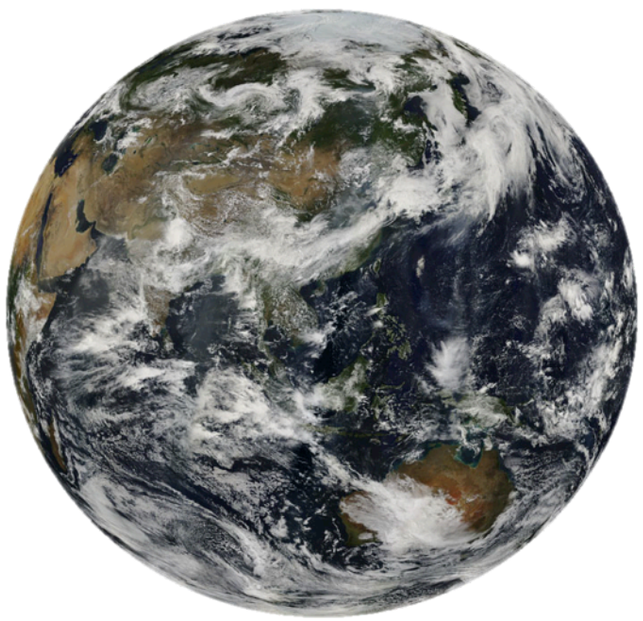
MODIS Atmosphere Team Webinar Series #2: Overview of Collection 6 Dark-Target aerosol product

Robert Levy (GSFC/613)
NASA Goddard Space Flight Center, Greenbelt, MD
and
Shana Mattoo, Leigh Munchak and Richard Kleidman (SSAI/613) ,
Falguni Patadia (MSU/613), Pawan Gupta (USRA/614)

2 July 2014



Atmosphere Team Webinar Schedule

http://aerocenter.gsfc.nasa.gov/ext/registration/

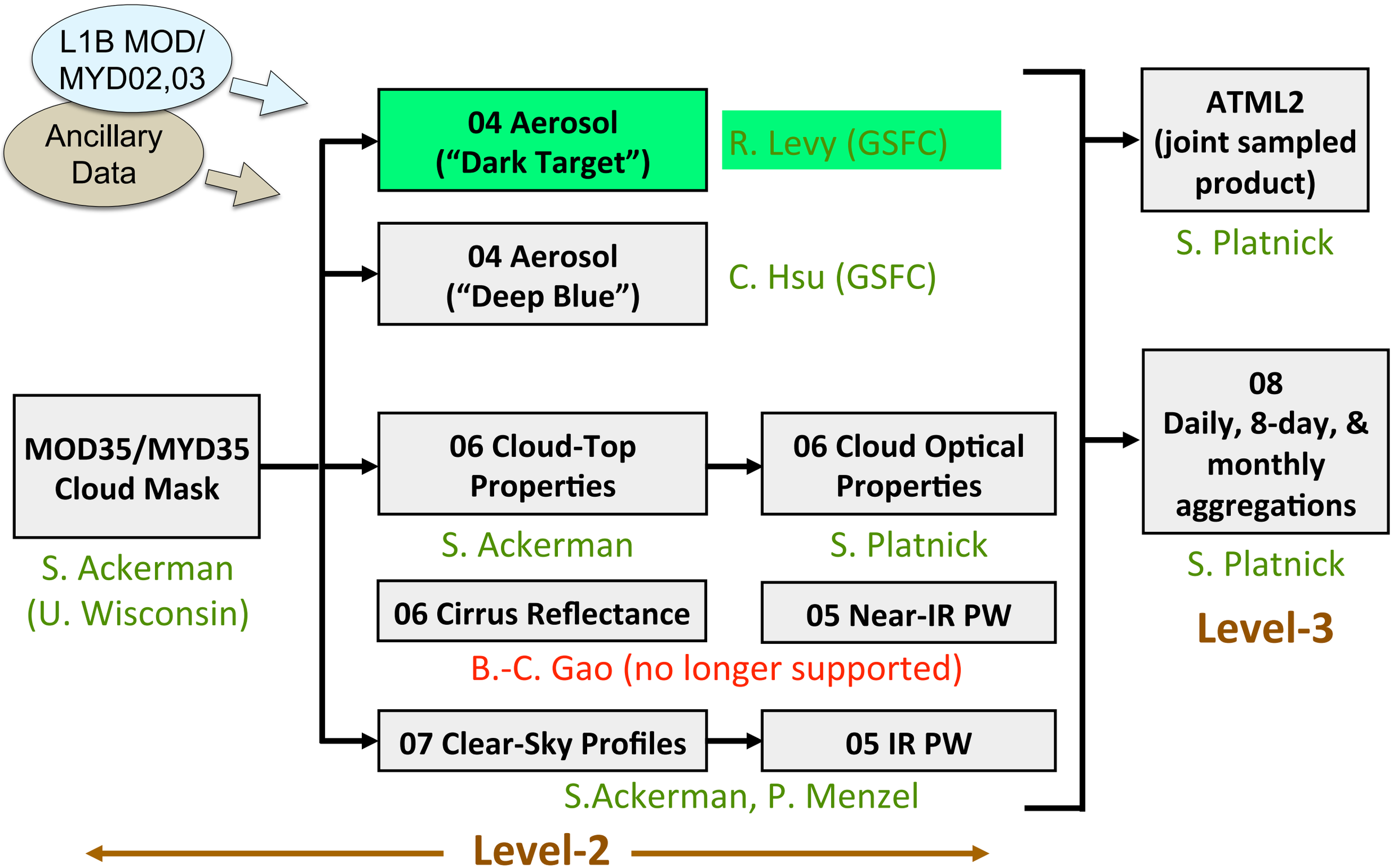
Topic	Presenter(s)	Date
Overview of Collect 6 update L1 Calibration Overview	Steve Platnick Jack Xiong	25-Jun-14
MODIS Dark Target Global 10 Km Product	Rob Levy	2-Jul-14
MODIS Aerosols Deep Blue	Andy Sayer	9-Jul-14
MODIS Aerosols Merged Dark Target: Deep Blue Product	Rob Levy / Andy Sayer	16-Jul-14
MODIS Dark Target 3 Km Product	Leigh Munchak	23-Jul-14

Outline

1. Overview (where we fit in the MODIS structure)
2. Basics of Aerosol Retrieval
3. Basics of DT ocean retrieval
4. Basics of DT land retrieval
5. Basics of products and validation
6. What's new for Collection 6 Level 2 (MxD04_L2)
7. New for Level 3 (in regards to aerosol)
8. Terra vs Aqua (and calibration and trends)
9. Summary

1. Overview

MODIS Atmosphere Team Product Organization and People



Nomenclature and Acronyms

- Product “Level” designations
  - Level-0 (**L0**): raw instrument data (digital counts)
  - Level-1B (**L1B**): calibrated/geolocated instrument data
  - Level-2 (**L2**): derived geophysical retrieval data (“pixel” level, along orbit)
  - Level-3 (**L3**): gridded data (spatial and/or temporal aggregation of geophysical products)
- MODIS “Collection”
  - refers to a (re)processing production run with consistent algorithms
  - **C5** production began began in summer 2006, reprocessing completed about a year later. C51 update in late 2008.
  - Collection 6 (**C6**) Aqua L2 production began in Dec 2013.
  - C6 Terra will hopefully begin soon.

MODIS Standardized Filenaming Convention

NASA Earth Science Data filenames for MODIS

MODIS: MxD04_L2.AYYYYDDD.HHMM.CCC.YYYYDDDHHMMSS.hdf

Definition of highlighted text:

MxD04 = Earth Science Data Type name (this is code for the "aerosol" product)

x = "O" for Terra or "Y" for Aqua

L2 = Denotes a Level-2 product (or L3 for Level-3, etc.)

A = indicates following date/time information is for the acquisition (observation)

YYYYDDD = acquisition year and day-of-year

HHMM = acquisition hour and minute start time

CCC = collection (e.g., '006' for Collection 6)

YYYYDDDHHMMSS = production data and time

hdf = denotes HDF file format

Note: There is also a new, higher resolution product: MxD04_3K, that is discussed in future webinar

Formatting of MODIS and many other NASA products

All MODIS products come in HDF-4 format.
In HDF format each file contains both data and metadata

SDS - Each parameter within a MODIS HDF file is referred to as an SDS (Scientific Data Set)

Status of MODIS C6 Production

- L1B exists for both Terra and Aqua (MxD02 and MxD03)
- Cloud Mask (MxD35) and Atmospheric Profile (MxD07) exist for both Terra and Aqua
- Reprocessing of MYD04_L2 products from Aqua MODIS started on 12-06-2013 and has completed.
  - Aqua L3 expected to begin in late June
  - Terra reprocessing to start after completion of Aqua L3
- Both C6 and C5 processing streams will continue in parallel for about a year before being exclusively C6.
- Aerosol algorithm has been ported to work on Near Real Time (NRT from LANCE). I don't know the schedule for production

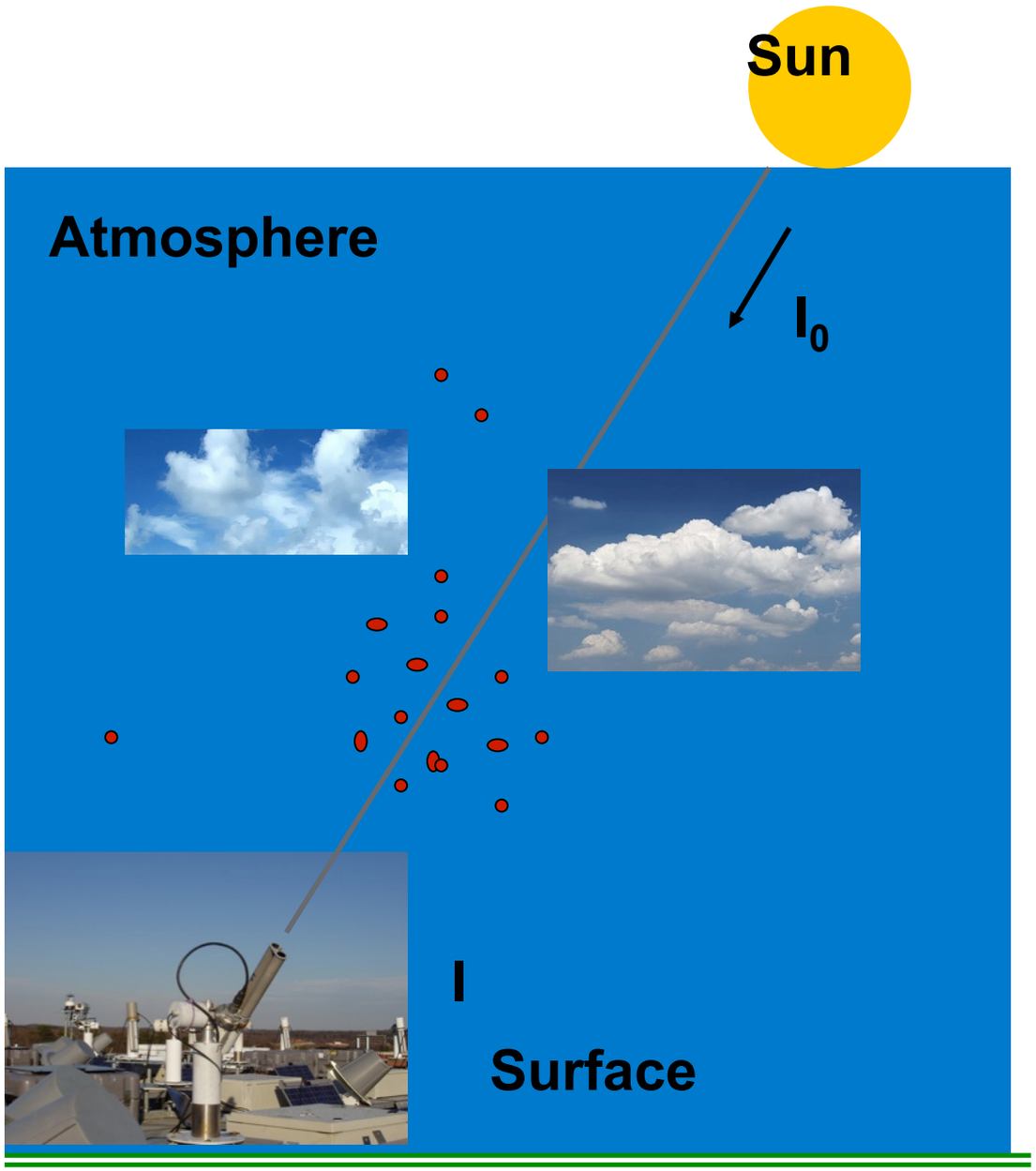
Useful Links

- Atmosphere Team Web Site
  - Home page, news, etc.: modis-atmos.gsfc.nasa.gov
  - L2 Global Browse imagery: http://modis-atmos.gsfc.nasa.gov/IMAGES/index.html. Selected products, resolution, longitude.
  - L3 Aqua MODIS Browse: TBD
  - C6 Algorithm and Product Documents: modis-atmos.gsfc.nasa.gov/products_C006update.html
  - Known problems page: modis-atmos.gsfc.nasa.gov/validation.html
- Product Distribution (LAADS)
  - Home page: ladsweb.nascom.nasa.gov/data/ (search, status, etc.)
  - ftp: ladsweb.nascom.nasa.gov/data/ftp_site.html

    e.g., allData/6/MYD04_L2/2014/001/<*filename*>
- Dark-target algorithm web page (in development)
  - Algorithm specific (history, lookup tables, specifics to aerosol retrieval)
  - http://darktarget.gsfc.nasa.gov

2. Quick overview of aerosol algorithms

What is Aerosol Optical Depth (AOD?)



The optical depth expresses the quantity of light removed from a beam by scattering or absorption during its path through a medium.

Vertical path optical depth (τ)

$$\frac{I}{I_0} = \exp(-M\tau)$$

Where M represents slant angle:

$$\tau = \tau_{aerosol} + \tau_{molecular} + \tau_{gas} + \tau_{cloud} + \tau_{etc}.$$

$$\tau_{aerosol} = AOD$$

AOD

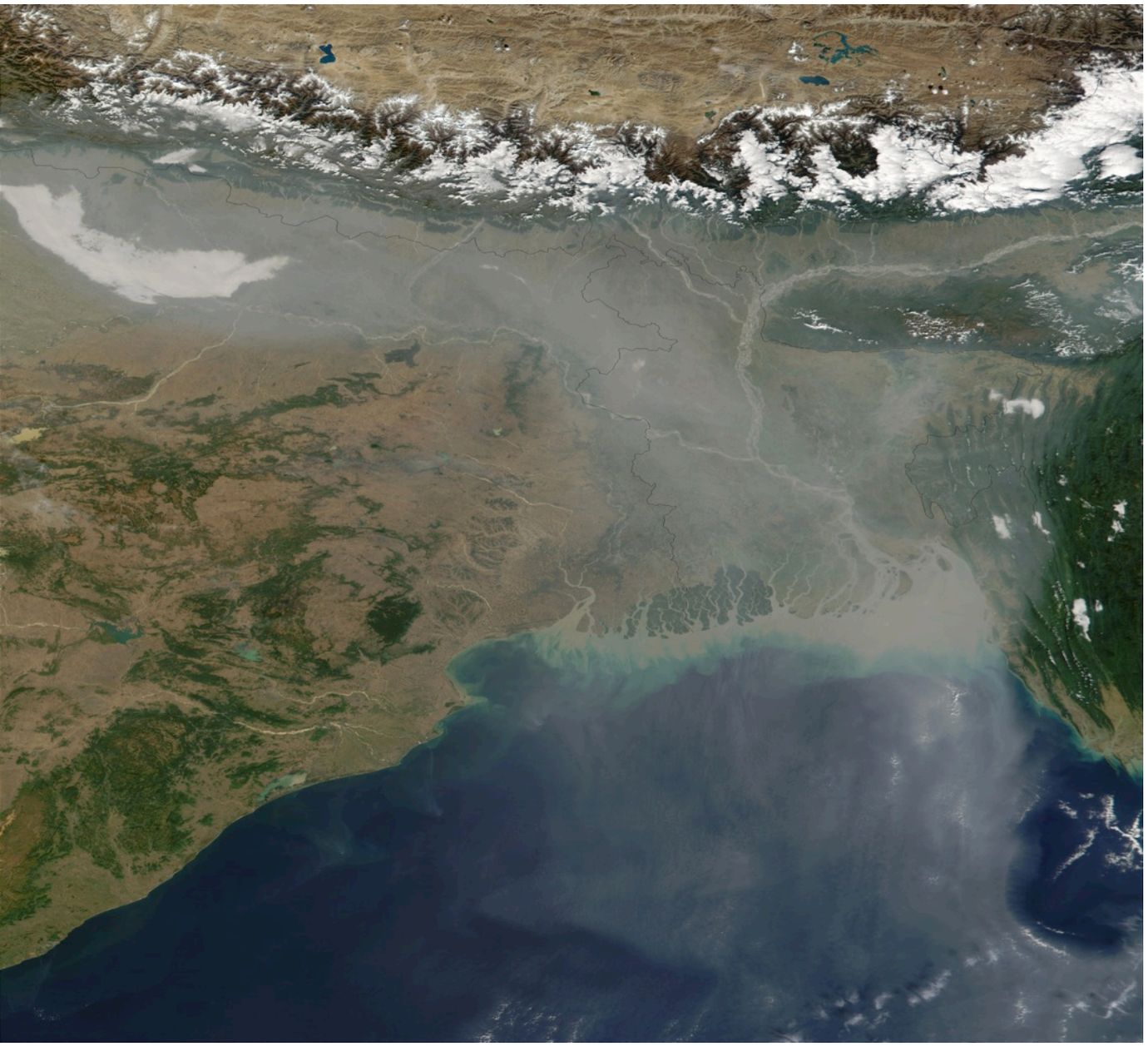
AOD is a unitless value.

