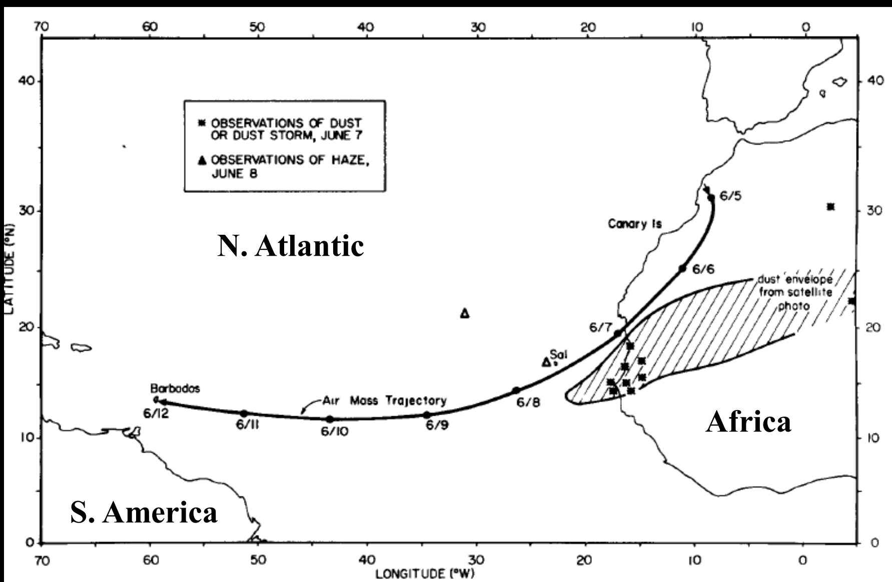
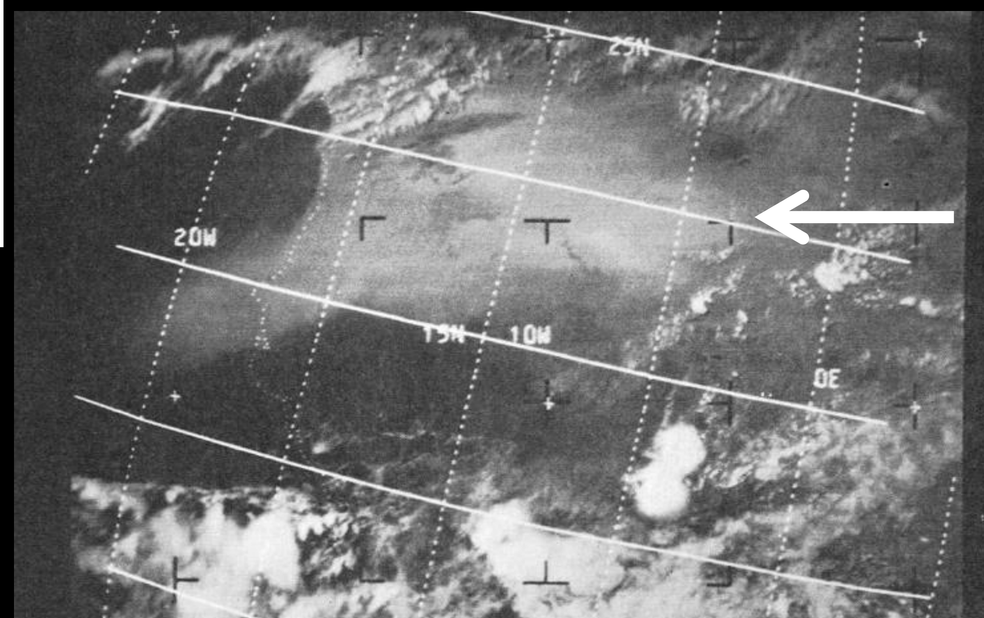
The EOS Aerosol Legacy –
Steps Toward Characterizing Aerosol-Climate Forcing

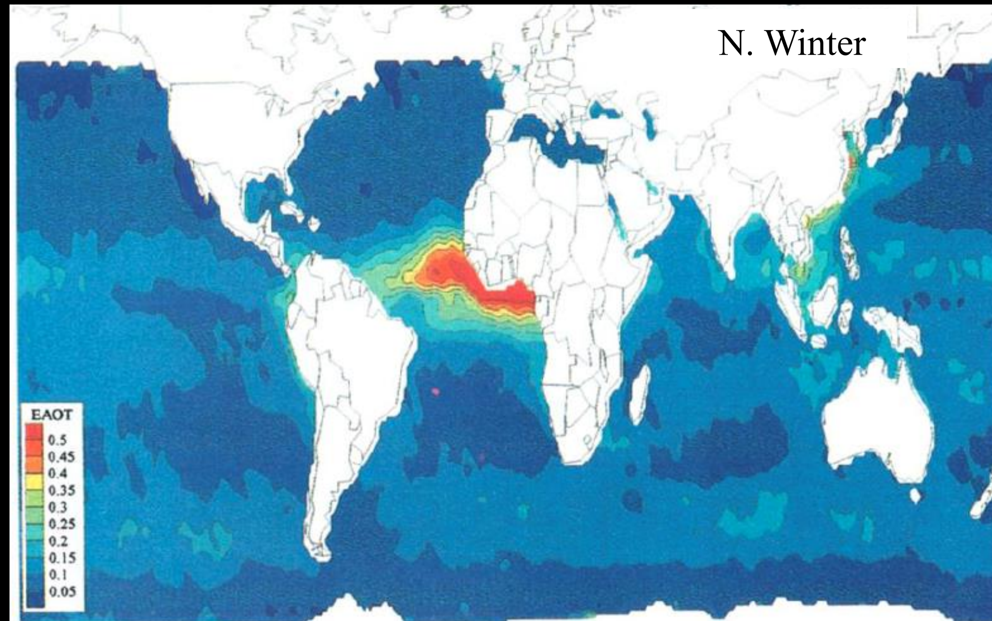
Ralph Kahn
NASA/Goddard Space Flight Center



