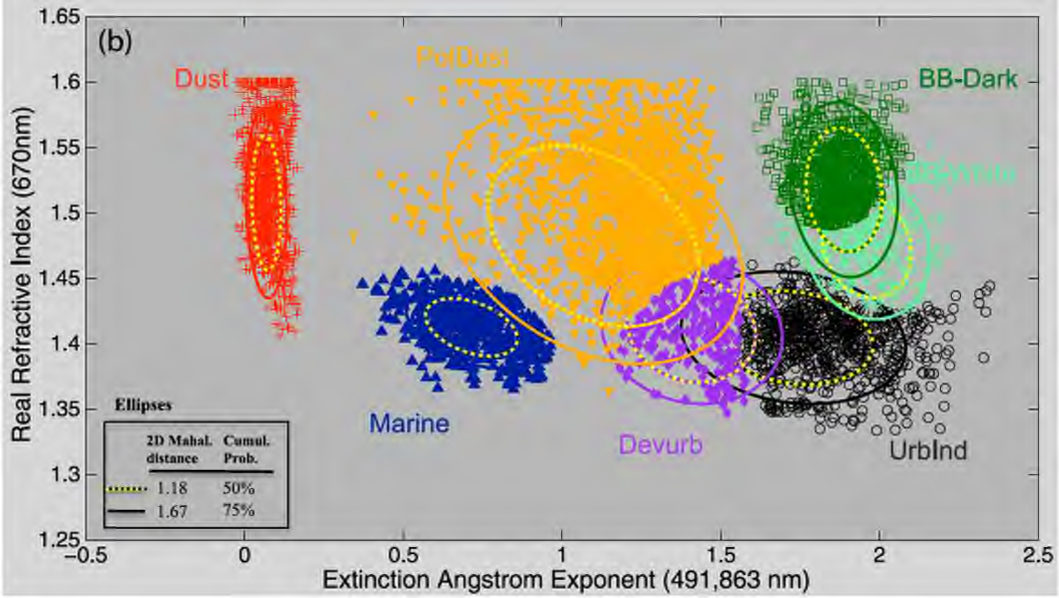
AERONET Aerosol Type 7-Grouping Classification

Four-parameter AERONET-derived classification:

- $EAE_{491,863}$
- SSA_{491}
- RRI_{670}
- $dSSA_{863\text{-}491}$



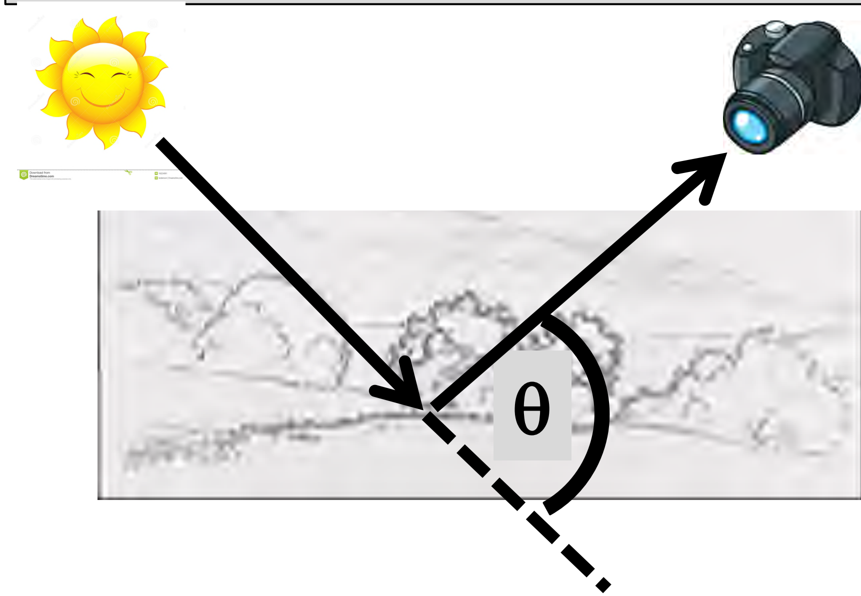
7 Groupings SSA_{491} vs. Extinction ANG

