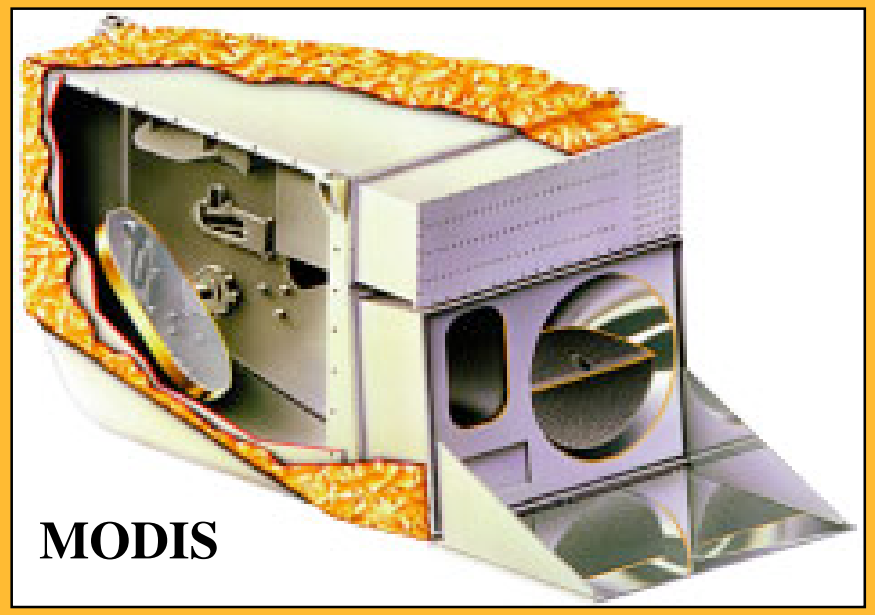
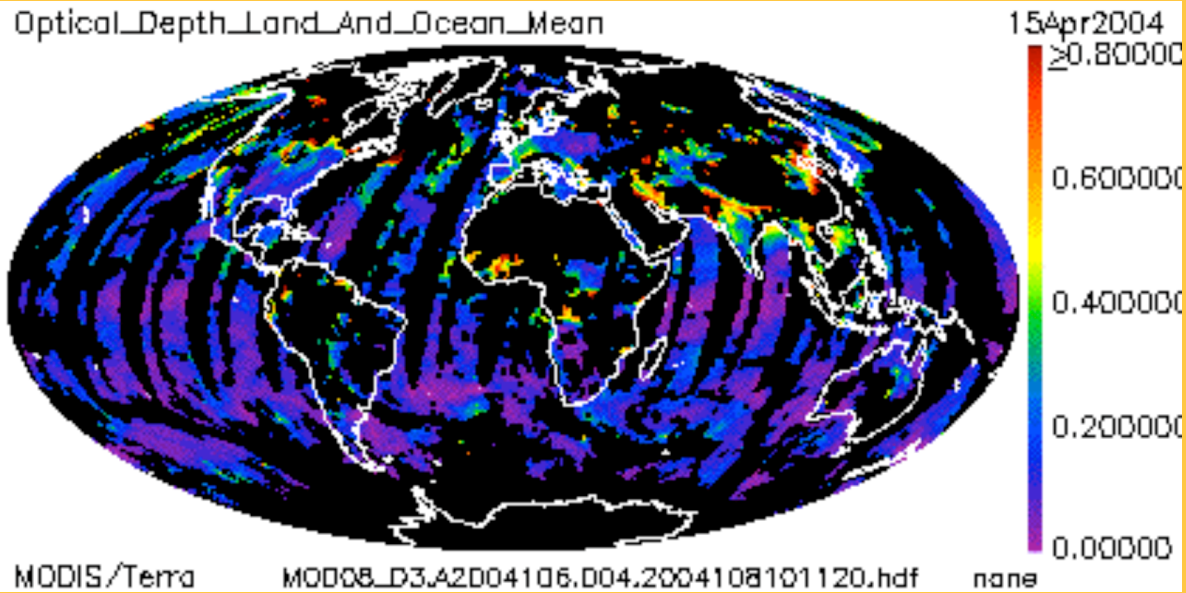
Passive Nadir and Multi-angle Aerosol Retrievals

Ralph Kahn
NASA Goddard Space Flight Center

With Contributions from many Colleagues (acknowledged on the relevant pages)