Sample AOD values:
0.02 - very clean isolated areas.
0.08 – background over ocean
0.2 – fairly clean
0.6 –polluted (Texas in the summer?)
1.5 – heavy smoke/dust event
>3.0 – Sun's disk obscured!

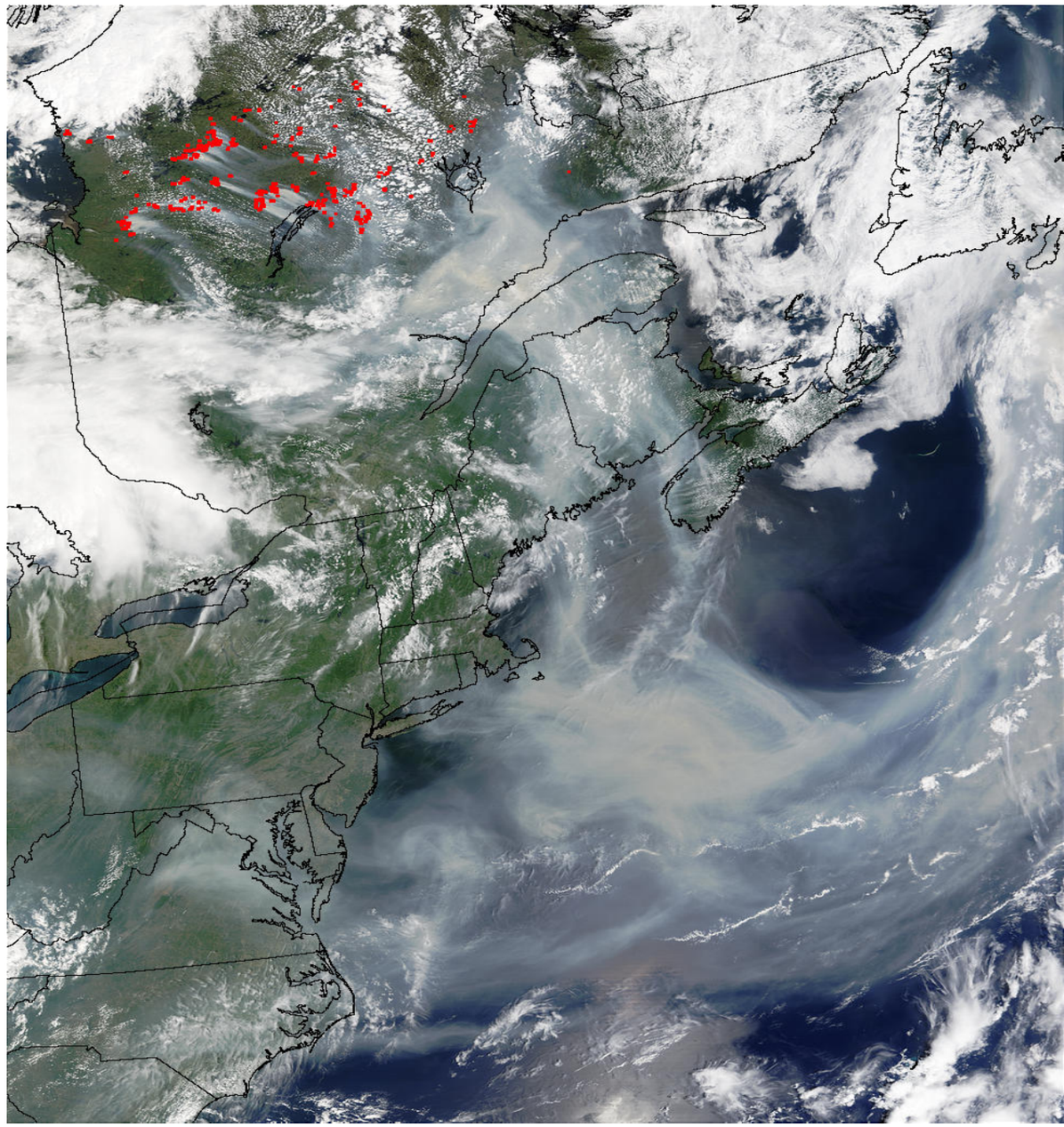
AOD is "spectral": varies with wavelength

Angstrom Exponent (AE: slope of AOD in visible)
<1.0 = "coarse" sized aerosol
>2.0 = "fine" sized aerosol.

Haze and Smoke from space



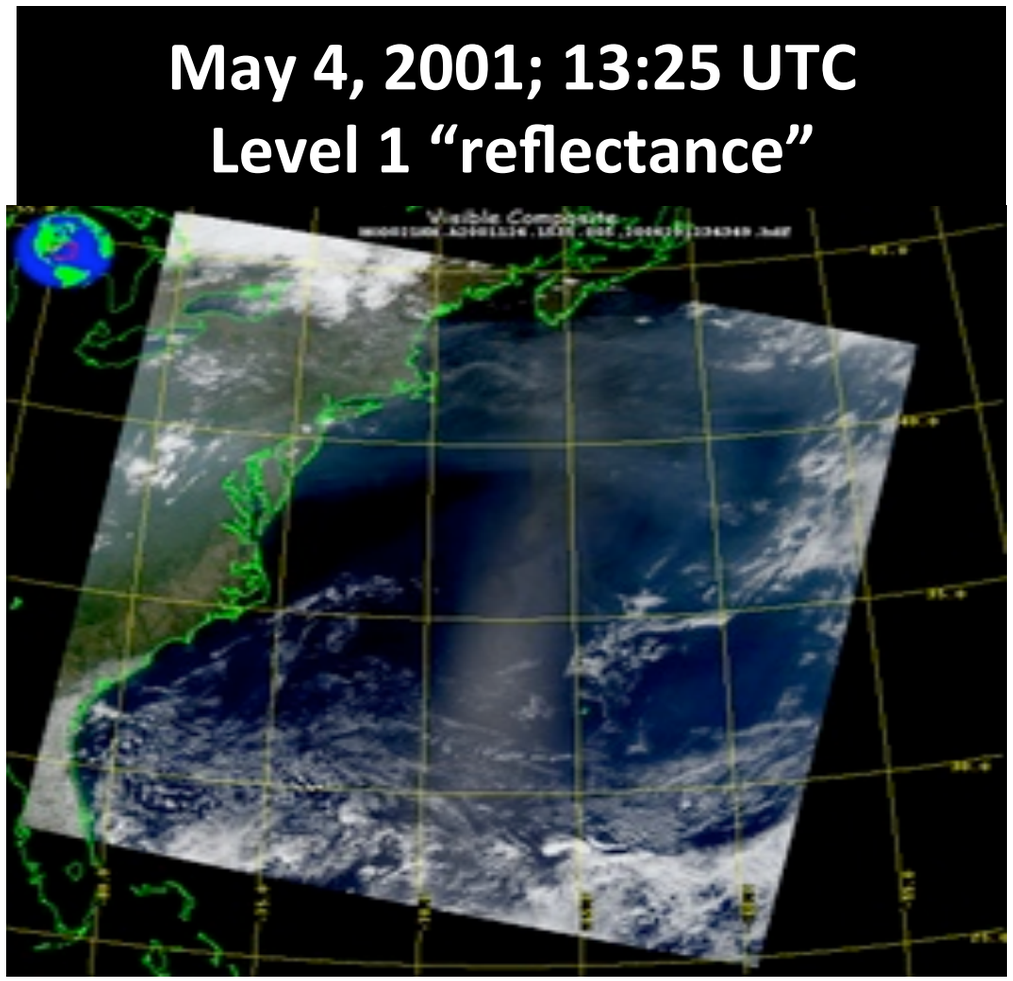
Haze over the Ganges/Bay of Bengal (4 December 2001)



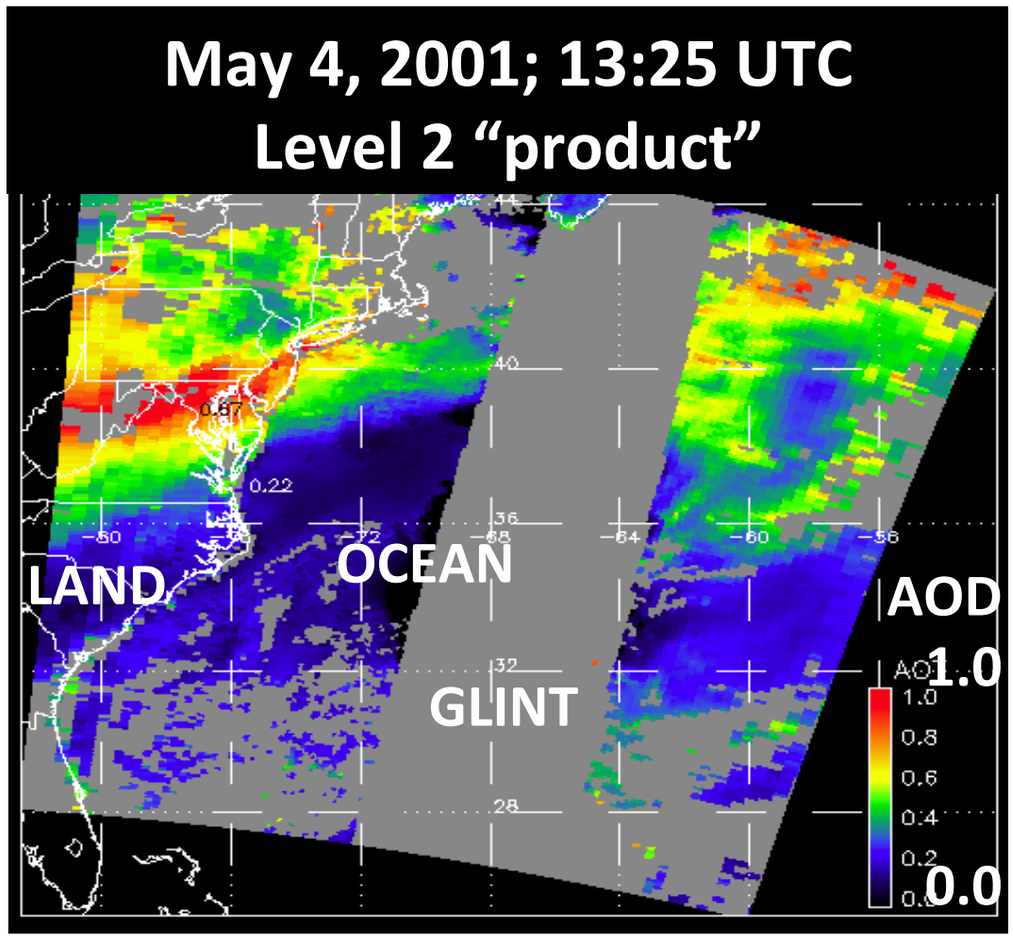
Smoke transported over Eastern Canada/USA (8 July 2002)

Aerosol retrieval from MODIS

What MODIS observes



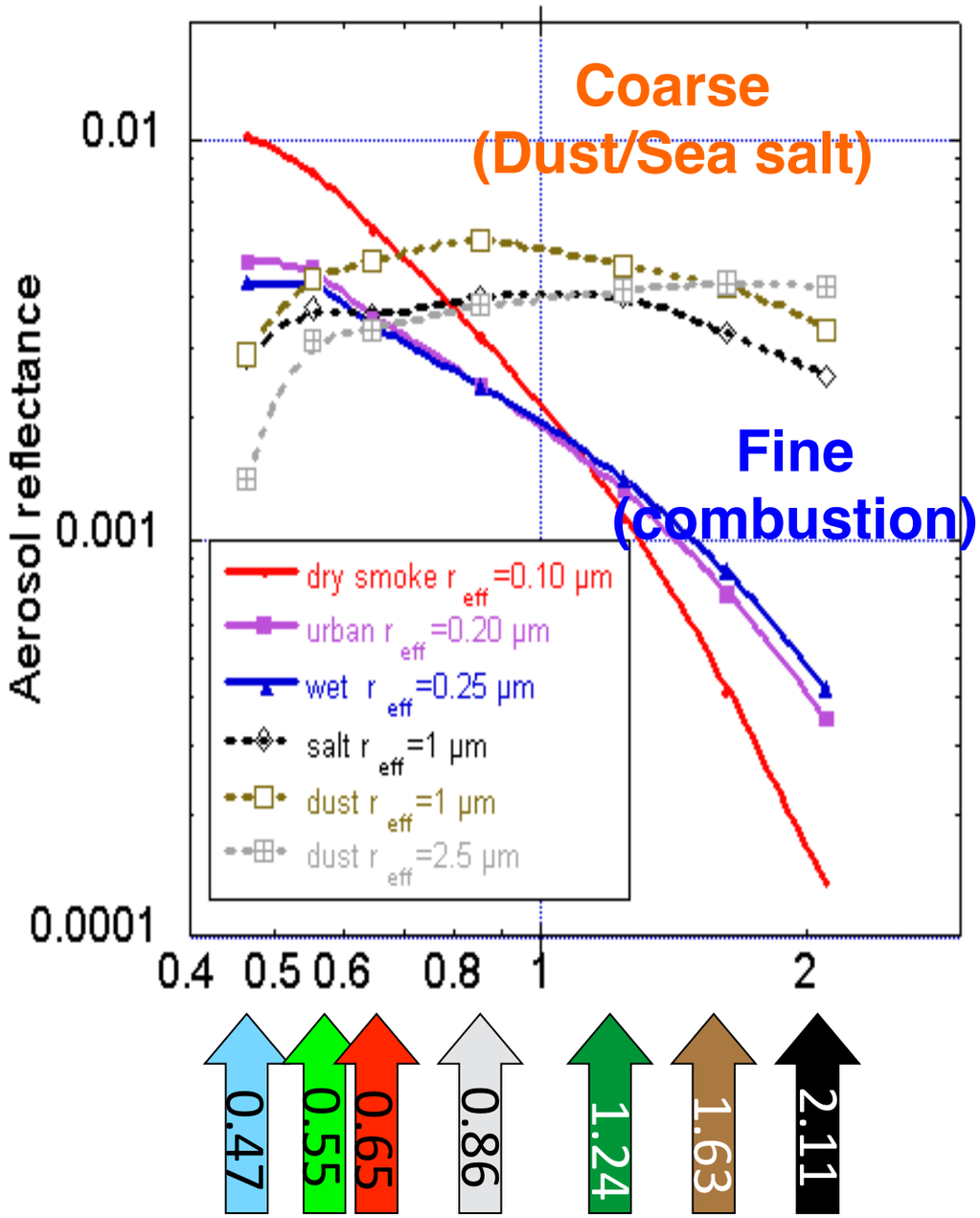
Attributed to aerosol (AOD)