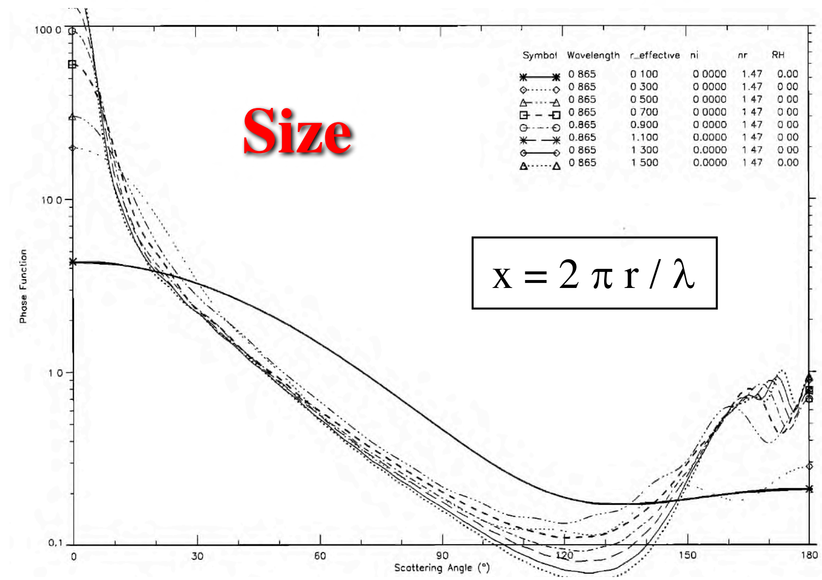


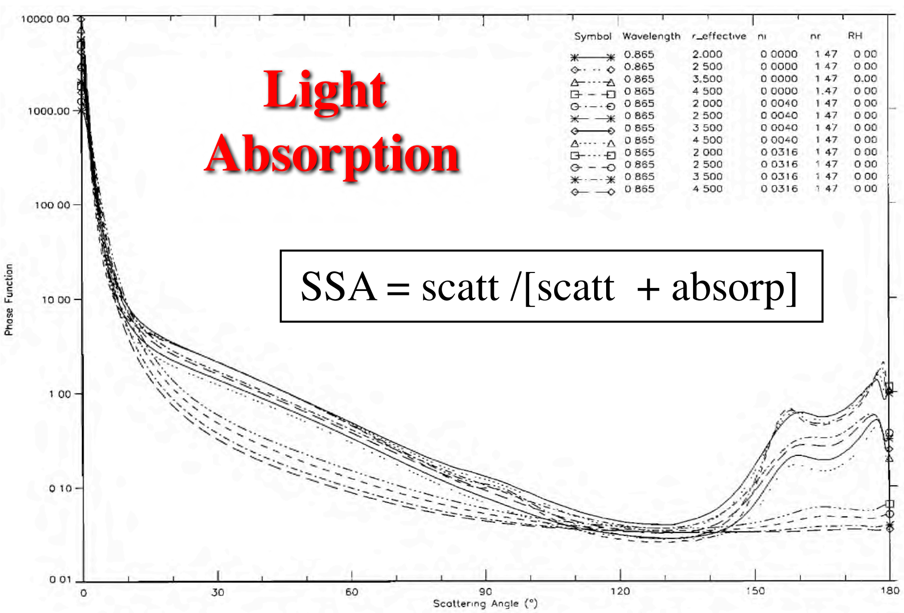
7 Groupings Real RI_{670} vs. Extinction ANG

Russell et al. JGR 2014

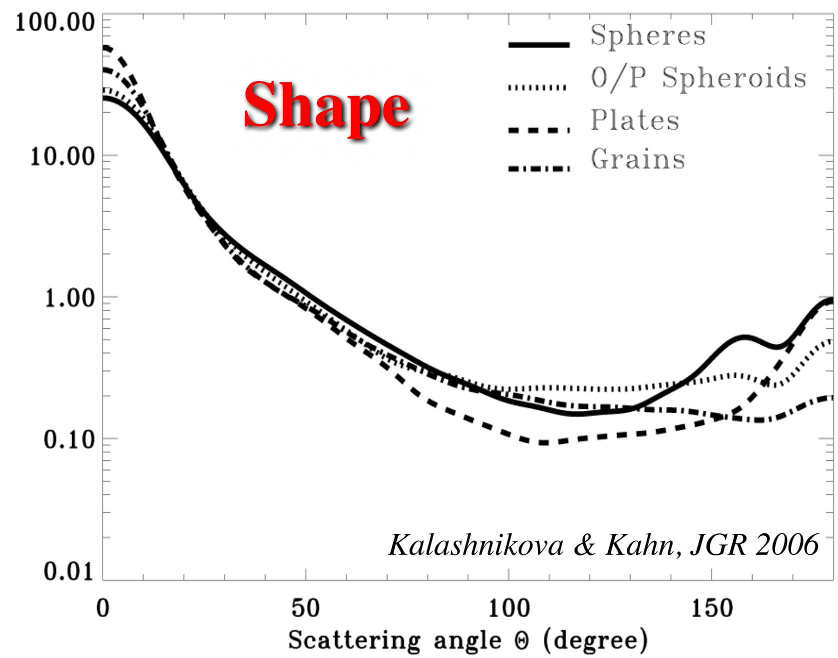
Single-scattering Phase Functions for **Different Particle Properties**





