SATELLITE Contributions to ACPC

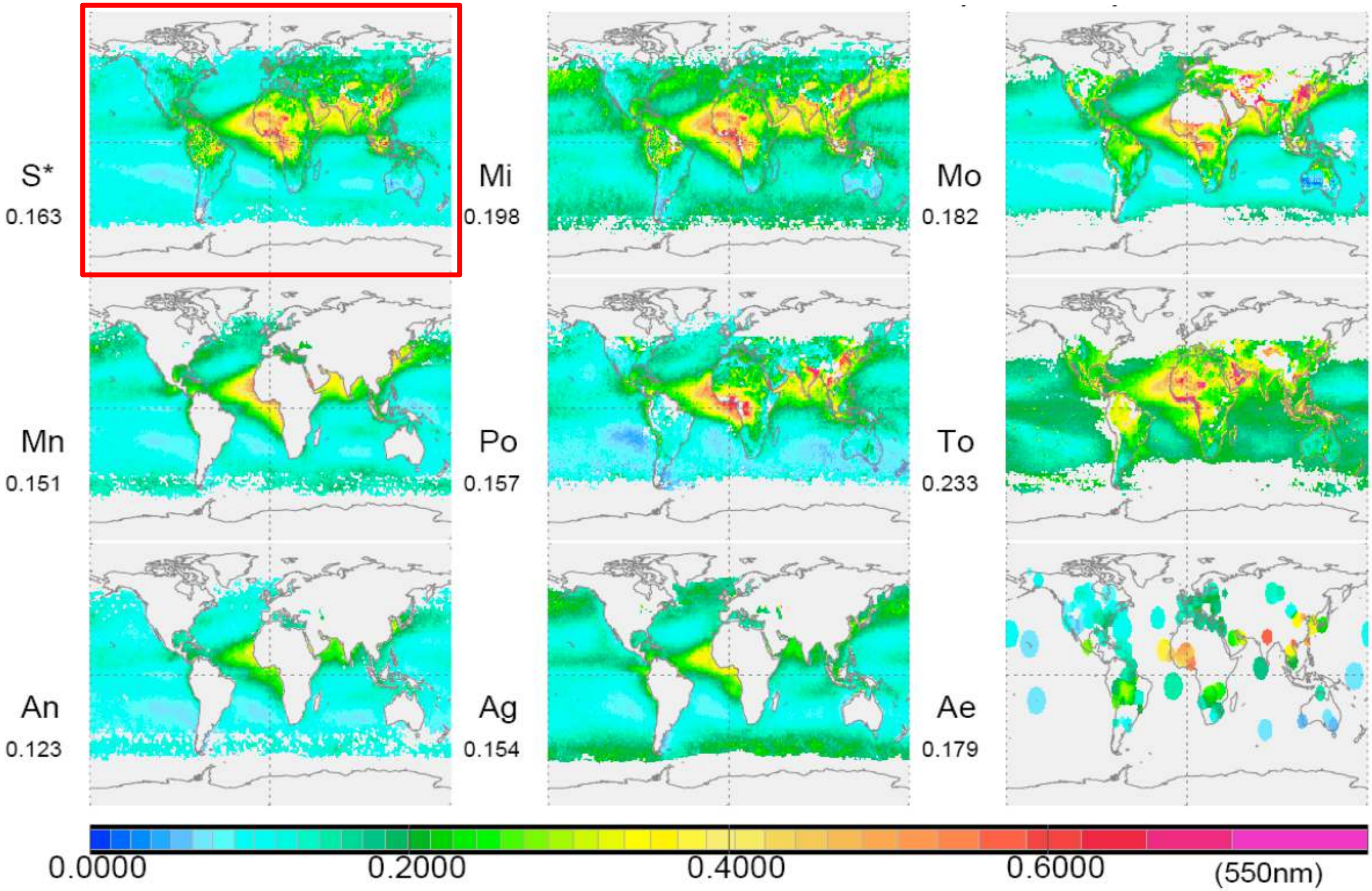
Ralph Kahn
NASA/Goddard Space Flight Center

Satellite "Direct" Measurement Capabilities

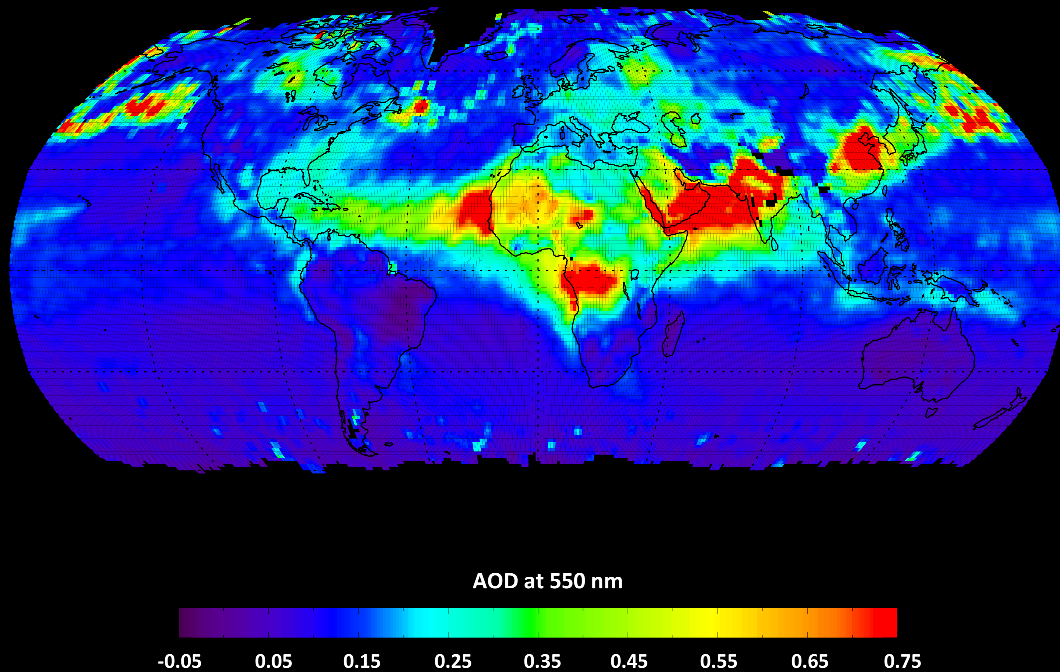
- *Polar orbiting imagers* provide ***frequent, global coverage***
- *Geostationary platforms* offer ***high temporal resolution***
- *Multi-angle imagers* offer ***aerosol plume height & cloud-top mapping***
- *Passive instruments* can retrieve total-column ***aerosol amount (AOD)***
- *Active instruments* determine aerosol & some cloud ***vertical structure***
- *UV imagers* and *active sensors can* retrieve ***aerosol above cloud***
- *Multi-angle*, *spectral*, *polarized* imagers obtain ***some aerosol type info.***
- *Active sensors* can obtain ***some aerosol type info., day & night***
- Satellite trace-gas retrievals offer ***clues about aerosol type***
- *Vis-IR imagers* can retrieve ***cloud phase***, r_c, T_c, p_c, τ_c, α_c, C_f, **LWP**

Need to be creative &
Play to the strengths of what satellites offer!!

Multi-year Annual Average *Aerosol Optical Depth* from Different Measurements + *Synthesis* (S*)



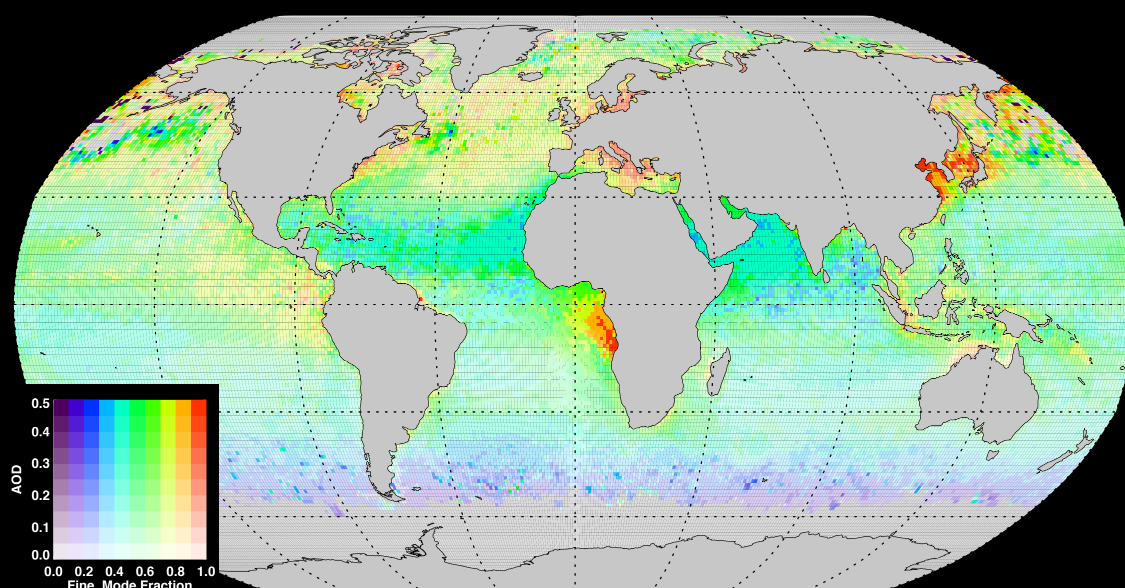
From: *Kinne et al. ACP 2006*



Mid-Visible
AOD
“Dark Target” + “Deep Blue”