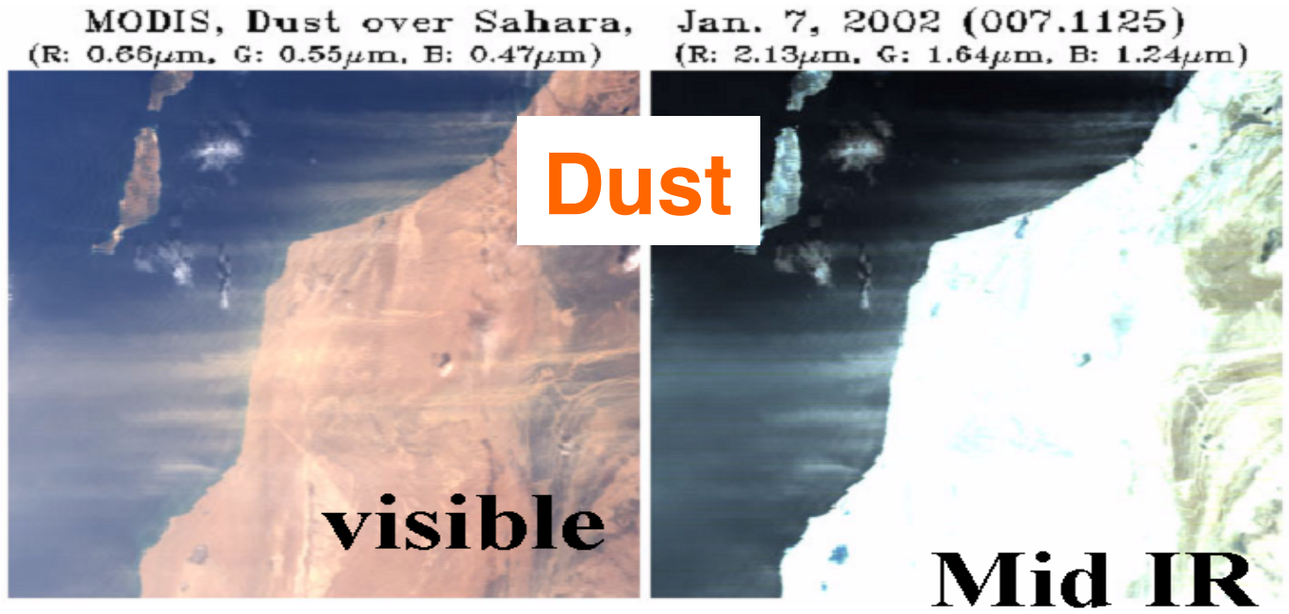
There are many different “algorithms” to retrieve aerosol from MODIS

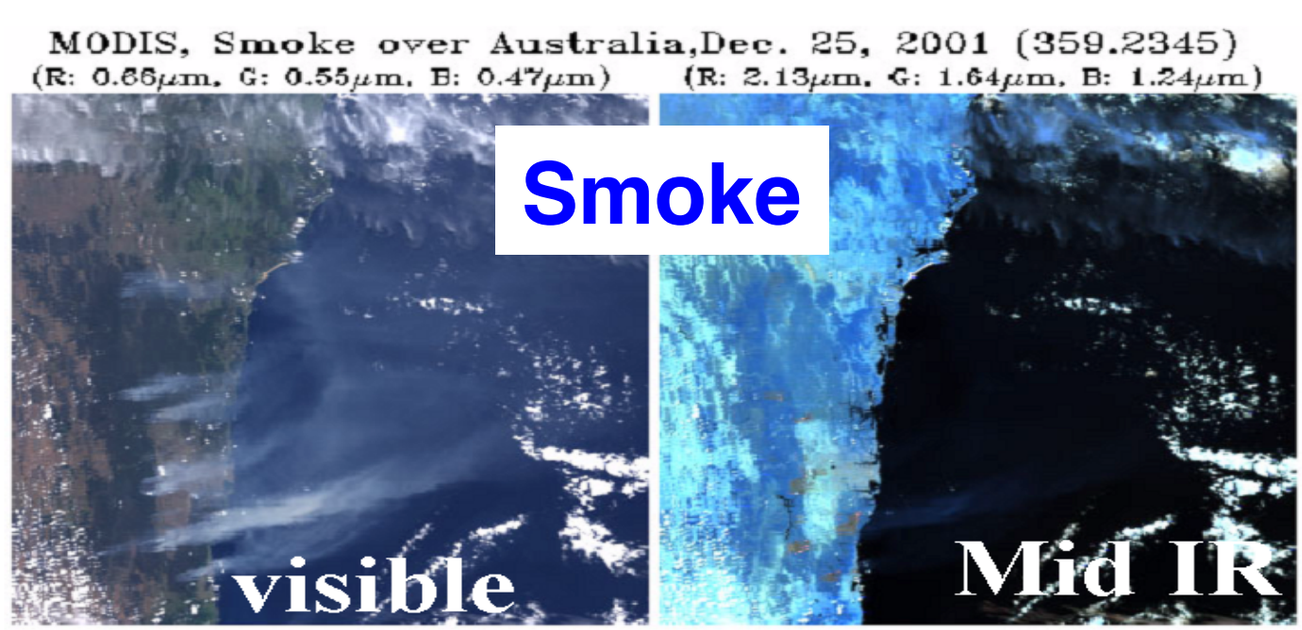
1. Dark Target (“DT” ocean and land; Levy, Mattoo, Munchak, Remer, Tanré, Kaufman)
2. Deep Blue (“DB” desert and beyond; Hsu, Bettenhousen, Sayer,..)
3. MAIAC (coupled with land surface everywhere; Lyapustin, Wang, Korkin,…)
4. Ocean color/atmospheric correction (McClain, Ahmad, …)
5. Etc (neural net, model assimilation, statistical, …)
6. Your own algorithm (many groups around the world)

AOD is “spectrally” (wavelength) dependent (which is primarily dependent on aerosol size)



MODIS “Channels”
Used for DT aerosol

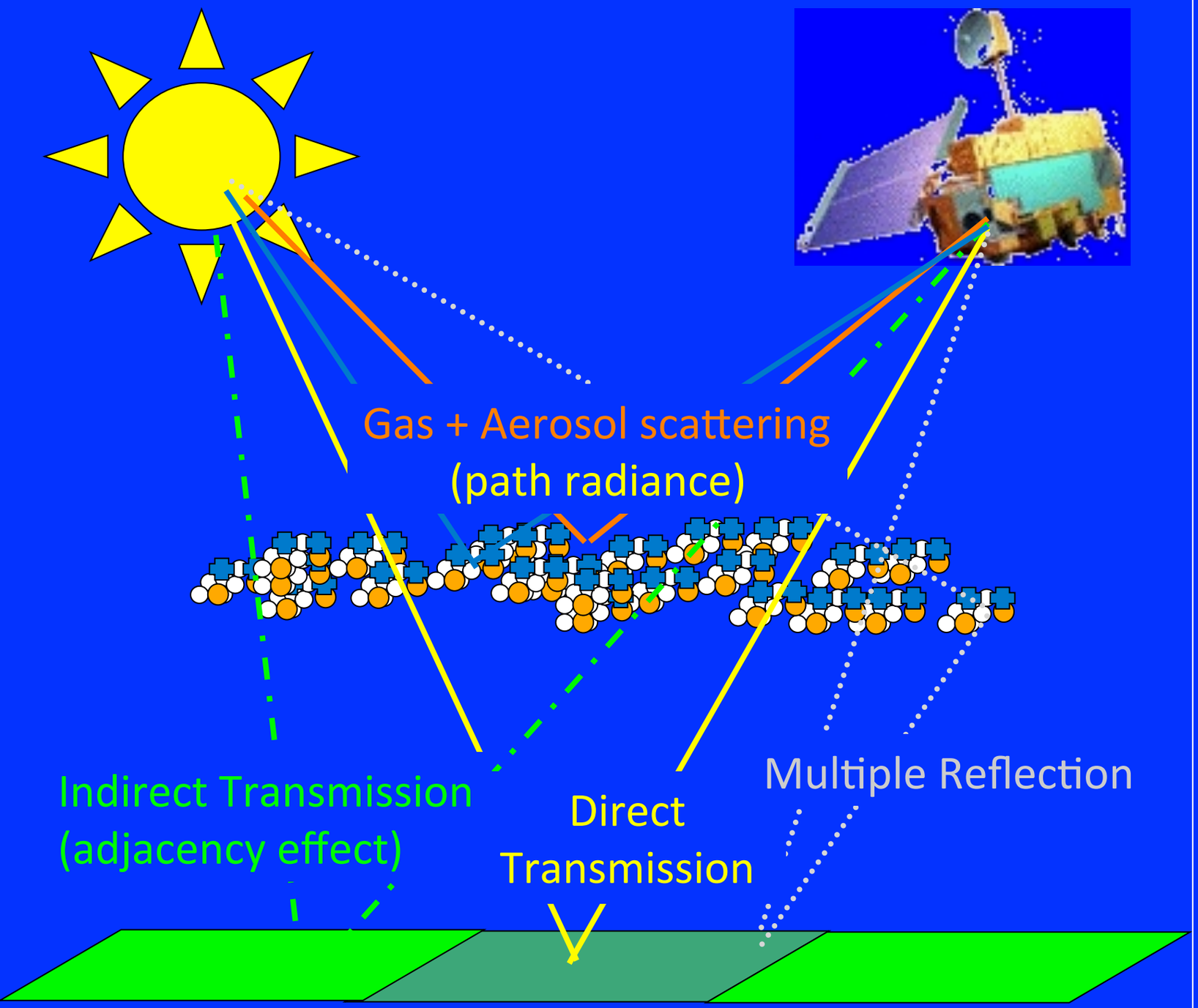




“Big” particles (e.g. Dust) reflect in IR
“Small” particles (smoke/pollution) do not.

Y. Kaufman, D. Tanré

Complicated “Clear sky” TOA Signal



Contributions from:

- Gas absorption (O_3, CO_2, etc)
- H_2O absorption
- Rayleigh (molecular) scattering
- Aerosol scattering and absorption
- Surface reflection
- Atmosphere / Surface interaction
- Contamination from neighboring pixels (clouds, etc)
- ??

… And clouds (%@(*%@!)

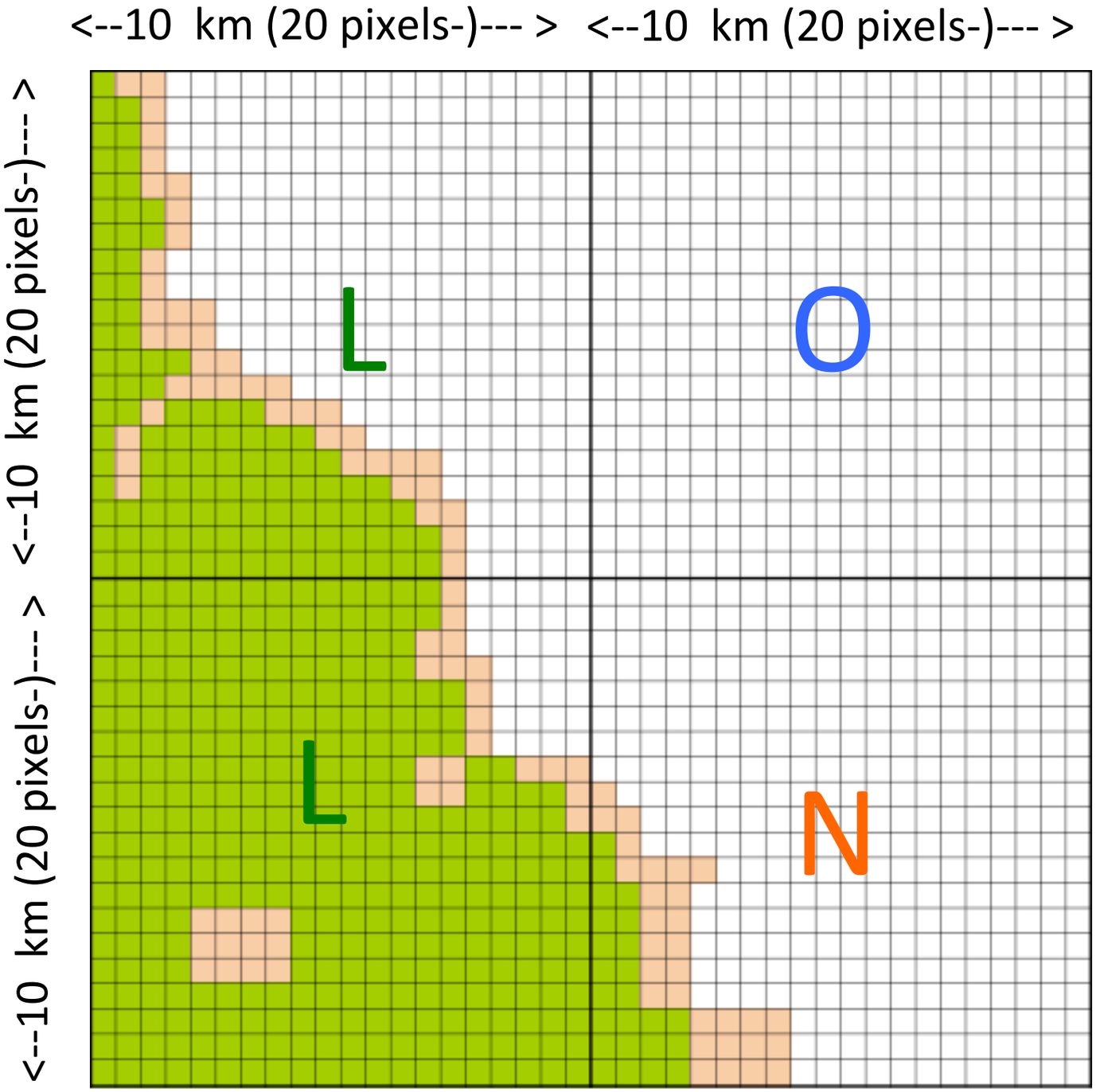
Developing a good "cloud mask"

Aerosol algorithm overview

Our aerosol remote sensing retrieval algorithm has multiple phases:

1. Organizing Level 1B radiance data into 10 km boxes for each 5 minute granule.
2. Removing distortion (gas absorption, angular effects) from the satellite signal
3. Deciding whether over "land" or "ocean"
4. Separating signal (aerosol) from noise (clouds, surface inhomogeneities, instrument issues, etc), includes "cloud masking"
5. Correctly interpreting the signal to AOD and aerosol size. "the retrieval"
6. Assigning quality assurance, reporting retrieved, derived, and diagnostic products. "the post-process"

Some basics



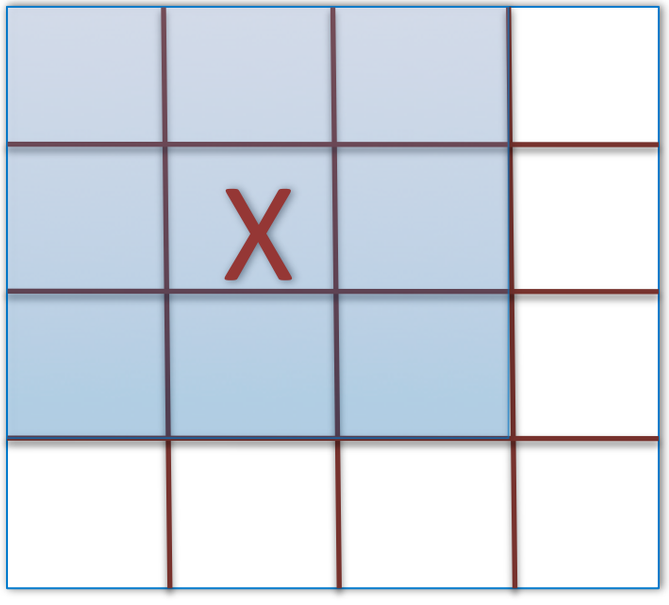
- Uses calibrated L1B reflectance data at primarily 500 m resolution.
- Splits up the granule into 20x20 boxes (~10 km at nadir).
- Corrects for “gas absorption” in each pixel (H_2O, O_3, CO_2).
- Decides whether pixel is “land” or “ocean”
  - If “all” pixels are ocean (white) then try Ocean retrieval algorithm
  - If “any” pixels are land (green), then try Land (must be at least 24)
  - Coastal or ambiguous (pale) pixels are Neither.
- Does appropriate retrieval

Cloud Masking

There are many “tests” for clouds in the MODIS scene.