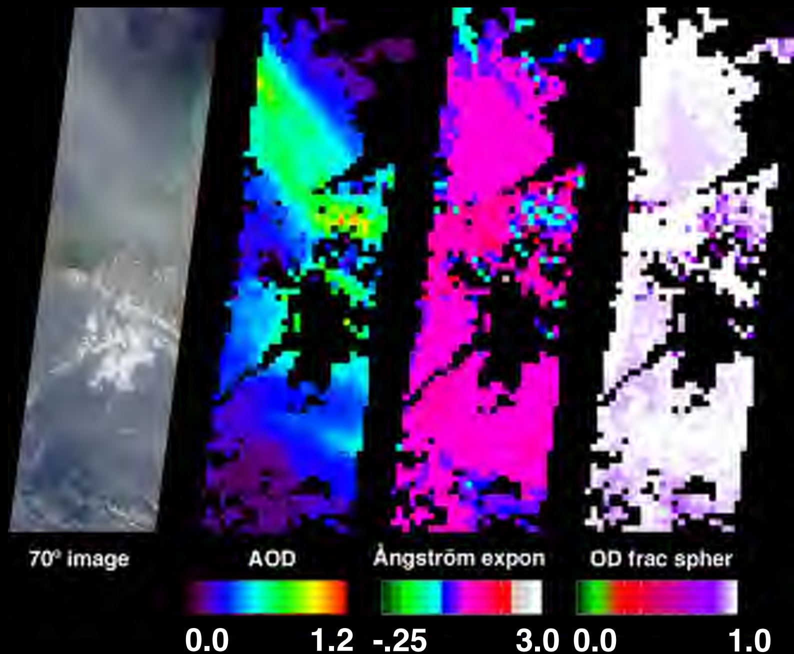


Kahn et al., JGR 1998



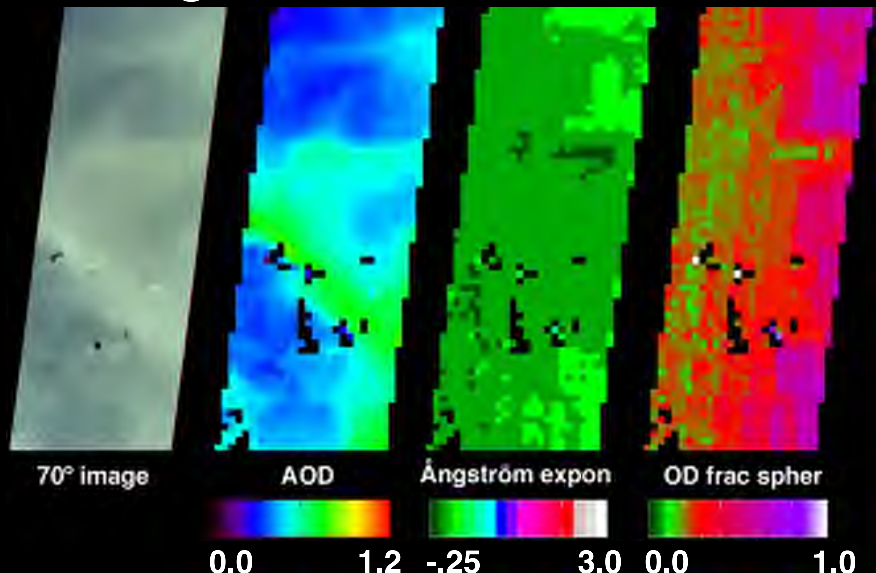
Smoke from Mexico -- 02 May 2002

Aerosol:
Amount
Size
Shape



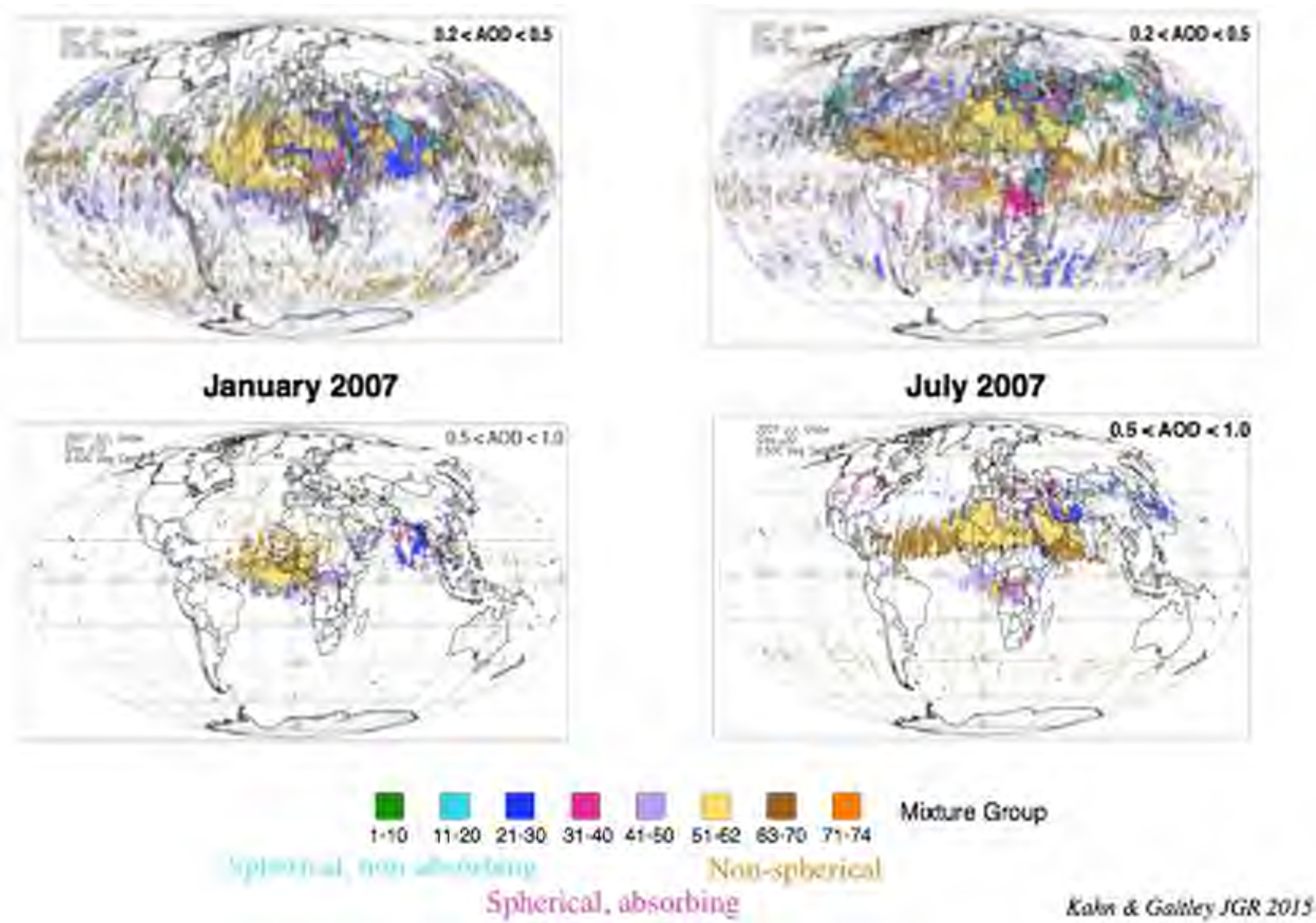
Medium
Spherical
Smoke
Particles

Dust blowing off the Sahara Desert -- 6 February 2004