MODIS
July 2010
Monthly Average

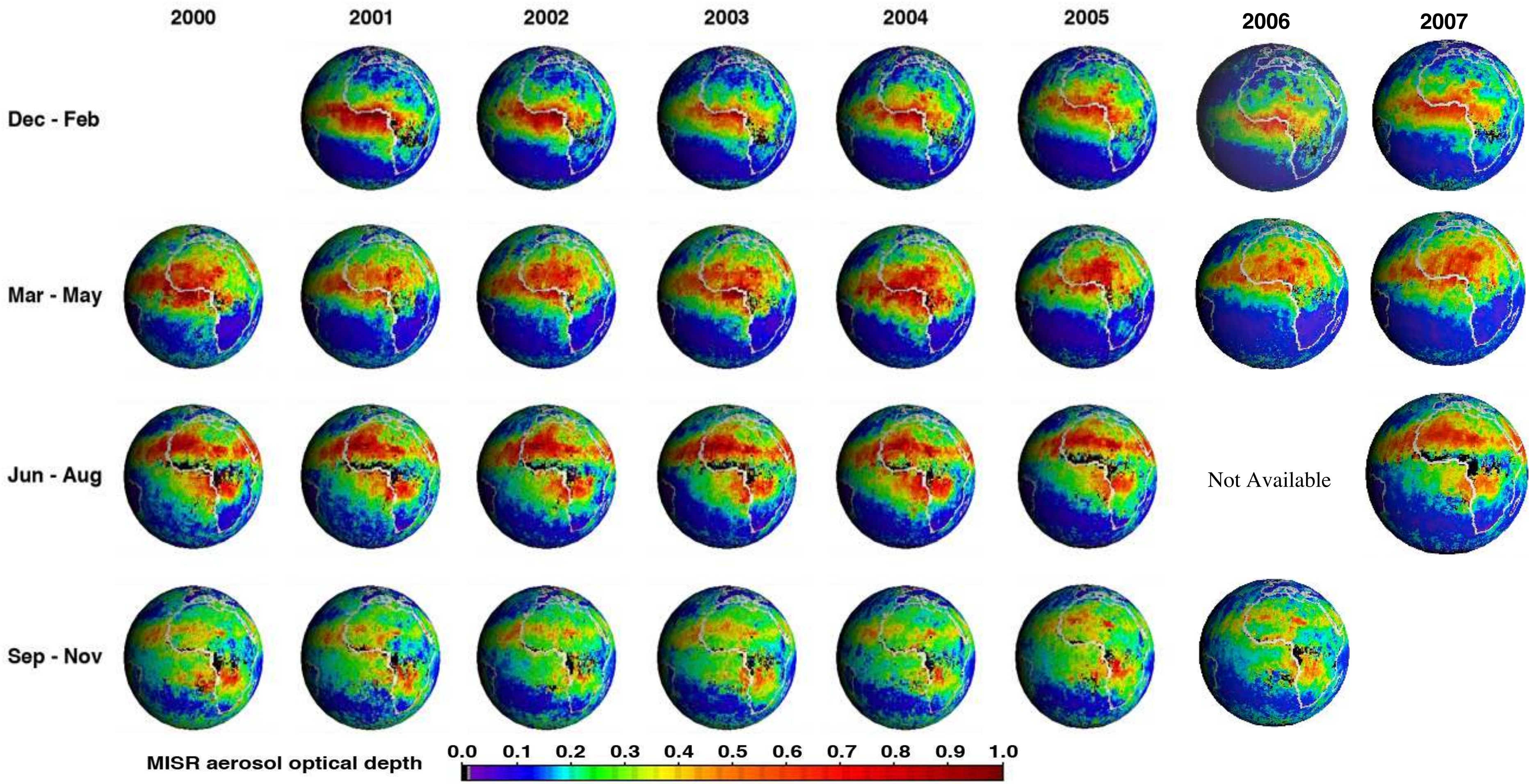
- Water & some Land
- Globe ~ Every 2 days
- ~ 10:30 AM & 1:30 PM



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

MODIS Team, NASA Goddard Space Flight Center

Eight Years of Seasonally Averaged Mid-visible Aerosol Optical Depth from MISR

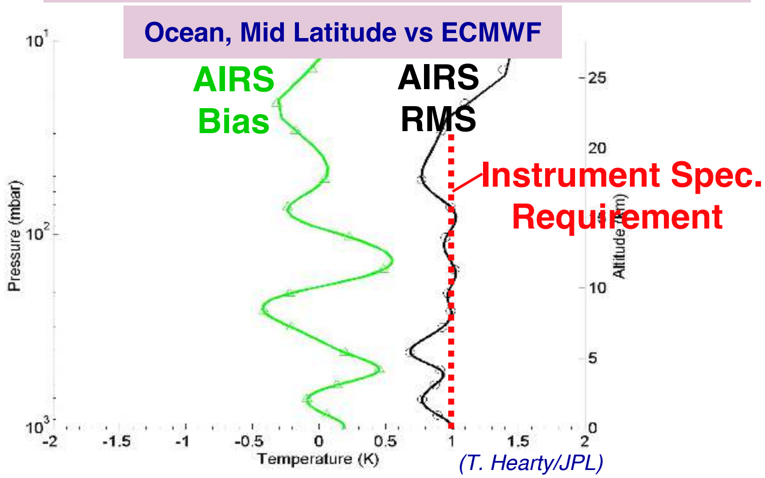


…includes bright desert dust source regions

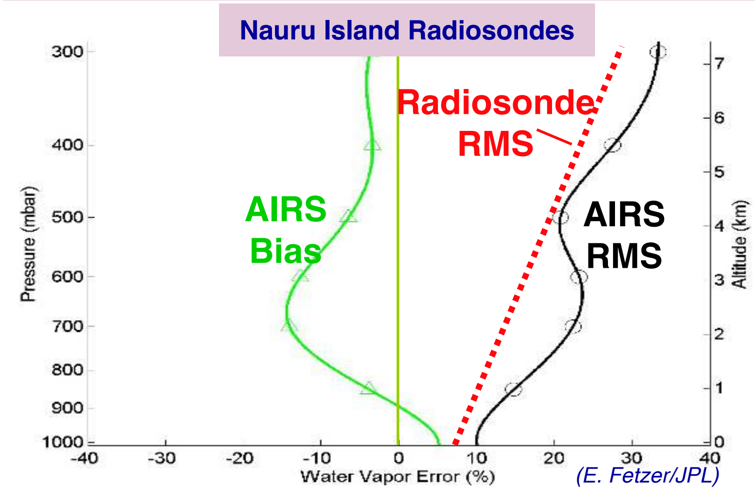
MISR Team, JPL and GSFC

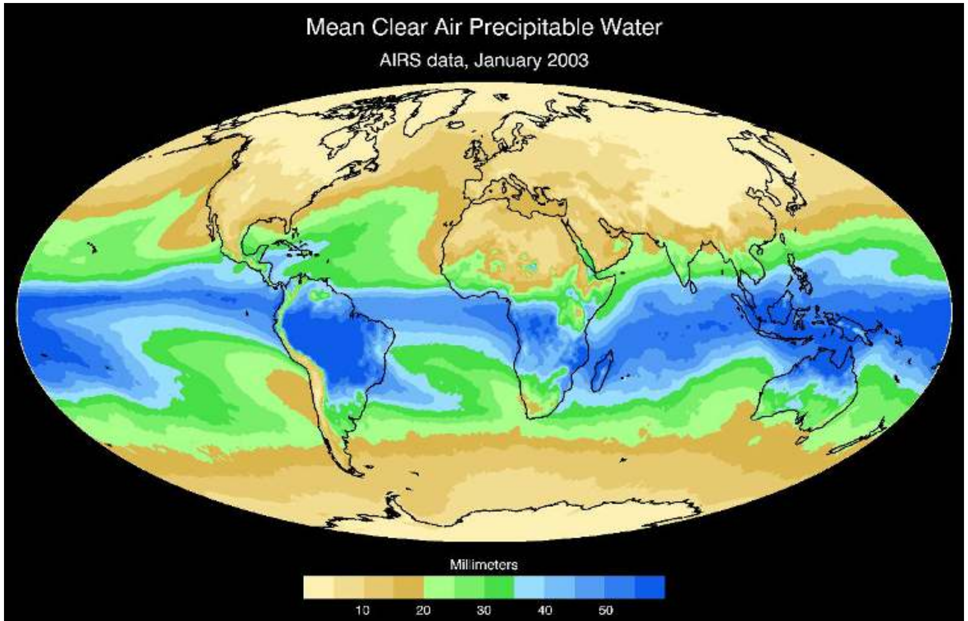
AIRS - Temperature & Water Vapor Profiles

Temperature Profiles
Accurate to 1K/km to 30 mb



Water Vapor Profiles
Match Observations 15%/2km





Overall Satellite ***Limitations***

- *Polar orbiters* provide ***snapshots only***
- Typically ~100s of meters or poorer ***horizontal resolution***
- Difficult to probe ***cloud base***
- *Passive instruments* offer little or no ***vertical information***
- *Active instruments* offer little ***spatial coverage***
- Bigger issues retrieving aerosols ***in the presence of clouds!***
- Cloud property retrievals can be aliased ***by the presence of aerosols***
- Little-to-no information about aerosol ***particle properties***

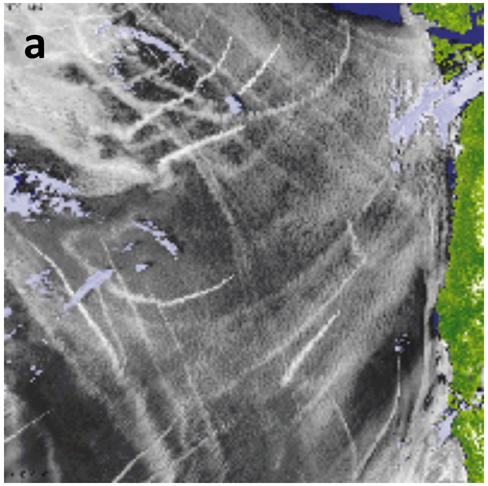
These points are summarized in ***Rosenfeld et al. Rev. Geophys. 2014***

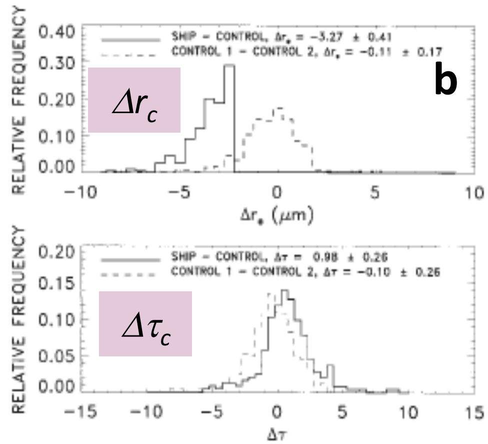
Finer Points on Satellite Aerosol Retrieval *Limitations*

- Difficult to retrieve aerosols that are ***collocated with cloud***
  -- ***Cloud-scattered light*** & cloud "contamination" can affect near-cloud aerosol retrievals
- Rarely can detect aerosol in ***droplet-formation region*** below clouds – need cloud & aerosol ***vertical distributions***
- Aerosols smaller than about ***0.1 micron diameter*** look like atmospheric gas molecules – must ***infer CCN*** number
- Must deduce aerosol ***hygroscopicity*** & ***MEE*** (composition) from qualitative "type" – size, shape, and SSA constraints
- Environmental (Meteorological) Coupling – Factors can ***co-vary***
  -- LWP can decrease as aerosol number concentration increases (also depends on atm. stability)
- Many aerosol-cloud interaction time & spatial scales do not match ***satellite sampling***

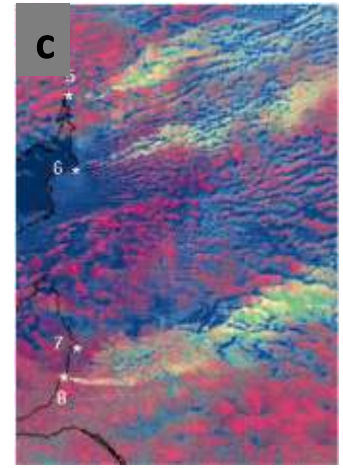
Satellites are fairly blunt instruments for studying aerosol-cloud interactions!!