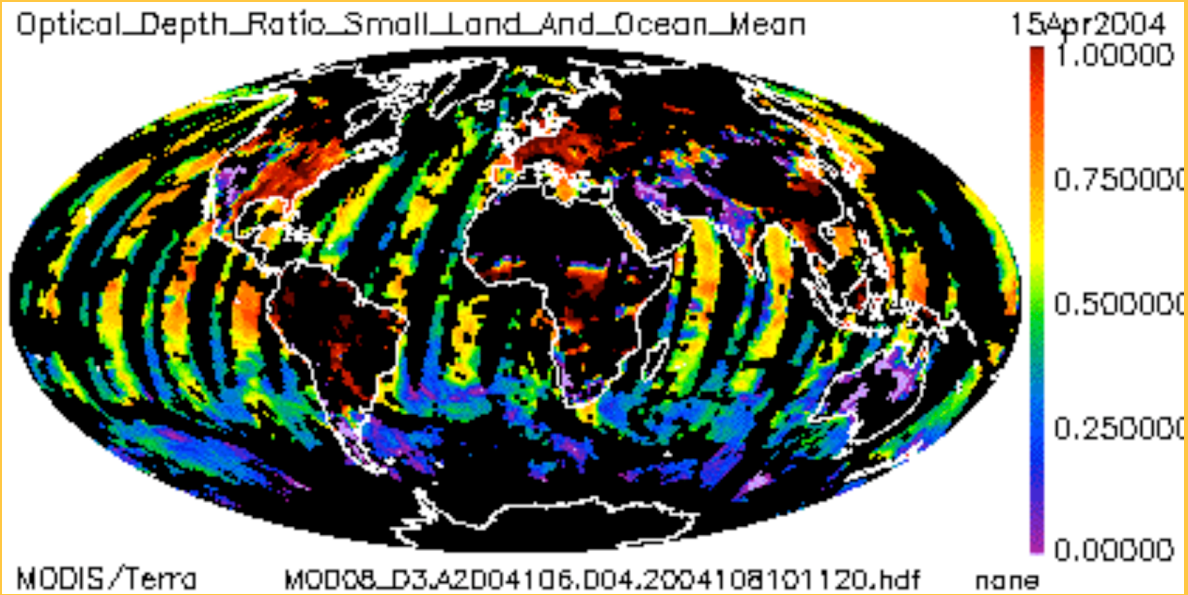


MODIS Daily Aerosol Products



Mid-vis AOD

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



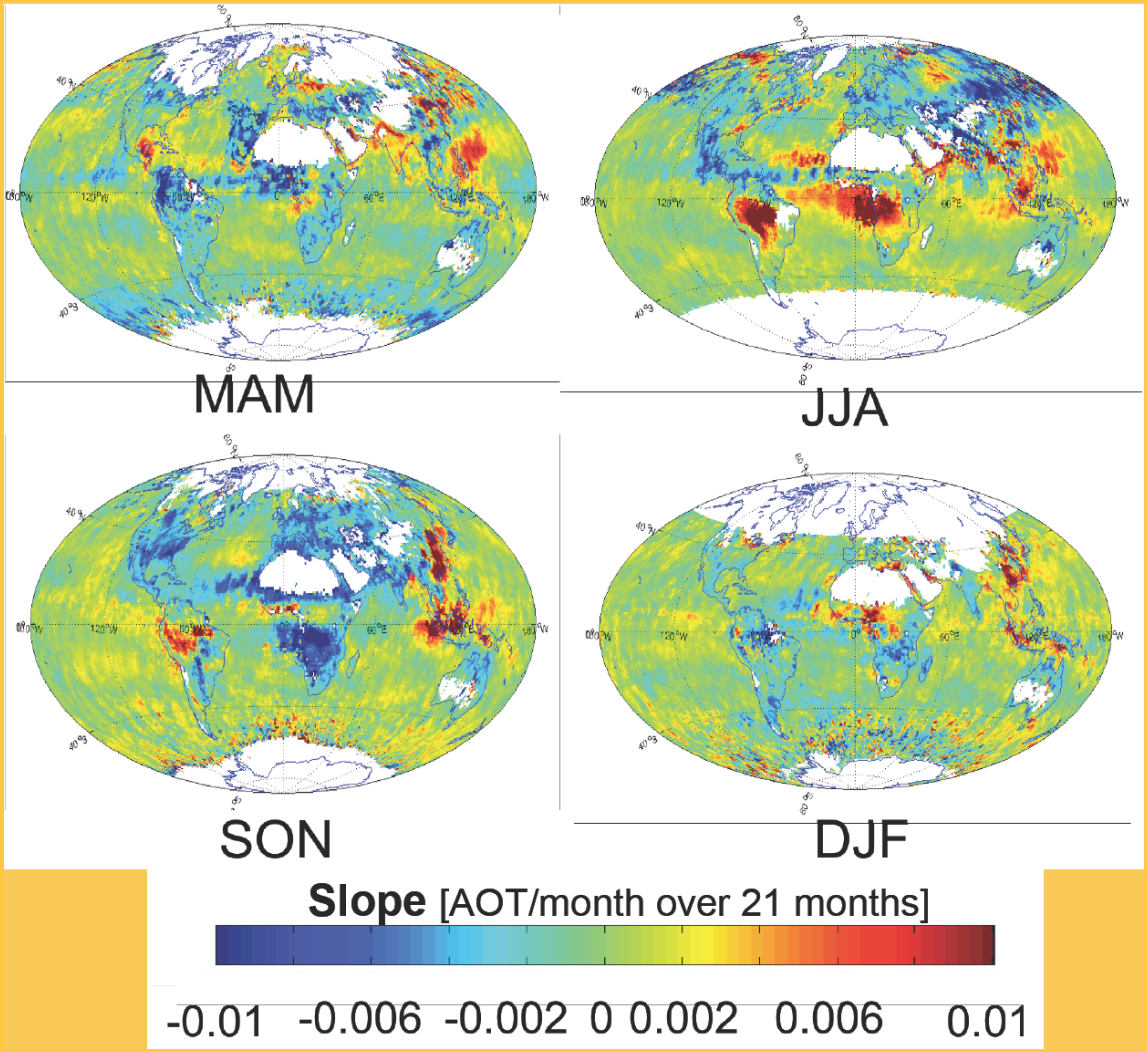
Fine/Coarse Ratio
Sensitive to PM_{10}

Direct Downlink

http://rapidfire.sci.gsfc.nasa.gov/realtime/

Source: MODIS Atmospheres Web Site

MODIS/Terra 7-Year Regional/Seasonal AOD Trends

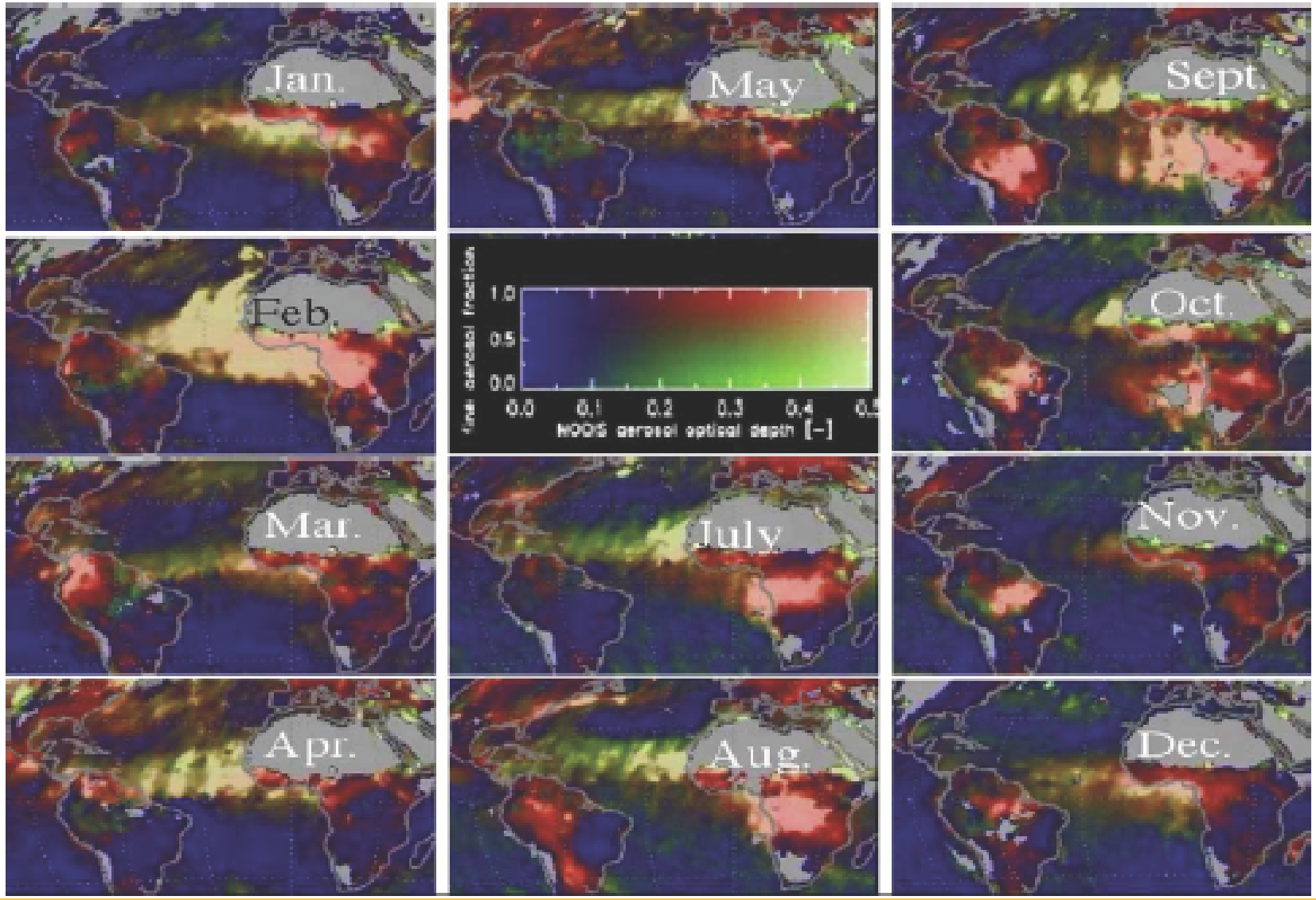


- Decrease over land, ***except*** E Asia + tropical Africa, S America, Indonesia burning seasons
- Increase over ocean, especially downwind of biomass burning areas

Remer et al, GRL submitted

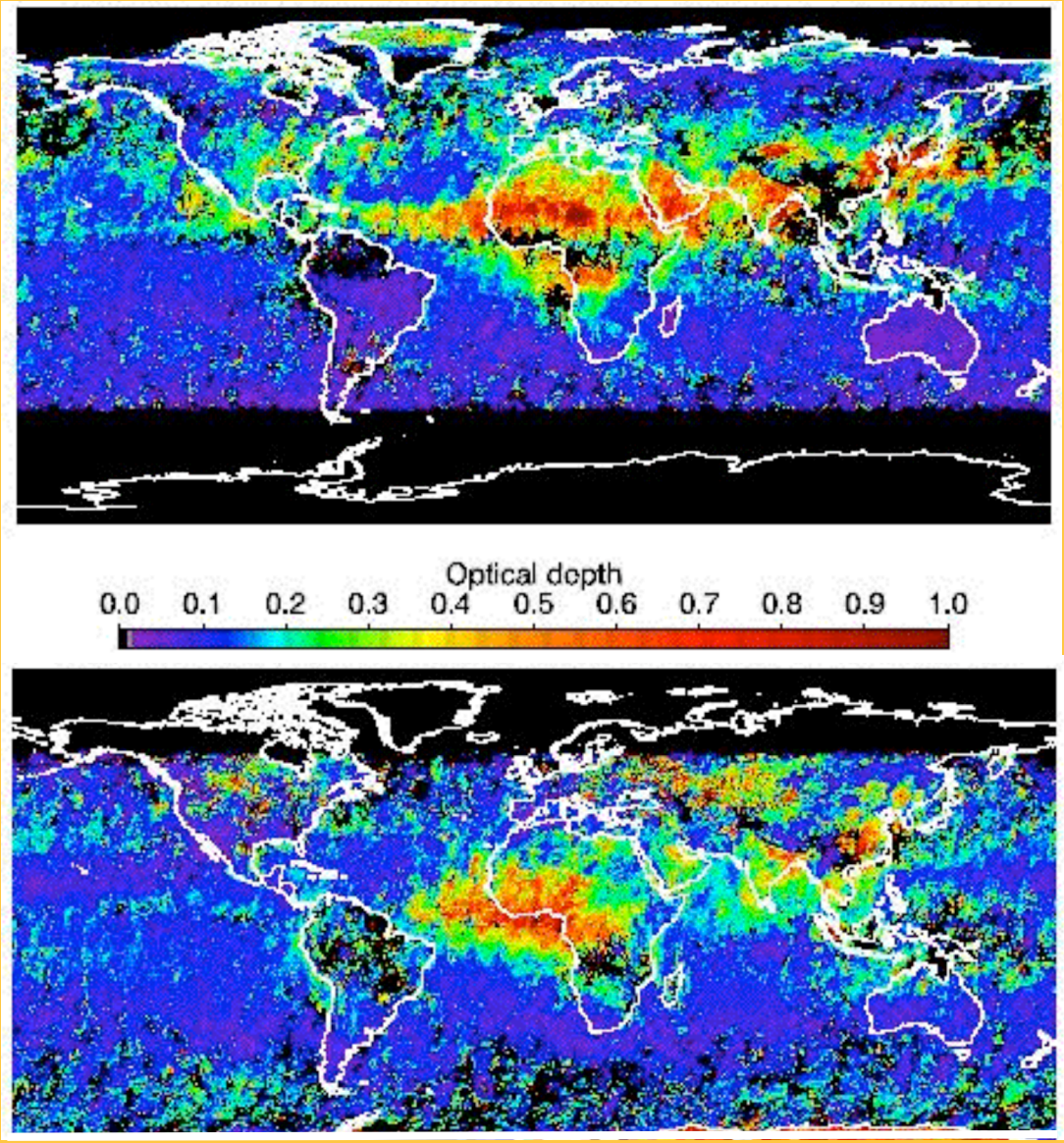
One MODIS Aerosol Type Classification:

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



Kaufman et al., JGR, 2005

MISR Monthly Global Aerosol Mid-VIS AOT



July 2005

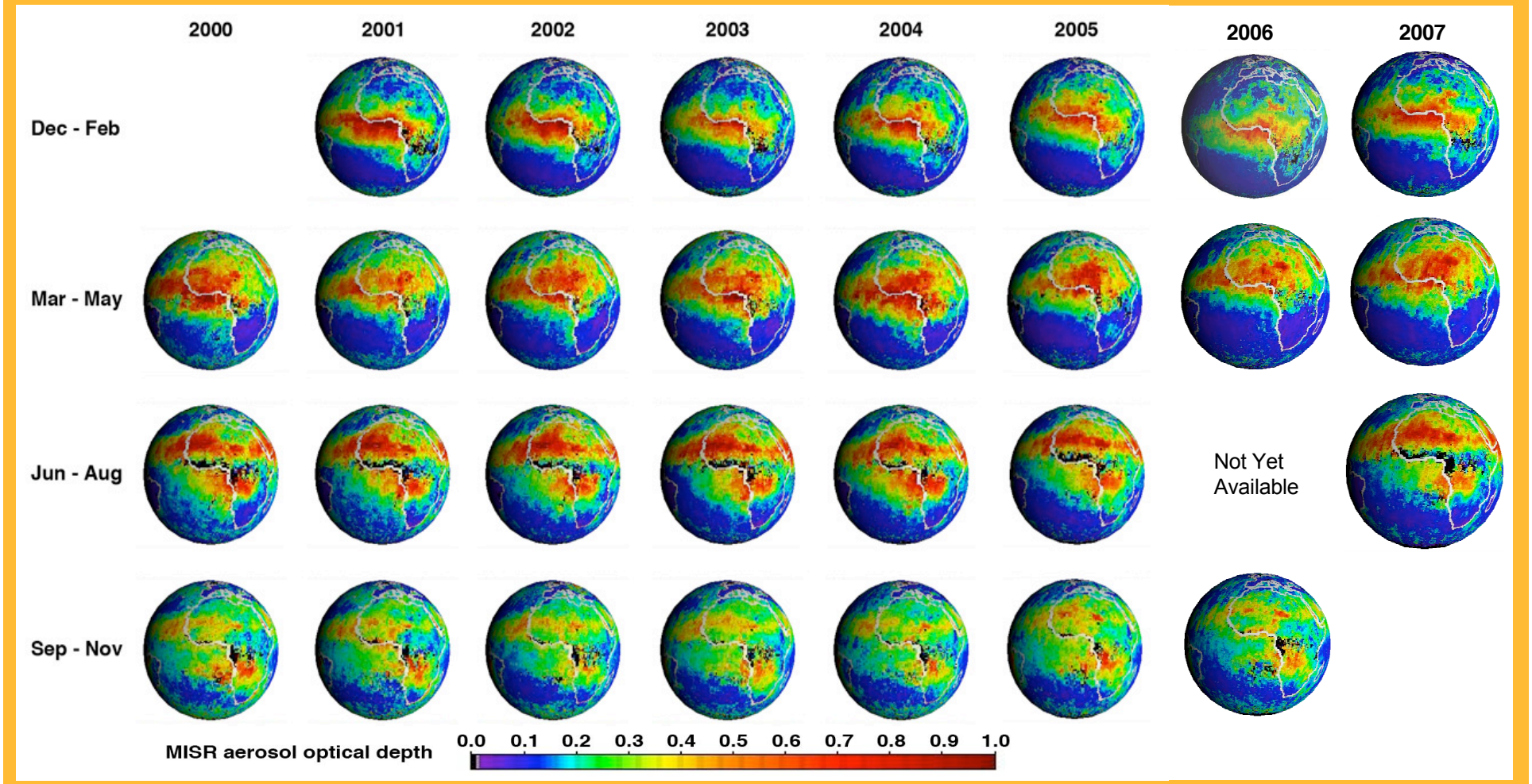
- **Land & Water**
- **Bright Surfaces**
- **Globe ~ weekly**
- **~ 10:30 AM**

[+ particle size, shape, SSA constraints]