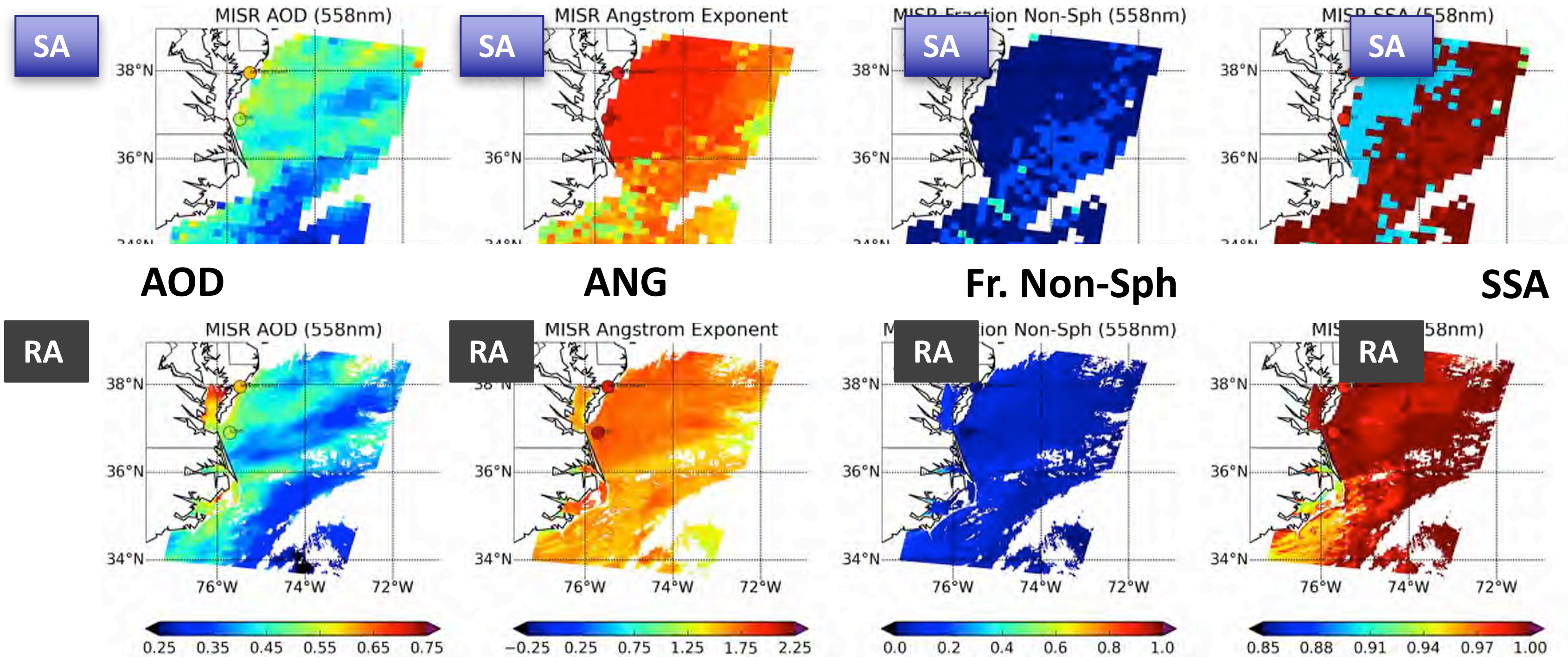
Large
Non-Spherical
Dust
Particles

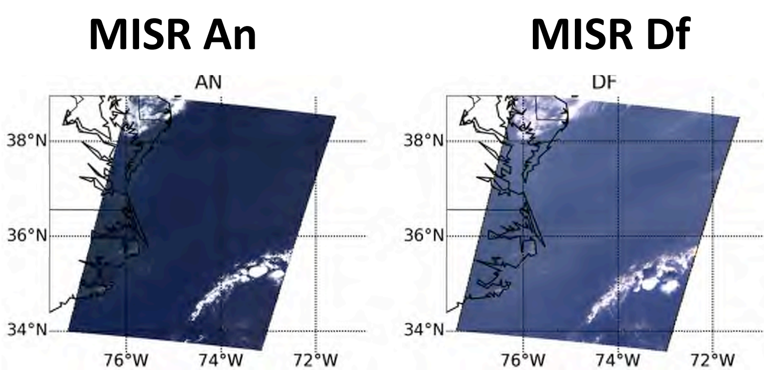
MISR Aerosol Type Discrimination

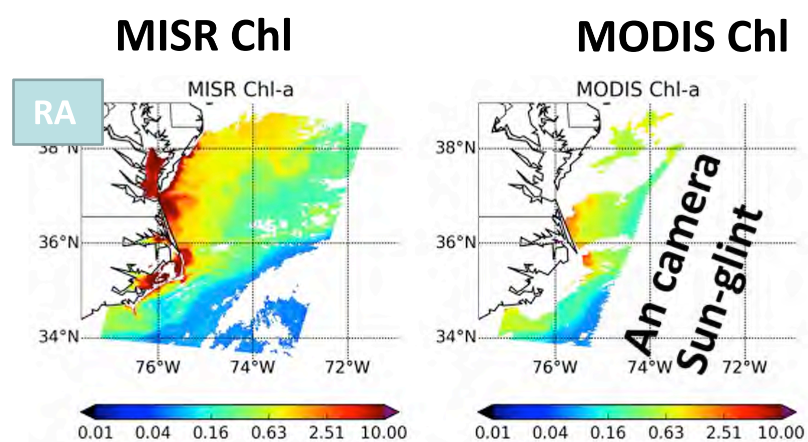


Kahn & Gaitley JGR 2015

MISR *Research Algorithm* With Self-consistent Ocean Surface Retrieval







Limbacher and Kahn AMT 2017