Historical Examples

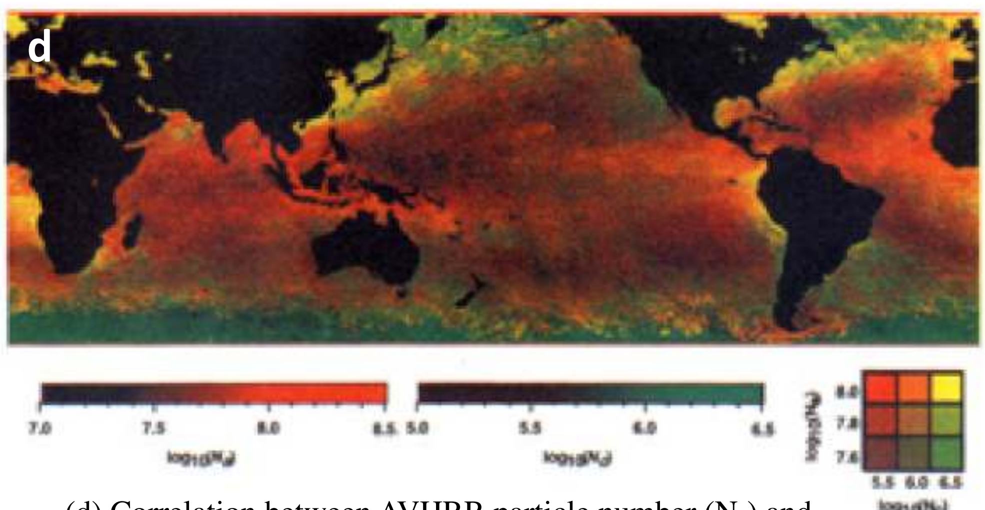




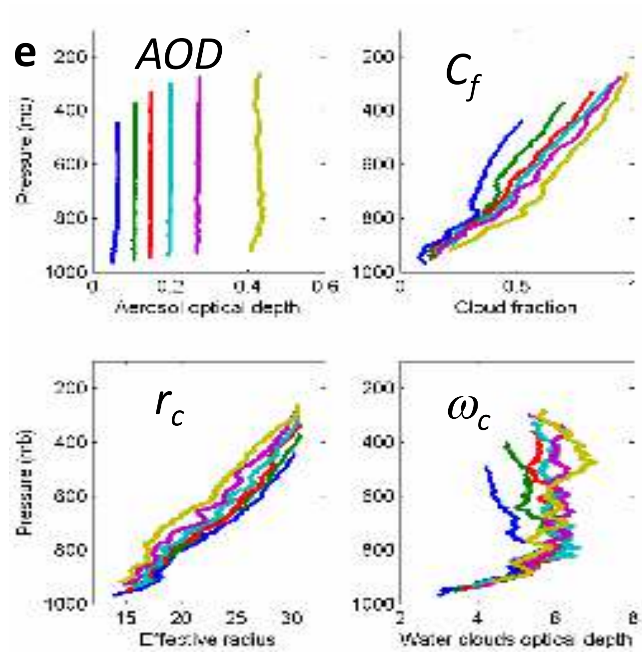
(a) Ship tracks off the coast of California, from AVHRR.
(b) Retrieved r_c and τ_c differences. [*Coakley & Walsh JAS 2002*].



(c) False-color AVHRR: Red indicates large droplets, yellow signifies smaller droplets [*Rosenfeld, Sci. 2000*]

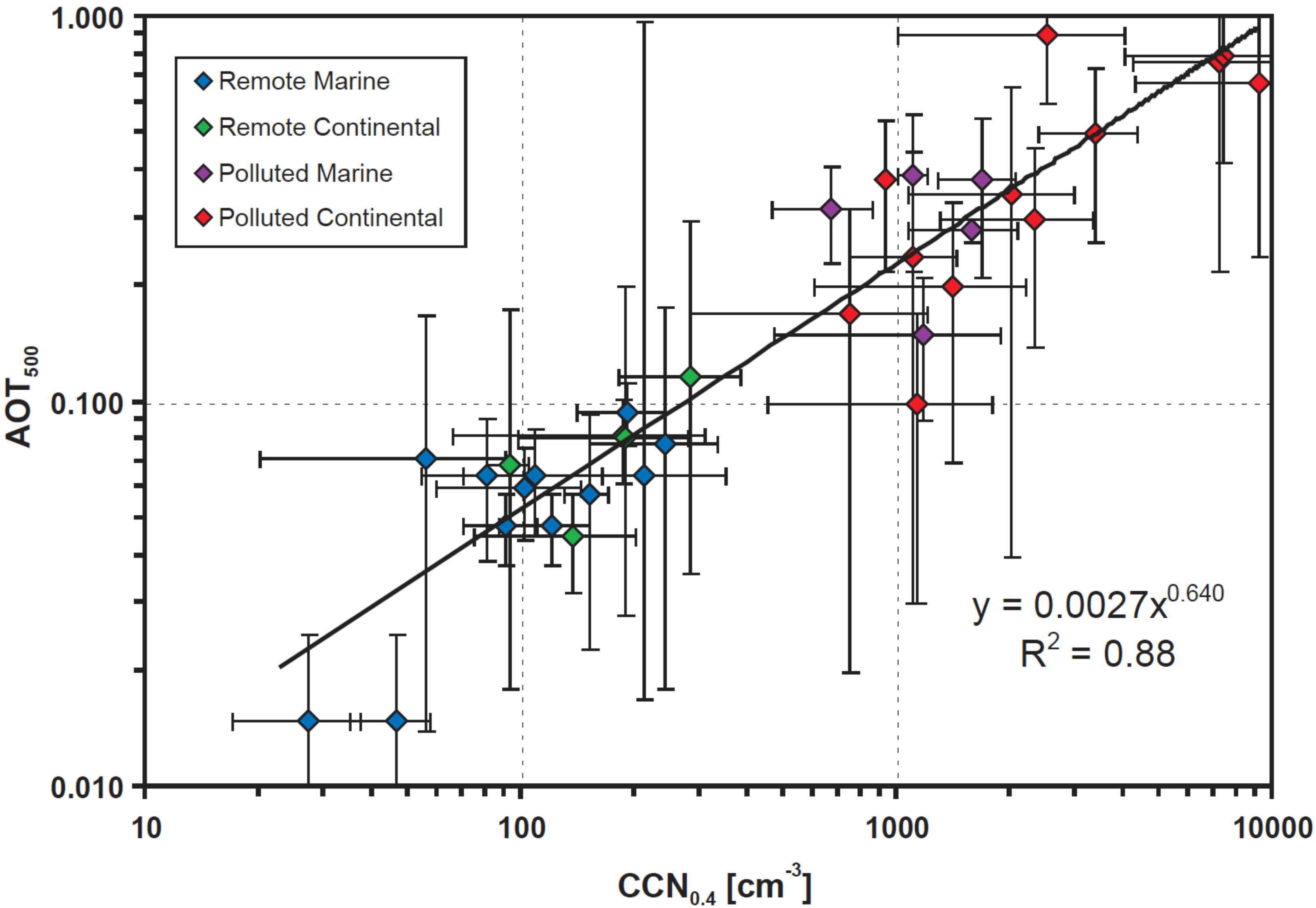


(d) Correlation between AVHRR particle number (N_a) and cloud droplet (N_c) concentrations, for 4 months in 1990; Yellow indicates high N_c with large N_a; red indicates high N_c despite small N_a. [*Nakajima et al., GRL 2001*]



(e) Atlantic convective cloud invigoration from MODIS; aerosol optical depth (AOD), cloud fraction (C_f), cloud droplet effective radius (r_c), water optical depth (ω_c) vs. height; p_c encoded in colors, increasing from blue to green. [*Koren et al.*

Correlation Between AOD from Space and CCN in Remote & Polluted Regions



Andreae ACP 2009

USING *AI* (= τ_a x *Ang*) to Estimate *CCN*

Kapustin, Clarke, et al., JGR 2006

- Test Idea: Smaller particles more likely to become *CCN*; ***Ang*** is a smaller quantity for larger particles
- ACE-Asia, Trace-P *in situ* **field data** – *CCN* proxy

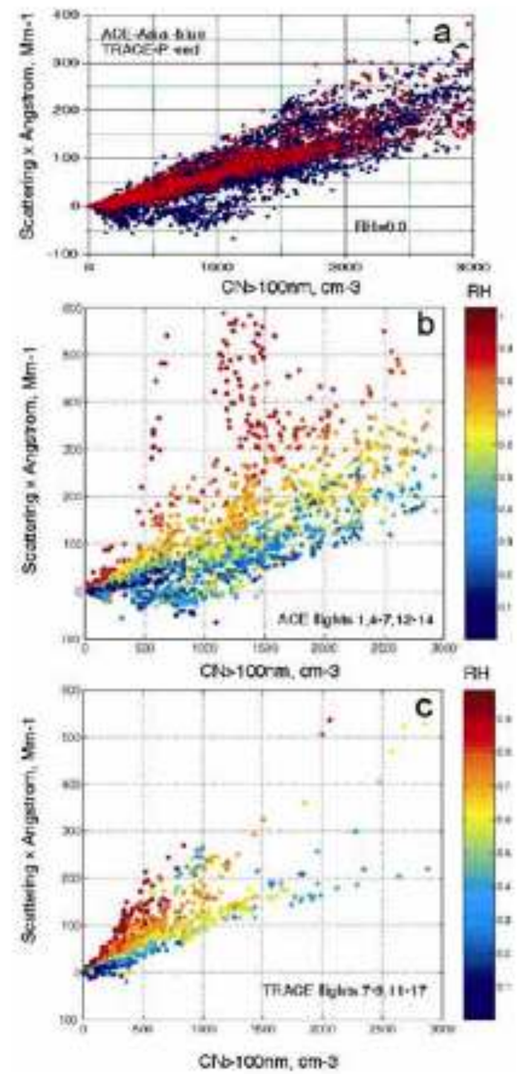
- **AI does not work quantitatively in general**, but can **if the data are stratified** by:

-- ***RH*** in the aerosol layer(s) observed by satellites
-- **Aerosol Type** (hygroscopicity; pollution, BB, dust)
-- **Aerosol Size** (*Ang* is not unique for bi-modal dist.)