- Spatial Variability Tests (clouds appear bumpy)
- Visible channel brightness (clouds appear bright)
- Visible channel gradients (aerosols appear “colored”)
- Cirrus Cloud Removal (high clouds obscure water vapor)
- IR tests: (clouds are colder than the surface)

MODIS "aerosol" cloud mask

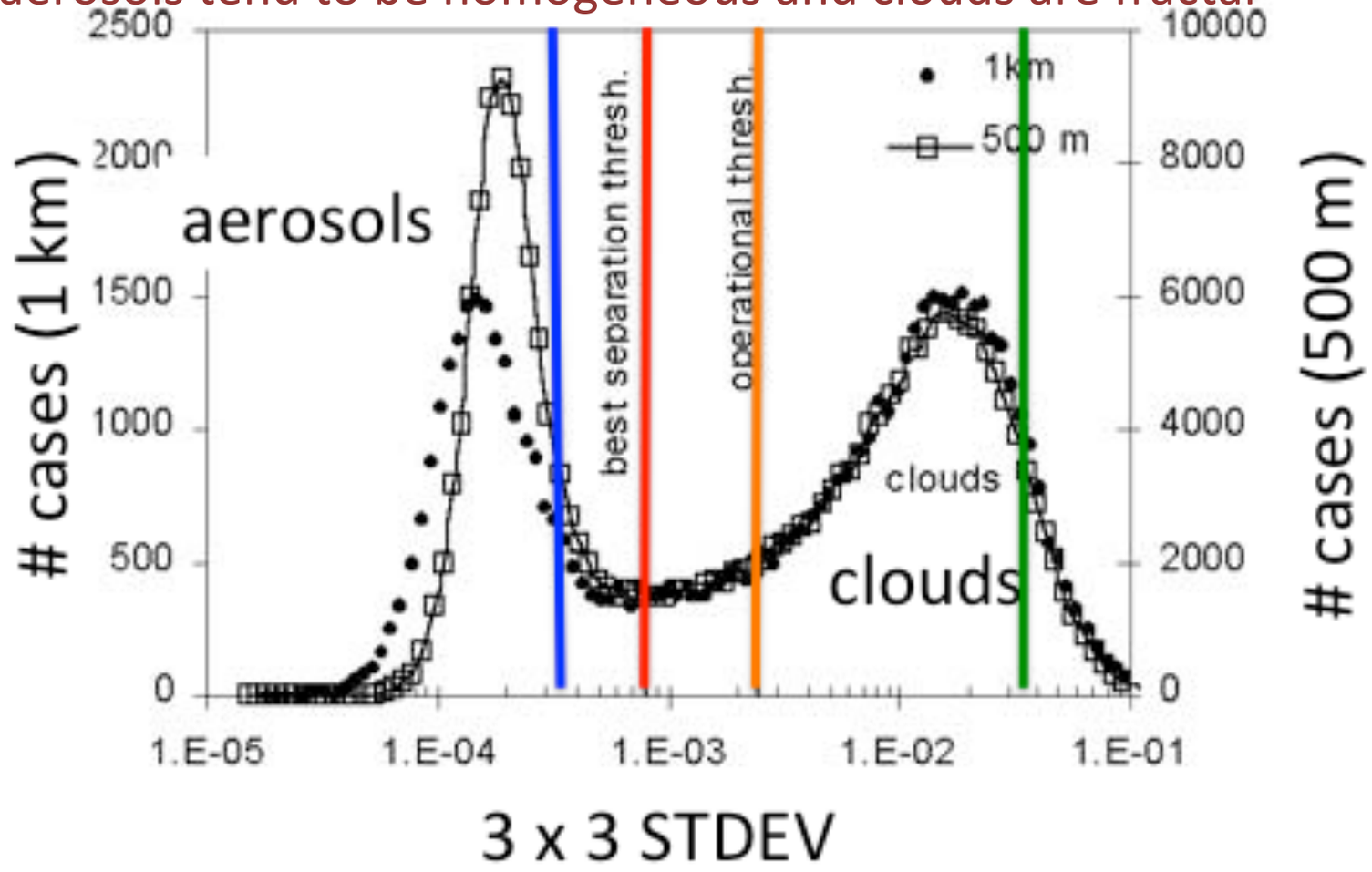


Calculate the standard deviation of the observed reflectance in every 3 x 3 set of pixels (at 500 m or 1 km).

If the STDEV > threshold THEN the center pixel is cloudy

For C6: Slight changes for thresholds and formulas

aerosols tend to be homogeneous and clouds are fractal



Martins et al., (2002)

Cloud Masking

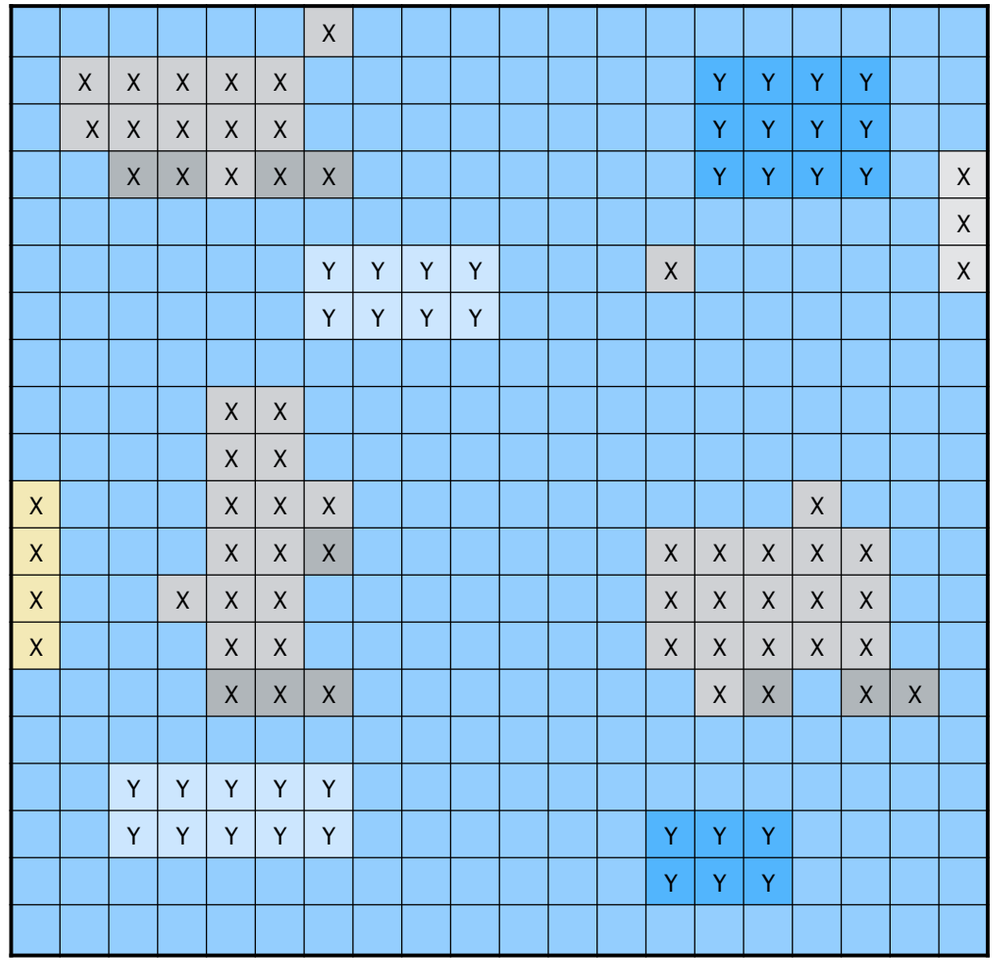
There are many “tests” for clouds in the MODIS scene.

- Different whether over land or ocean
- Could be an entire webinar on its own.

3. Basics of ocean retrieval

Ocean retrieval: preliminaries

- Know that 100% of 20x20 (500 m) pixels are “ocean”
- Cloud masking (pixel de-selection) is performed
- More pixel de-selection (underwater sediments, glint, etc)
- → We have N* “clear” pixels (not marked with “X”)



- Sort N* pixels in ascending order in terms of reflectance magnitude, remove 25% darkest and 25% brightest (residual cloud contamination including shadows)
- → We have N “clear” pixels (not “X” or “Y”)

- Calculate average reflectance of N pixels in six channels
  - (0.55, 0.65, 0.86, 1.24, 1.63, 2.11 μm)

We have removed clouds, found the best pixels, …..

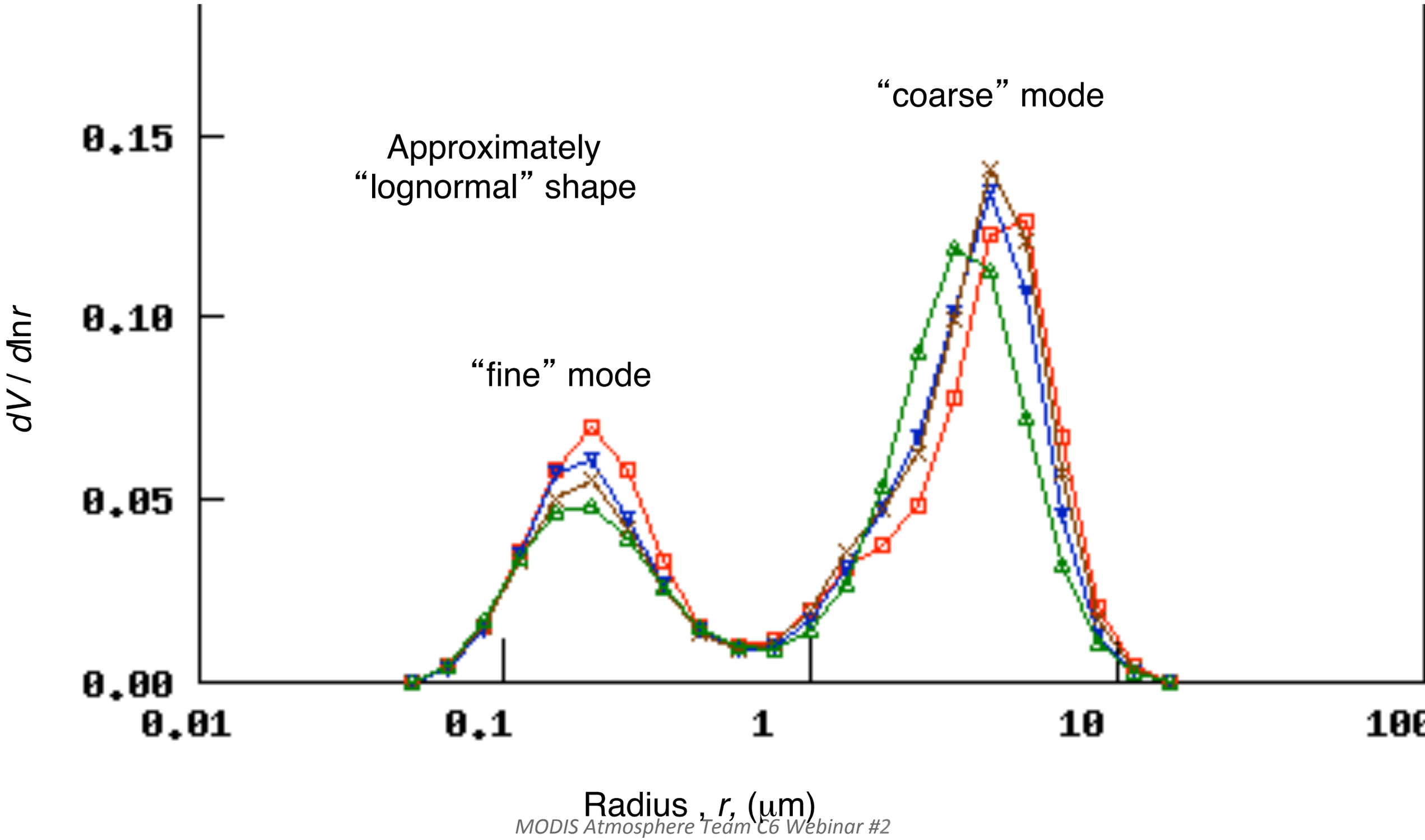
Let's retrieve aerosol ! (Ocean)

We need to make several assumptions to correctly Infer the aerosol characteristics from the remaining signal.

Assumptions include:

- Surface reflectance contribution as function of wind speed (whitecaps + glint + underwater radiance + …)
- Ambient aerosol is bi-modal (a superposition of "fine" and "coarse" aerosol)

Ambient Size Distribution is approximately bi-lognormal (e.g., from AERONET)



Physical properties of aerosol
Relationship to optical properties

If we understand:

- Size distribution: Assumed as superposition of lognormals, *i*, with radii $r_{v,i}$, standard deviation σ_i, and total volume $V_{0,i}$

  For one lognormal mode:

$$\frac{dV}{d\ln r} = \frac{V_{0,i}}{\sigma_i\sqrt{2\pi}}\exp\left(-\frac{\ln(r/r_{v,i})^2}{2\sigma_i{}^2}\right)$$

- Spectral Complex Refractive index, $m_{\lambda,I}$
- Shape distribution: Spherical? Spheroids?

These aerosol properties are directly linked to spectral scattering / absorption (extinction) properties through Mie theory (if spherical), or other theory (e.g. T-matrix for collection of spheroids).

We can calculate spectral aerosol "reflectance" for a variety of aerosol types. These are our LOOKUP TABLES!

Aerosol "models" over ocean
Are represented by theoretical "modes"

Fine (Small) Mode	Refractive Index λ=0.47-->0.86μm	r_g	σ	r_{eff}	Comments
1	1.45-0.0035i	0.07	0.40	0.10	Water Soluble
2	1.45-0.0035i	0.06	0.60	0.15	Water Soluble
3	1.40-0.0020i	0.08	0.60	0.20	Water Soluble with humidity
4	1.40-0.0020i	0.10	0.60	0.25	Water Soluble with humidity
Coarse (Big) Mode	**Refractive Index λ=0.47-->0.86μm**	**r_g**	**σ**	**r_{eff}**	**Comments**
5	1.35-0.001i	0.40	0.60	0.98	Wet sea salt type
6	1.35-0.001i	0.60	0.60	1.48	Wet sea salt type
7	1.35-0.001i	0.80	0.60	1.98	Wet sea salt type
8	1.53-0.003i (0.47) 1.53-0.001i (0.55) 1.53-0.000i (0.66) 1.53-0.000i (0.86)	0.60	0.60	1.48	Dust-like type
9	1.53-0.003i (0.47) 1.53-0.001i (0.55) 1.53-0.000i (0.66) 1.53-0.000i (0.86)	0.50	0.80	2.50	Dust-like type

ATBD

Look Up Tables - LUT

Radiative transfer code is time consuming.