Satellite *Aerosol Type* Summary

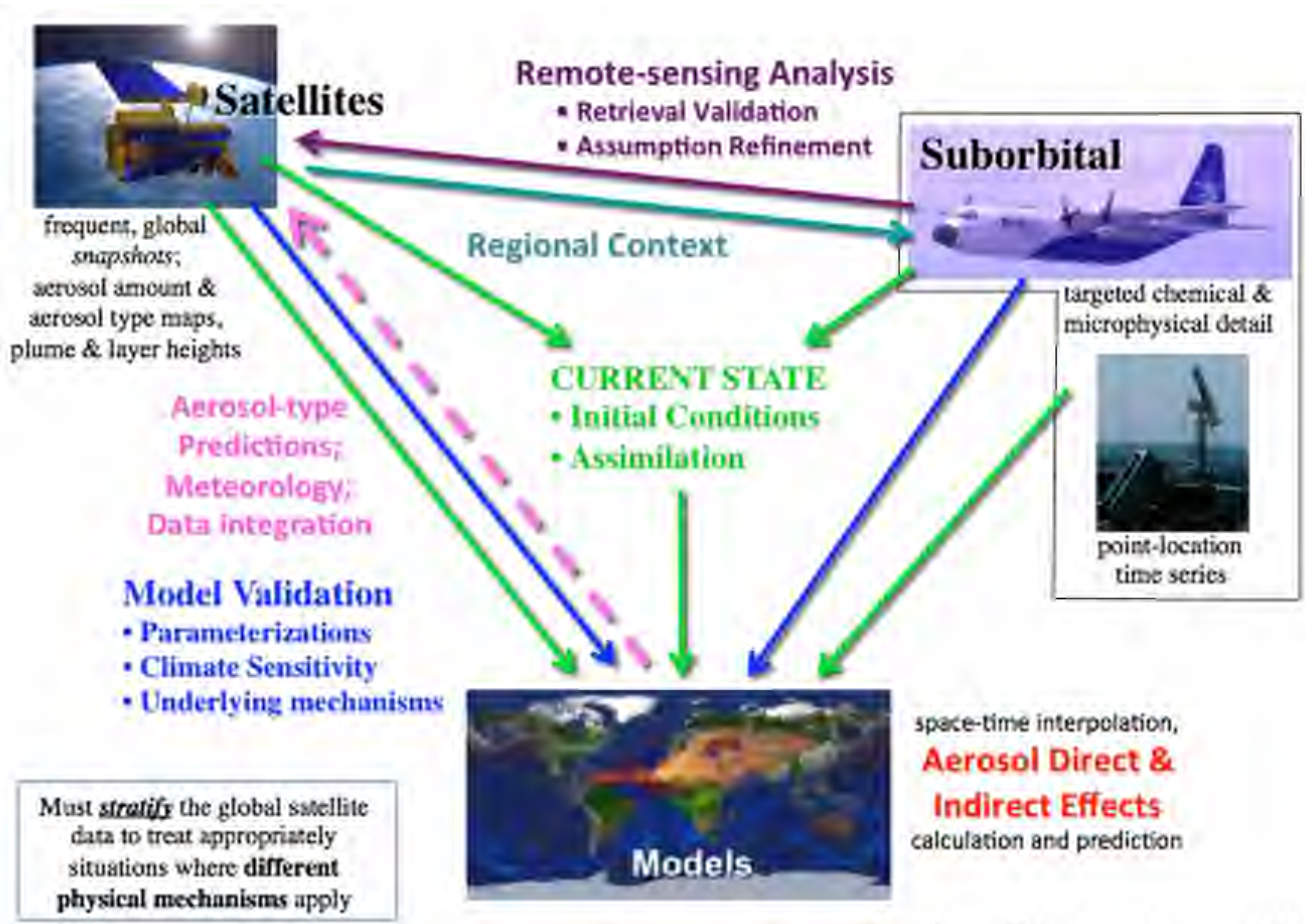
- Remote-sensing can provide optical constraints interpreted as particle ***Size, Shape, and Indices of Refraction***

- A ***further*** interpretative step, entailing additional assumptions, reports particle ***Chemical Composition***

- Remote-sensing ***sensitivity to particle properties is much more dependent than AOD on retrieval conditions*** (***Not*** straightforward to provide quantitative uncertainty estimates)

- *Validation Data* for aerosol type are ***very limited***

  -- *Model simulations* and *In Situ measurements* can help



Adapted from: Kahn, Survy. Geophys.