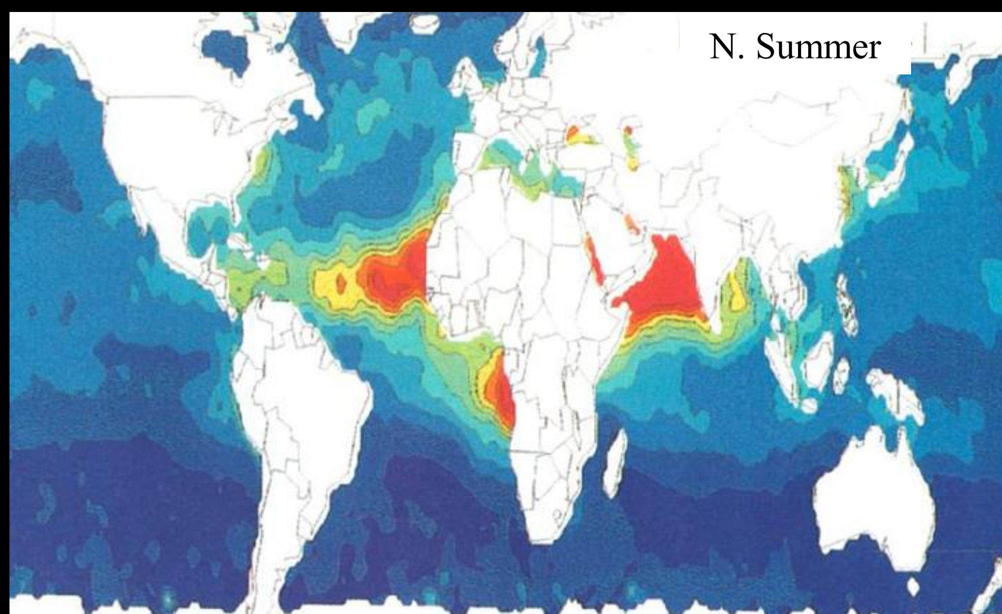


Saharan Dust Storm
8-day trajectory
Beginning 07 June 1967
ESSA 5 Satellite

Prospero et al., Earth & Planet. Sci. Let. 1970

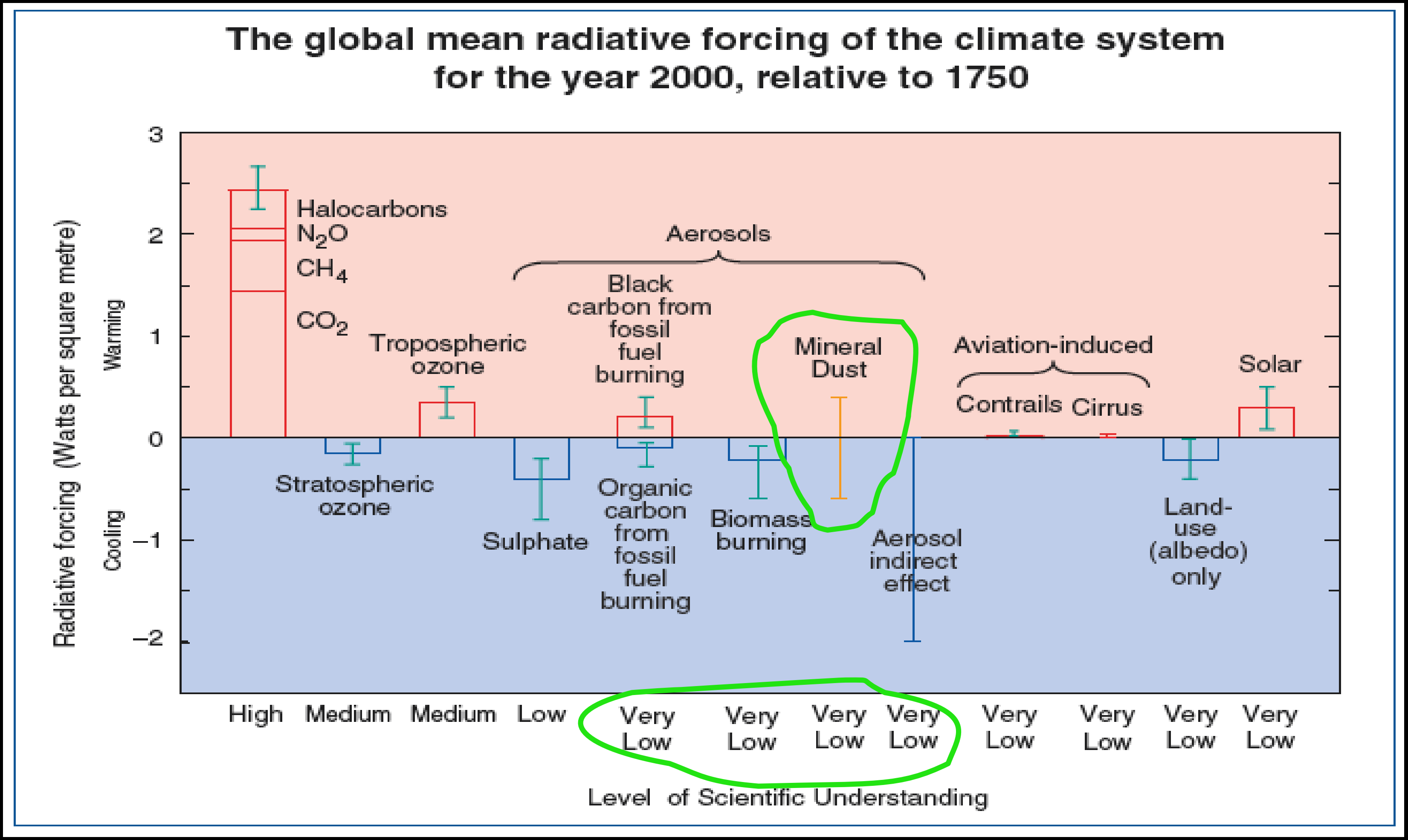


AVHRR
July 1989-June 1991
Aerosol Optical Depth



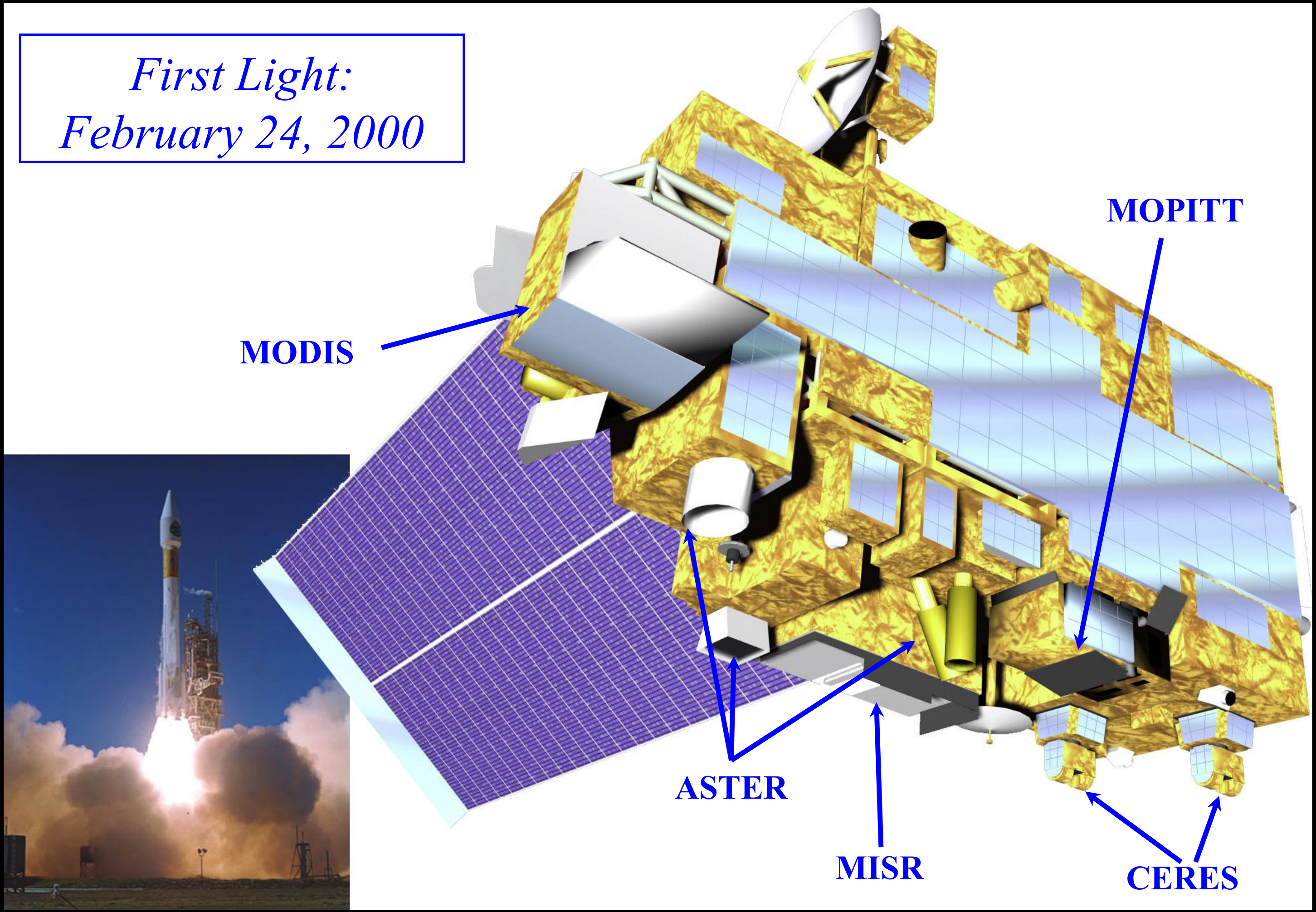
Husar, Prospero, & Stowe JGR 1997

The State of Aerosol-Climate-Forcing Understanding c. 2001

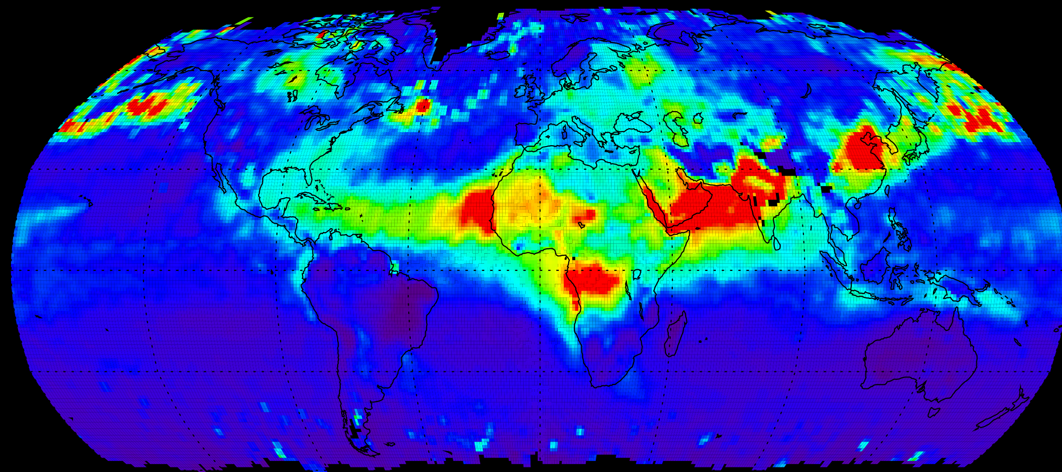


IPCC AR3, 2001

The NASA Earth Observing System's Terra Satellite



Terra Project Office / NASA Goddard Space Flight Center

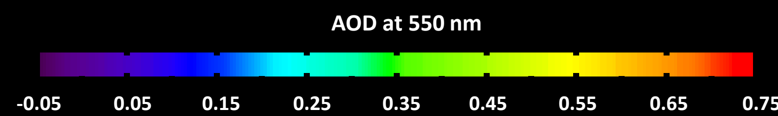


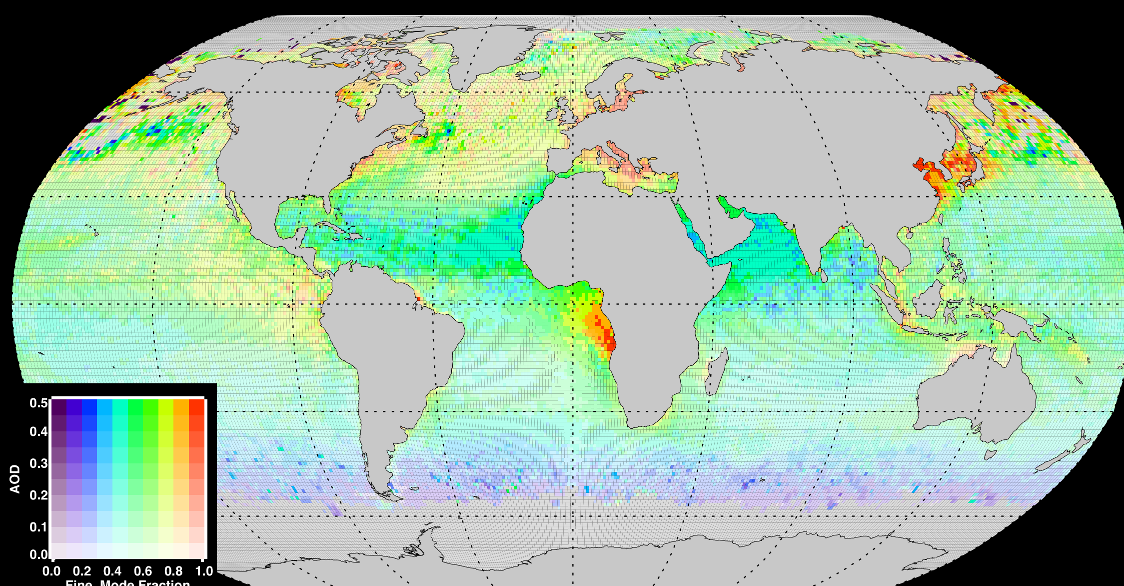
Mid-Visible AOD

MODIS

July 2010
Monthly Average

"Dark Target" +
"Deep Blue"

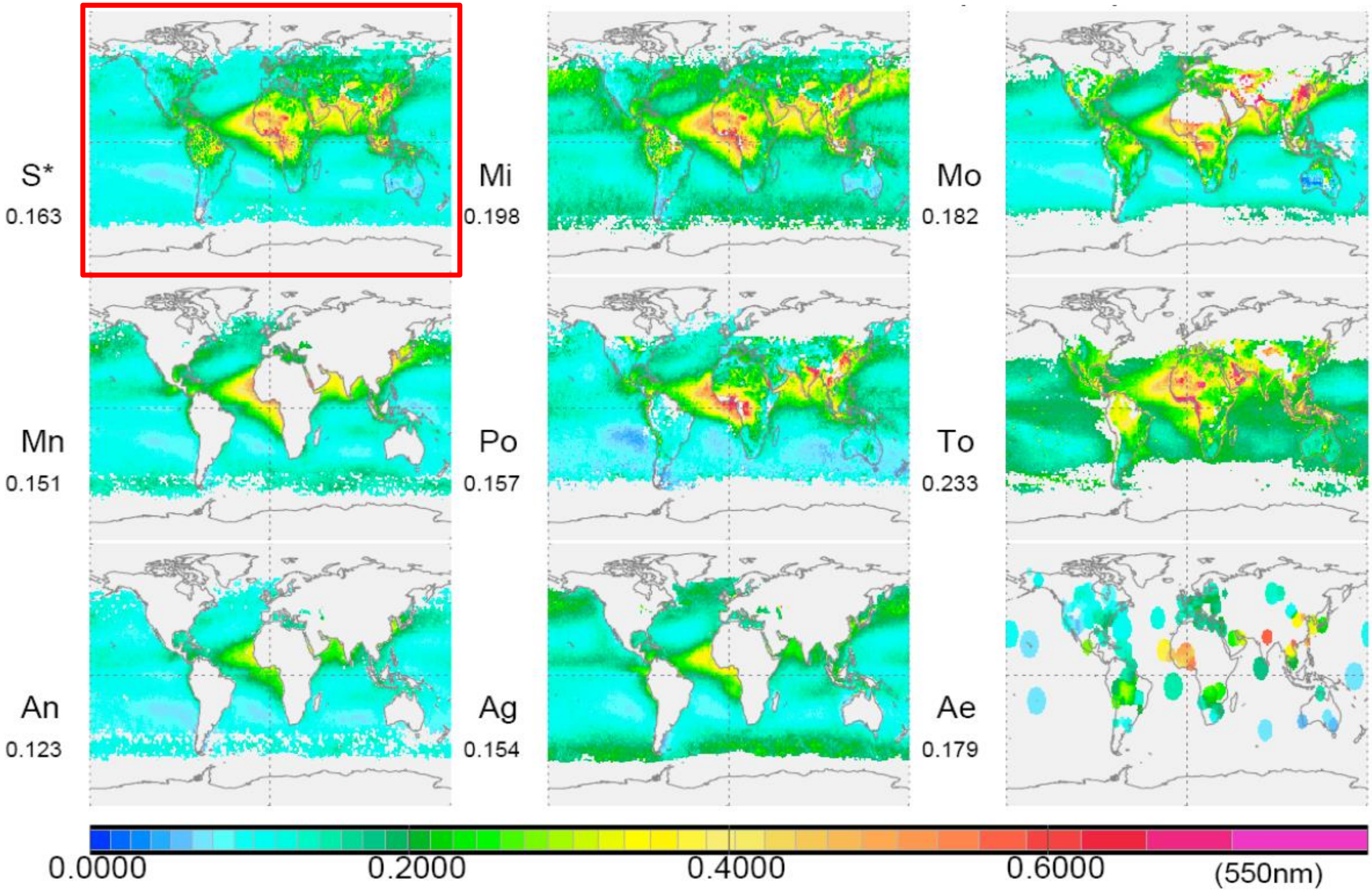




Fine-Mode
Fraction
+ AOD

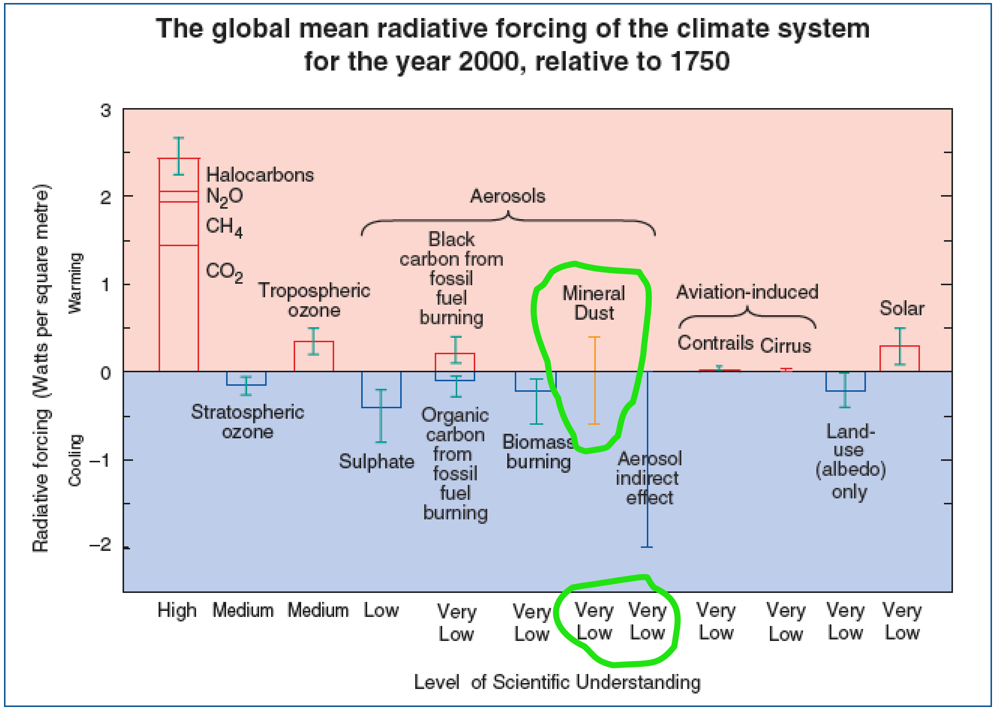
MODIS Team, NASA Goddard Space Flight Center