Practically, in addition to τ_a and *Ang*, this requires:

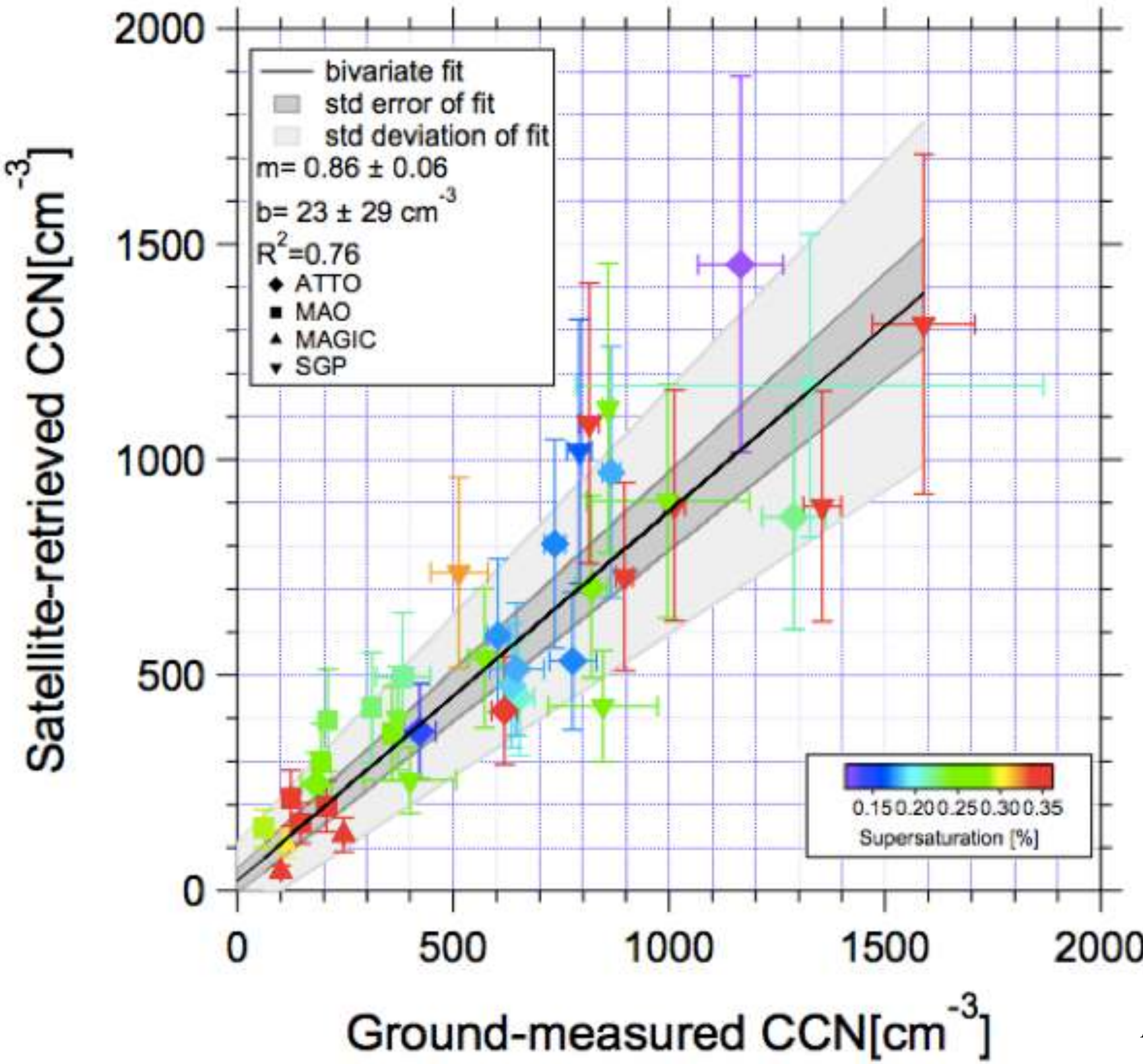
-- Vertical **humidity structure**
-- **Height-resolved** aerosol **type**
-- **Height-resolved size** dist.
[extrapolated to small sizes(?)]

This study includes enough detail to assess *AI* ~ N_a *and* *AI* ~ *CCN*



AI vs. *in situ CCN* proxy
(a) all ACE (blue) & Trace-P, **dry**
(b) ACE - OPC-only, amb. *RH*
(c) TP - OPC-only, amb. *RH*

Deducing CNN & W_b for non-PPT, BL Convective Clouds

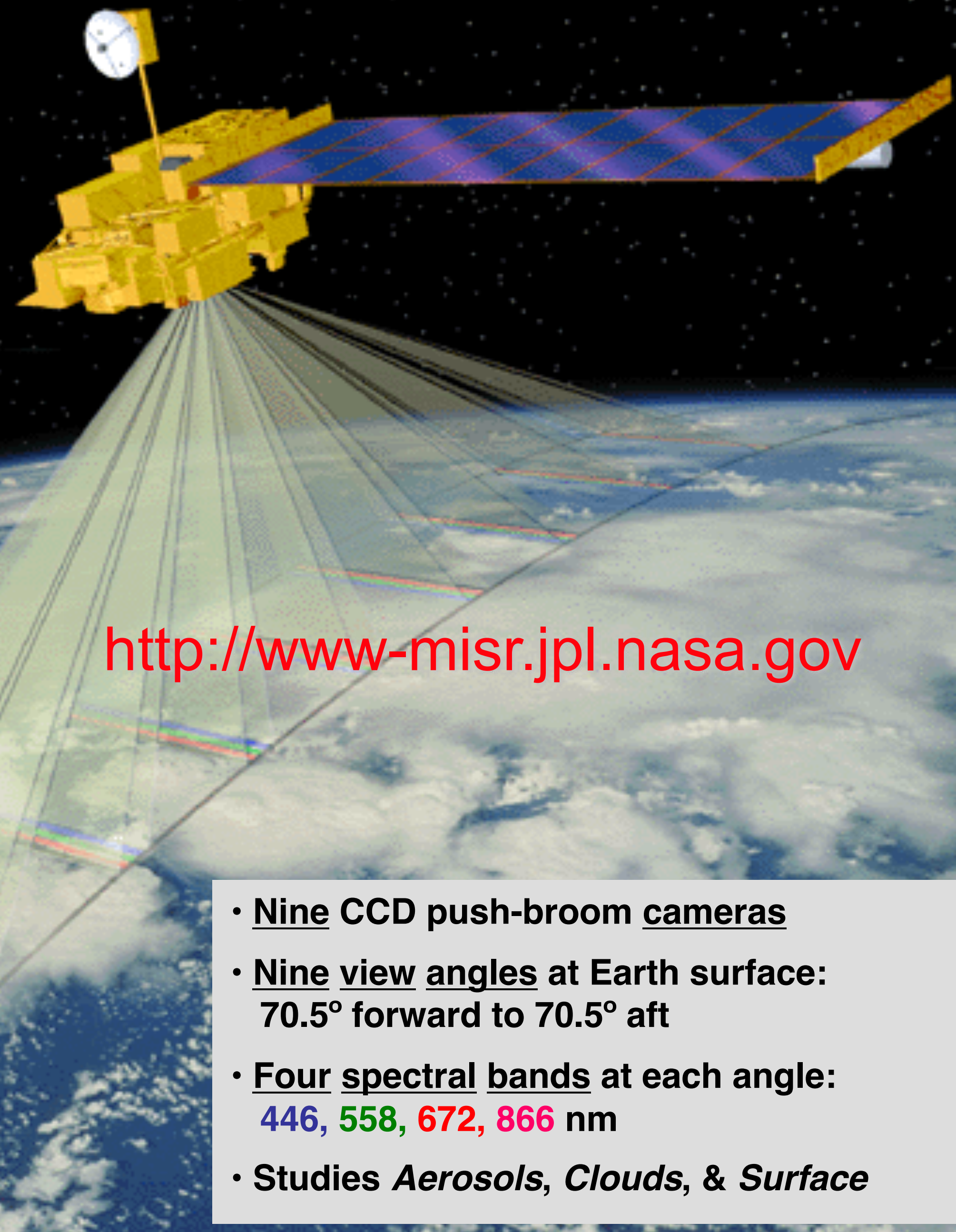


Rosenfeld et al. PNAS 2016

***See*: Poster by Ayal Hashimshoni**

Multi-angle Imaging SpectroRadiometer

MISR



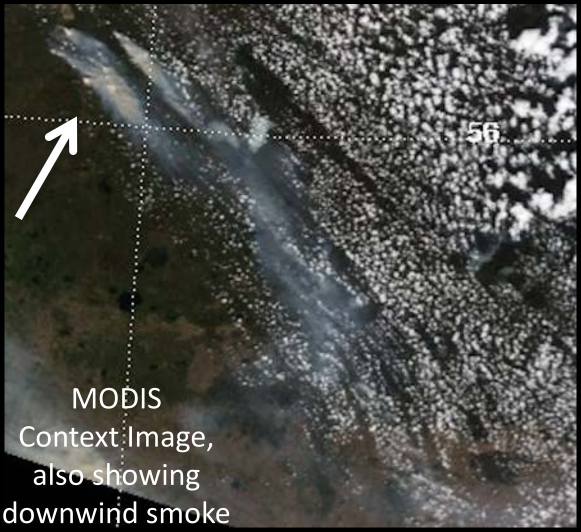
http://www-misr.jpl.nasa.gov

- **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***

Ft. McMurray Wildfire Smoke Plume Heights

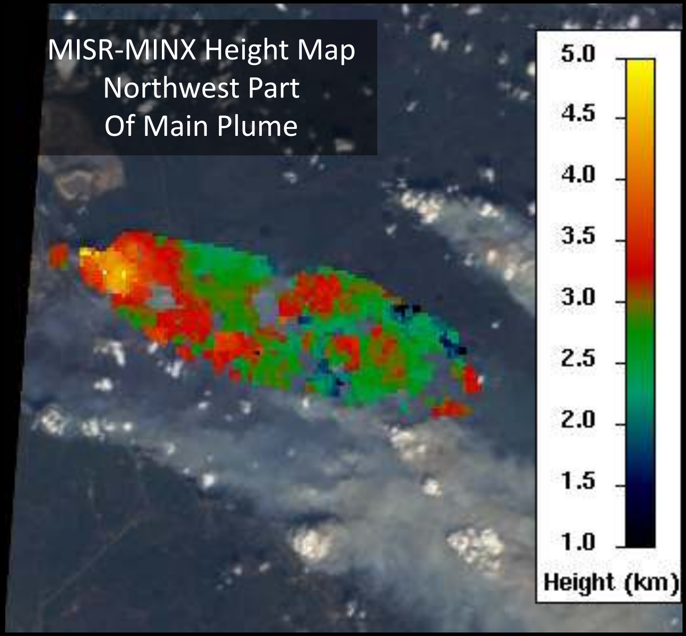
MISR Active Aerosol Plume-Height (AAP) Project 06 May 2016

The ***height*** at which smoke is lofted 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.