SAM-CAAM

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

[This is currently a ***concept-development effort***, not yet a project]

Primary Objectives:

- Interpret and *enhance ~17 years of satellite aerosol retrieval* products
- *Characterize statistically particle properties* for major aerosol types globally, to provide detail unobtainable from space, but needed to *improve*:

-- Satellite aerosol *retrieval algorithms*

-- The *translation between satellite-retrieved aerosol optical properties and* species-specific aerosol mass and size tracked in *aerosol transport & climate models*

Kahn et al., BAMS 2017

SAM-CAAM *Concept*

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

- ***Dedicated Operational Aircraft*** – routine flights, 2-3 x/week, on a continuing basis
- ***Sample Aerosol Air Masses*** accessible from a given base-of-operations, then move; project science team to determine schedule, possible field campaign participation
- Focus on *in situ* ***measurements required*** to characterize particle ***Optical Properties*** (esp. ***Light Absorption***), ***Composition***, ***Hygroscopicity***, and ***Mass Extinction Efficiency***
- ***Process Data Routinely*** at central site; instrument PIs develop & deliver algorithms, upgrade as needed; data distributed via central web site
- Peer-reviewed paper to identifying ***4 Payload Options***, of varying ambition; subsequent selections based on agency buy-in and available resources

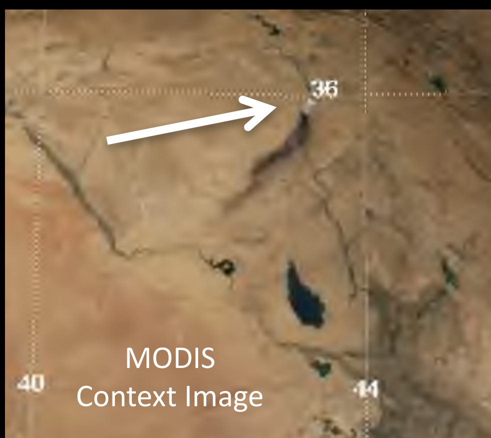
SAM-CAAM is feasible because:
Unlike aerosol amount, ***aerosol microphysical properties tend to be repeatable*** from year to year, for a given source in a given season

Kahn et al., BAMS 2017

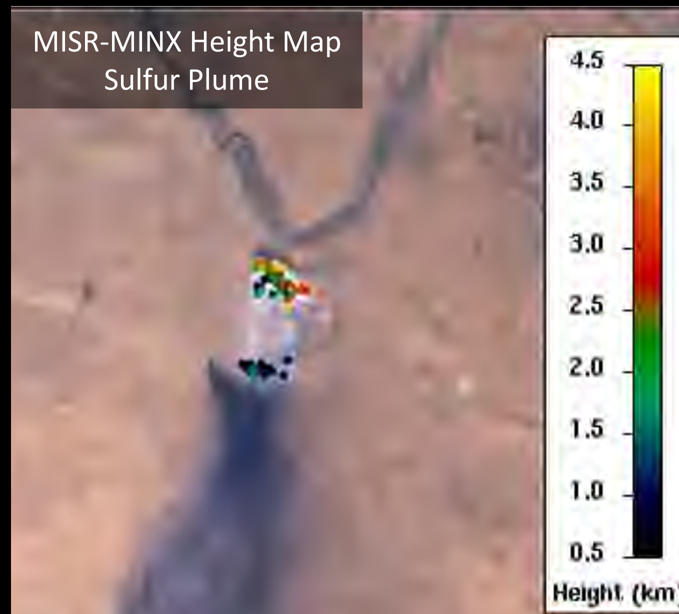
Iraq's Mishraq Sulfur Plant and Oil Well Smoke Plume Heights