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



Kinne et al. ACP 2006

However, Even DARF and Anthropogenic DARF are *NOT* Solved Problems (Yet)



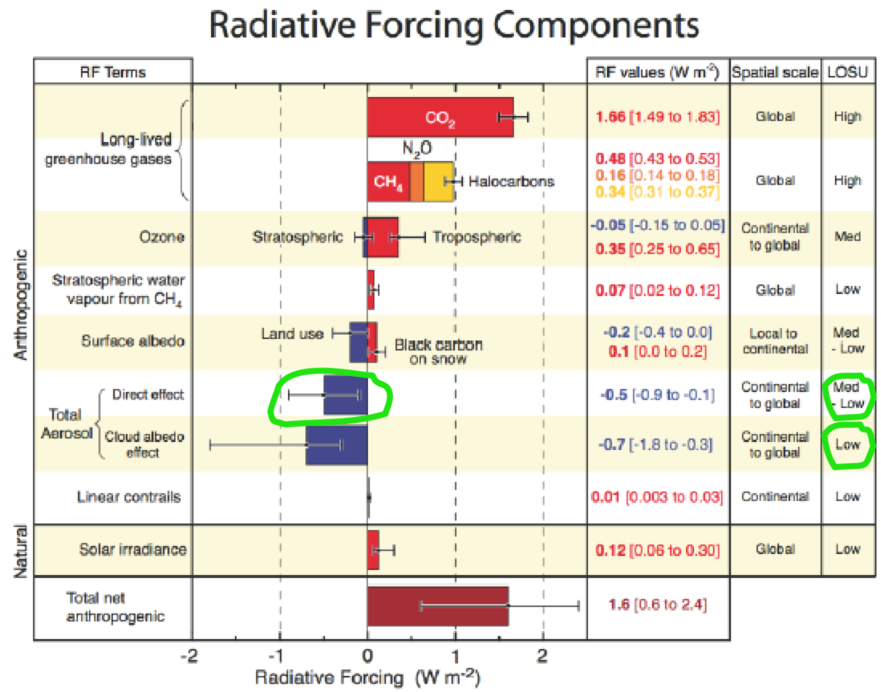


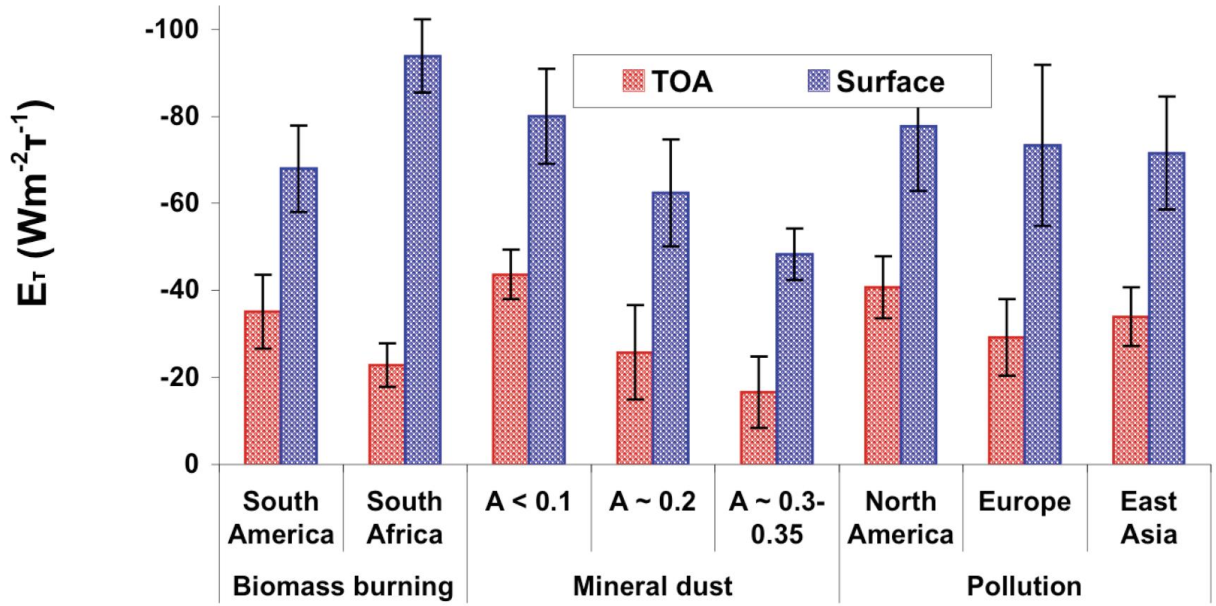
FIGURE SPM-2. Global-average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and other important agents and mechanisms, together with the typical geographical extent (spatial scale) of the forcing and the assessed level of scientific understanding (LOSU). The net anthropogenic radiative forcing and its range are also shown. These require summing asymmetric uncertainty estimates from the component terms, and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have a very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature. Range for linear contrails does not include other possible effects of aviation on cloudiness. {2.9, Figure 2.20}

IPCC AR3, 2001
(Pre-EOS)

IPCC AR4, 2007
(EOS + ~ 6 years)

AOD Alone is Not Enough – Even for Direct Aerosol Radiative Forcing

Direct Aerosol Radiative *Forcing Efficiency* per unit AOD

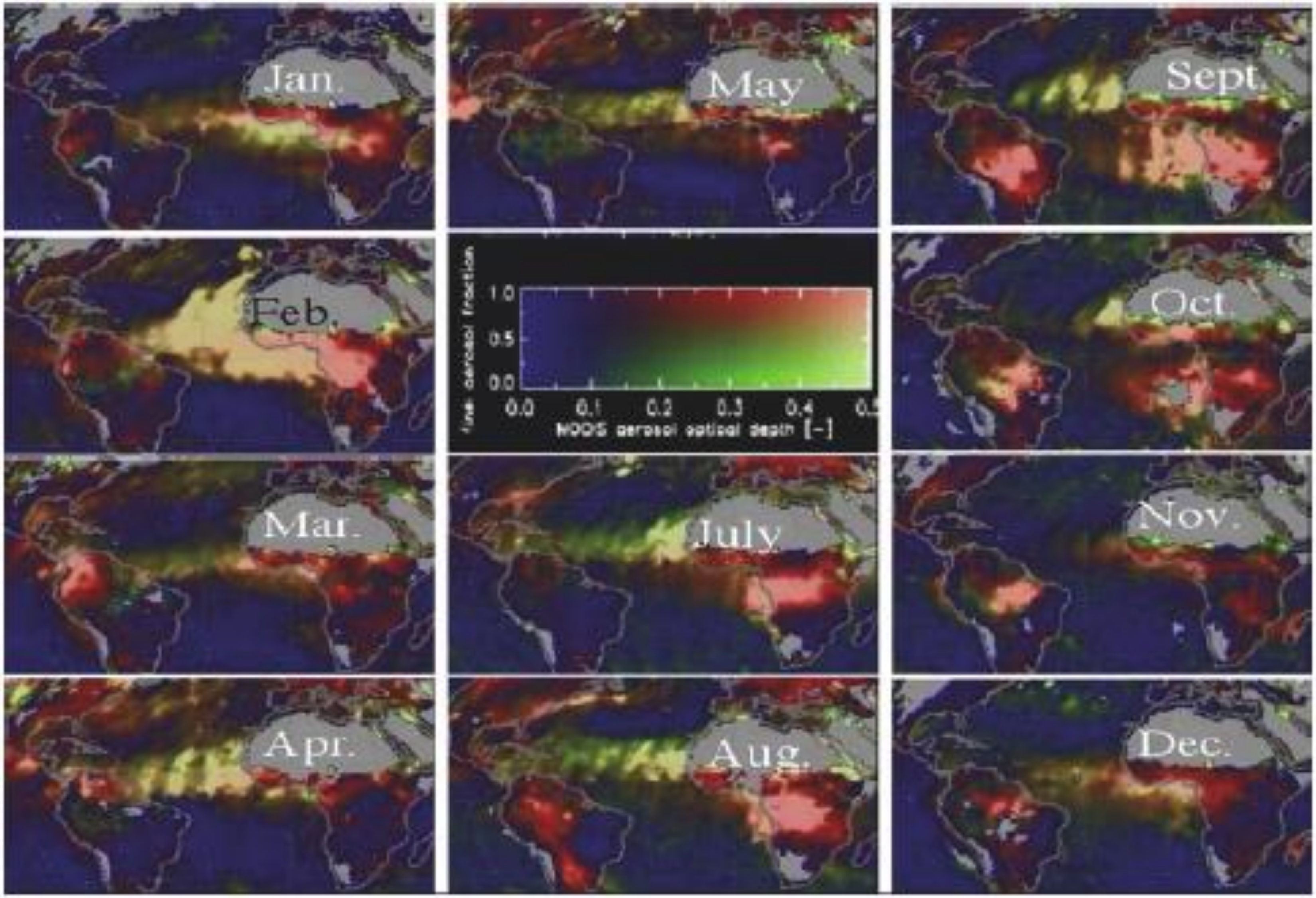


From: Zhao et al., JGR 2005

- ***Aerosol SSA, Vert. Dist.,*** and ***Surface Albedo*** critical, esp. for ***Surface Forcing***
- For ***Indirect Forcing***, ***Hygroscopicity*** and ***CCN # Concentration*** are critical

One MODIS *Aerosol Type* Classification:

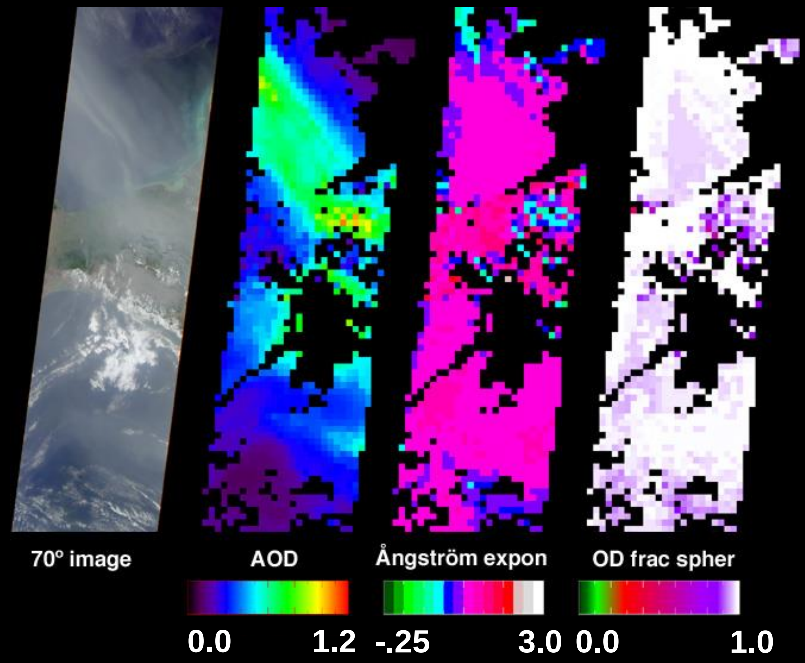
Low AOT (blue), **High AOT+Coarse** (green), **High AOT+Fine** (red)