- **Sensitive to $PM_{2.5}$**

January 2005

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

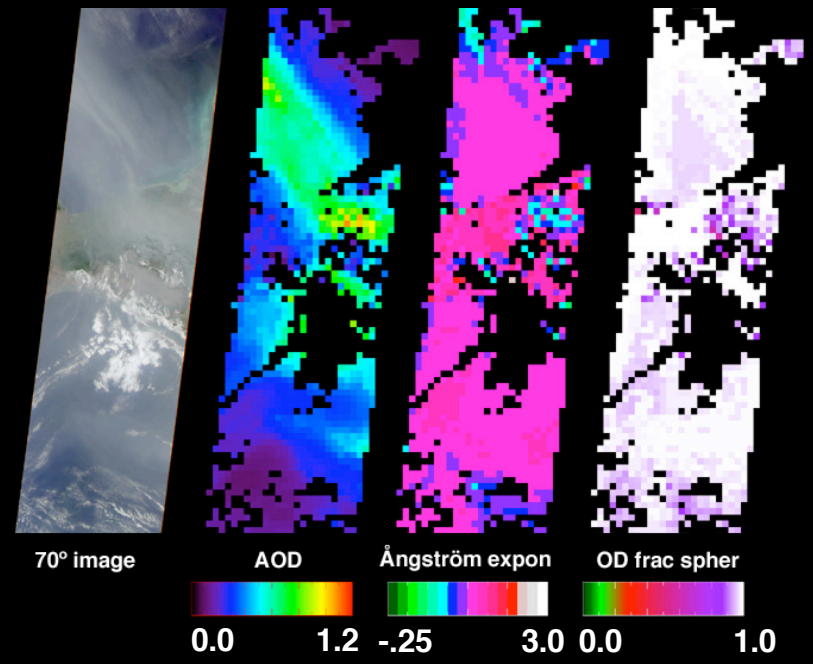


…includes bright desert dust source regions

MISR Team, JPL and GSFC

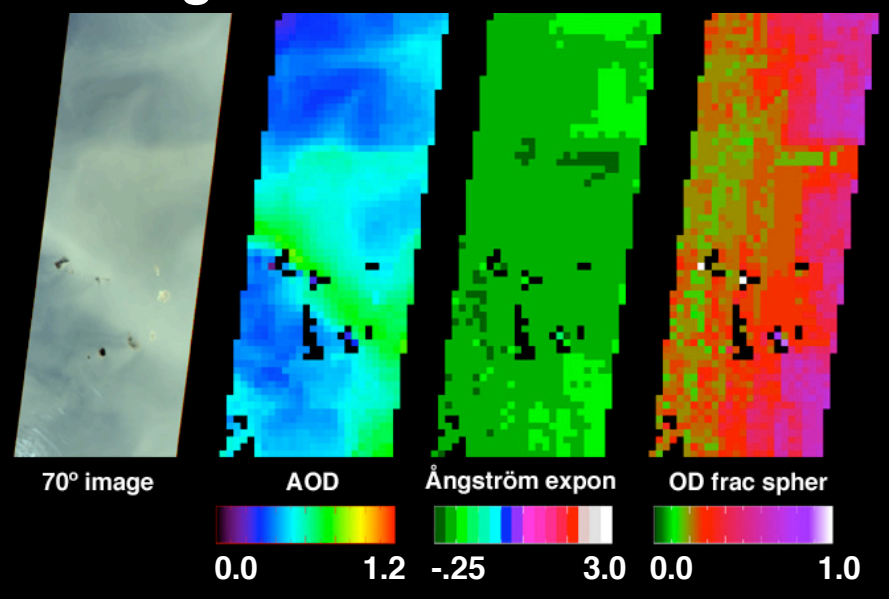
Smoke from Mexico -- 02 May 2002

Aerosol:
Amount
Size
Shape



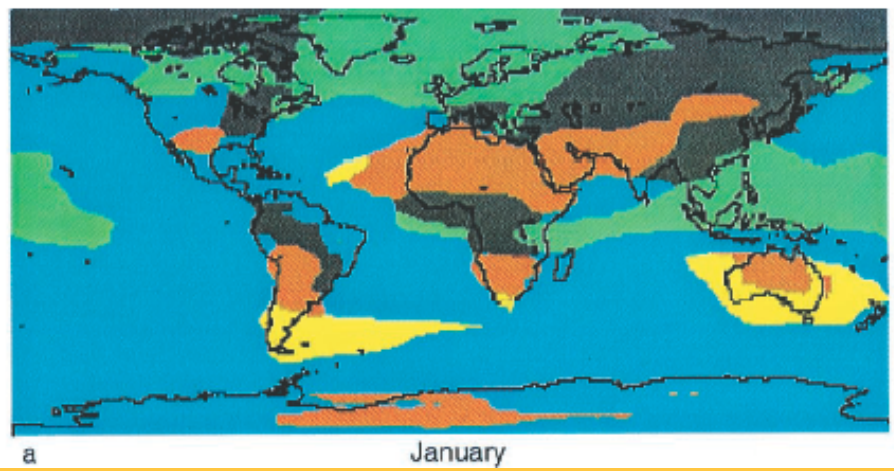
Medium
Spherical
Smoke
Particles

Dust blowing off the Sahara Desert -- 6 February 2004

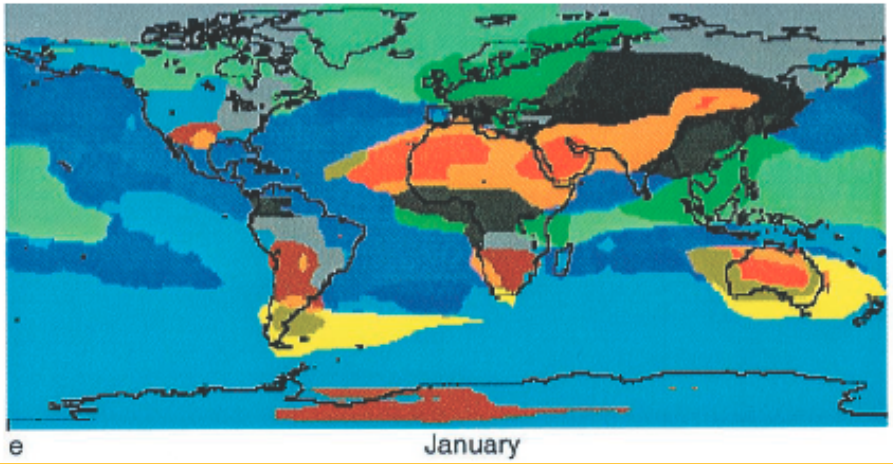


Large
Non-Spherical
Dust
Particles

We are aiming for Regional-to-Global Aerosol Type Discrimination something like this…



5 Groupings Based on Aerosol Properties



13 Groupings Based on Aerosol Properties

Global, **Monthly** Aerosol Maps Based on Expected MISR Sensitivity

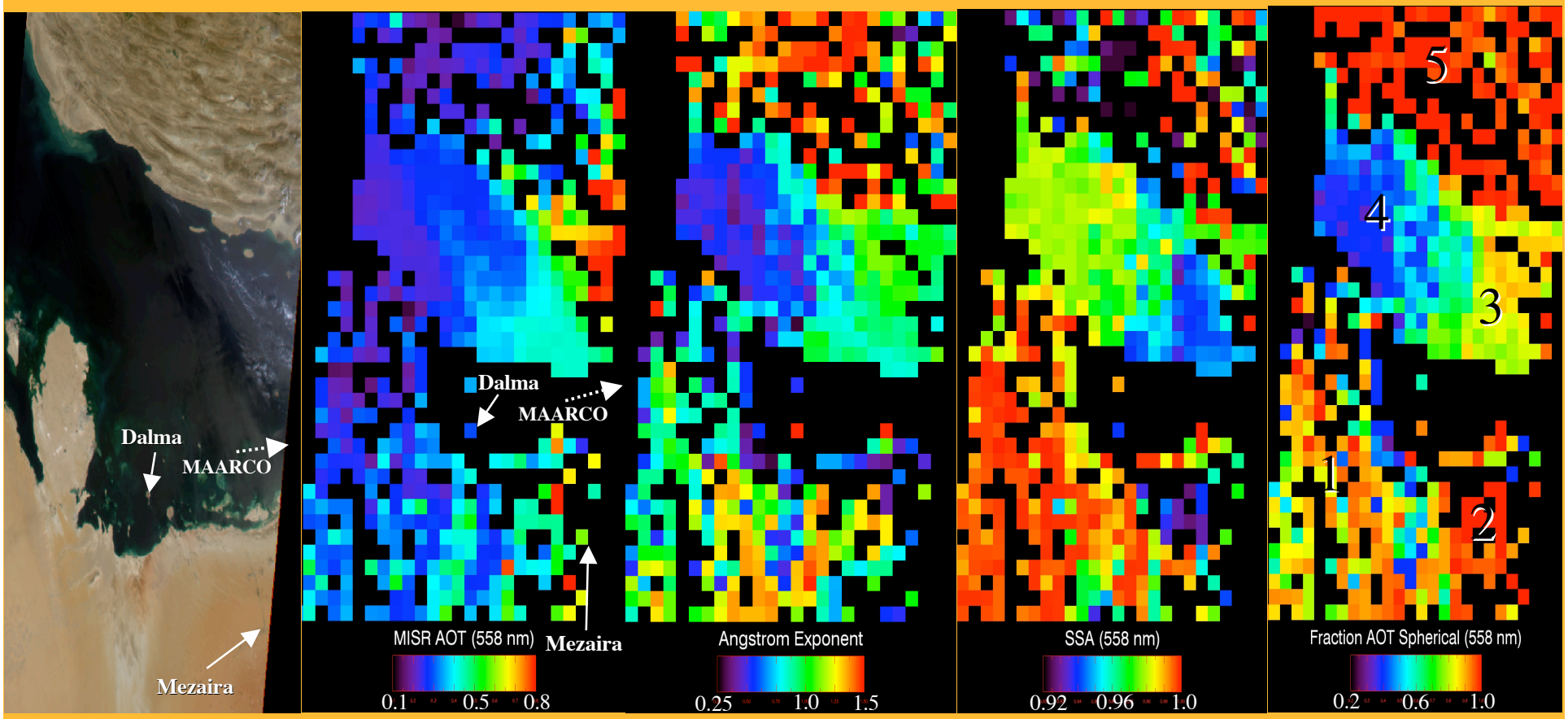
The examples shown here are simulated from aerosol transport model calculations…

We currently achieve this kind of discrimination using the MISR Research Retrieval in **localized areas** [examples follow], but **not yet reliably on the global scale**.