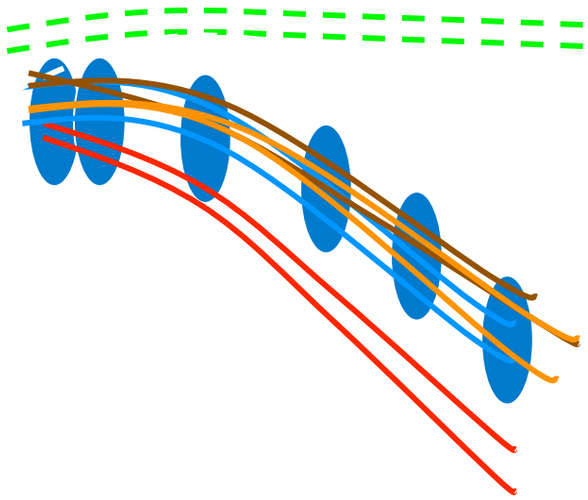
To run more efficiently we make use of a set of pre-computed tables for the various sets of possible angles and amounts of aerosol.

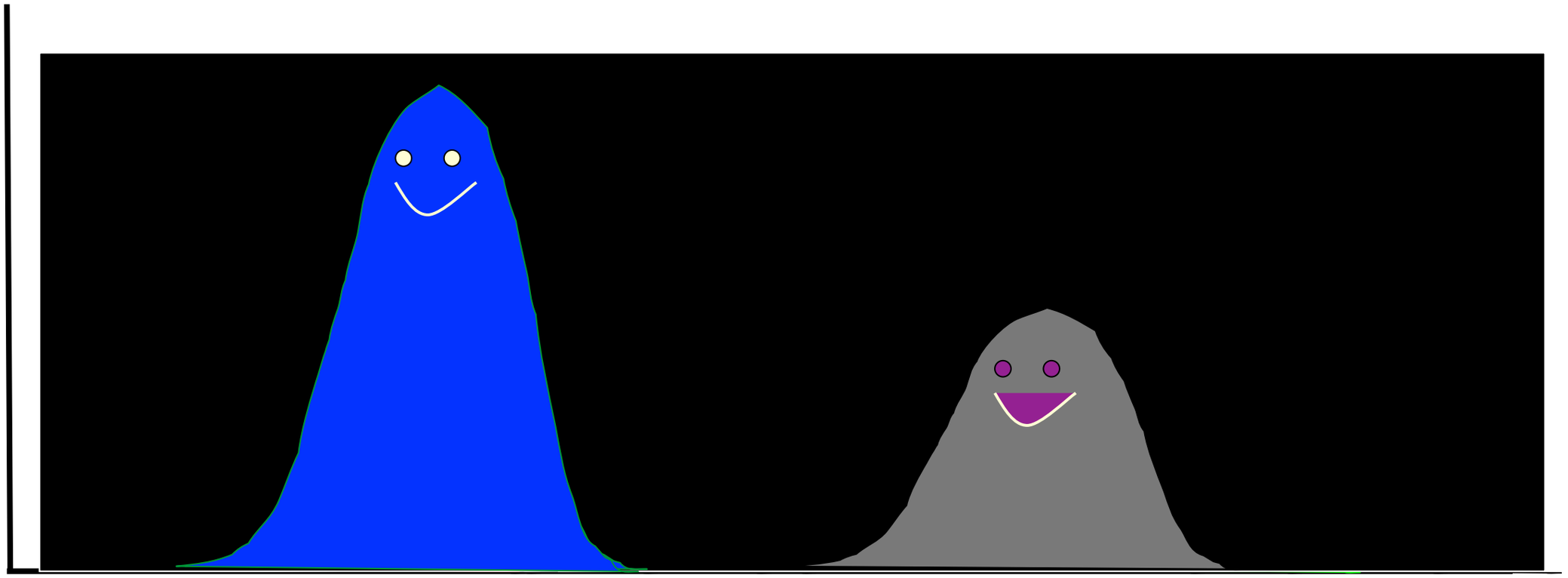
- $\rho_\lambda^a, T_\lambda, s_\lambda$: (path radiance, transmission, backscattering)
  Combination of Rayleigh + Aerosol

- ρ_λ^s: (surface reflectance)
  Combination of foam / whitecaps (assuming wind speed) + water leaving radiance" (nonzero at 0.55 μm only)

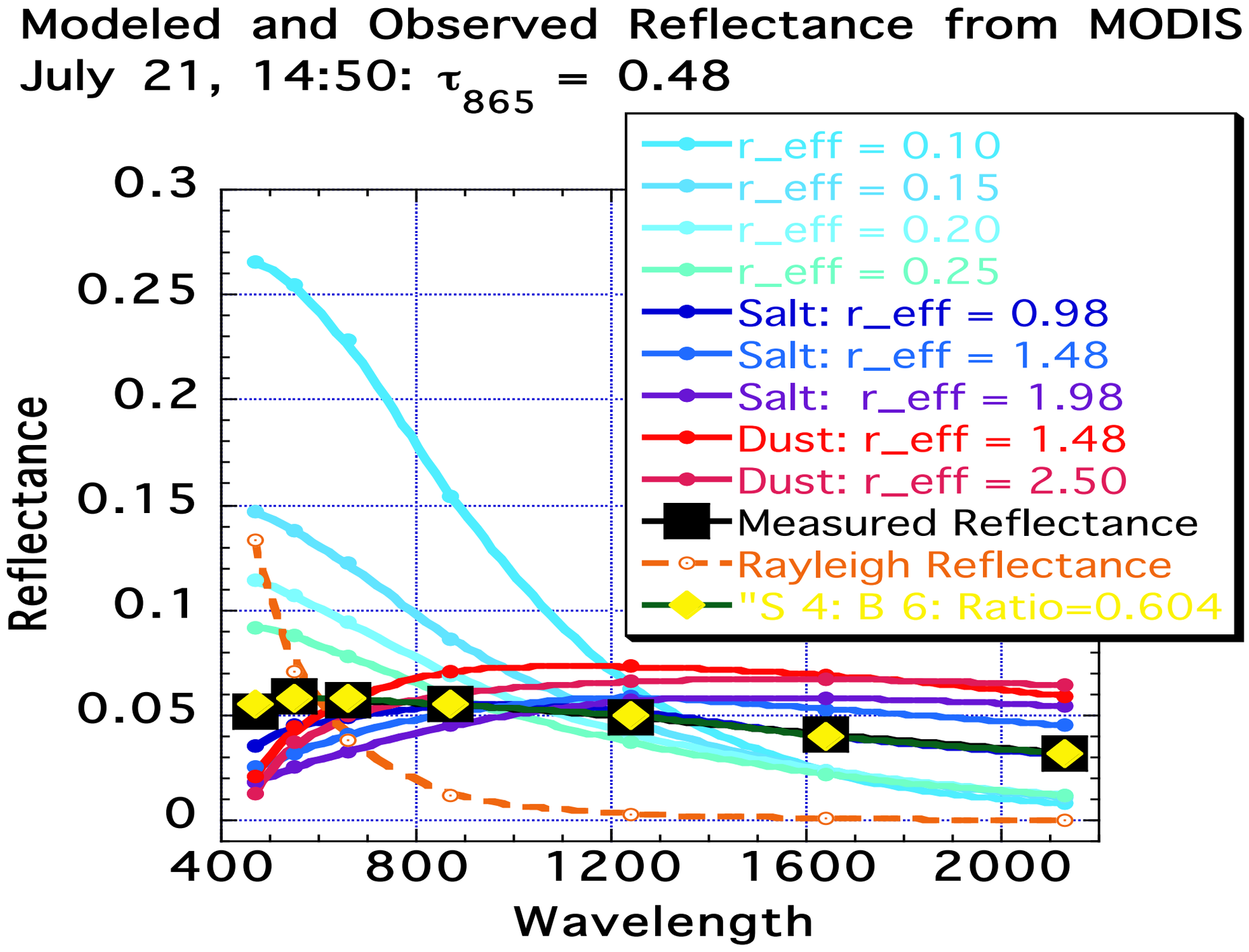
MODIS aerosol retrieval over ocean

Find one coarse mode and
one fine mode
that combine to match the
observed spectral reflectances





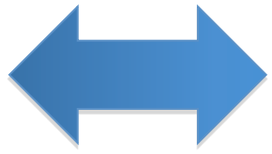
MODIS Ocean Aerosol Retrieval



Remote Sensing of Spectral Aerosol Properties: A Classroom Experience
(Levy and Pinker, BAMS, 2007)

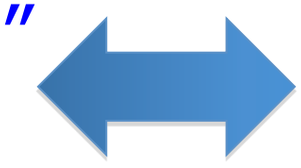
MxD04 Aerosol Products over Ocean

"Effective_Optical_Depth_Average_Ocean"
Retrieved AOD at 7 wavelengths
(.47, .55, .66, .86, 1.24, 1.63, 2.13 μm)



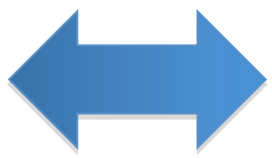
AOD

"Optical_Depth_Ratio_Small_Ocean_0.55*"
Fraction of Fine Mode AOD at 0.55



Fine Mode Fraction

"Optical_Depth_Small_Average_Ocean"
AOD * Fine Mode Ratio



Fine AOD

There are many other parameters, some derived, some diagnostic. See documentation for details!

Quality Assurance is Extremely Important!!

QA indicates the confidence in the quality of the retrieval.

Quality_Assurance_Ocean
Scale is 0 (low) – 3 (high)

Recommend: Ocean QA > 0

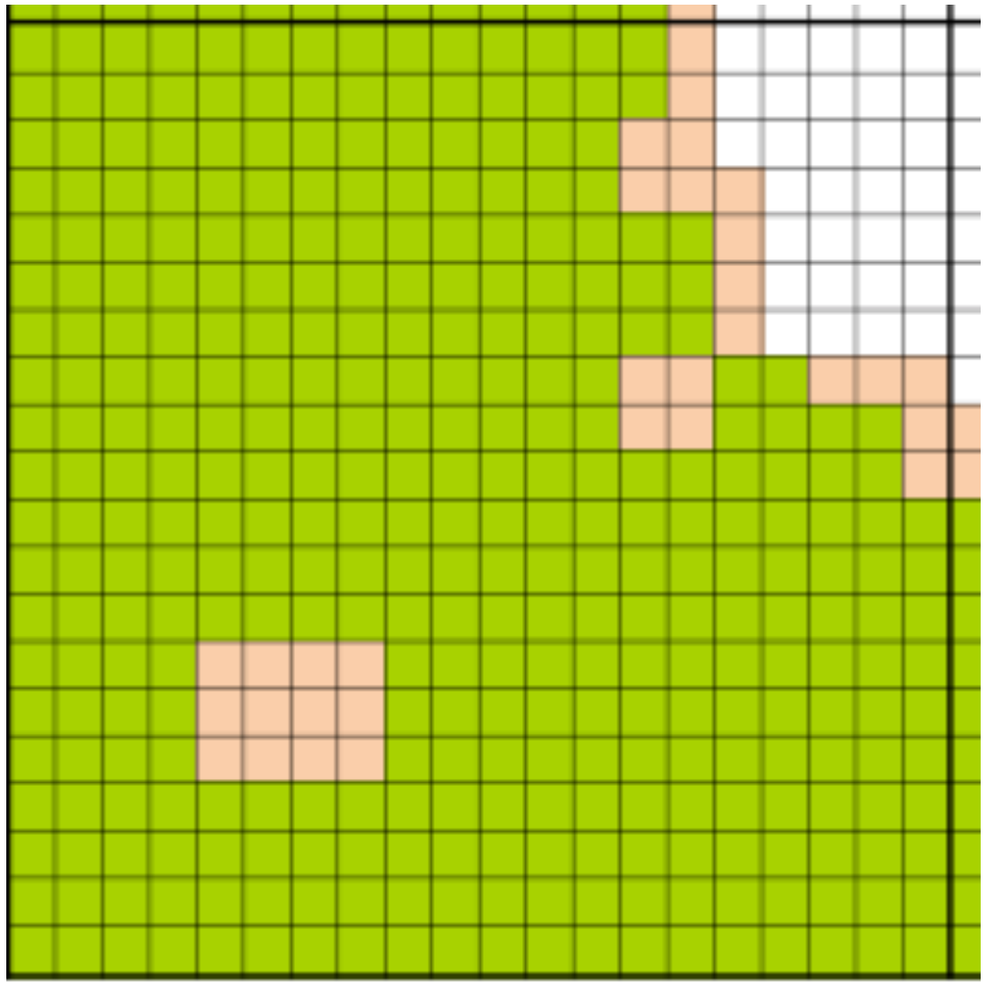
Main Factors:

- Number of pixels “N” (out of 400)
- Error fitting (difference between observation and LUT)
- How close to glint?
- Are retrieved quantities “realistic?”
- Is aerosol signal so “low” that aerosol properties cannot be retrieved?
- Etc

4. Basics of land retrieval

Land retrieval: preliminaries

- Know that at least some % of 20x20 (500 m) pixels are “land”
- Cloud masking (pixel de-selection) is performed
- More pixel de-selection (inland water, surface heterogenitity, snow, ice, etc)
- → We have N* “clear” pixels



- Sort N* pixels in ascending order in terms of reflectance magnitude, remove 20% darkest and 50% brightest (residual cloud contamination including shadows, biasing towards “dark” targets)
- → We have N “clear” pixels

- Calculate average reflectance of N pixels in five channels
  - (0.47, 0.65, 0.86, 1.24, 2.11 μm)

Structure of land retrieval

We need to make several assumptions to infer the aerosol characteristics from the reflectance signal (average of N pixels)

- Dark targets: Surface reflectance contribution is related spectrally

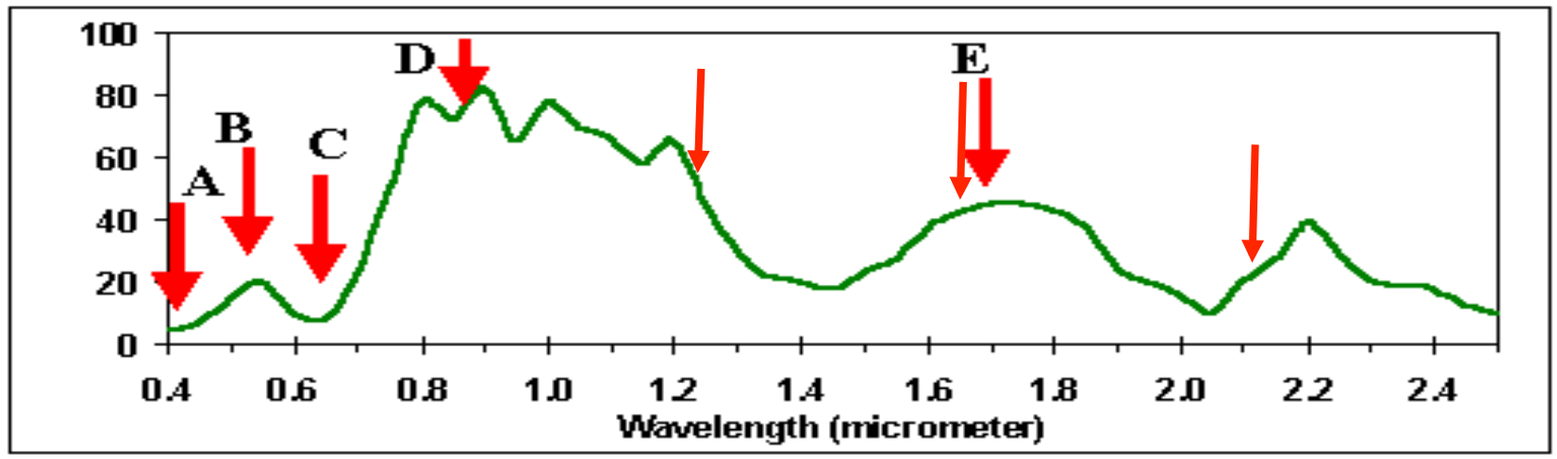
Vegetation reflectance:

$\rho^s_{0.66} \approx 0.55 \rho^s_{2.1}$

$\rho^s_{0.47} \approx 0.50 \rho^s_{0.66}$

Depends on

$\rho_{0.86}, \rho_{1.2}, \rho_{2.1}$ and Θ

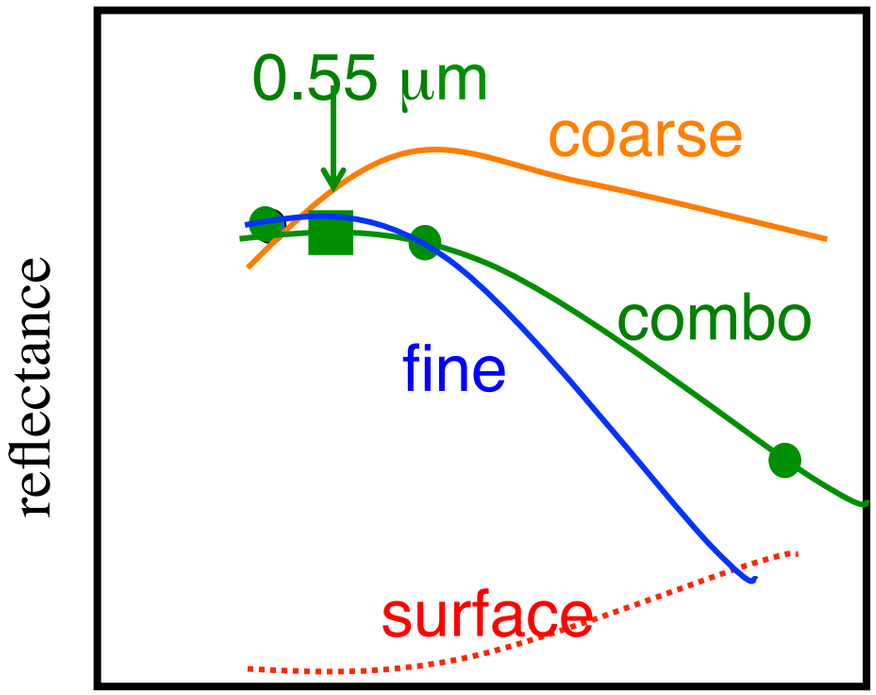


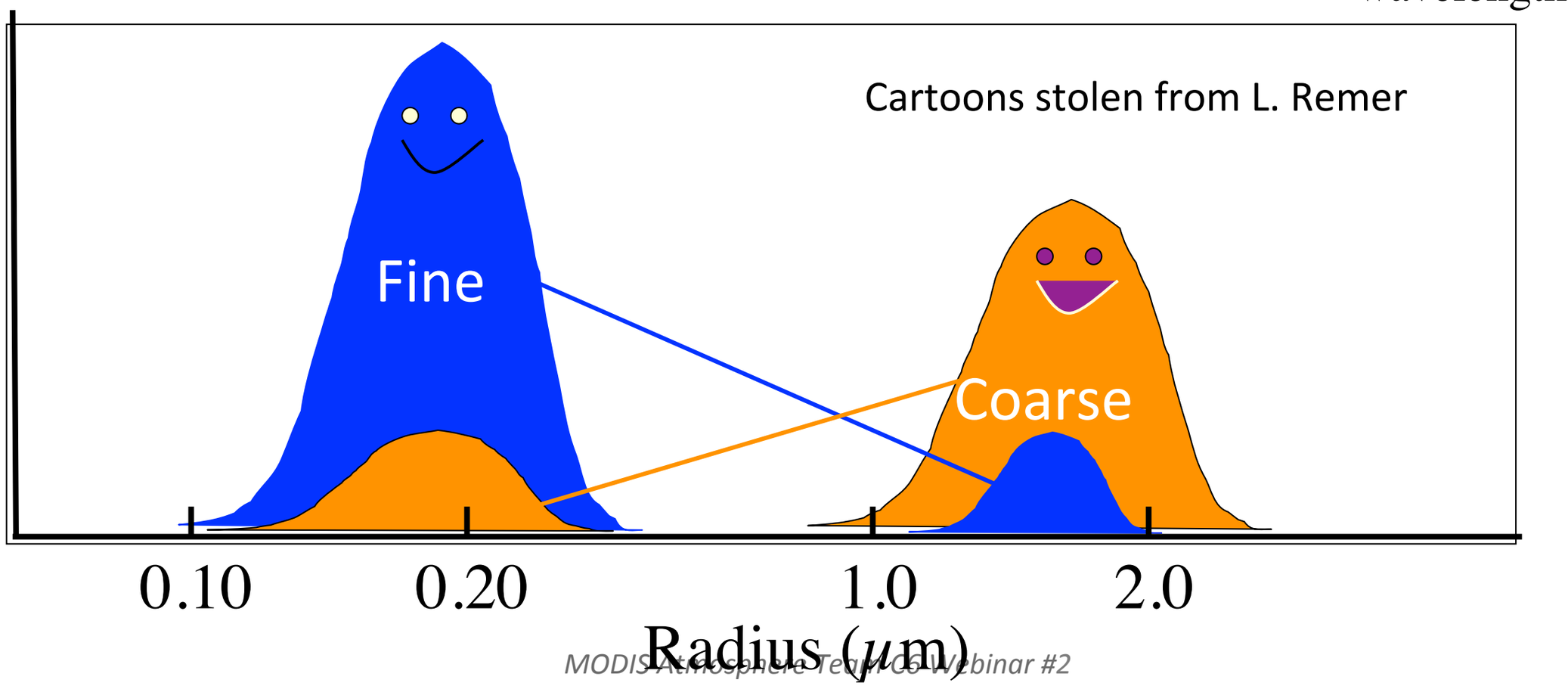
- Ambient aerosol is multi-modal (a superposition of “fine” and “coarse” aerosol models, each are bi-modal).

- Aerosol type is related to when in the year, and where in the world. We have to assume aerosol type

Retrieval: Inversion over "dark" targets

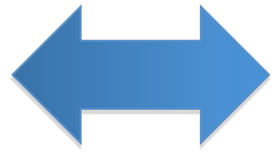
Calculate optical loading τ and weighting η of fine-dominated model (to total τ), combined with the surface reflectance ρ_s, that best matches the observed spectral reflectance.





MxD04 Aerosol Products over Land

"Corrected_Optical_Depth_Land"
Retrieved AOD at 4 wavelengths
(0.47, 0.55, 0.66, 2.11 μm)



AOD

"Optical_Depth_Ratio_Small_Land"
Fraction of Fine Model AOD at 0.55

Fine Mode Fraction

There are many other parameters, some derived, some diagnostic. See documentation for details!

Quality Assurance is Extremely Important!!

QA indicates the confidence in the quality of the retrieval.

Quality_Assurance_Land
Scale is 0 (low) – 3 (high)

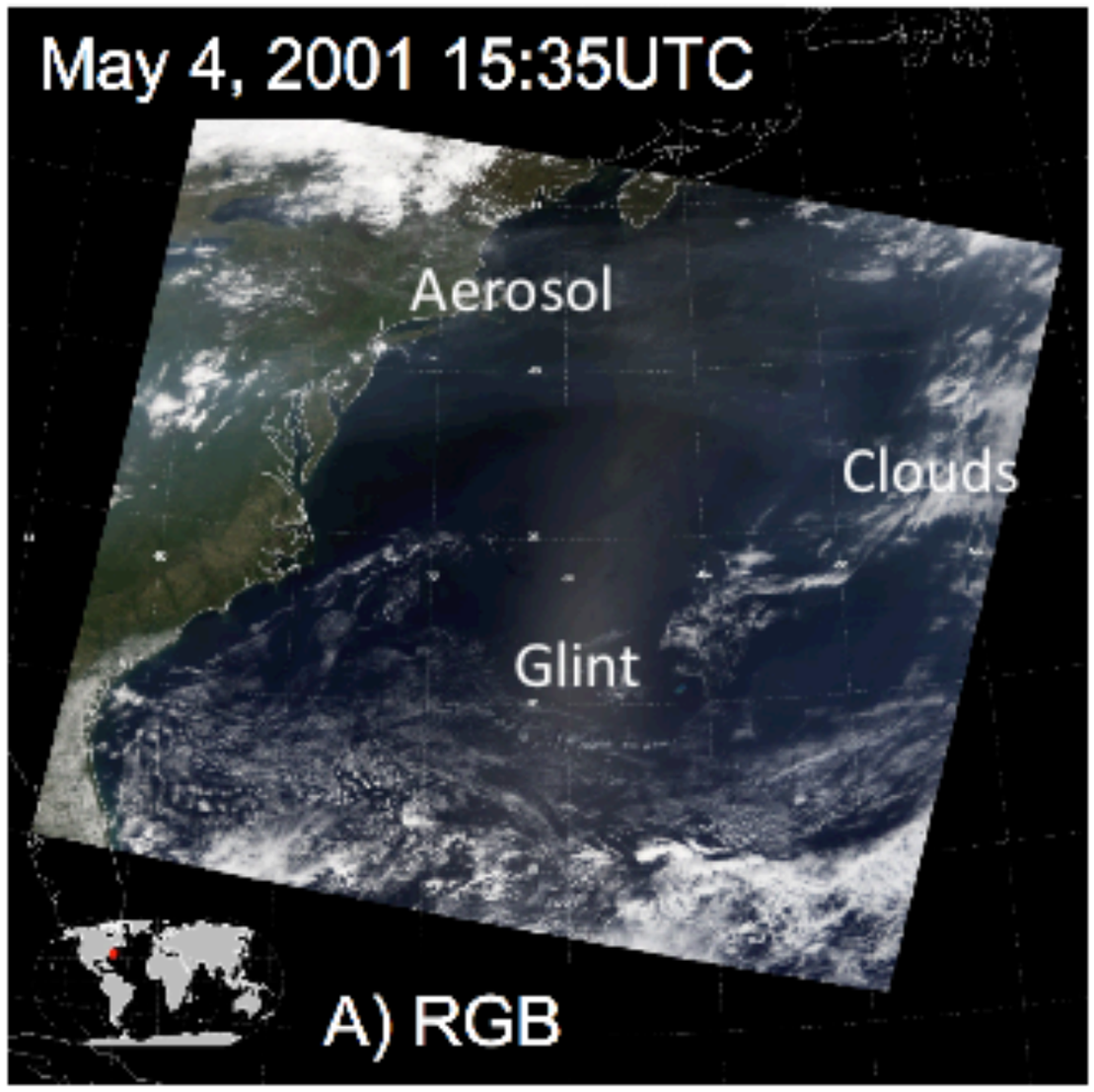
Recommend: Land QA ≥ 1

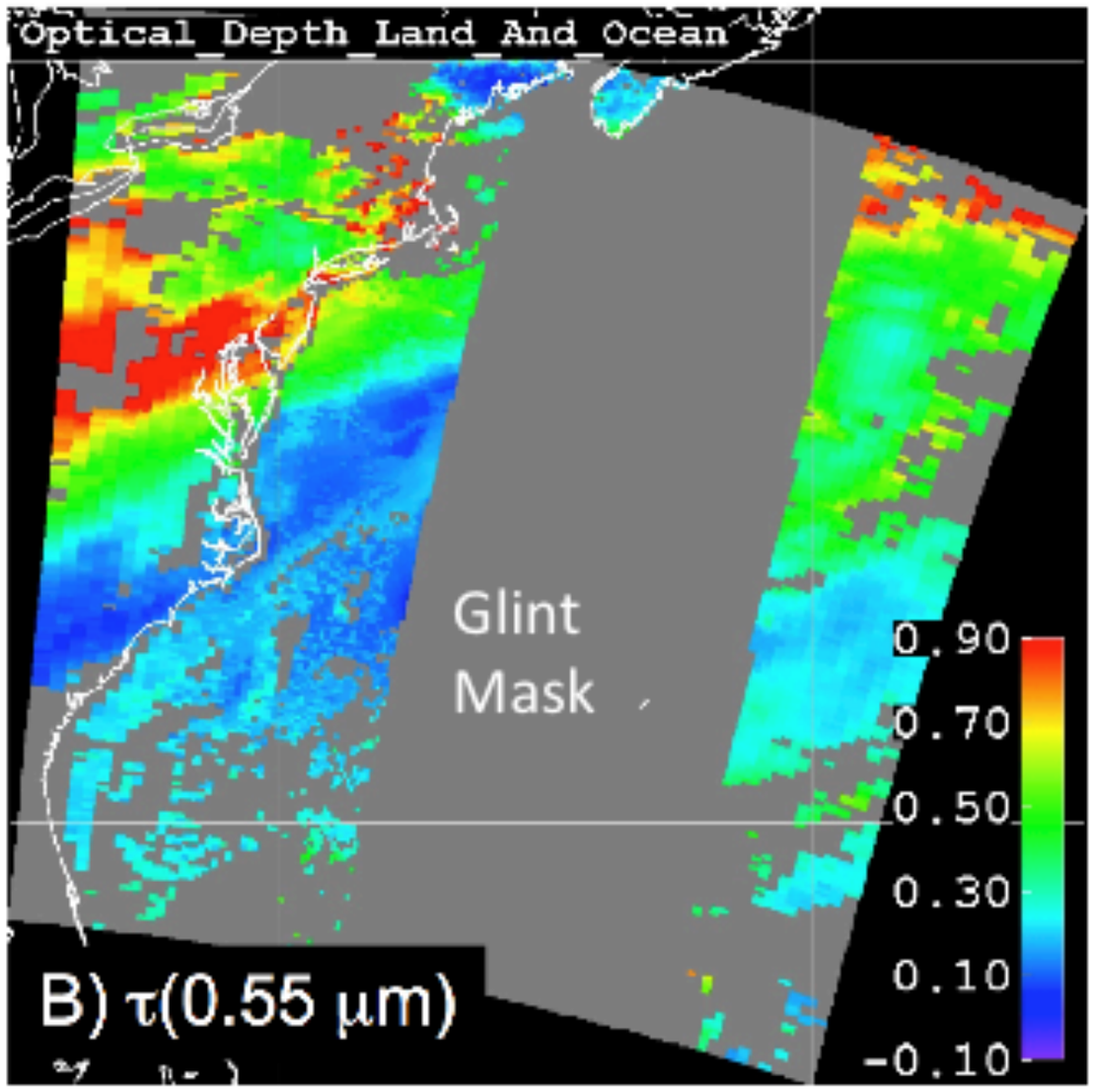
Main Factors:

- Number of pixels “N” (out of 400)
- Error fitting (difference between observation and LUT)
- Are retrieved quantities “realistic?”
- Is aerosol signal so “low” that aerosol properties cannot be retrieved?
- Is surface “brighter” than desirable?
- Etc