Kaufman et al., JGR, 2005

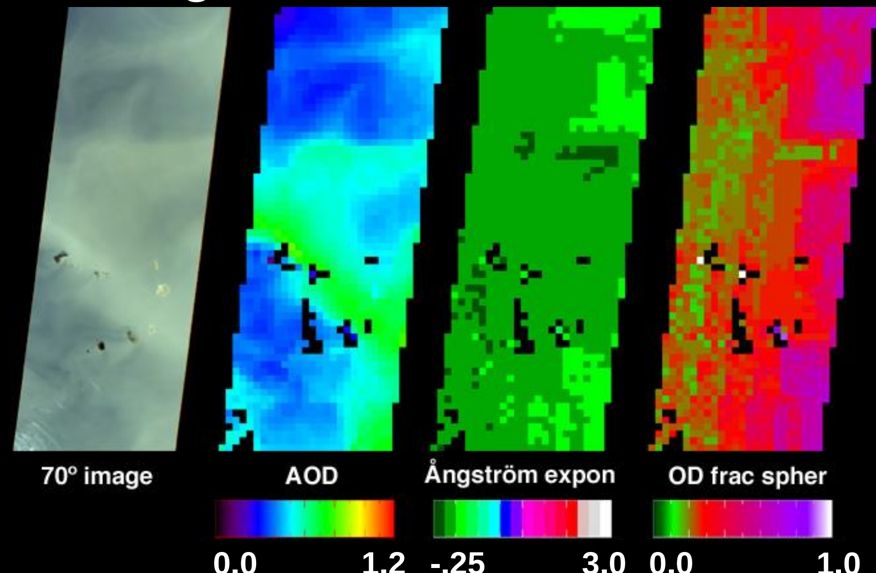
Smoke from Mexico -- 02 May 2002

<u>Aerosol:</u>
Amount
Size
Shape



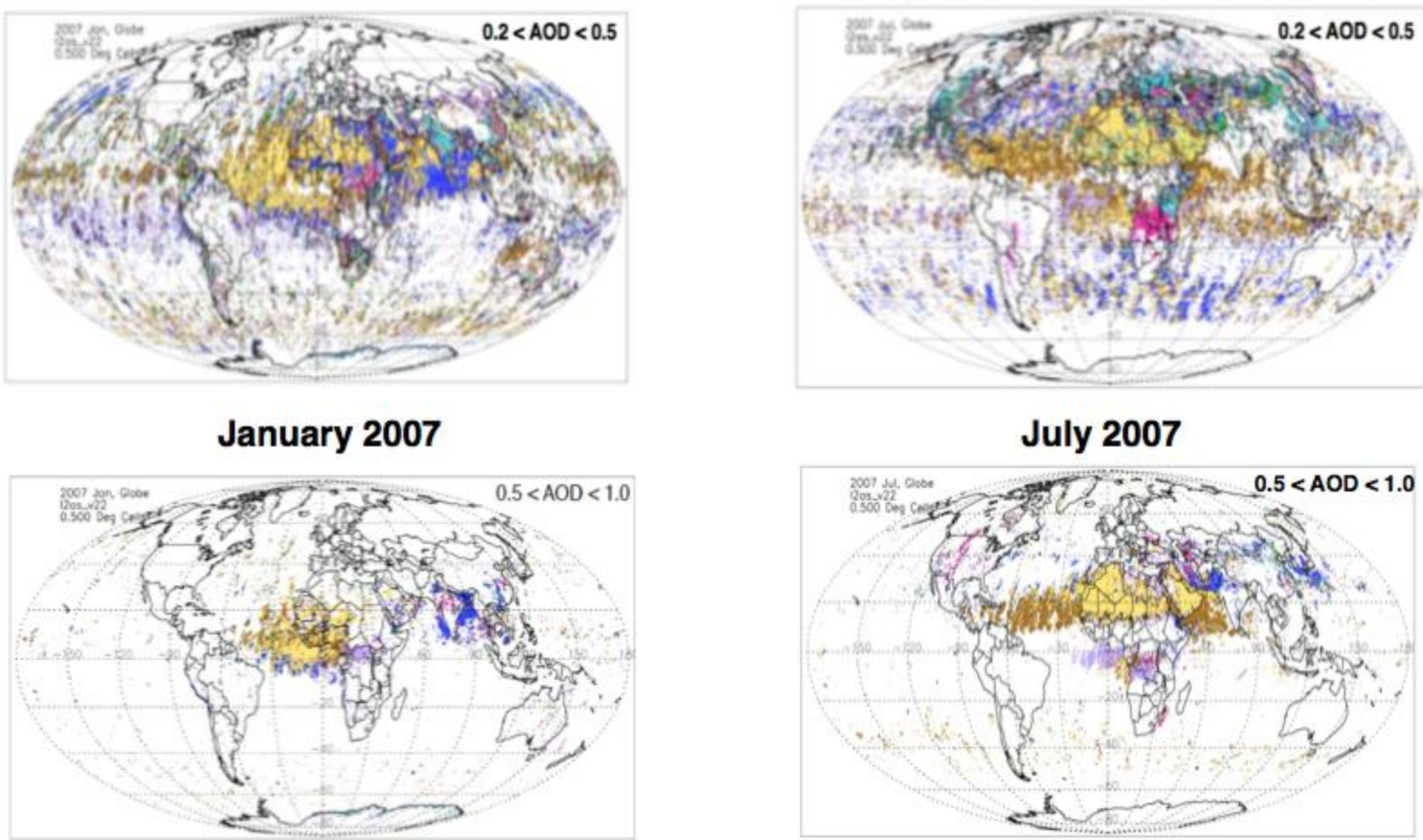
Medium
Spherical
Smoke
Particles

Dust blowing off the Sahara Desert -- 6 February 2004



Large
Non-Spherical
Dust
Particles

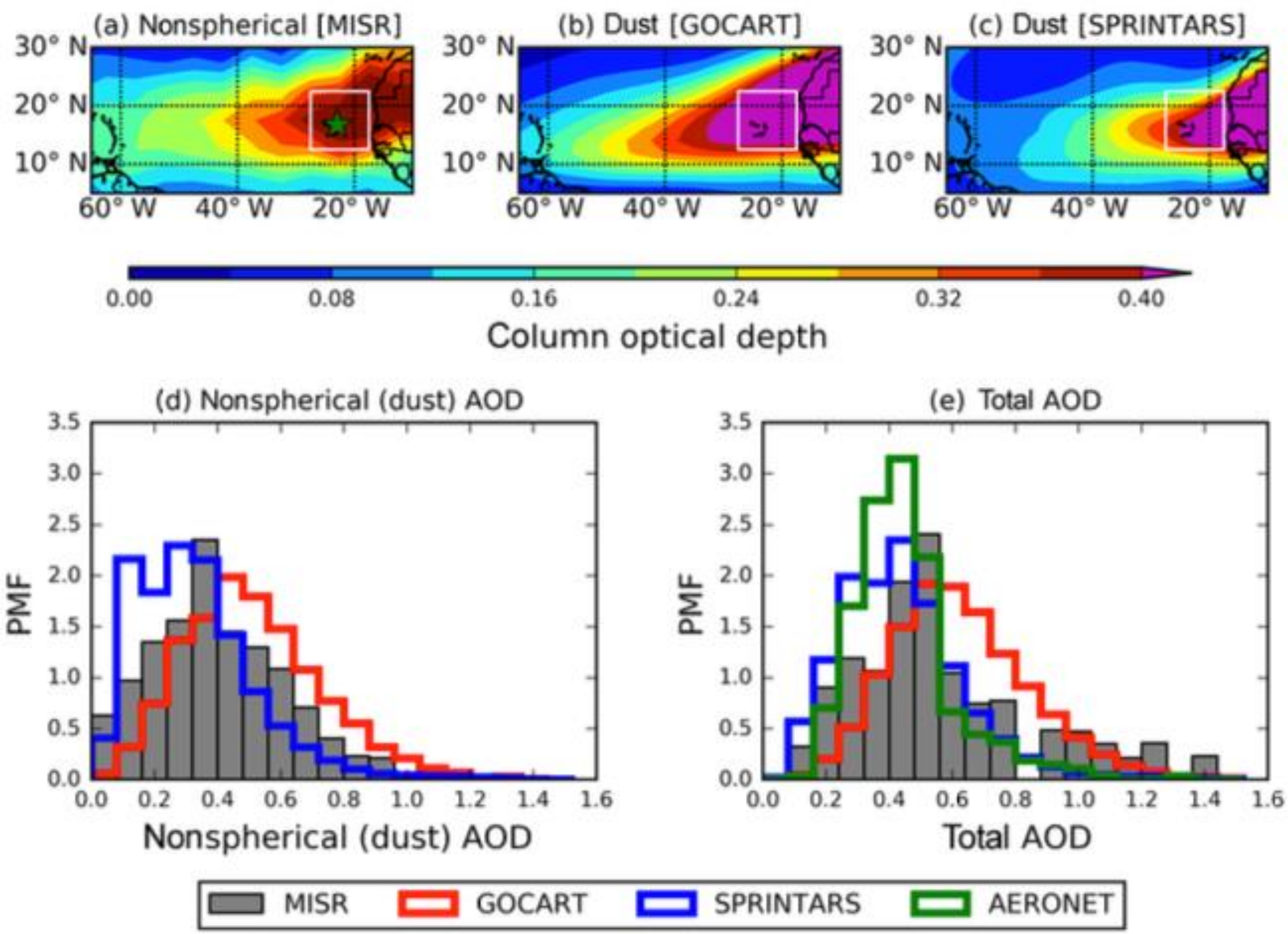
MISR ***Retrieved-Physical-Properties*** **Aerosol Type Discrimination**



Kahn & Gaitley JGR 2015

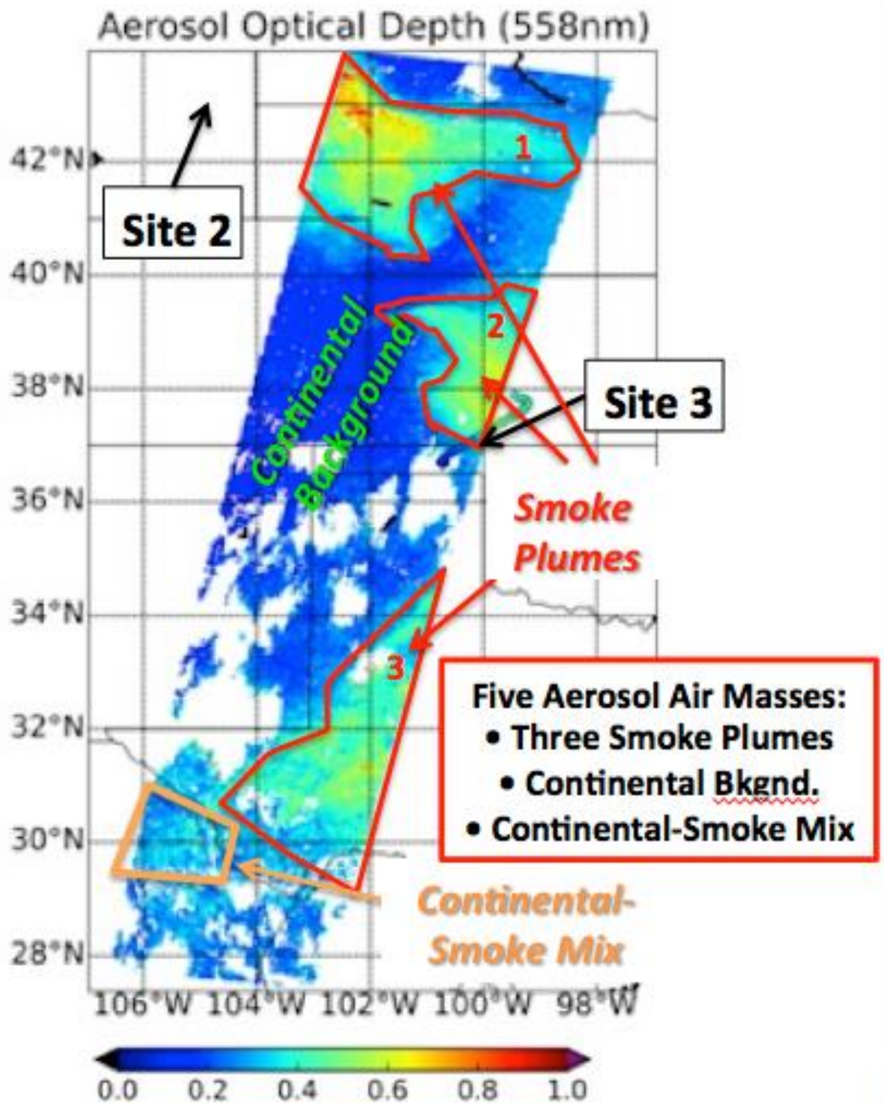
MISR Non-spherical (Dust) AOD Climatology