Kahn et al., JGR 2001

MISR Regional Aerosol *Air Mass Types*

Dust + Pollution -- UAE-2 Campaign September 01, 2004 (MISR V16)



MISR 26˚f Image | **MISR AOT** | **Angstrom Exponent** | **SSA** | **Fract Spherical**

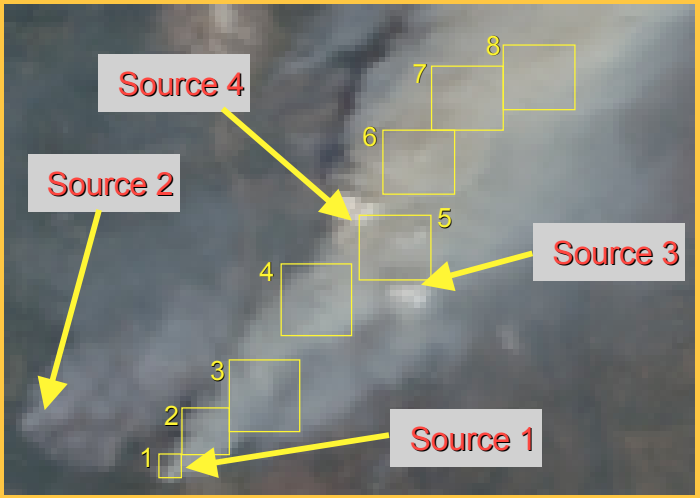
Four-to-five aerosol air masses - Higher ANG --> Lower SSA

West Side (including Dalma) **Spherical**, **clean** + **Dust** mixtures dominate

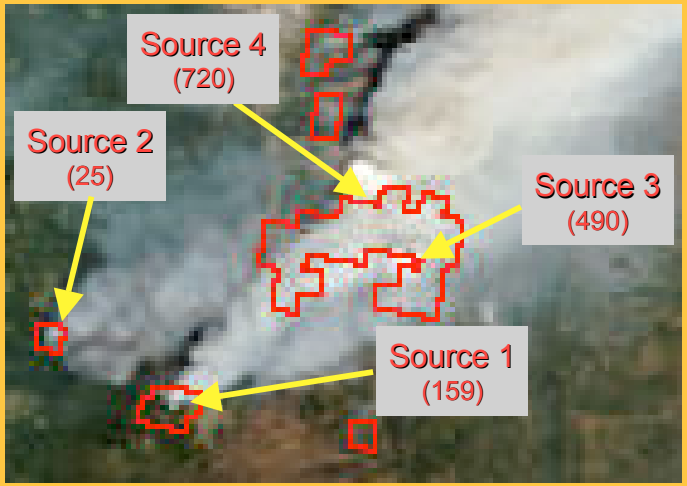
East Side (includes Sir Bu Nuair, MAARCO off swath) **more Pollution**, **less Dust**

Kahn, Reid, Holben, JGR, in preparation

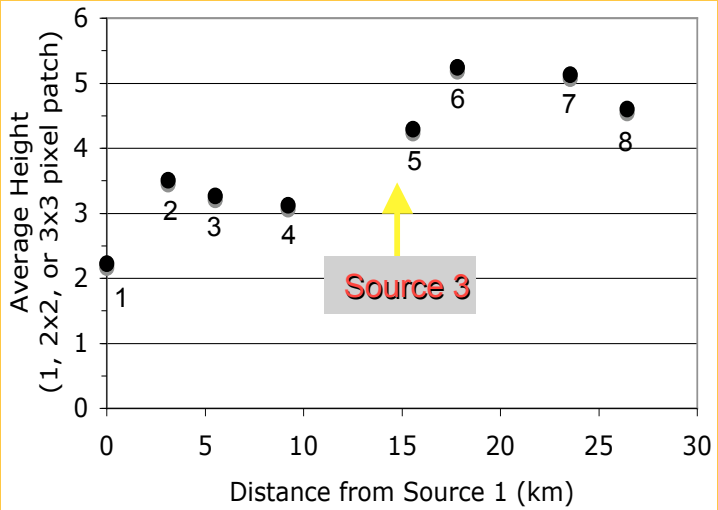
Detail of Wildfire Source Region
Oregon Fire Sept 04 2003



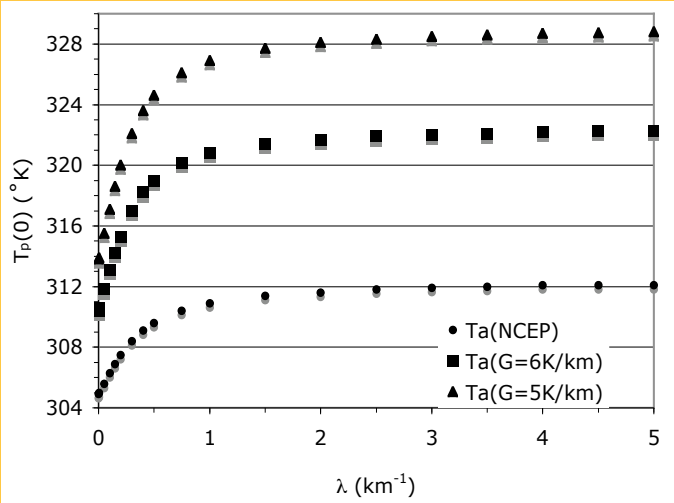
MISR Nadir 275 m Image



MODIS Image + Fire Product



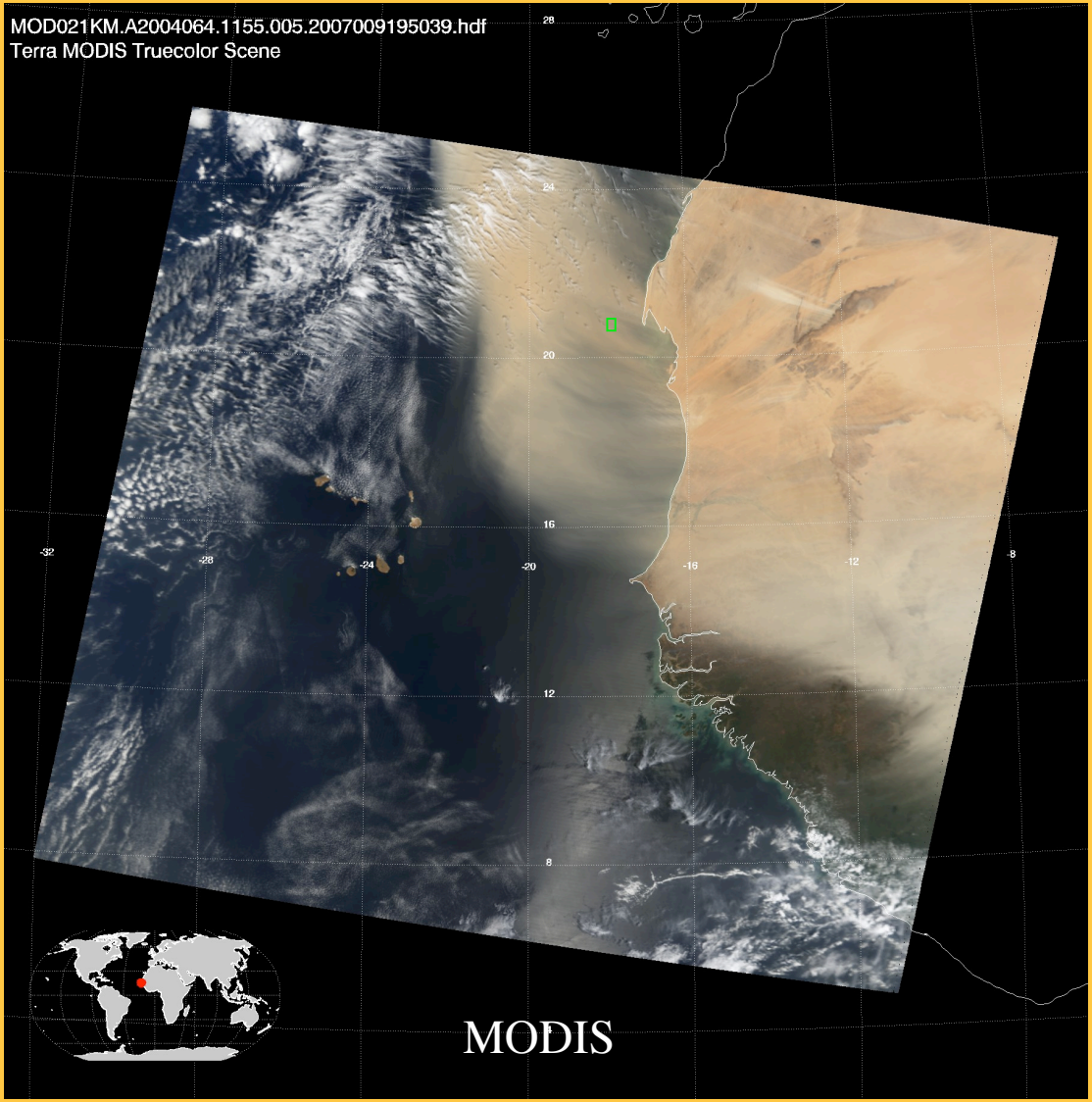
MISR Plume Heights for Patch 1 Sub-patches

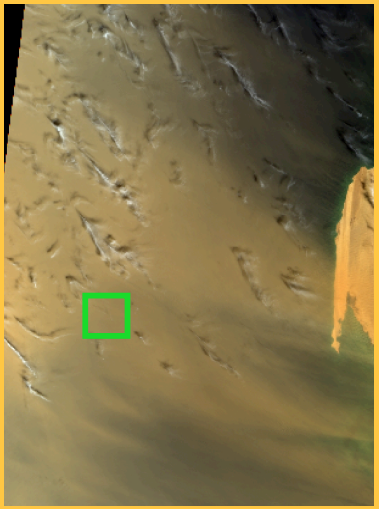


Very Simple Plume Parcel Model

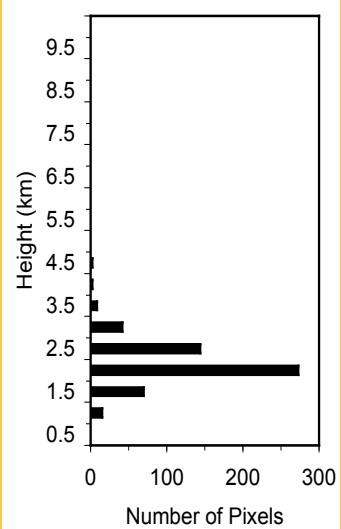
Transported Dust

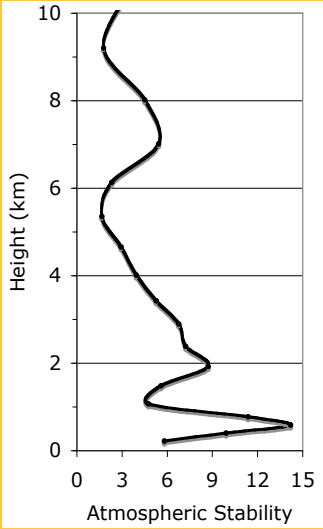
Atlantic, off Mauritania March 4, 2004 Orbit 22399