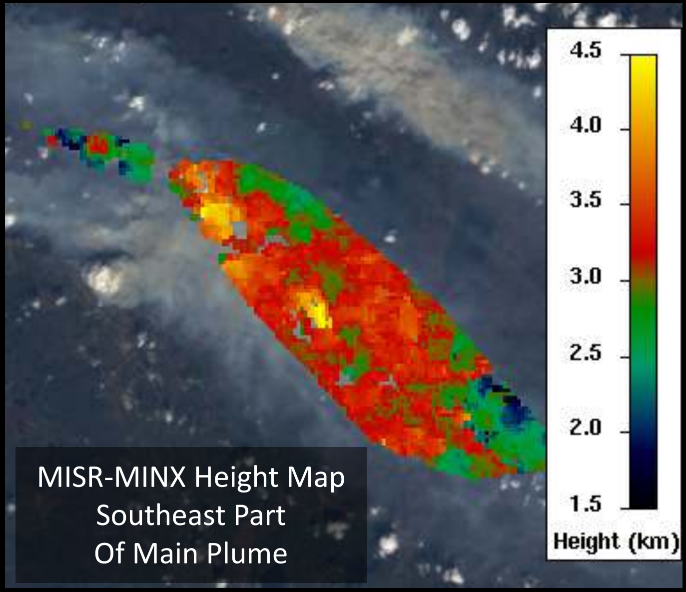


MODIS Context Image, also showing downwind smoke

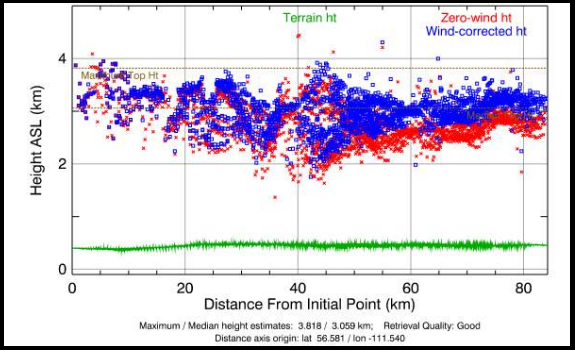
Parallax, the change in apparent plume position relative to the surface, as observed from the NASA Earth Observing System's Multi-angle Imaging Spectroradiometer (***MISR***) instrument, makes it possible to map the height of ***smoke***, ***dust***, and ***volcanic plumes*** near-source, where plume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



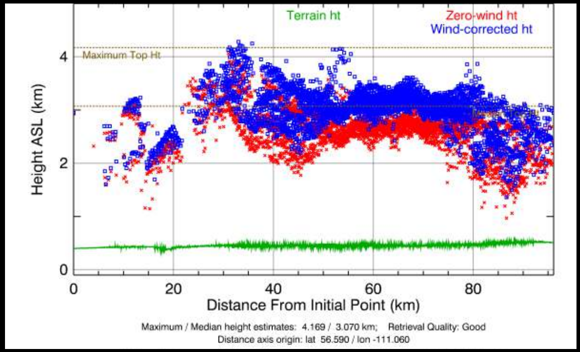
MISR-MINX Height Map Northwest Part Of Main Plume



MISR-MINX Height Map Southeast Part Of Main Plume



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

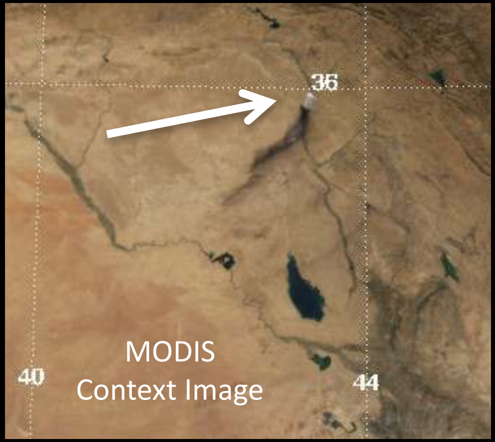


***R. Kahn*, T. Kucsera / NASA GSFC**
T. Canty, R. Bolt, CJ Vernon / U. Maryland

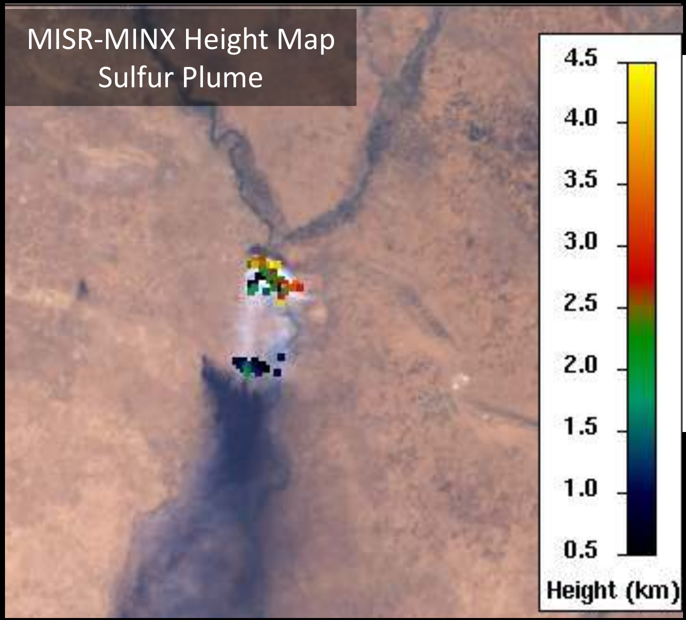
Iraq's Mishraq Sulfur Plant and Oil Well Smoke Plume Heights

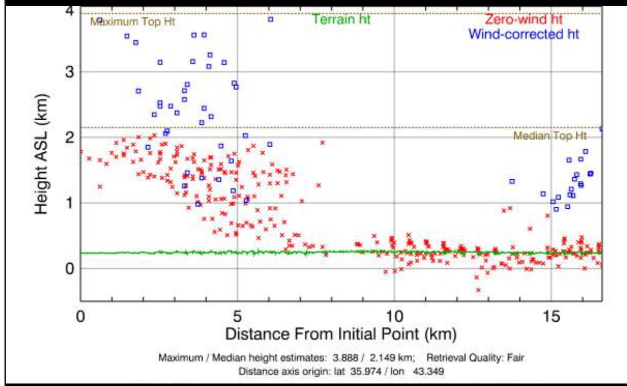
MISR Active Aerosol Plume-Height (AAP) Project 21 October 2016

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.