5. Products and “validation”

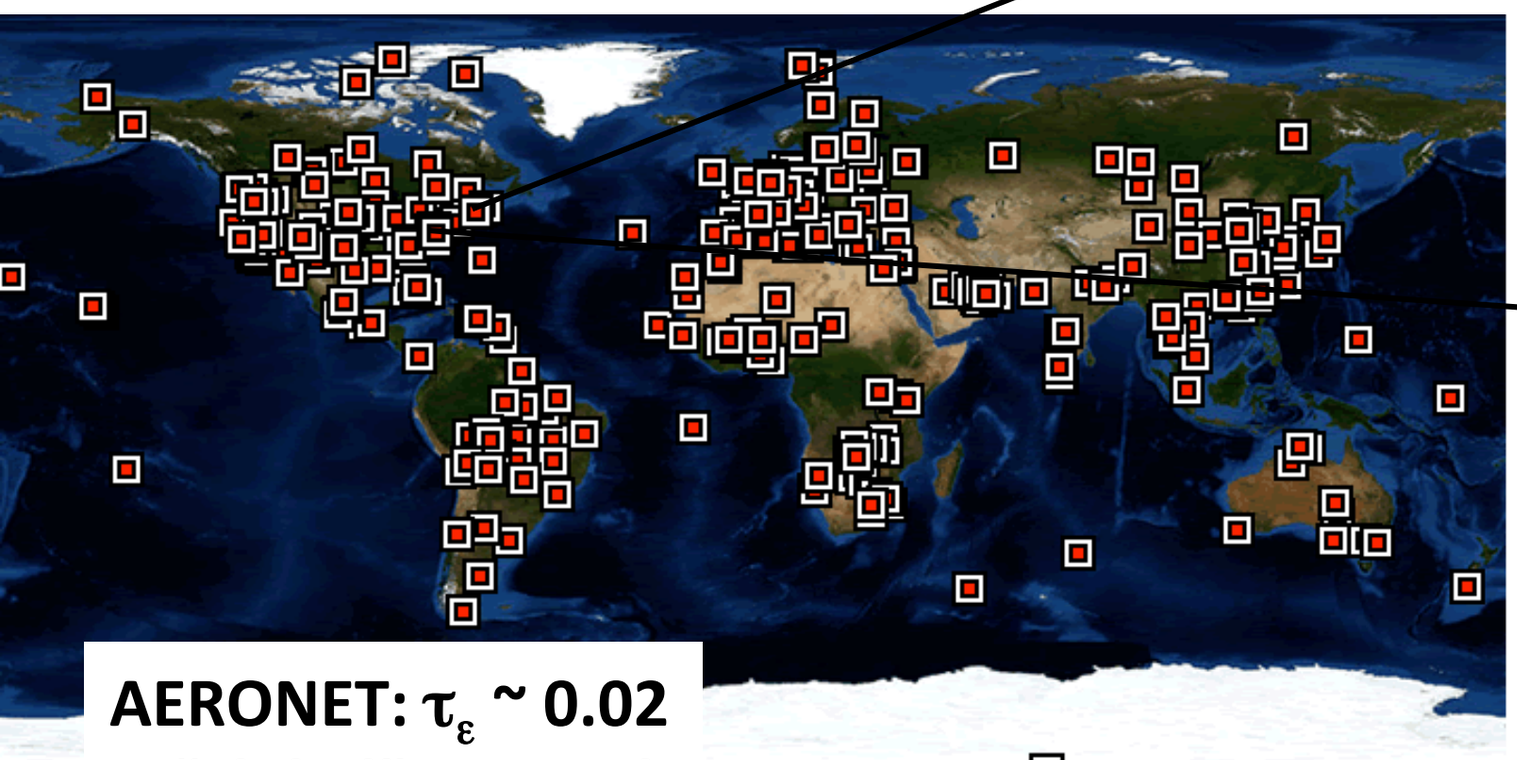
aerosol retrieval combined land/ocean





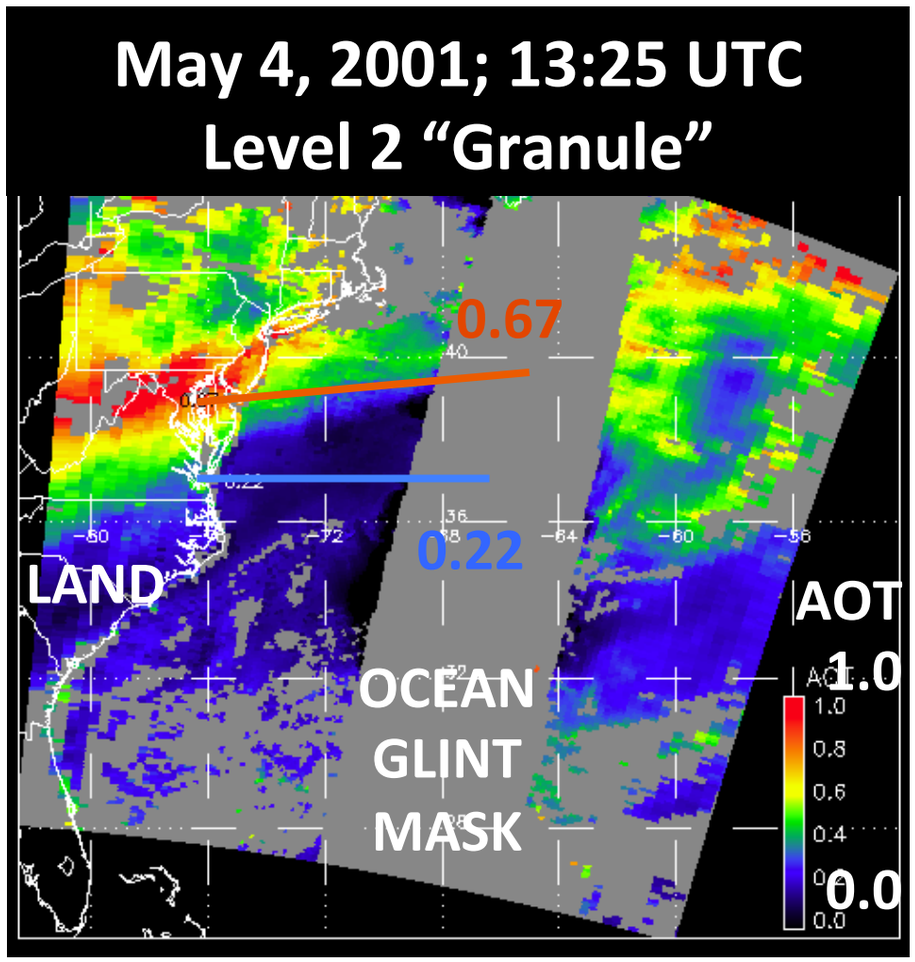
Can we believe the results?

- Self Consistency
  - Visual check
  - No Angle dependency
  - Valid cloud mask
  - Land / Ocean continuity
- Comparison with “ground truth” (e.g. sunphotometer)



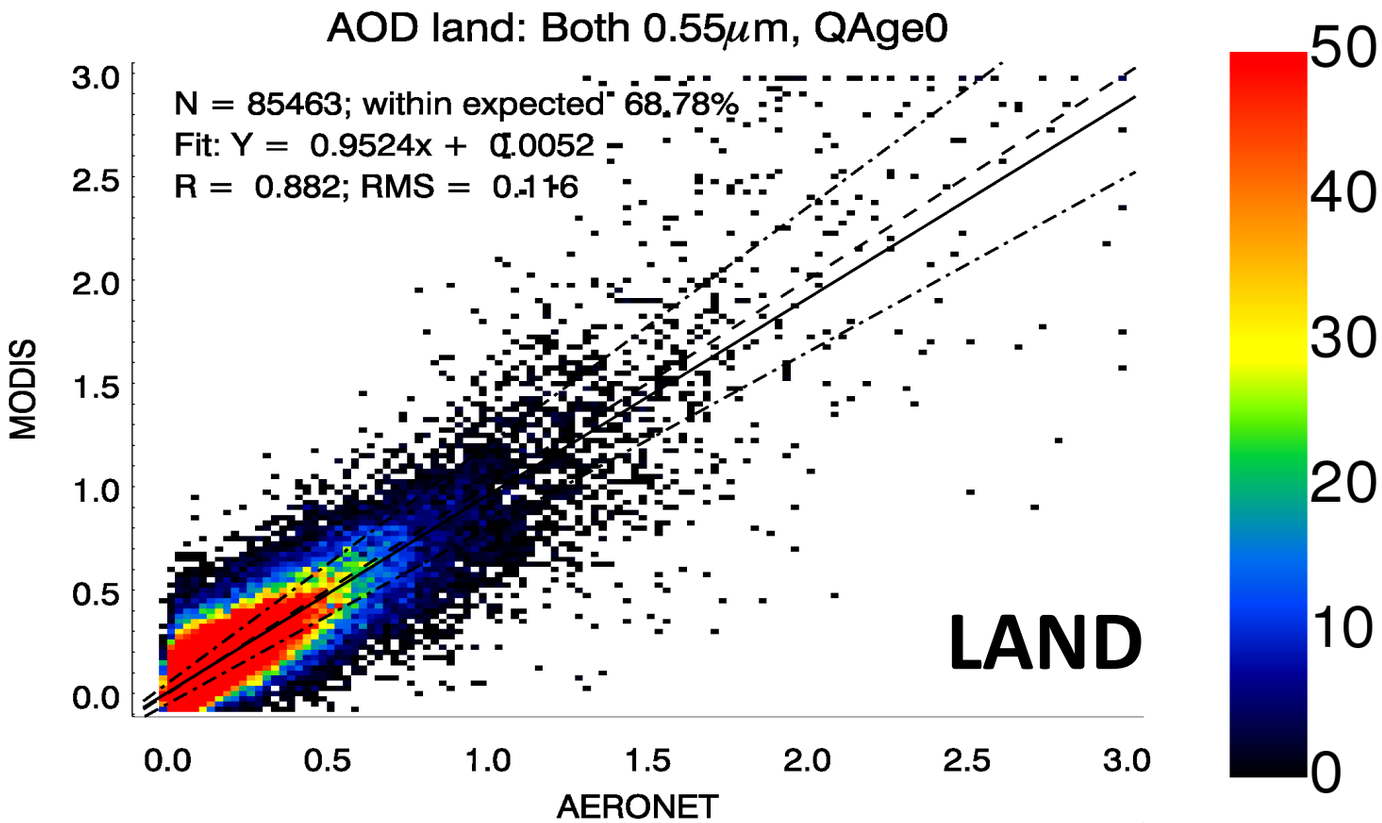
AERONET: τ_ε ~ 0.02
A “global” network

Validation: expected error for C5 data



First steps:

- Pictures look good
- Compare both land and ocean products to AERONET, separately
- Validation: 66% are within "Expected Error" (EE) defined as
- Land: $\pm(0.15\tau + 0.05)$
- Ocean: $\pm(0.05\tau + 0.04)$



Levy et al., ACP 2010

6. MODIS Collection 6!

Published in Atmospheric Measurement Techniques (open access journal):

Levy, R. C., Mattoo, S., Munchak, L. A., Remer, L. A., Sayer, A. M., Patadia, F., and Hsu, N. C., "The Collection 6 MODIS aerosol products over land and ocean", *Atmos. Meas. Tech.*, ***6***, 2989-3034, doi:10.5194/amt-6-2989-2013, 2013.

Many updates for C6, including calibration

Aerosol algorithm overview

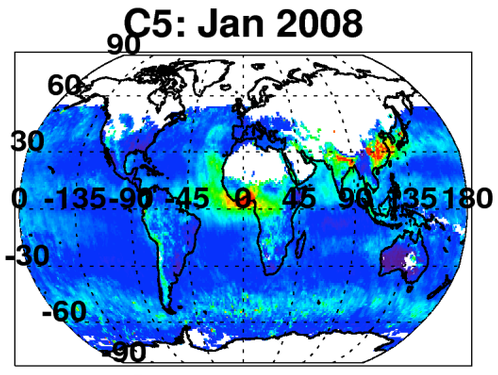
Our aerosol remote sensing retrieval algorithm has multiple phases:

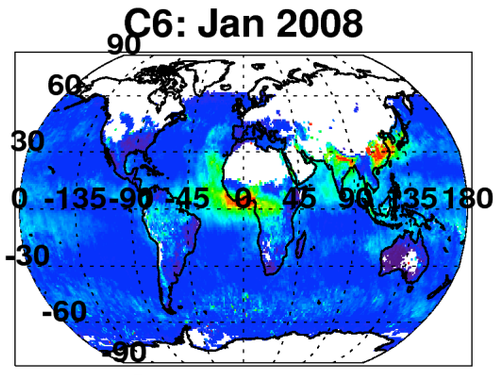
1. Organizing Level 1B radiance data into 10 km boxes for each 5 minute granule.
2. Removing distortion (gas absorption, angular effects) from the satellite signal
3. Deciding whether over "land" or "ocean"
4. Separating signal (aerosol) from noise (clouds, surface inhomogeneities, instrument issues, etc), includes "cloud masking"
5. Correctly interpreting the signal to AOD and aerosol size. "the retrieval"
6. Assigning quality assurance, reporting retrieved, derived, and diagnostic products. "the post-process"

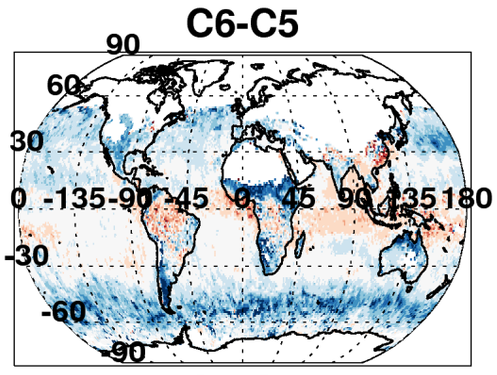
For Collection 6, all aspects of retrieval algorithm were fine tuned and upgraded.