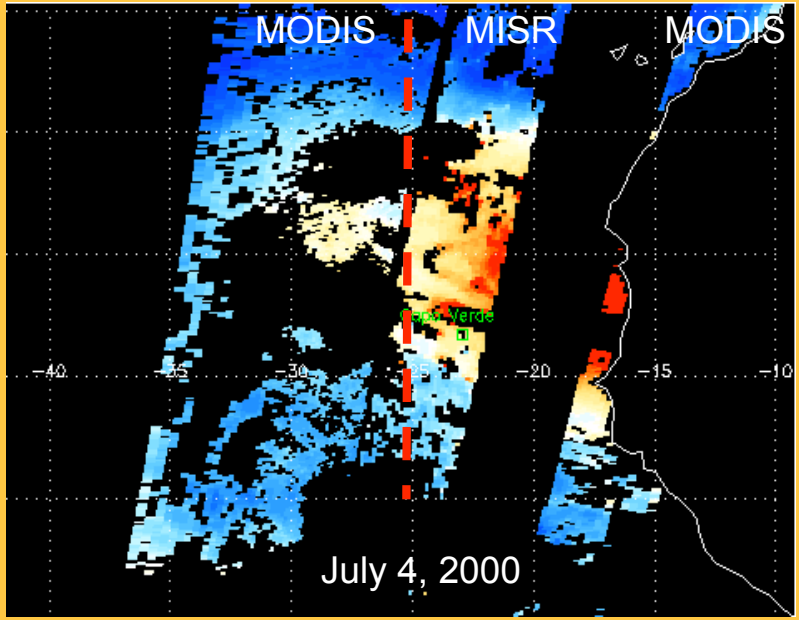
MISR



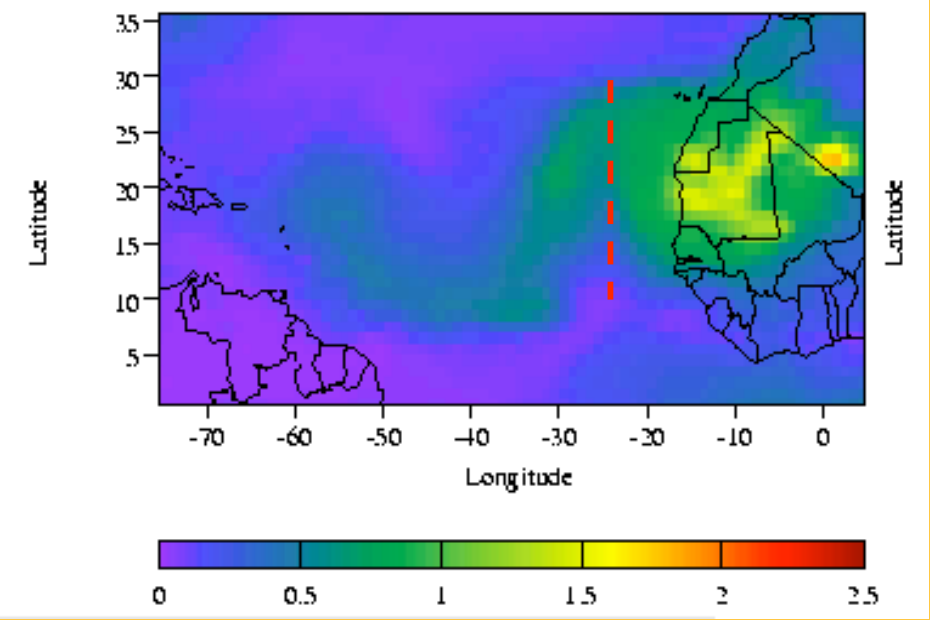


From: *Kahn, et al.*, JGR 2007

Dust Plume Transport: Measurements & Models



MISR + MODIS AOT Observations



NAAPS Model Dust

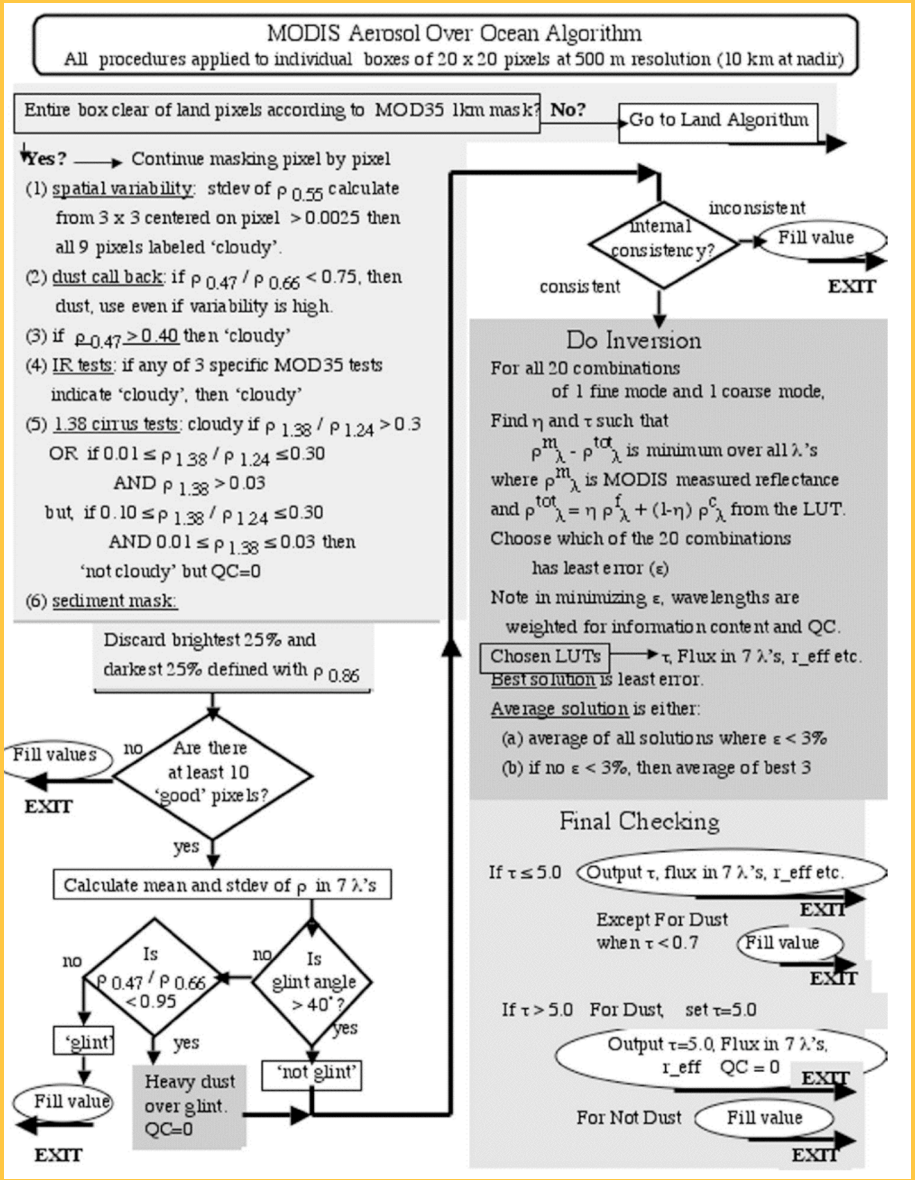
NAAPS model dust plume extent predictions:

- **In qualitative agreement with MISR & MODIS**
- **Magnitudes differ…**

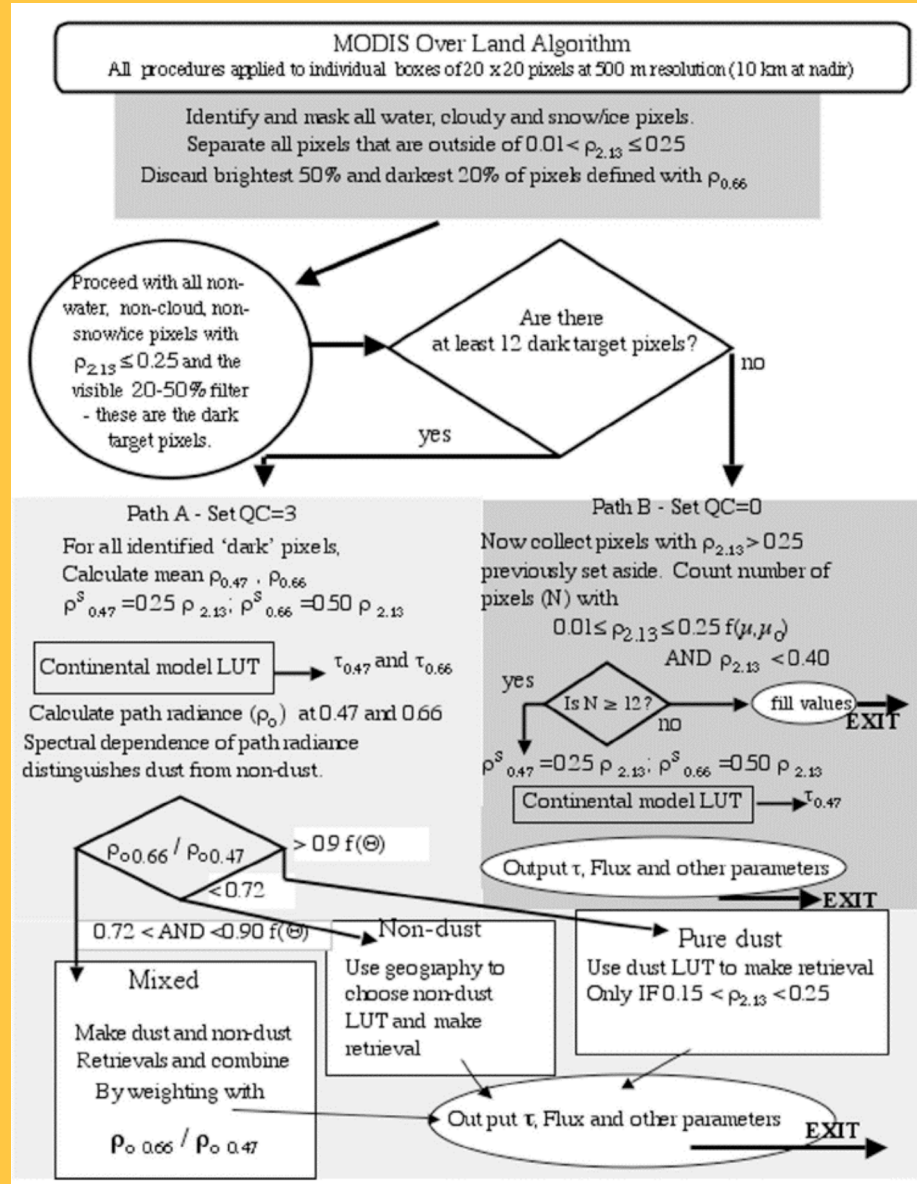
Models are the keys to **synthesizing observations, filling gaps, obtaining quantitative material flux, radiative forcing impacts…**