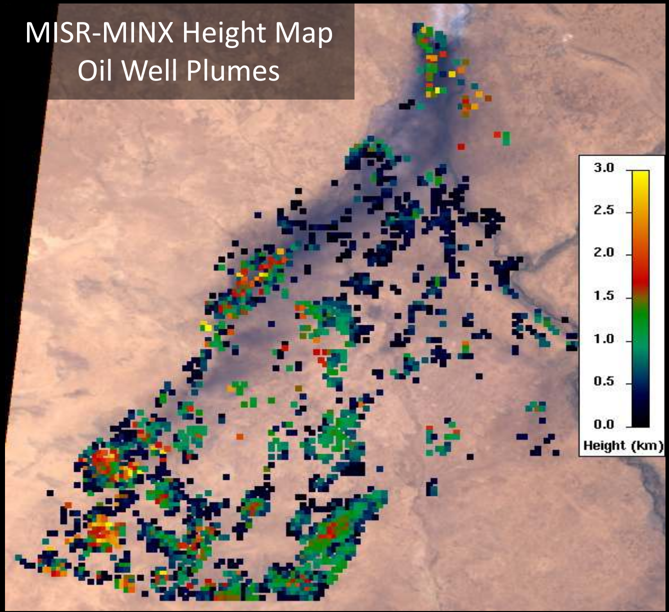


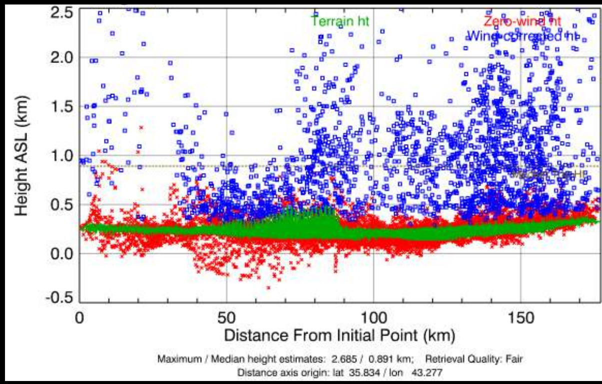


Zero-wind & Wind-Corrected

MISR Height Profiles

Downwind from Near-source

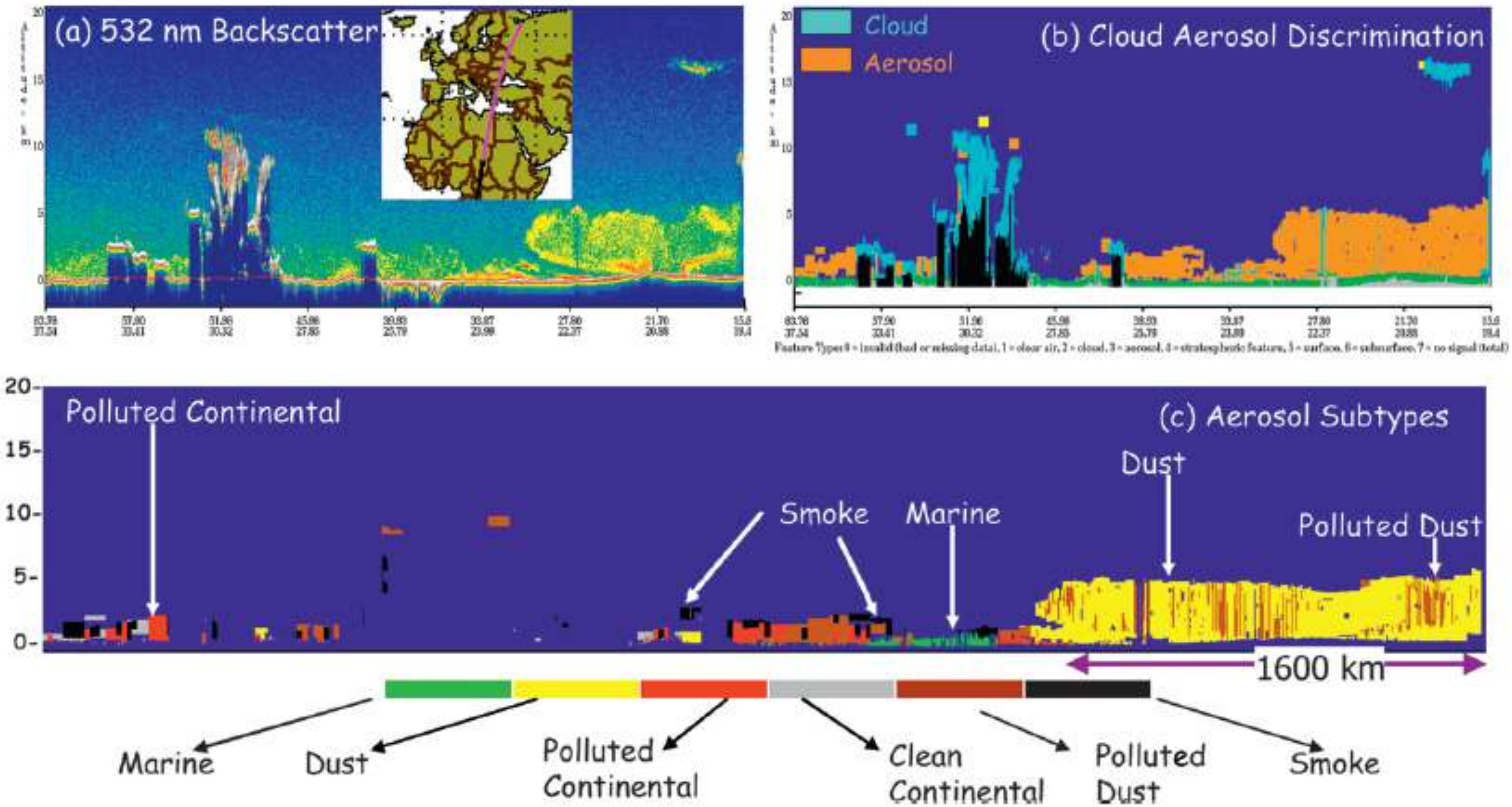




R. Kahn, **T. Kucsera** / NASA GSFC

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

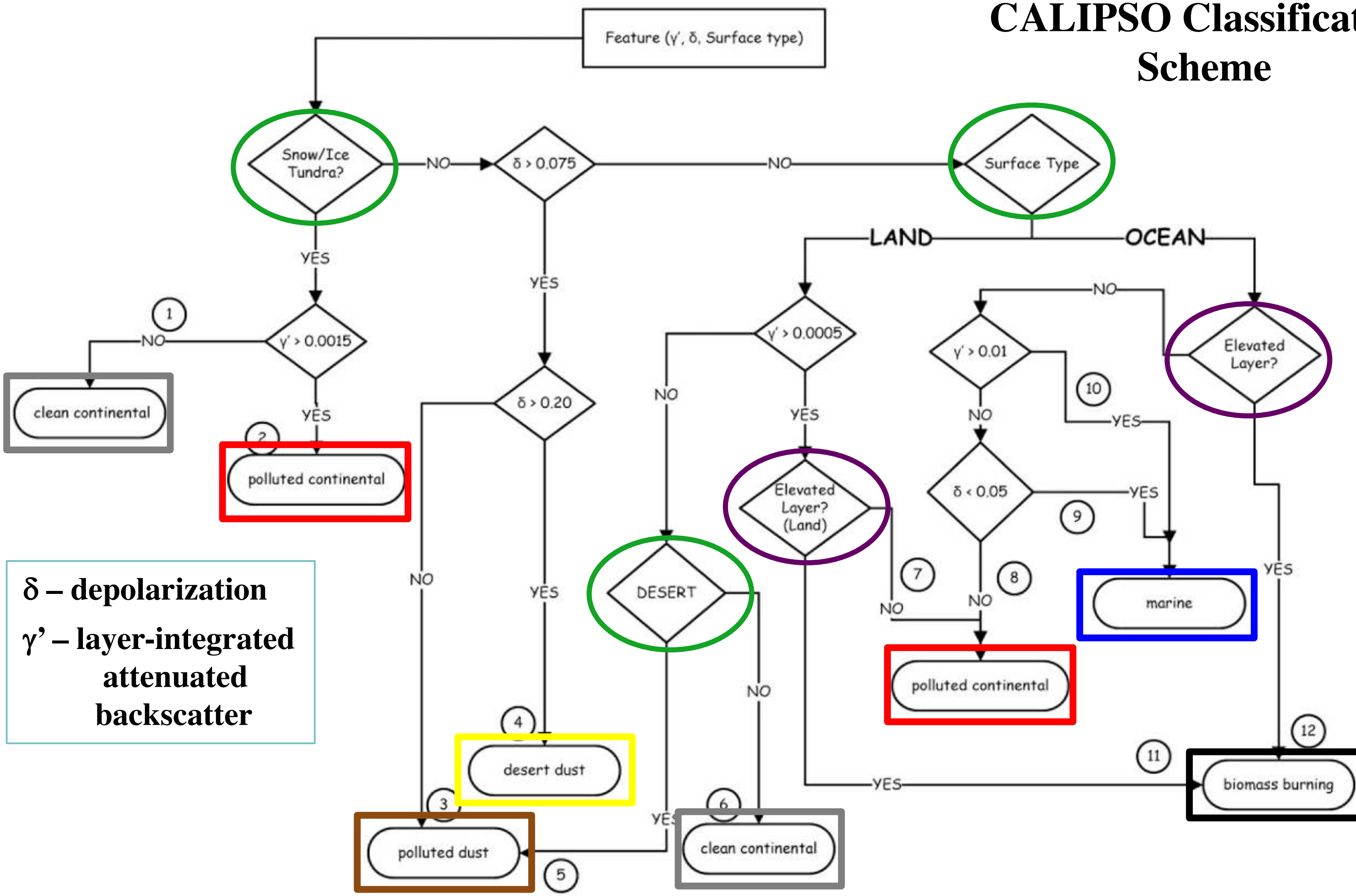
The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)



Omar et al., JAOT 2009

CALIPSO *Interpretive* 6-Aerosol-Type Classification

CALIPSO Classification Scheme

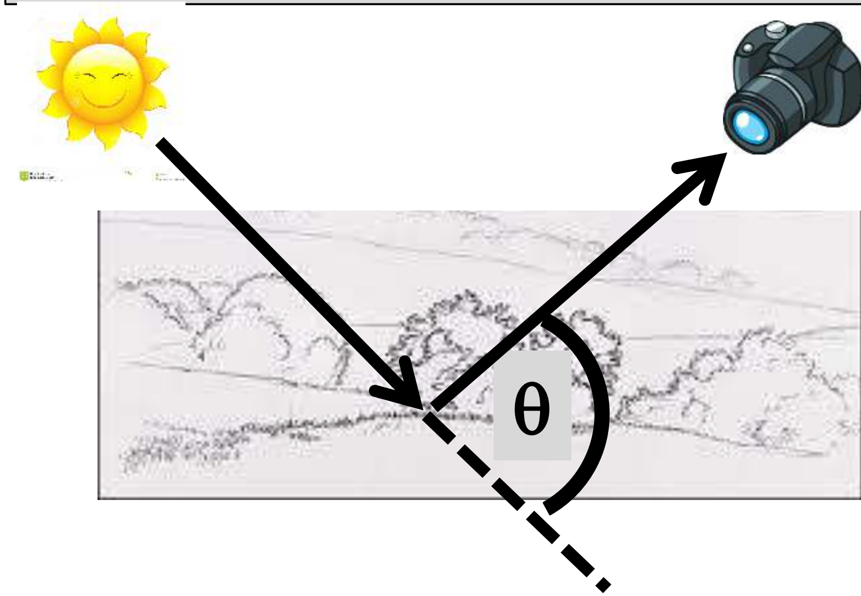


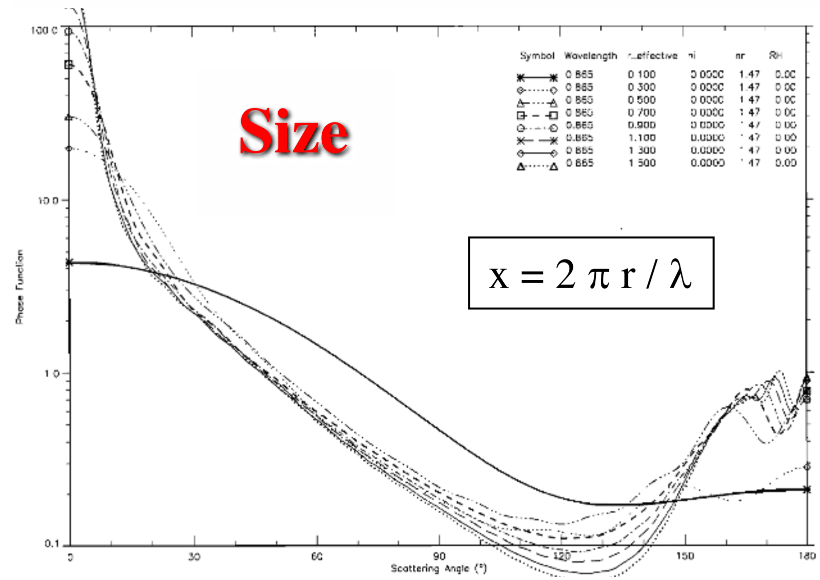
δ – depolarization

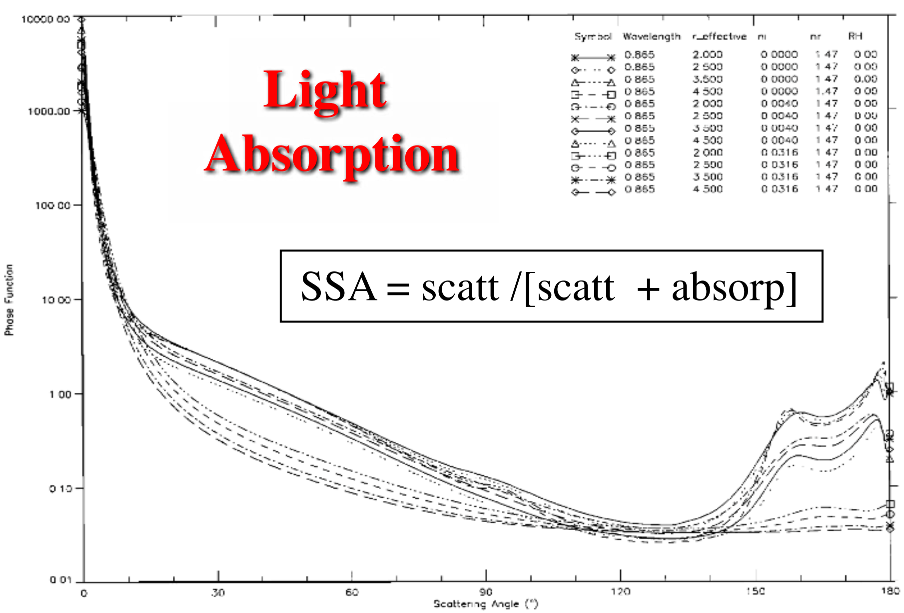
γ' – layer-integrated attenuated backscatter