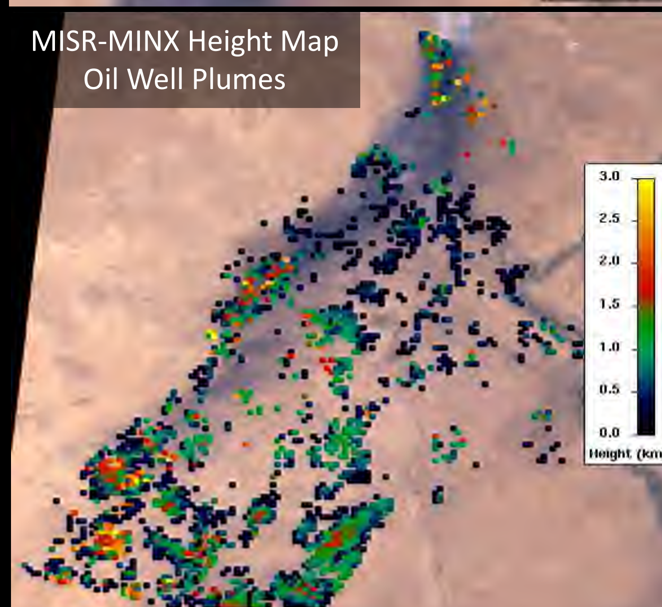
MISR Active Aerosol Plume-Height (AAP) Project 21 October 2016

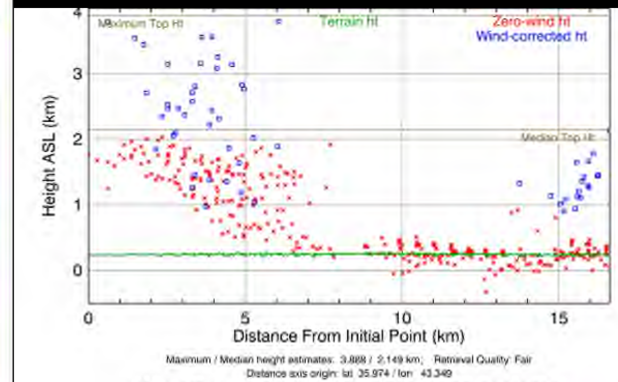
The ***height*** at which smoke is injected into the atmosphere affects ***how long*** it will stay aloft, ***how far*** it will travel, and ***how much of an impact*** it will have on air quality downwind, and regional climate. In ***northern Iraq***, at least two people have lost their lives, up to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



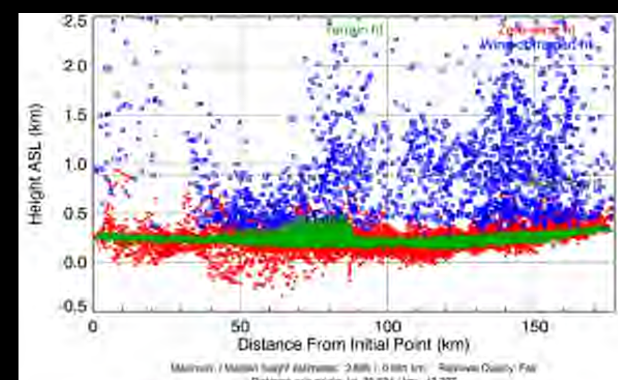




Zero-wind & Wind-Corrected

MISR Height Profiles

Downwind from Near-source



R. Kahn, **T. Kucsera** / NASA GSFC

T. Canty, R. Bolt, CJ Vernon / U. Maryland

Backup Slides

SAM-CAAM *Required Variables*

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

1. AEROSOL PROPERTIES FROM *IN SITU* MEASUREMENTS & INTEGRATED ANALYSIS

	Abbrev.	Required Variable
1	EXT	Spectral Extinction
2	ABS	Spectral Absorption
3	GRO	Hygroscopic Growth
4	SIZ	Particle Size
5	CMP	Particle Type (a composition constraint)
6	PHA	Single-scattering Phase Function
7	MEE	Mass Extinction Efficiency
8	RRI	Real Refractive Index

Kahn et al., BAMS 2017

SAM-CAAM *Required Variables*

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

2. METEOROLOGICAL CONTEXT

	Abbrev.	Required Variable
9	CO	Ambient Gases ($CO + O_3 + NO_2$)
10	T; P; RH	Standard Ambient Meteorological Variables
11	LOC	Geographic Location

3. AMBIENT REMOTE-SENSING CONTEXT

	Abbrev.	Required Variable
12	A-EXT & A-ABS	Ambient Spectral Extinction & Absorption
13	A-PHA	Ambient Particle Phase Function
14	A-CLD	Ambient Cloud & Large-Particle Size/Type
15	HTS	Aerosol Layer Heights

Kahn et al., BAMS 2017