Kalashnikova and Kahn. JGR submitted

MODIS Aerosol Retrieval Algorithm Steps



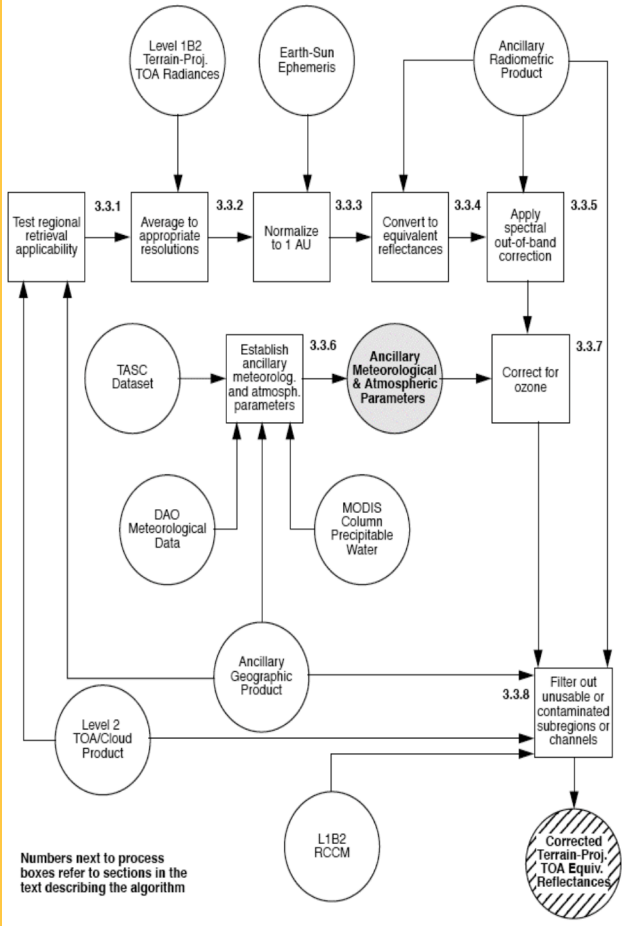
Ocean

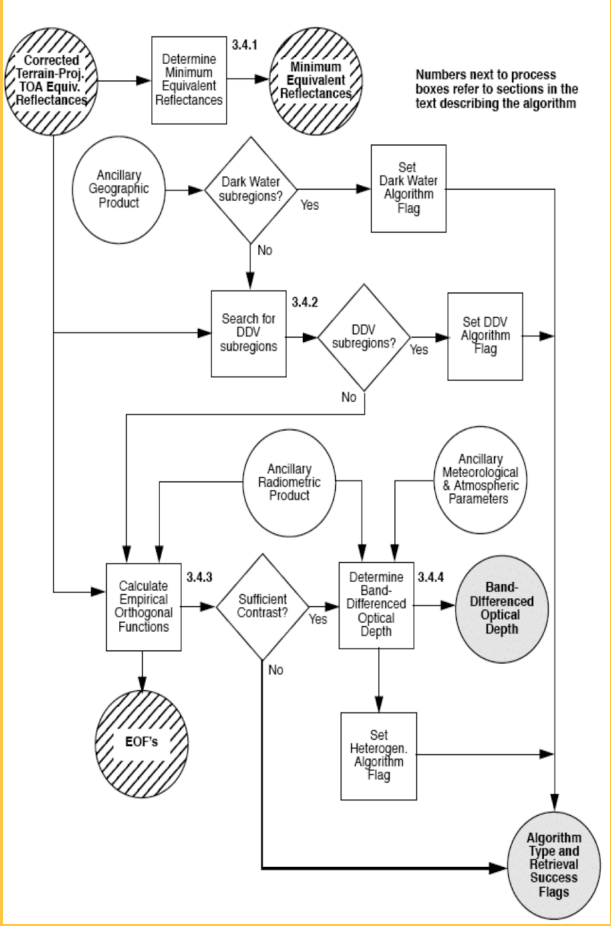


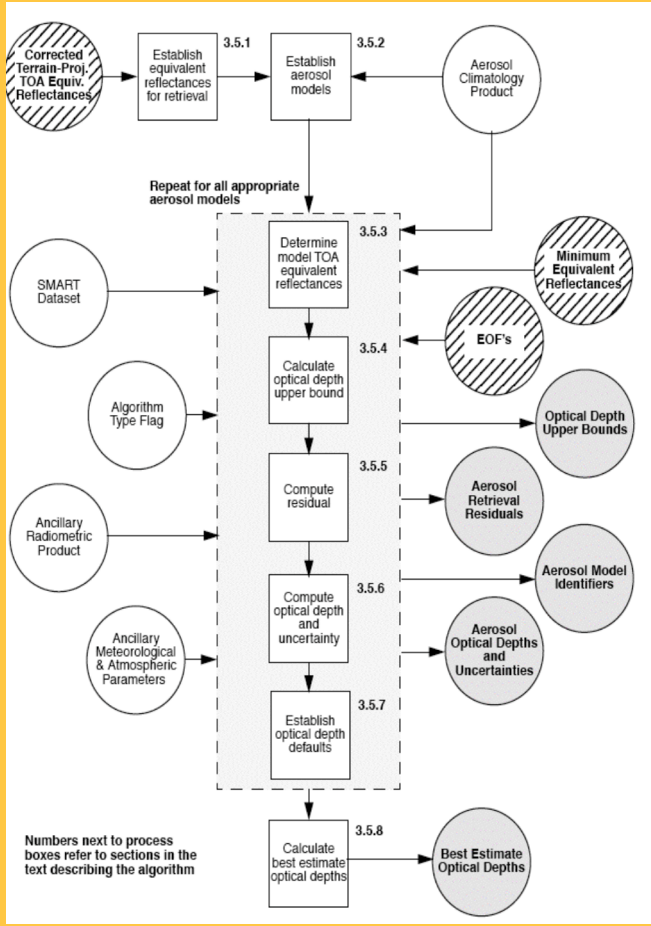
Land

Remer et al., JAS 2005

Broad Outline of MISR Aerosol/Surface Retrieval Algorithm Steps







Stage 1
- Cloud, terrain masks
- Band & Gas corrections
- Convert to Eq. Reflectance

Stage 2
- Select water or land algorithm
- Aggregate Eq. Reflectances
- Calculate EOFs if land

Stage 3
- Compare measurements with pre-calculated options
- Calculate uncertainties

Key Algorithm Inputs & Assumptions

Stage 1
- Calibration (band corrections, etc.)
- Surface Type Information (terrain type, snow mask, wind, etc.)
- Atmospheric gas concentrations (O_3, H_2O_v, etc.)
- Ephemeris & solar input
- Cloud masking

Stage 2
- Aggregation (How to select & process the Stage 1 reflectances)
- Retrieval approach (What to assume or derive about aerosols & surface)**

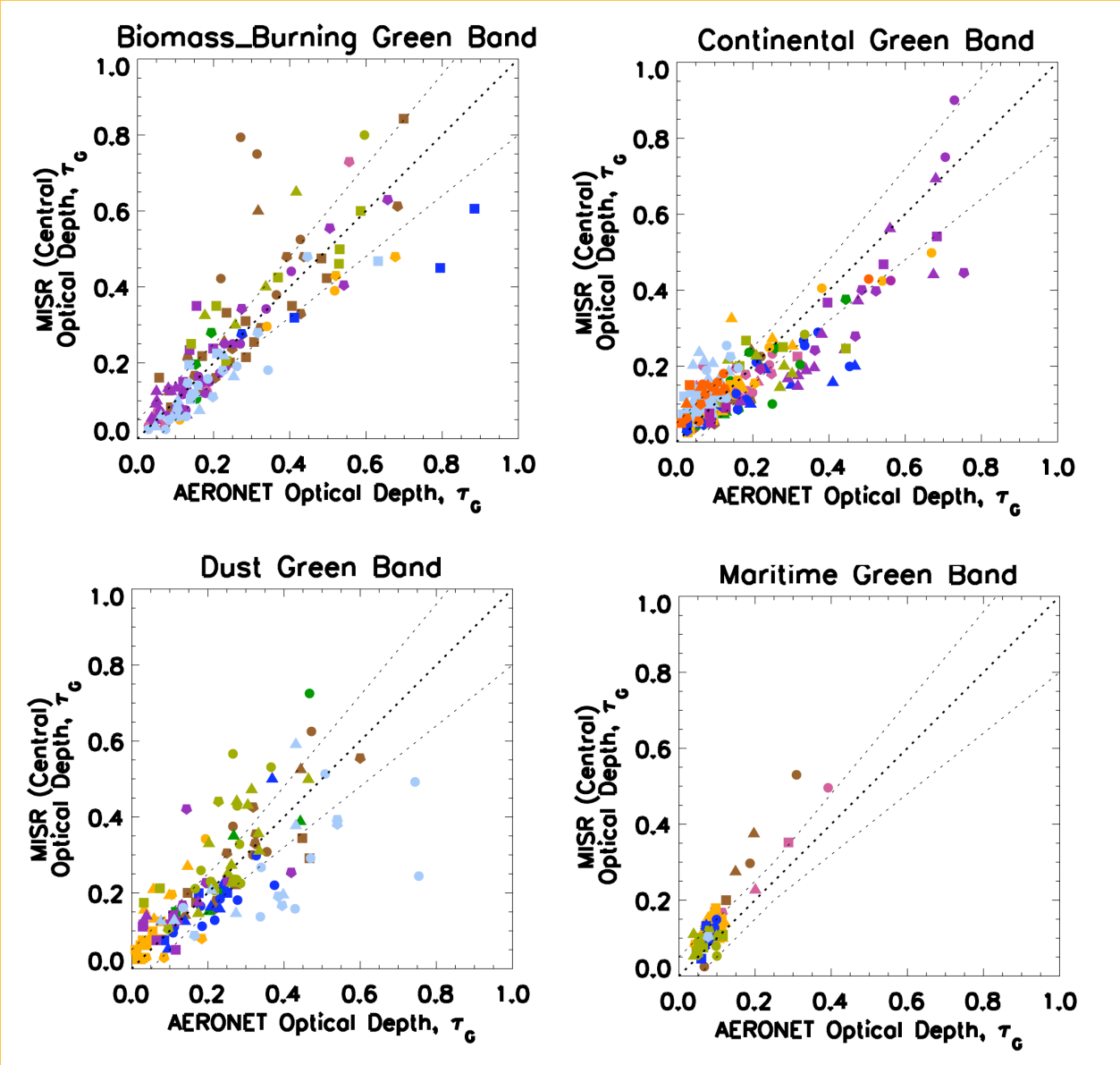
Stage 3
- Aerosol components & mixtures
- Aerosol vertical distribution
- Radiative transfer code(s)
- Look-up table resolution
- Acceptance criteria
- Uncertainty metrics

** Retrieved Quantities ←→ Information Content of the data

Pre-launch Sensitivity Studies, Post-launch Validation

Scatter Plots Showing 579 MISR-AERONET Coincident AOT Events

32 sites, during 2001-2002; Stratified by Expected Aerosol Type



Overall:

- **About 2/3 fall within 0.05 or 20% * AOT**
- **About 1/3 fall within 0.02 or 10% * AOT**

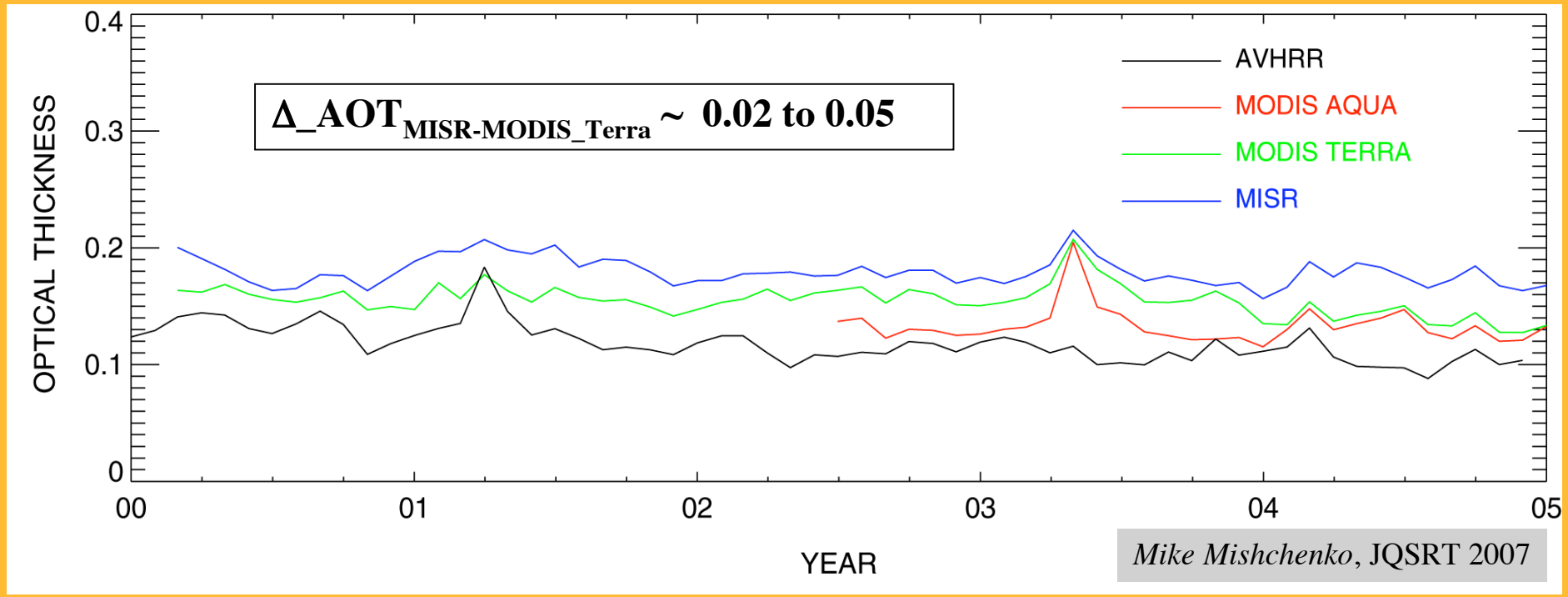
Correlation Coeffs. > 0.8 in all categories except Dusty, which are > 0.72

MISR Product: Version 12

From: Kahn, et al., JGR 2005

MISR - MODIS - AVHRR Five-Year Monthly, Global AOT Comparison

[Based on Standard "Level 3" Gridded Products]



This is now a *quantitative* matter: ***What precisions & accuracies are needed*** for climate (and health) applications?