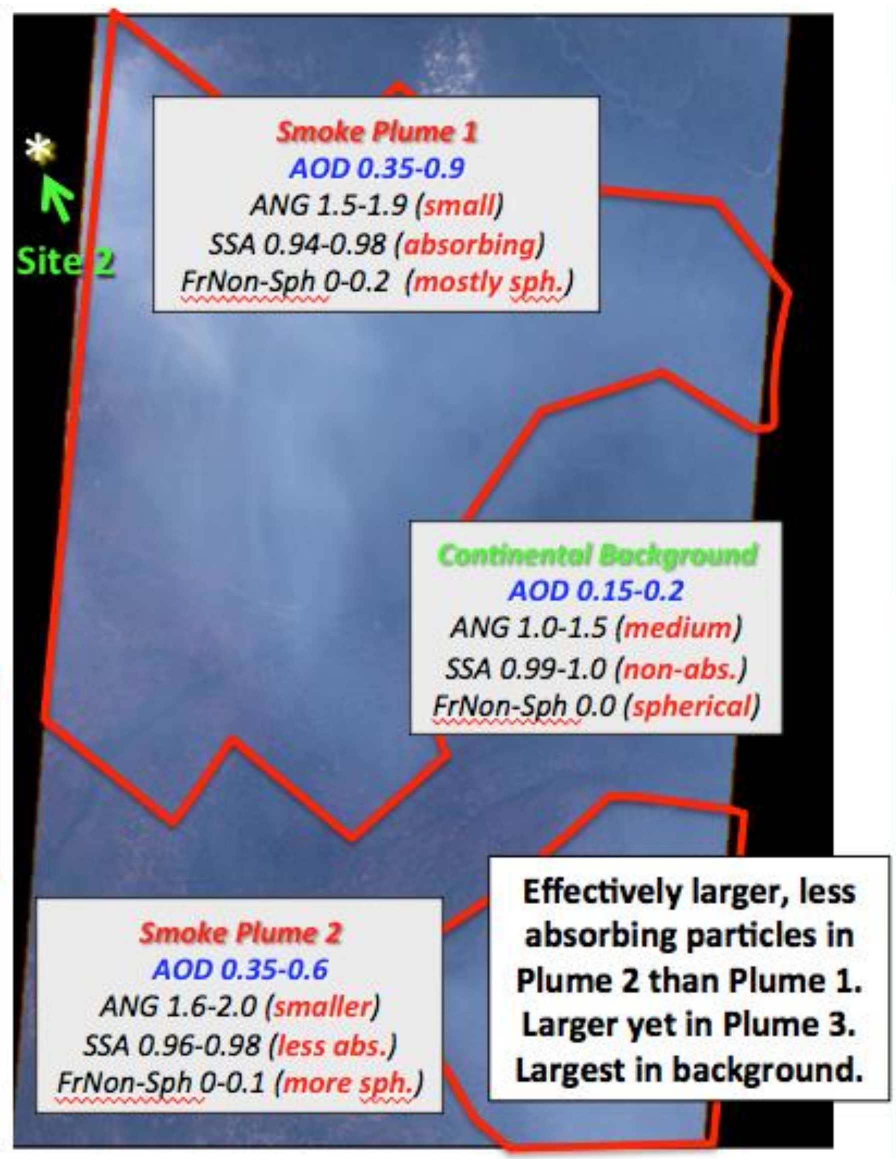
Eight Julys – 2000 - 2007



Lee et al. ACP 2016

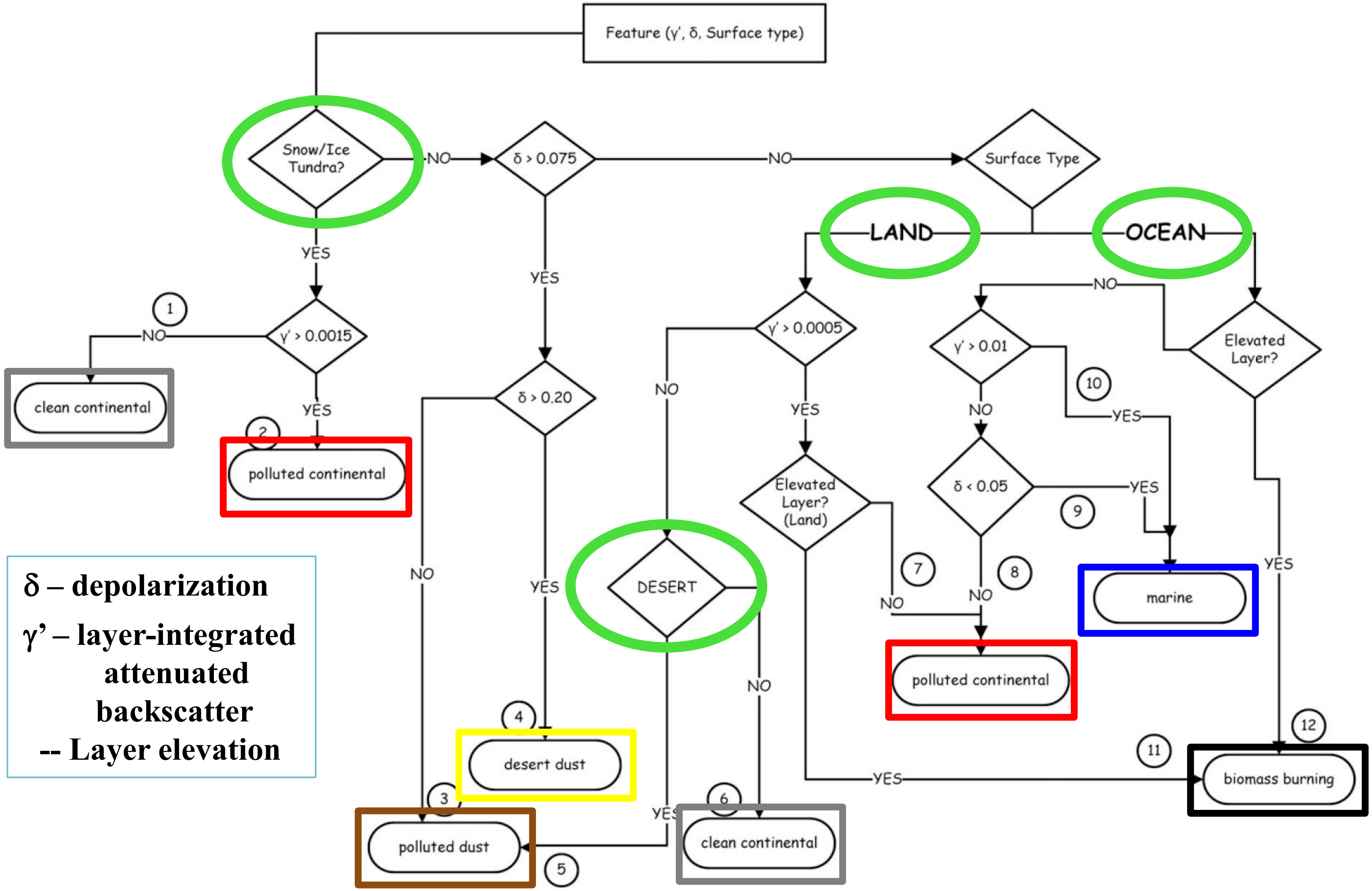
SEAC4RS – MISR Overview 19 August 2013





Passive-remote-sensing ***Aerosol Type*** is a ***Total-Column-Effective***, ***Categorical*** variable!!