Omar et al., JAOT 2009

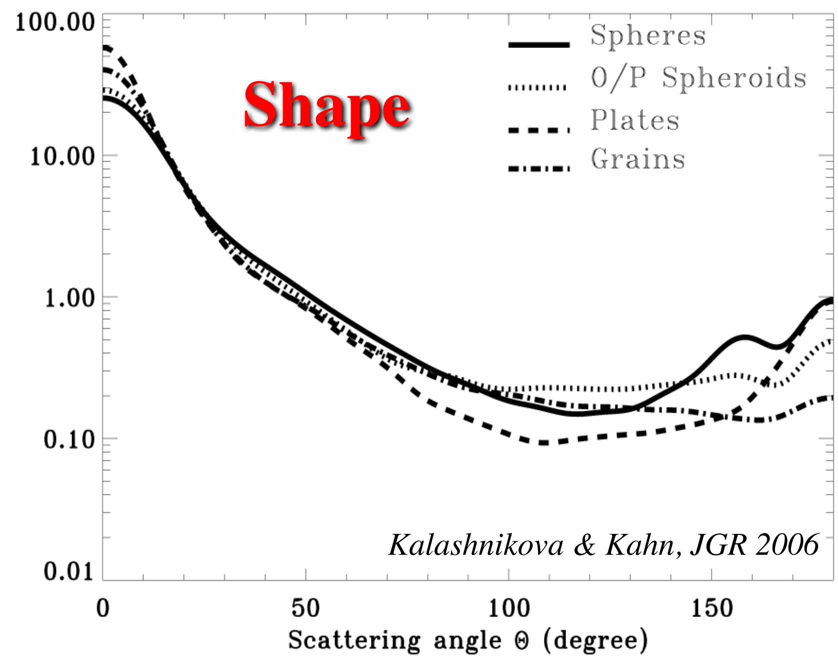
Single-scattering Phase Functions for **Different Particle Properties**



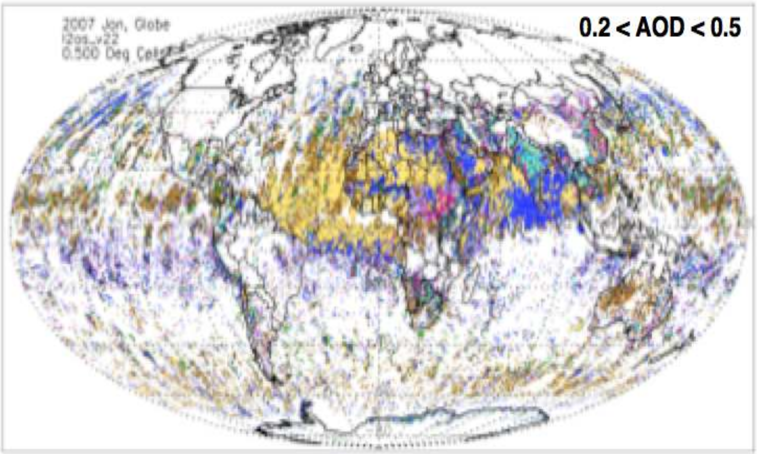


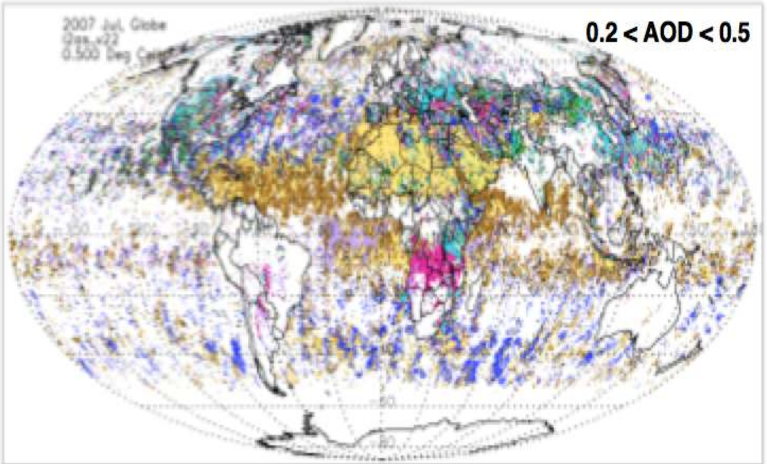


Kahn et al., JGR 1998



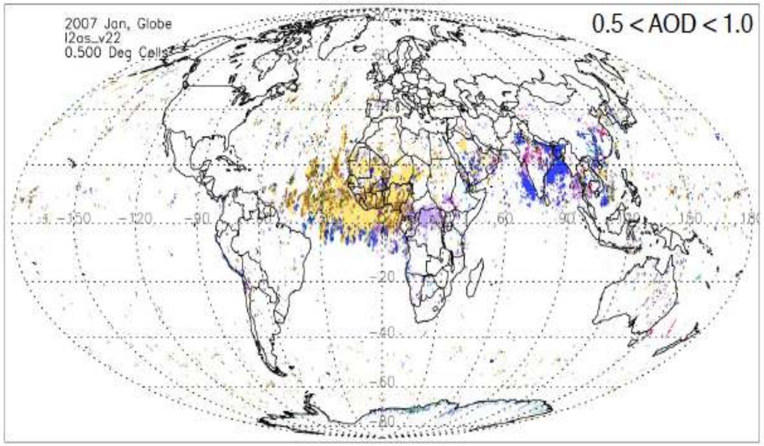
MISR Aerosol Type Discrimination

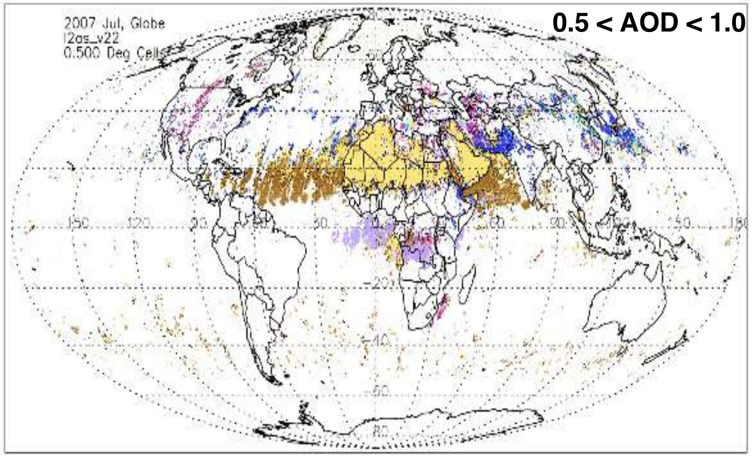




January 2007

July 2007





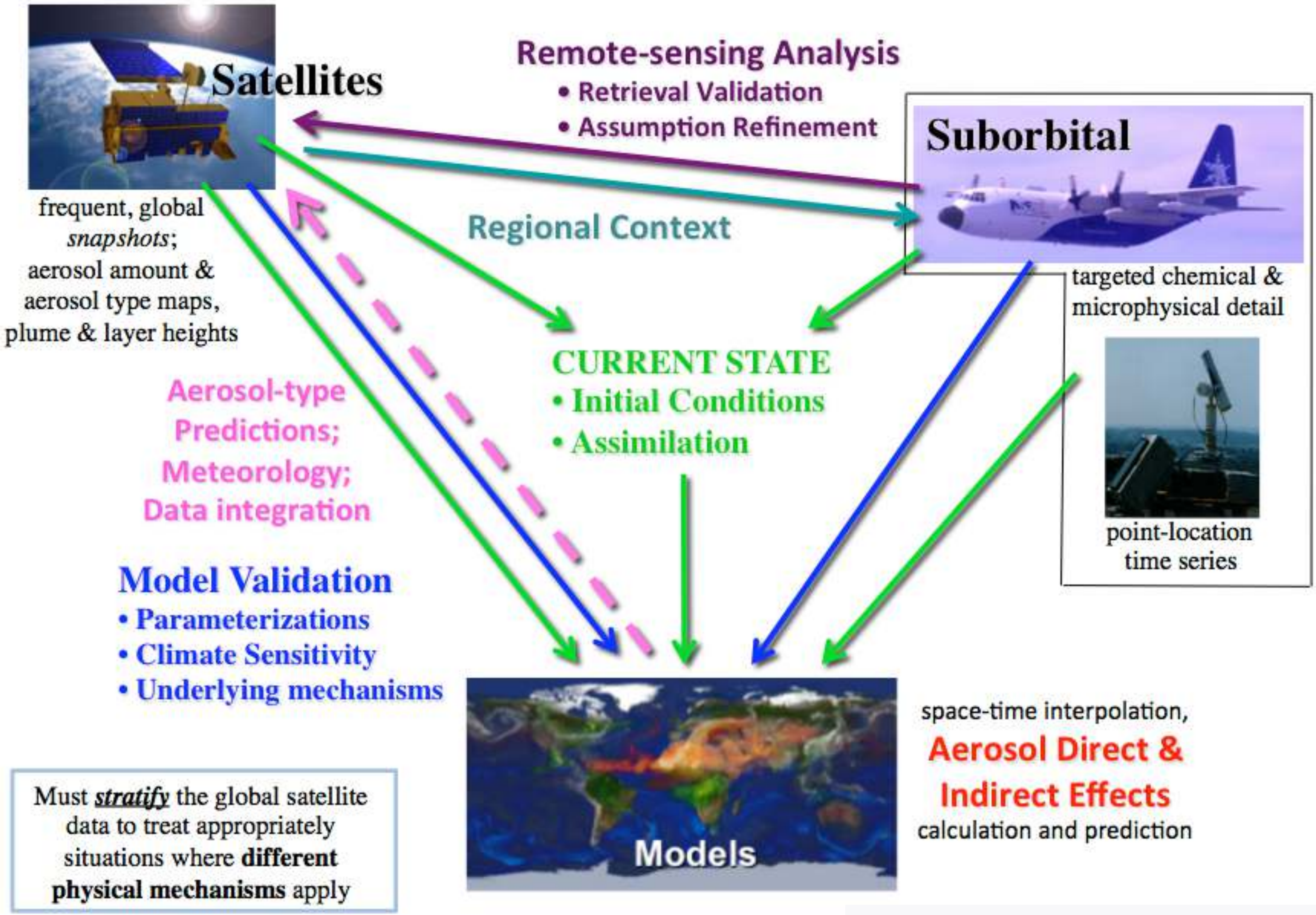
Mixture Group: 1-10 | 11-20 | 21-30 | 31-40 | 41-50 | 51-62 | 63-70 | 71-74