MISR & MODIS Mid-Visible AOT Sensitivities Reported Currently

- MISR: **0.05 or 20% * AOT** overall; ***better over dark water***
  [*Kahn et al*., 2005]

- MODIS: **0.05 or 20% * AOT** over land
  0.03 or 5% * AOT over dark water [*Remer et al*. 2005]

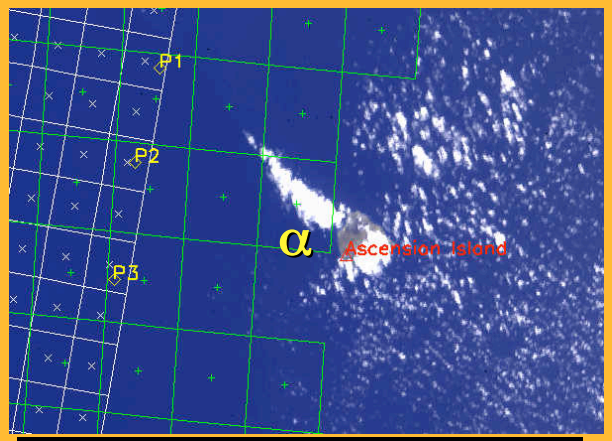
Based on AERONET coincidences (cloud screened by ***both*** sensors)

--> For global, monthly AOT, AEROCOM uses
MISR over land, MODIS over water

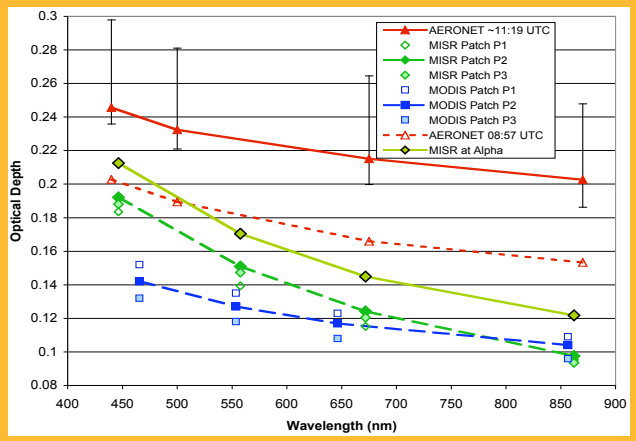
Direct Radiative Forcing: Need AOT to <~ 0.02

MISR-MODIS-AERONET *Sampling* Differences

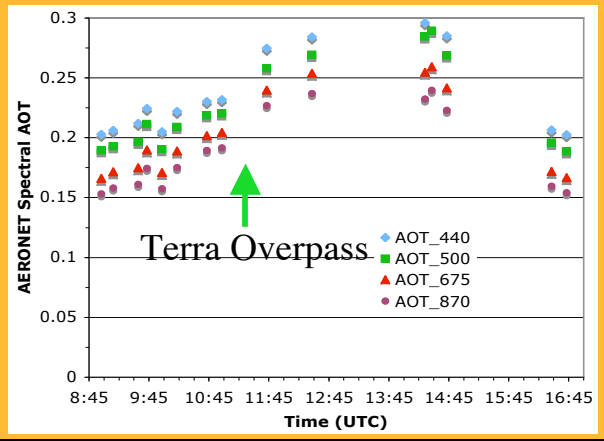
[Ascension Island 18 February 2005]



Sampling: MISR; MODIS; AERONET



AOT Snapshot: ARNET> MISR >MODIS



AERONET Time Series - Changing AOT

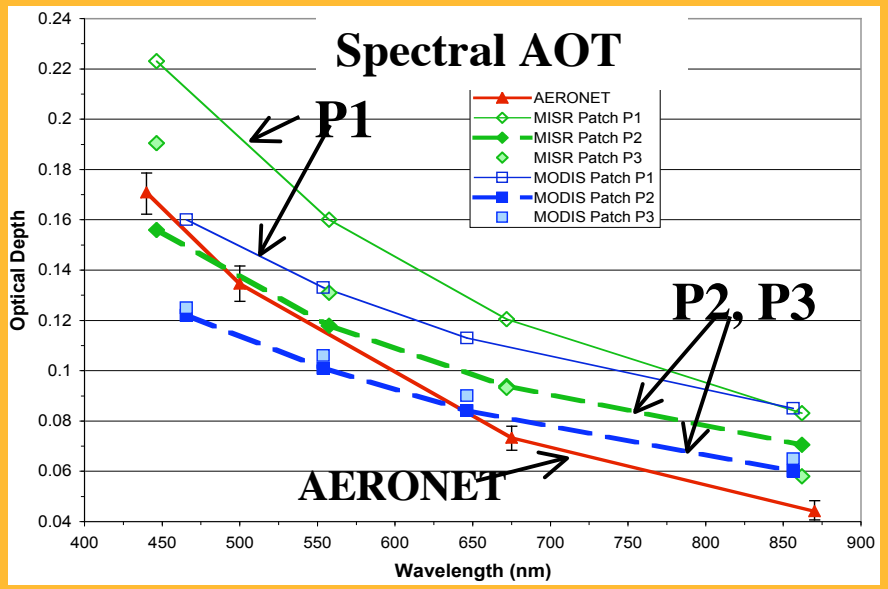
Clean, maritime aerosol air mass, but AOT changes 60% across RH boundary

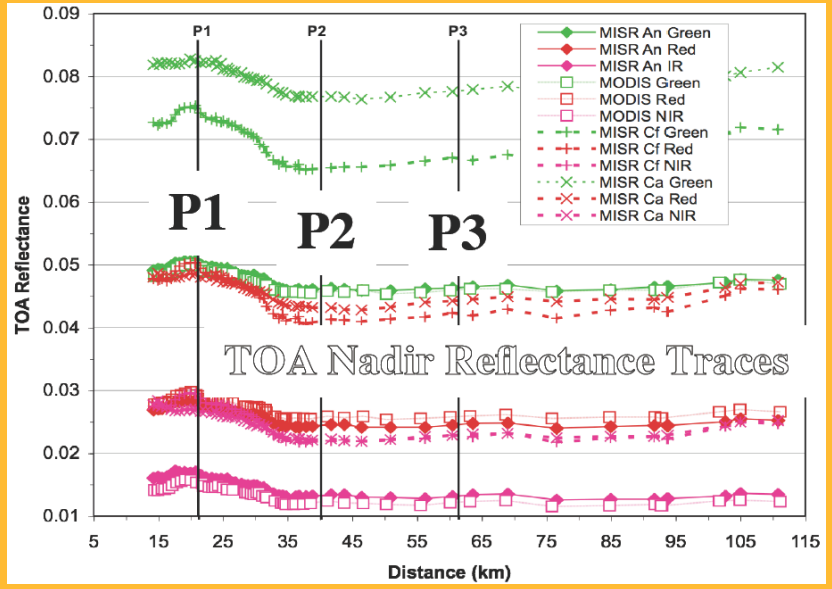
Using any one of these to represent the entire region AOT --> large errors
Taken together, they give a better picture…

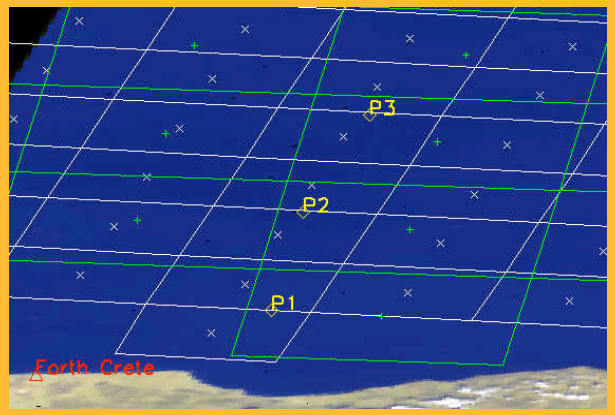
Kahn et al., JGR 2007

MISR-MODIS assumed *Lower Boundary Condition* Differences

[Forth Crete 13 September 2003]



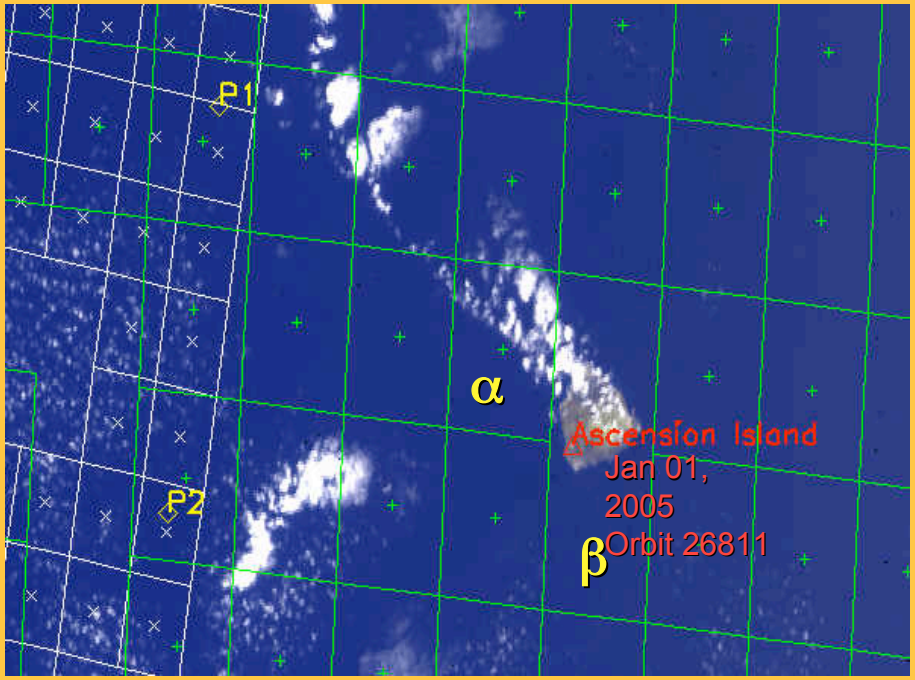


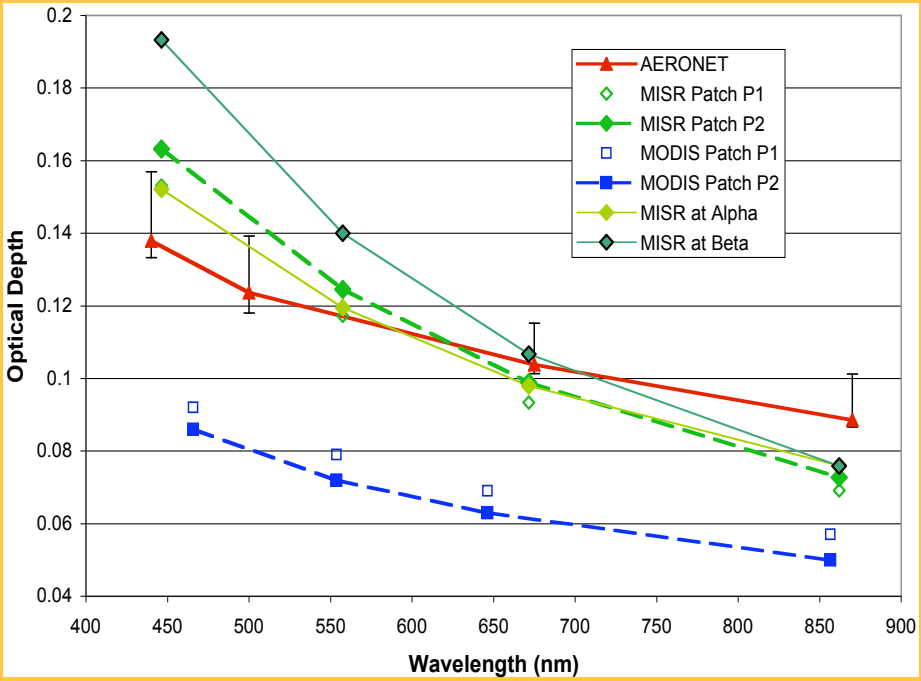


- $AOT_{mid\text{-}vis} >\sim 0.1$
- P2, P3 match AERONET to ~ 0.01
- P1 $\Delta_AOT_{mid\text{-}vis}$ ~ +0.03 to 0.04
- P1 Δ_refl ~ +0.005 [G, R, NIR]