CALIPSO 6-Type *Interpretive Composition* Classification Scheme



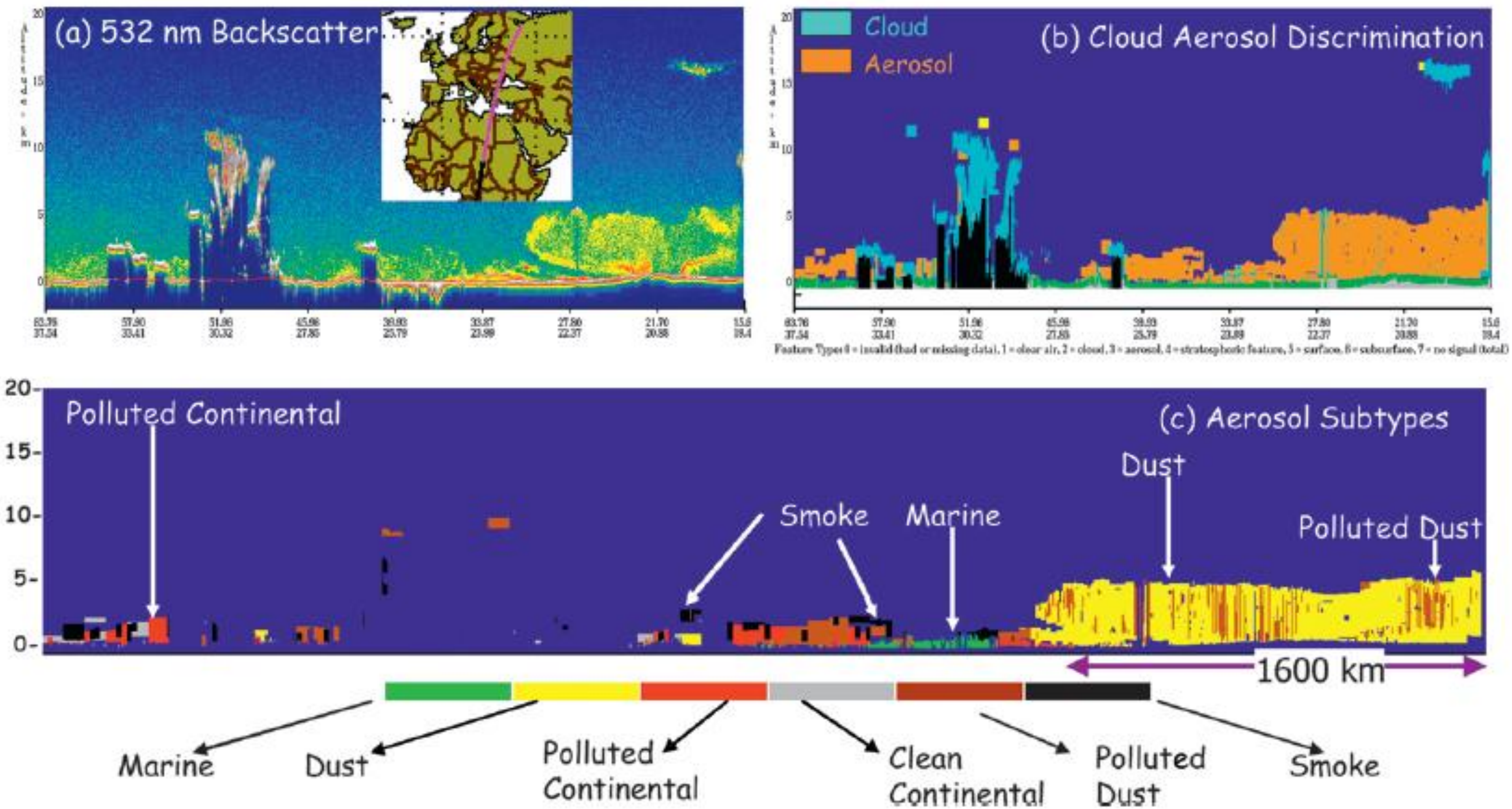
δ – depolarization

γ' – layer-integrated attenuated backscatter

-- Layer elevation

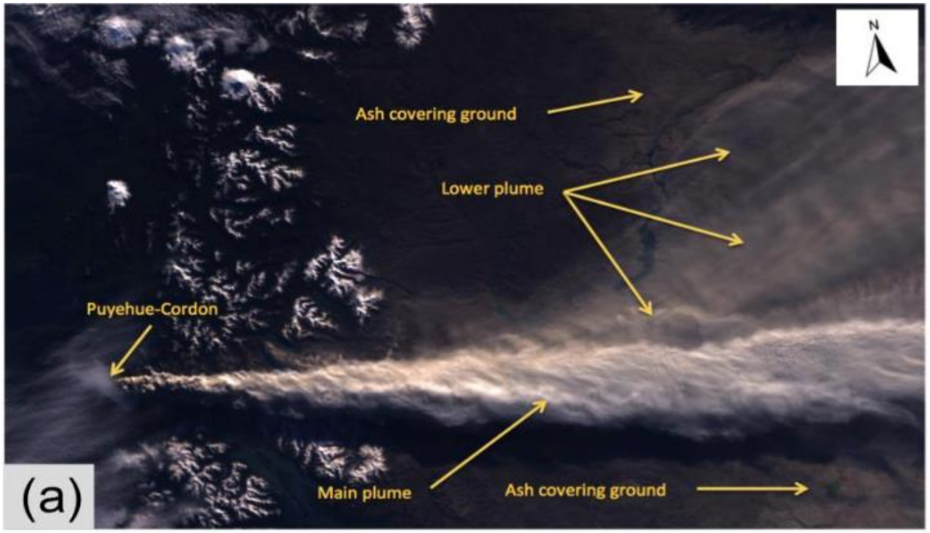
Omar et al., JAOT 2009

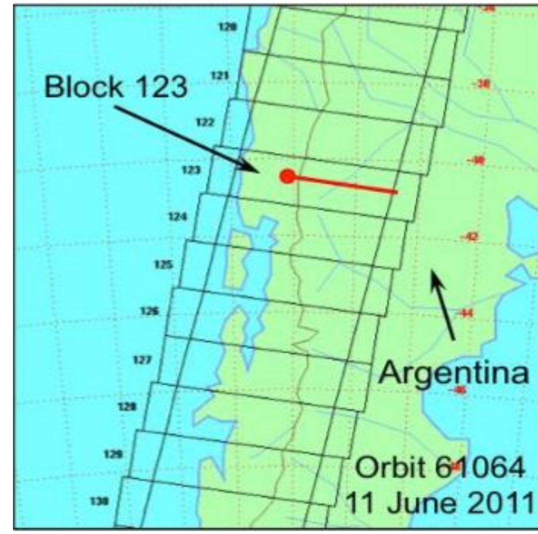
CALIPSO 6-Grouping Aerosol Type Classification

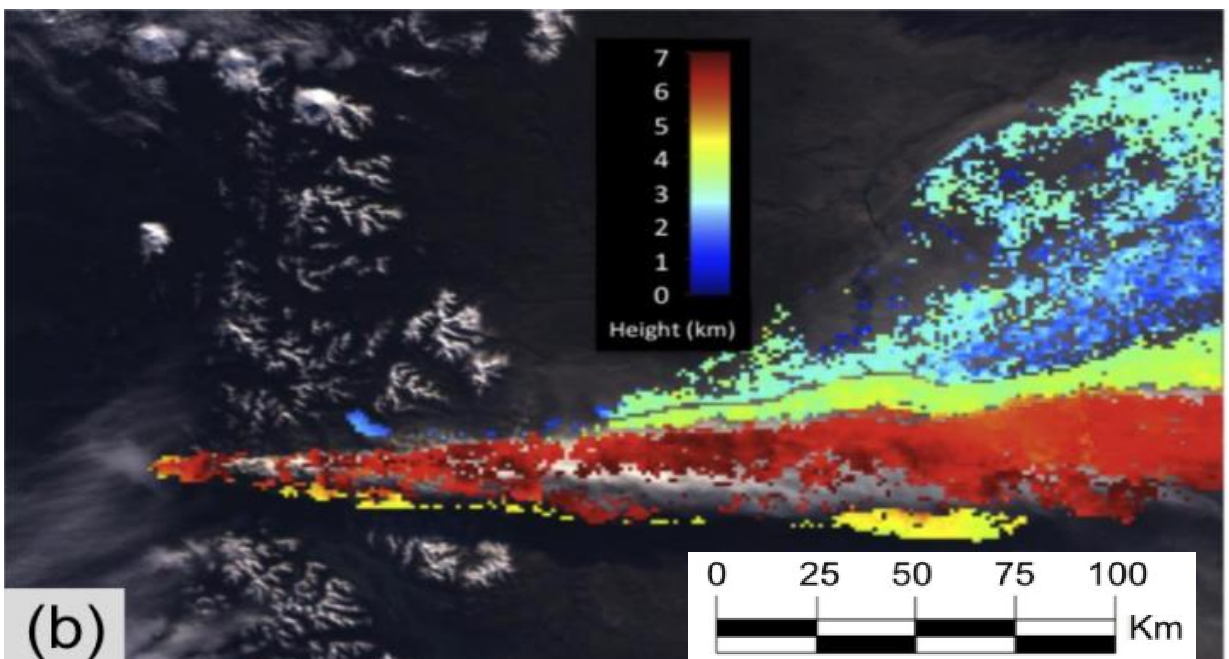


Omar et al., JAOT 2009

MISR Stereo-Derived Plume Heights
Puyehue-Cordon Volcano 11 June 2011





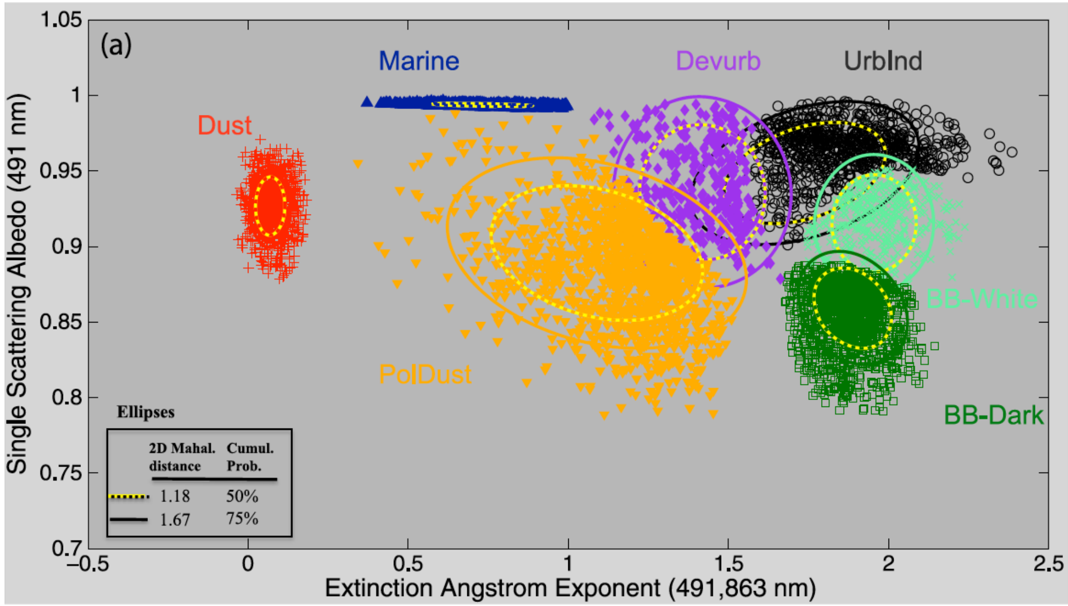


Nelson et al.
Remt. Sens. 2013

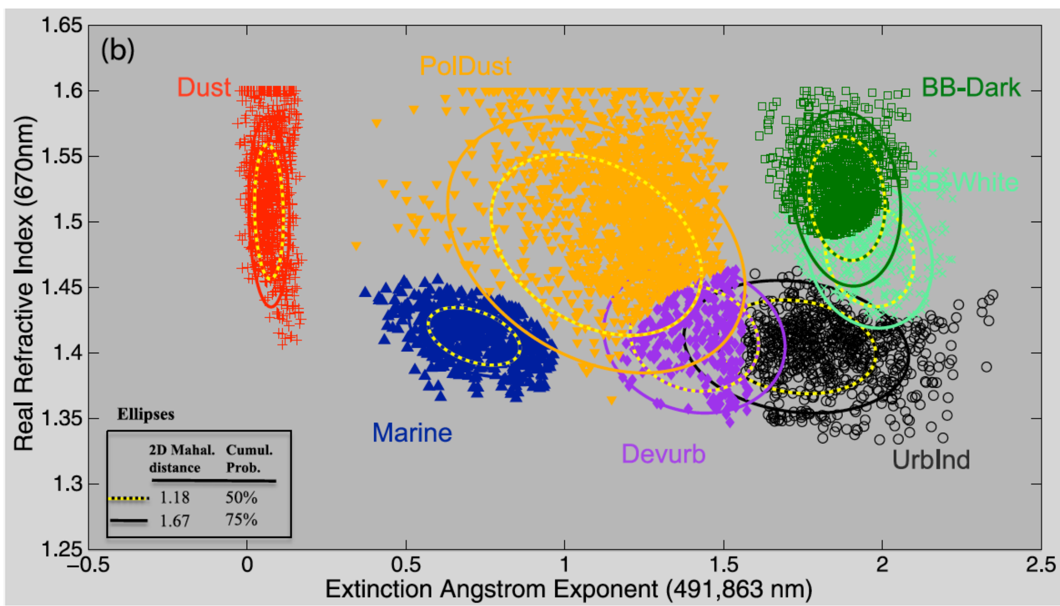
AERONET Aerosol Type 7-Grouping Classification

Four-parameter AERONET-derived classification:

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



7 Groupings SSA_{491} vs. Extinction ANG



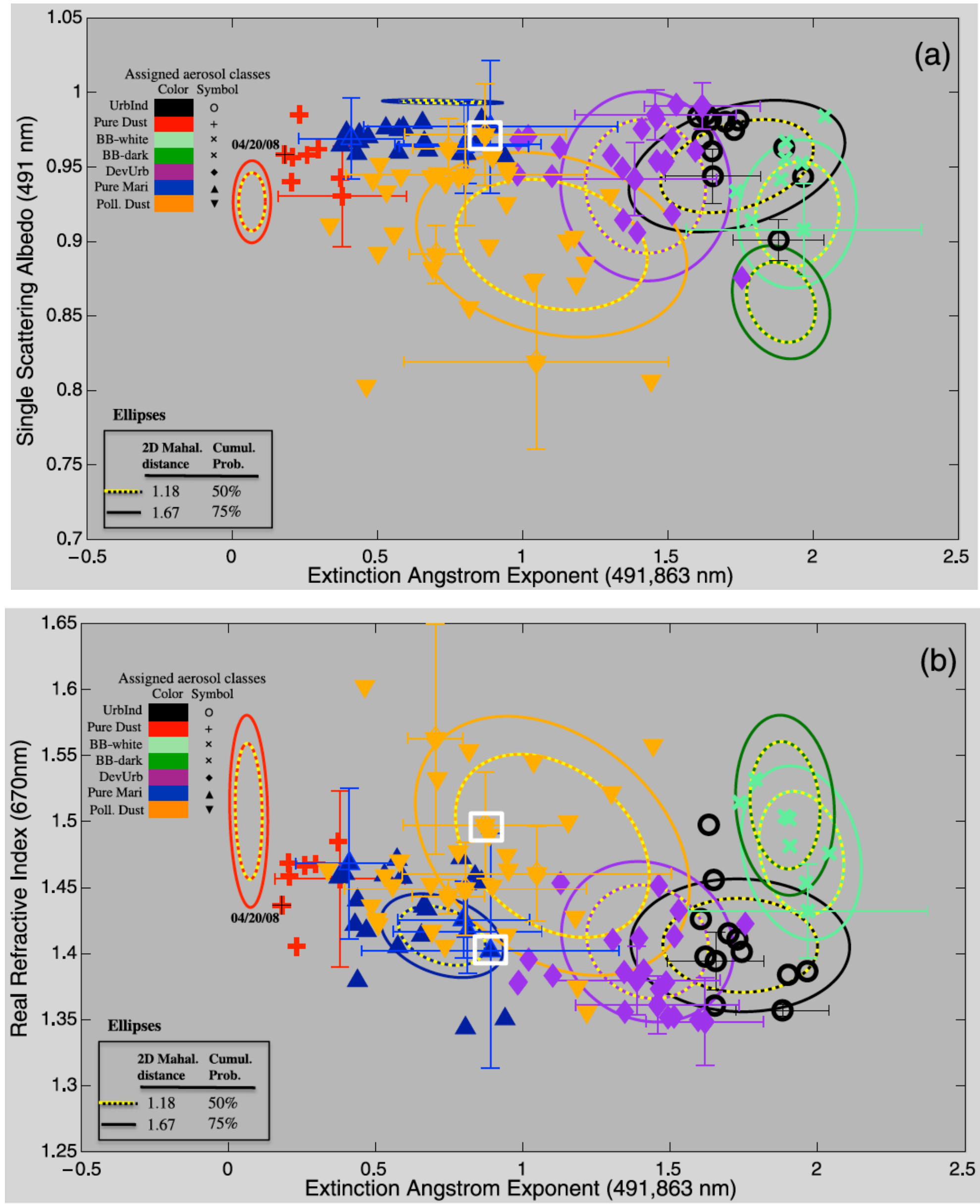
7 Groupings Real RI_{670} vs. Extinction ANG