Spherical, non-absorbing

Spherical, absorbing

Non-spherical

Kahn & Gaitley JGR 2015



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*

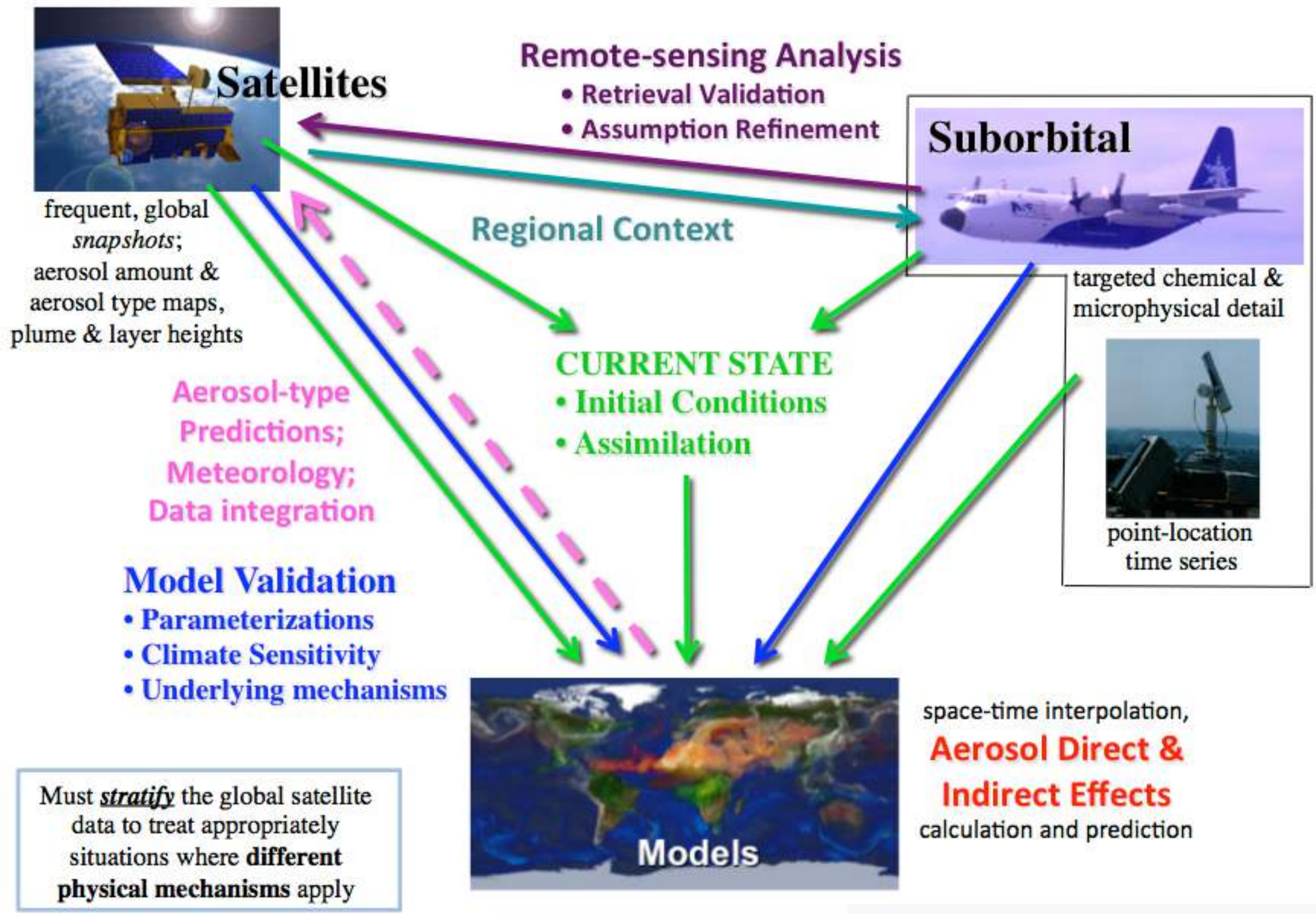
Kahn et al., BAMS in press

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



Adapted from: Kahn, Survy. Geophys.

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

SAM-CAAM *Required Variables*

[Systematic Aircraft Measurements to Characterize Aerosol Air Masses]

2. METEOROLOGICAL CONTEXT

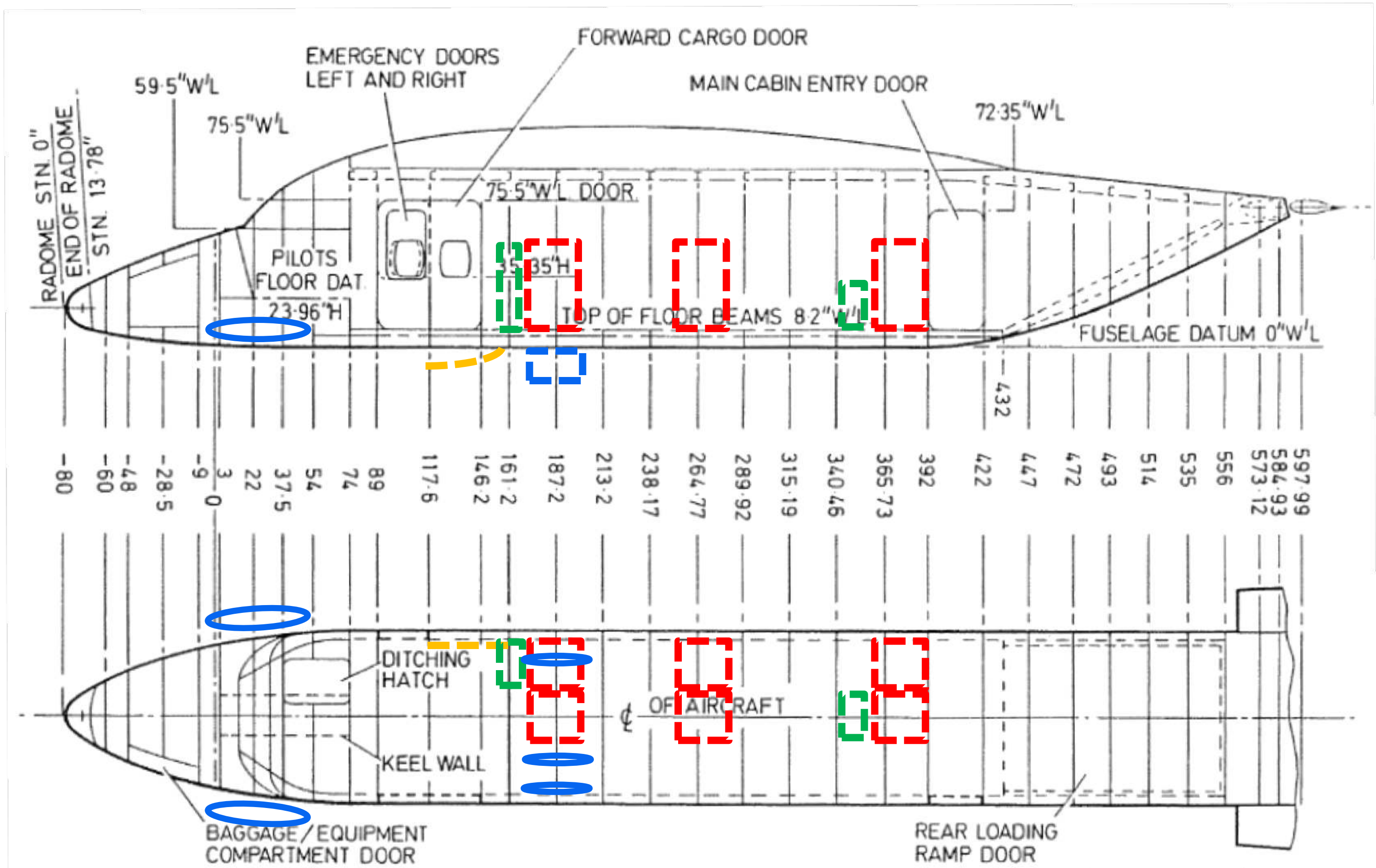
	Abbrev.	Required Variable
9	CO	Ambient Gases ($CO + O_3 + NO_2$)
10	T; P; RH	Standard Ambient Meteorological Variables
11	LOC	Geographic Location

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

NASA C-23B Sherpa

Notional Payload Accommodation



Schematic of a notional layout of the SAM-CAAM Payload Option C in the NASA C-23B Sherpa aircraft. Two-bay racks are shown in red, in-cabin floor-mounted instruments in green, external probes in blue, and the aerosol inlet in gold.

Box Model Considerations

• **Spatial Domain:** 5° x 5° (~500 km)
3-D Spatial Resolution: ~10 – a few 100 m

• **Temporal Coverage:** (at least) 24 hours, multiple times
Temporal Resolution: ~ (at least) 1-3 hours

• ***Need top, bottom, and *side* fluxes***

Satellites *Cannot* Provide All This

But satellites can provide ***context*** over the domain

… and some ***validation*** of the modeling

What is the ***fractional coverage*** of different cloud types in the domain?
How do the TOA ***radiative fluxes vary*** with atmospheric conditions?
What are the ***background AOD*** and aerosol type gradients?
What are the cloud-top, aerosol layer, and aerosol ***plume heights***?