An $A_{0,558nm}$ increase, from 0.8% to 1.5%, can account for the entire AOT difference

Kahn et al., JGR 2007



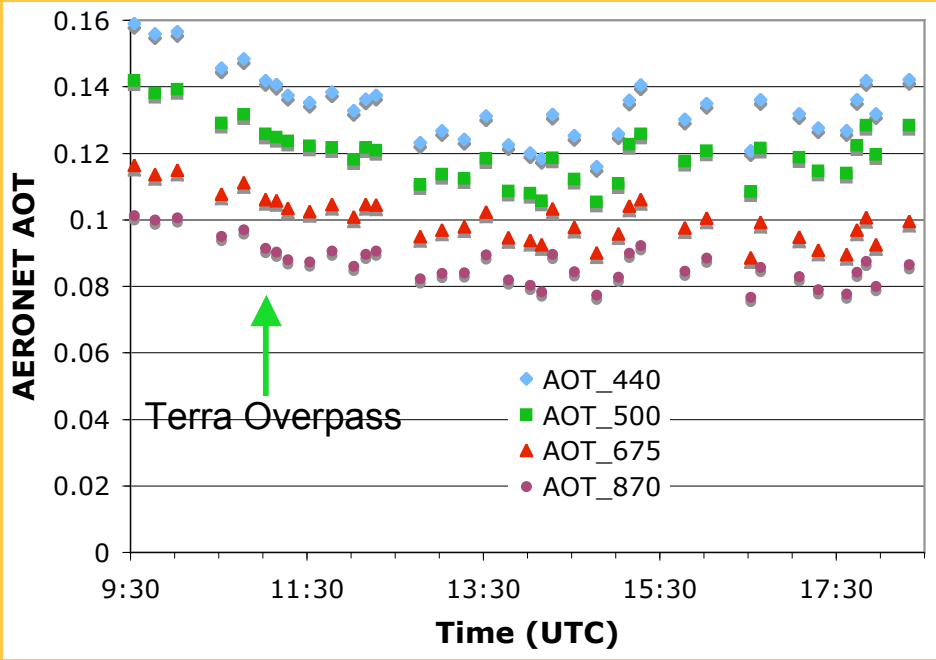


Ascension Island Jan 01 2005

Orbit 26811 Path 200 Blk. 97

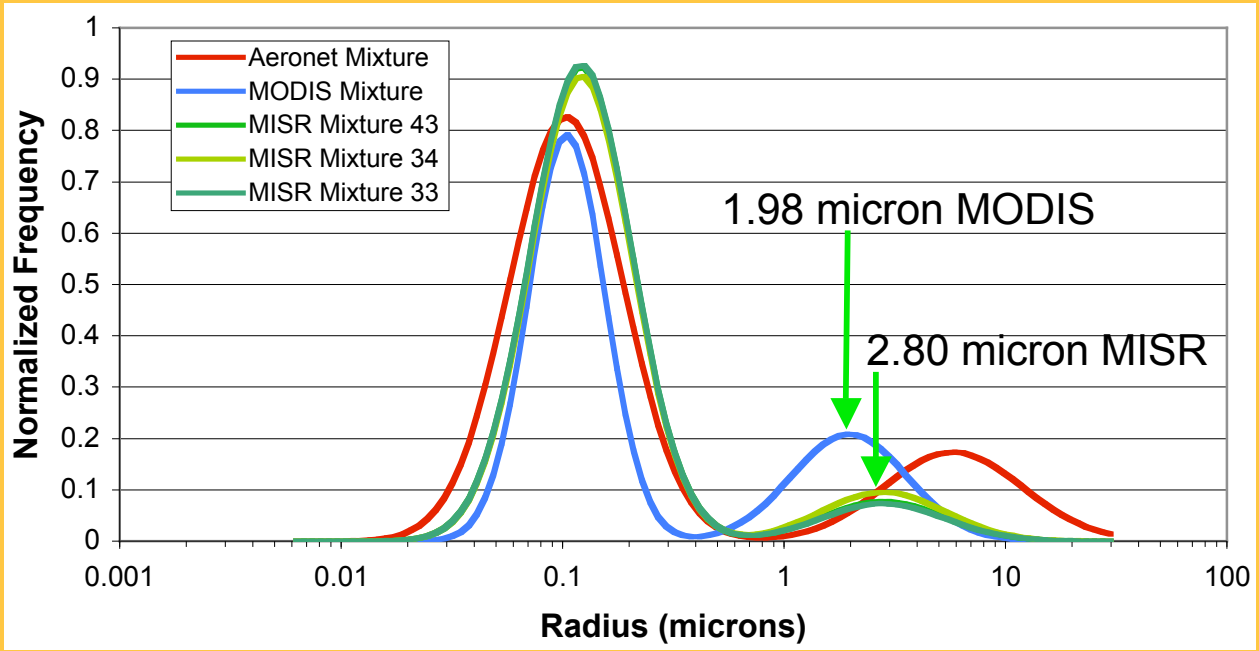
Particle Properties Question

- **Clean Maritime** aerosol air mass
- **No AOT decrease** toward P1 & P2
- MISR spectral AOT slope **too steep**
  --> particle sizes(?)



Ascension Island Jan 01 2005

Orbit 26811 Path 200 Blk. 97

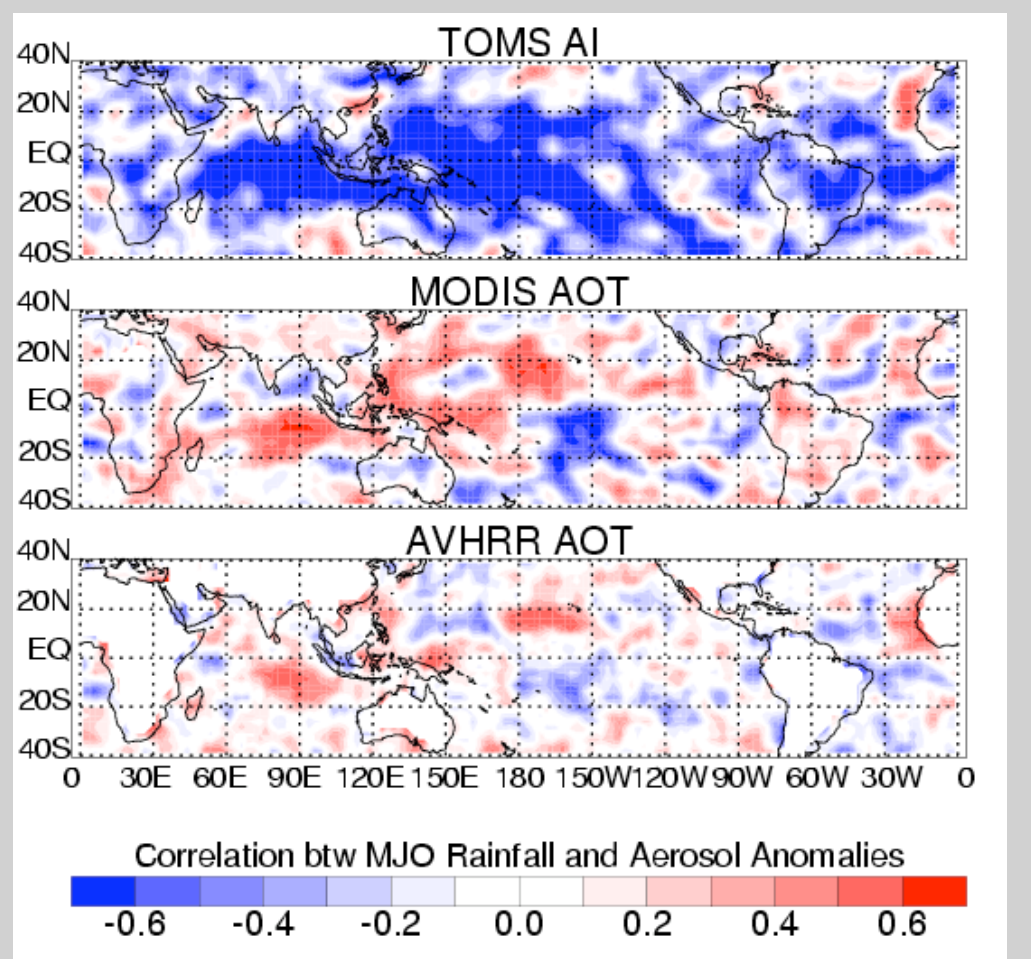


MISR, MODIS, and AERONET Retrieved Particle Size Distributions

- AERONET **spectral AOT independent** of AERONET-retrieved size distribution
- Good AERONET **spectral AOT fit** with **MODIS particles**
- MISR **V17** Standard Algorithm **lacks spherical aerosol between 1 and 2.80** micron

--> **Add 1.28, 1.5 and 2** micron aerosol back into MISR Standard algorithm

Zero-lag Correlations Between MJO Rainfall Index and TOMS-AI, MODIS, and AVHRR Satellite Aerosol Products



TOMS AI (-)
[UV absorption]

MODIS AOT (+)
[scattered light]

AVHRR AOT (+)
[scattered light]

"+" vs. "-" Correlations-->

***Cloud Masking* can be important at these space/time scales**

From: *Tian, Waliser et al.*, JGR *in press*

Where We Stand Currently **on Using MISR/MODIS AOT for Climate Studies**

We have ***Many Successes***

But for quantitative applications this is not easy…

We must beat down the ***Remaining Uncertainties*** as much as possible:

- Measurement Sampling
- Calibration
- Lower Boundary Condition
- Particle Properties
- Cloud Screening
- Level 3 Aggregation

The teams are working on all of these…

Where We Are Heading

- Algorithm that integrates data from ***Multiple Sources***

  -- ***UV***, ***Vis***, ***Near-IR*** & ***Polarization*** -> {AOT, type, vert. dist.}

  -- Improve ***Coverage***

  -- NRT ***Met***, ***Gas*** concentration, & ***Surface*** information

  -- Active sensor precise aerosol ***Vertical Distribution***

- Could an ***Aerosol Transport Model*** be part of the retrieval process?

  -- Include detail from ***Sub-orbital Measurements***

  -- Use prior knowledge about aerosol ***Air Mass Continuity***

  -- "Interpolate" snapshots to a ***Uniformly sampled*** output

  -- Provide detailed SSA & chemical ***Speciation***

Los Alamos Fire, New Mexico May 9, 2000

MISR 60˚ Forward

MISR Nadir

MISR 60˚ Aft