Russell et al. JGR 2014

PARASOL data at Forth Crete
Projected onto the AERONET Aerosol Type Classification

Four-parameter AERONET-derived classification:

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

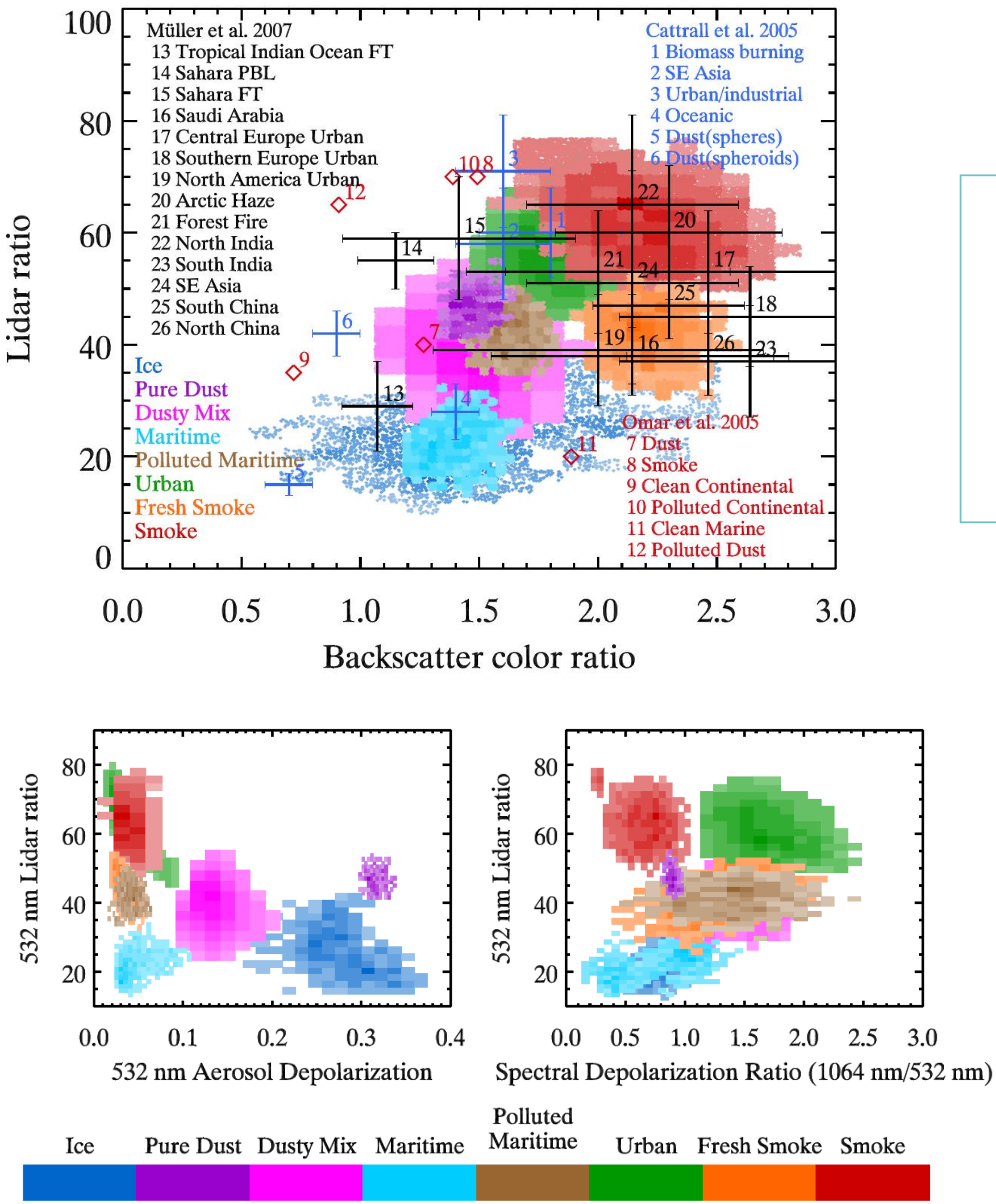


7 Groupings
SSA_{491} vs. Extinction ANG

7 Groupings
Real RI_{670} vs. Extinction ANG

Russell et al. JGR 2014

HSRL Aerosol Type 8-Grouping Classification

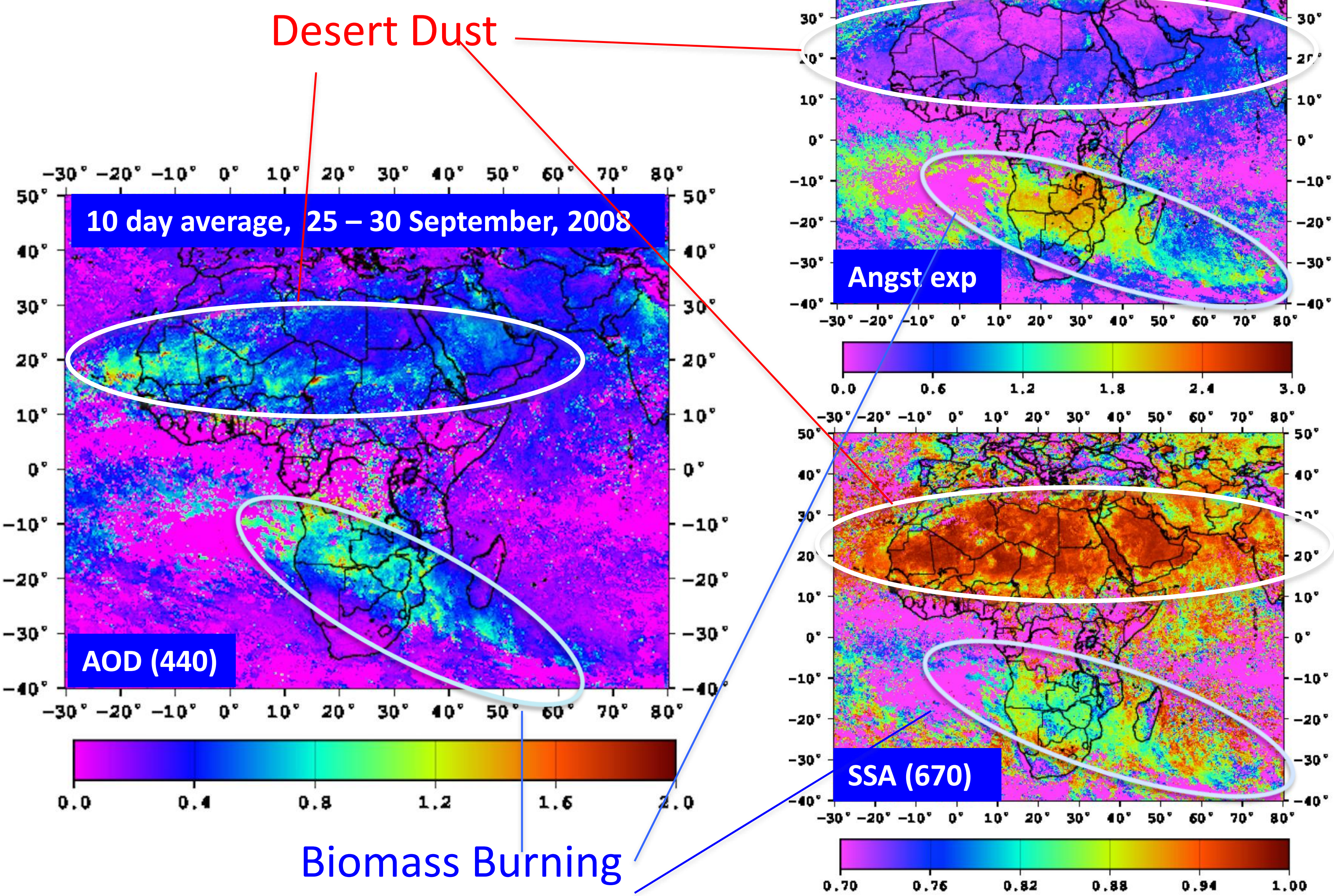


Four-parameter AERONET-derived classification:

- α_{532}/β_{532}
- β_{1064}/β_{532}
- δ_{532}
- $\beta_{1064}/\delta_{532}$

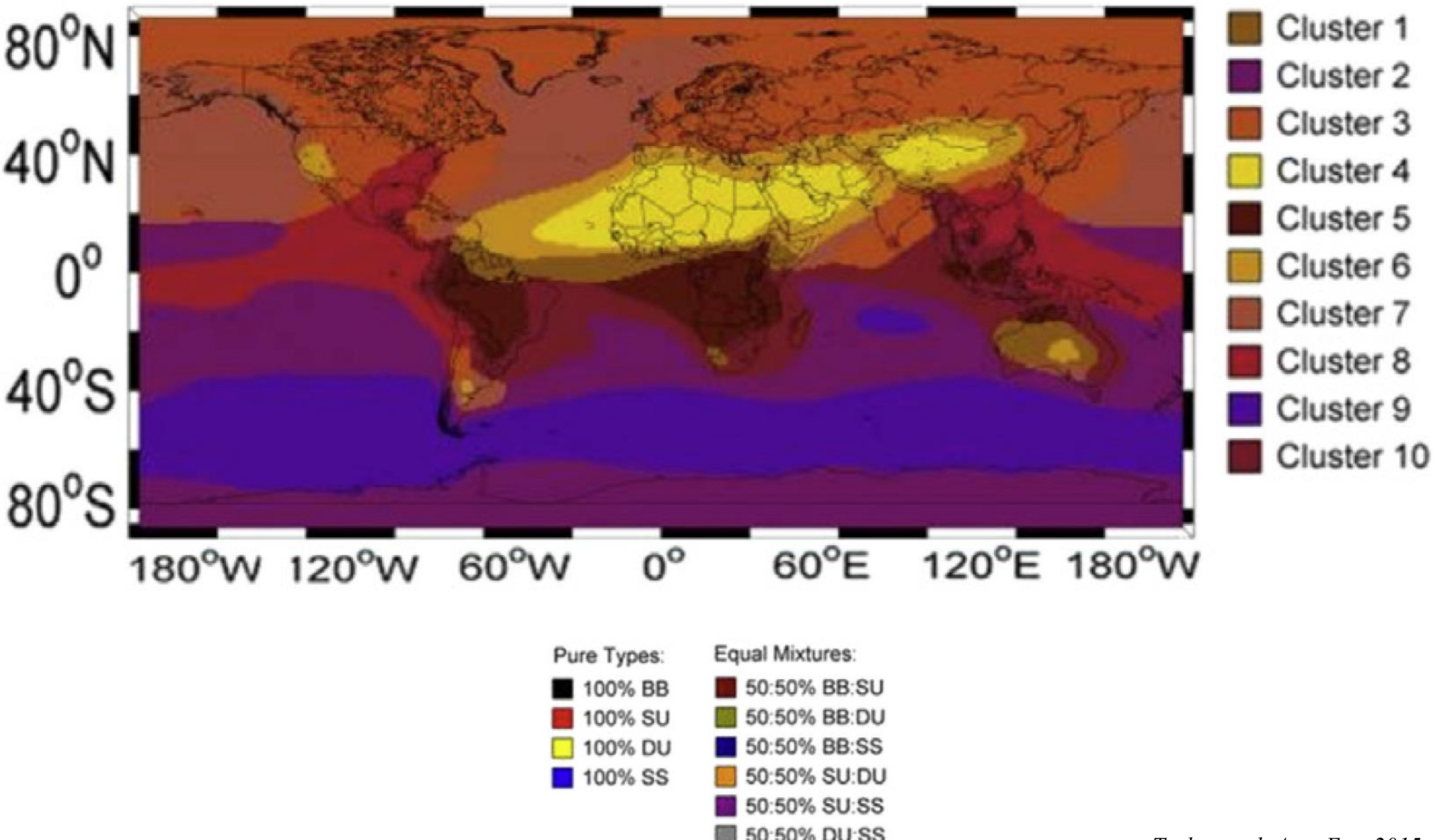
Burton et al. JGR 2012

GRASP: towards aerosol classification



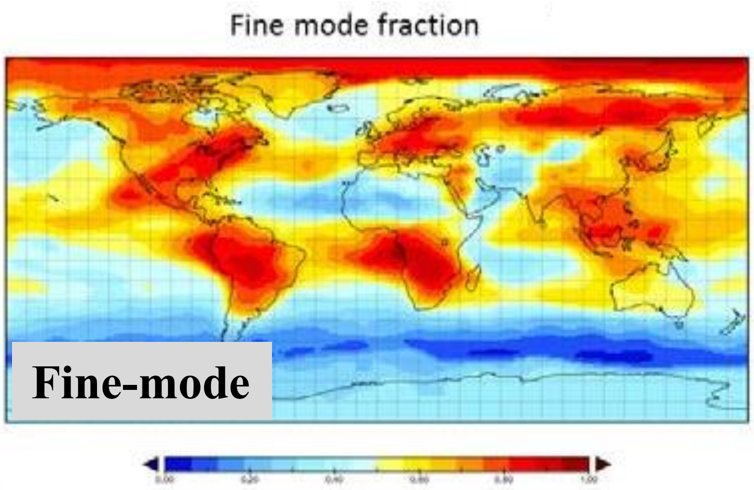
Dubovik et al. 2011, 2014

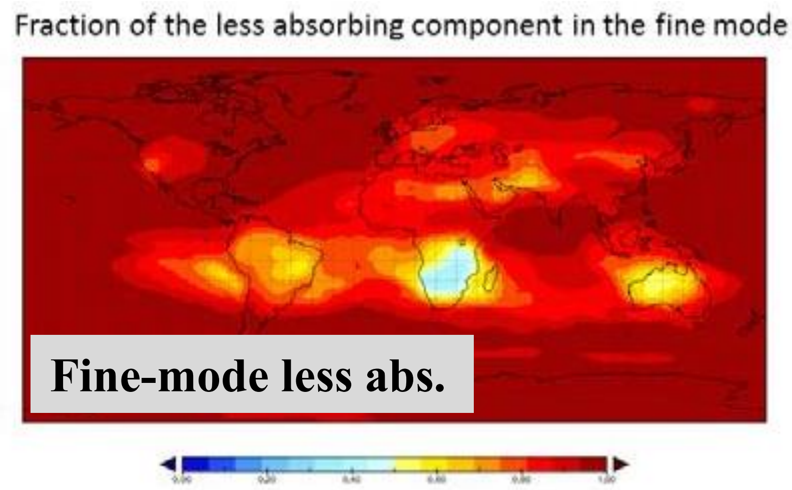
GoCART *Model-Based Aerosol-Type* Clustering

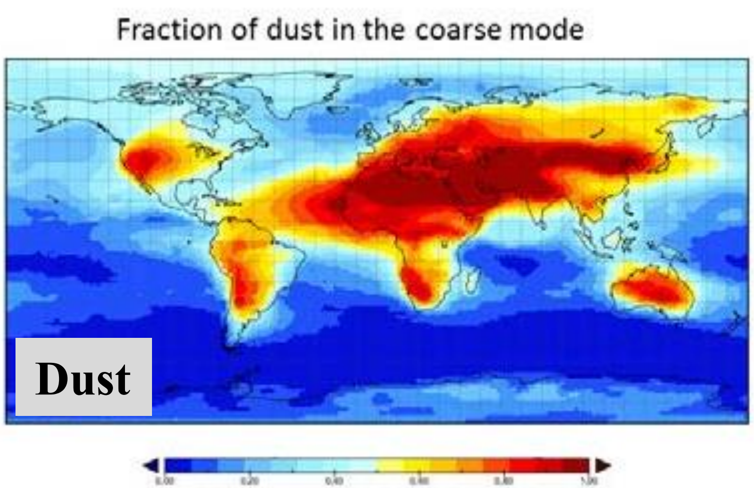


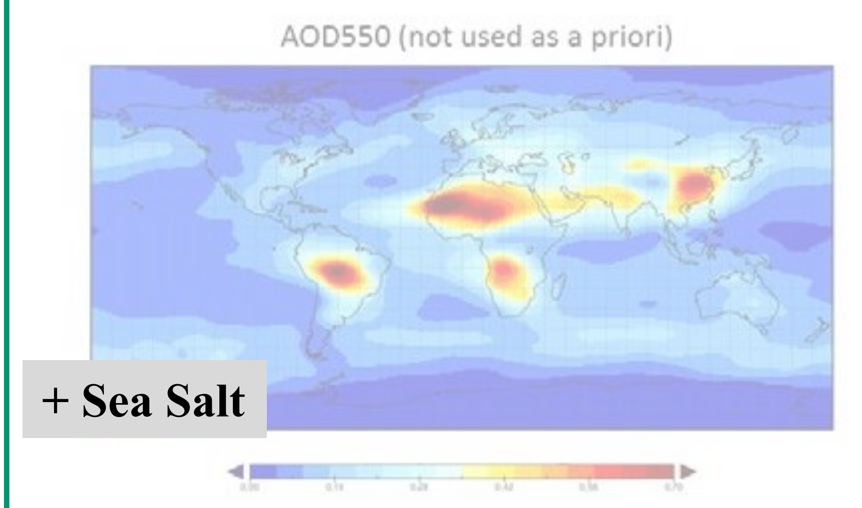
Taylor et al. Atm. Env. 2015

AOD mixing (fractions) Model-based, from AeroCom









From: Thomas Popp

Aerosol Type Validation Approach

- No ***"Ground Truth"*** except from Field Campaigns (***Golden Days***)

  -- Unlike ***Spectral AOD*** (and ***ANG***) from AERONET
  Particle Properties derived from AERONET entail ***many more assumptions***

  -- ***Far fewer*** Satellite-AERONET Sky-scan that Direct-sun Coincidences

- ***Self-consistency*** Tests

  -- ***Qualitative***, but useful

  -- ***Regional*** and ***Temporal Behavior*** (stratified) vs. ***Expectation***

- ***Comparisons*** with AERONET proxies

  -- Compare ***Seasonal***, ***Inter-annual*** patterns ***Statistically***

  -- ***Fine-mode Fraction*** (FMF)

  -- ***Effective radius*** (r_e) and ***variance*** (σ) [two modes – ***issue with def. of "modes"***]

  -- ***Single-scattering albedo*** (*SSA*) [for AOD_440 > 0.4; AERONET SZA > 50°]

  -- ***Sphericity*** (*"%Sph."*) [for AERONET ***ANG*** < 1.0 only – few coincidences w/AOD>0.2]

Kahn & Gaitley, JGR, 2015

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 15+ 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*

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***, ***Chemical Type***, and ***Mass Extinction Efficiency*** (MEE)
- ***Process Data Routinely*** at central site; instrument PIs develop & deliver algorithms, upgrade as needed; data distributed via central web site
- Peer-reviewed Paper 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

Aerosol Type Summary

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

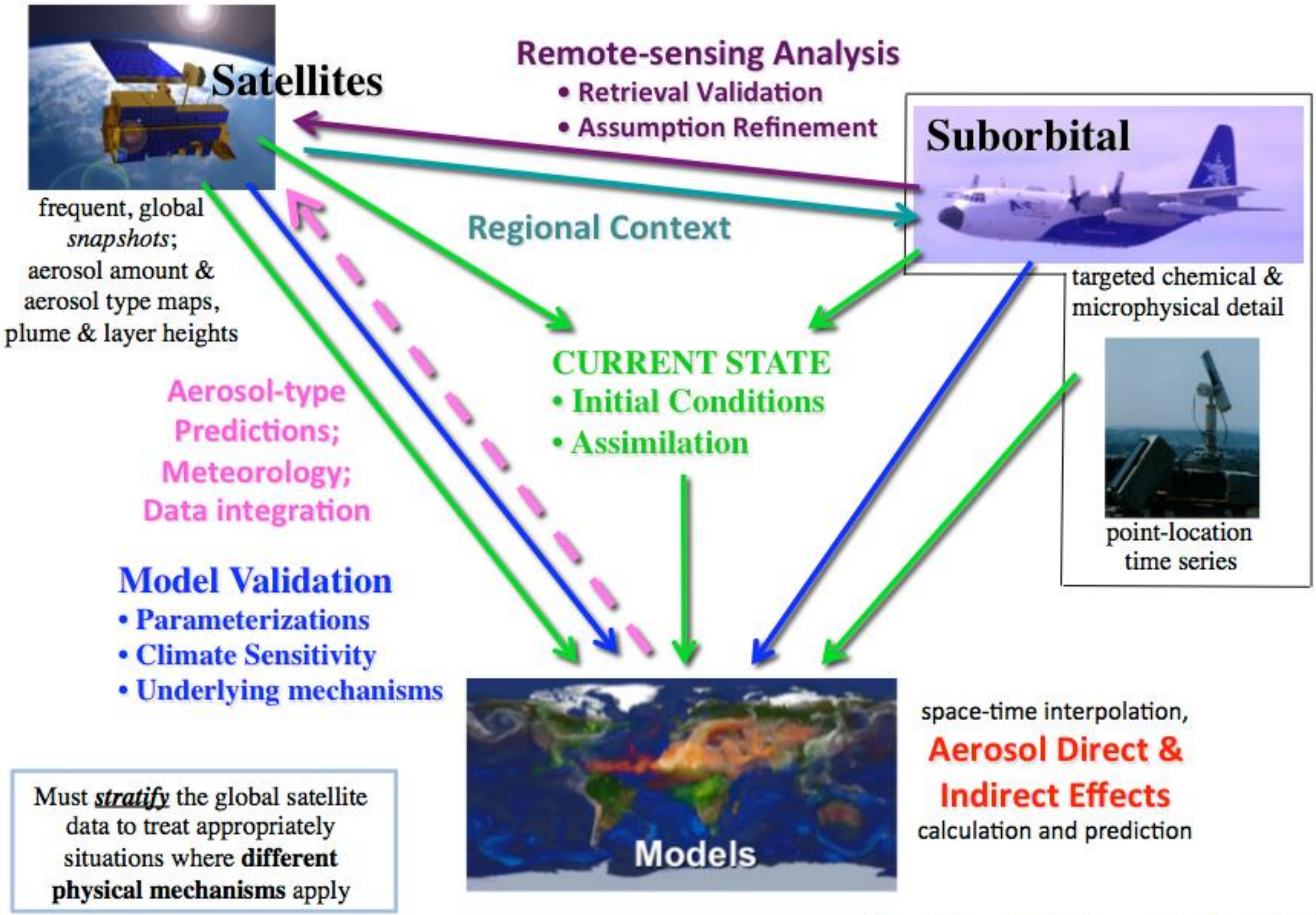
- A ***further*** interpretative step, entailing additional assumptions, reports particle ***Chemical Composition***

- Remote-sensing ***sensitivity to particle properties is much more dependent than AOD on retrieval conditions***

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

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

- Better ***aerosol type*** constraints lead to ***improved AOD*** retrievals



Adapted from: Kahn, Survy. Geophys.