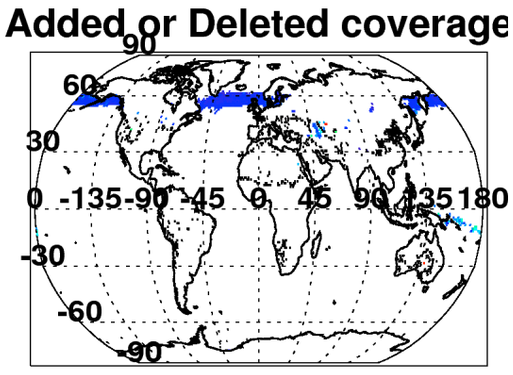
Overall changes (C6 vs C5): Aqua, 2008

Jan

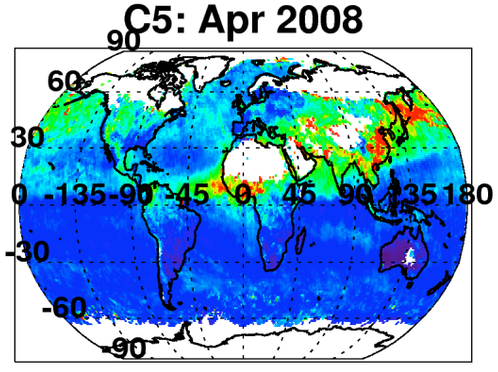


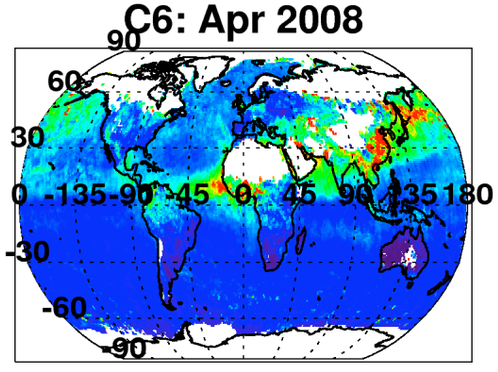


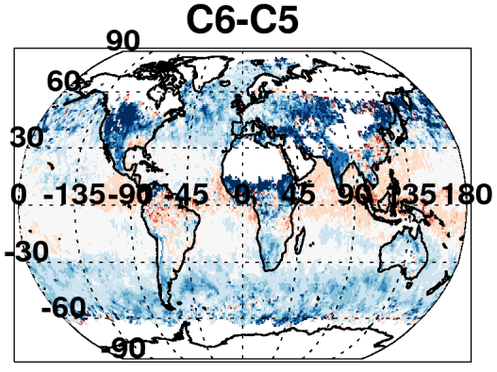


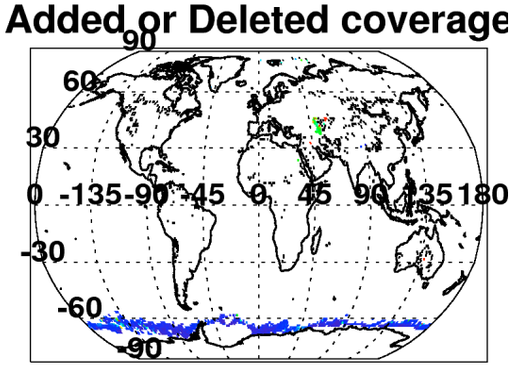


Apr

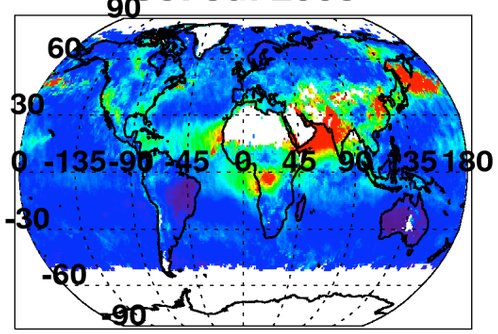


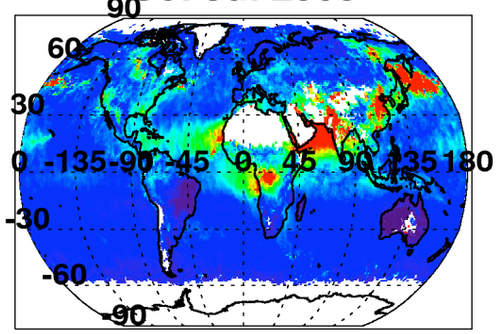


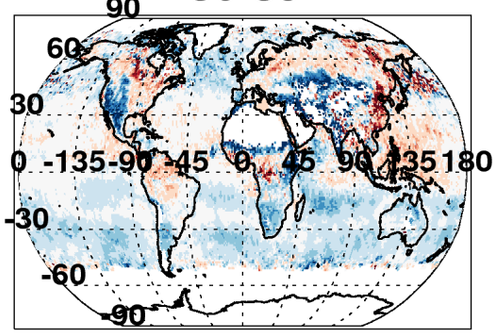


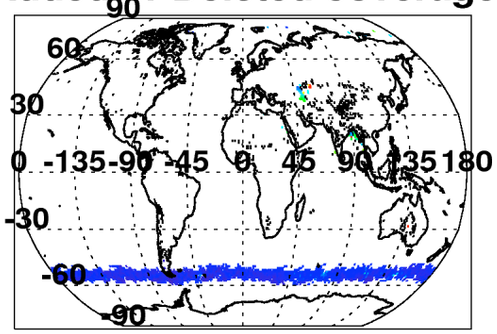


Jul

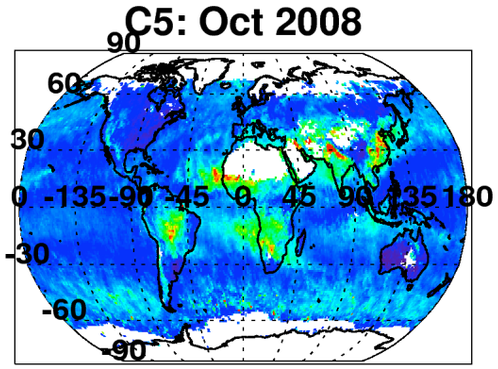


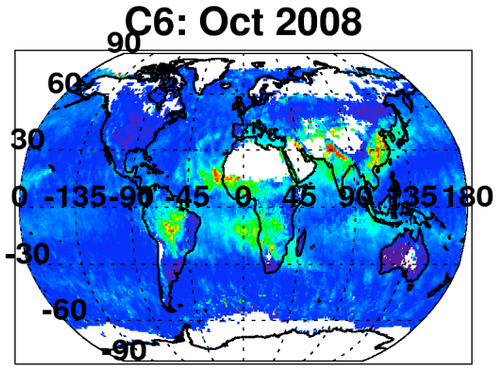


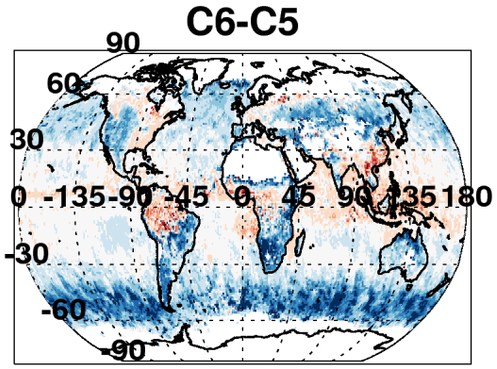


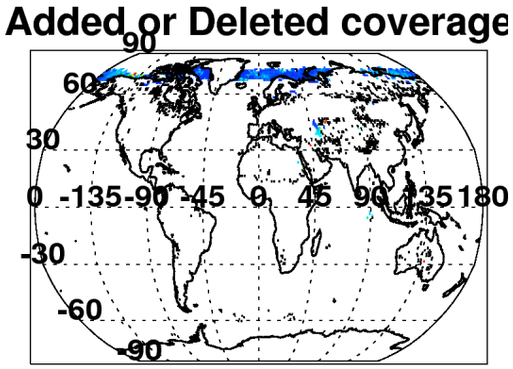


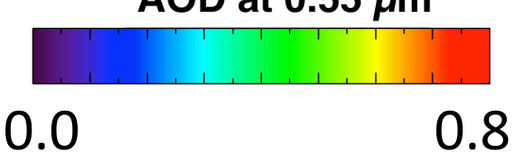
Oct

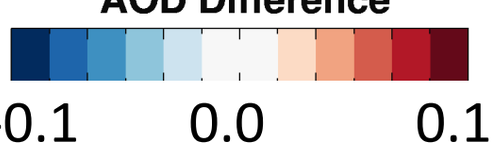




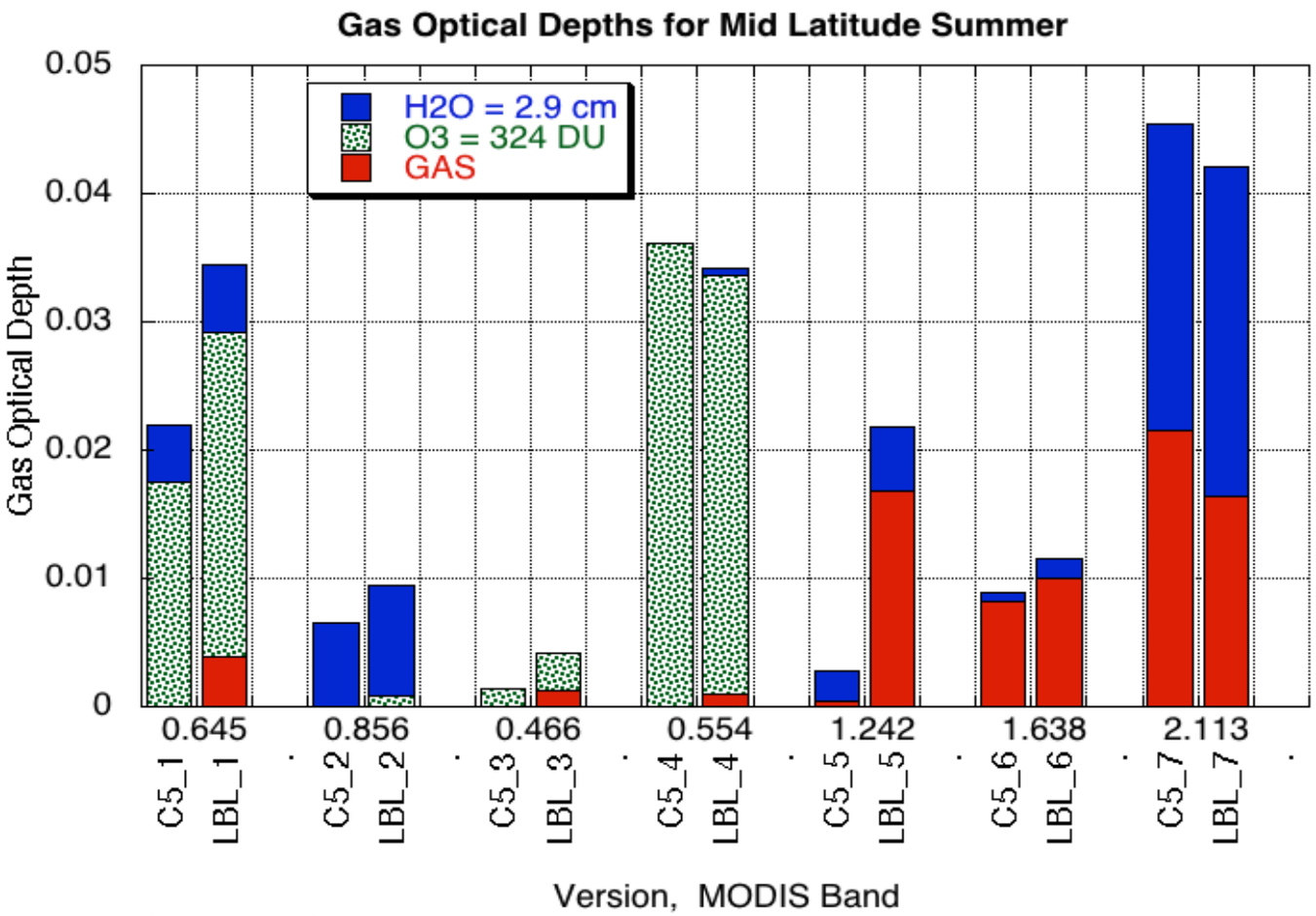


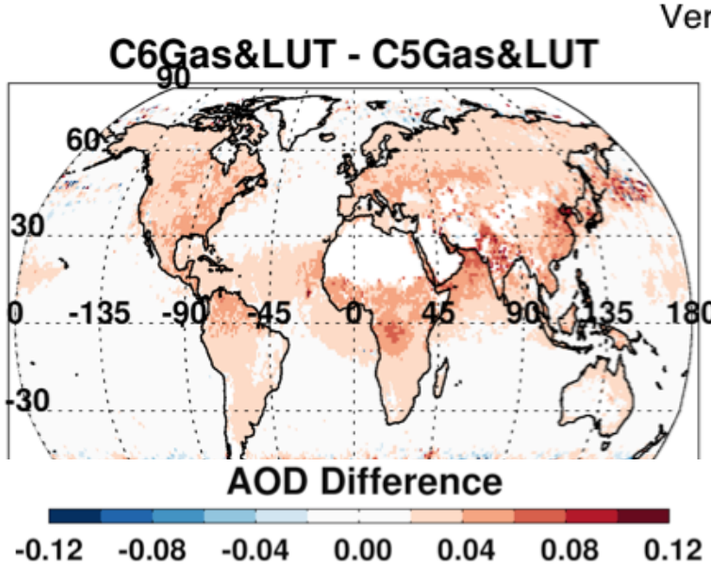






Correction for gas absorption and Rayleigh optical depth





Upshot: global AOD increased by 0.02

Although in atmospheric "windows", there is still absorption from: water vapor, ozone, CO_2 & other gases.

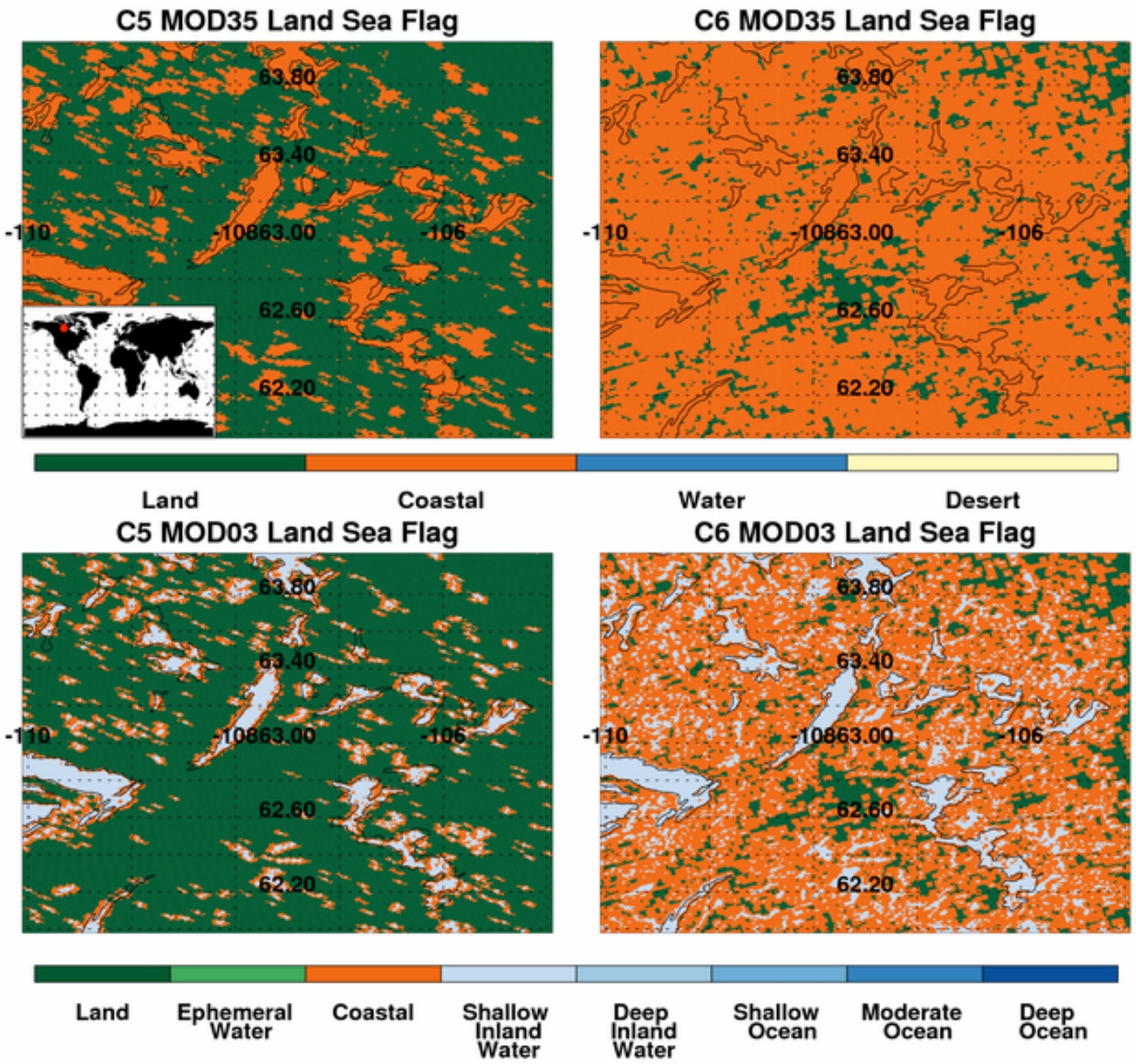
Absorption of these gases varies by wavelength! And can be up to optical depths of 0.05! Must account for accurately!

For C6:

Use modern Radiative Transfer code to account for gas absorption

Recalculate center wavelengths and Rayleigh optical depths

Land/Sea Flag Land or Ocean?



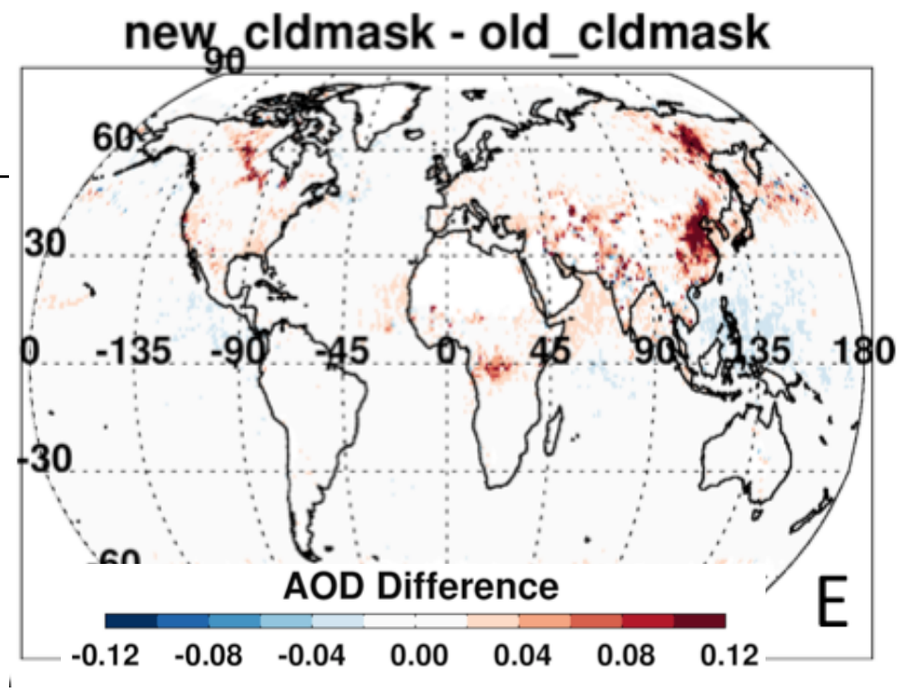
- If all pixels in the 10 x 10 kilometer box are ocean the Ocean Algorithm is used.
- If any land pixels are observed in the 10 Km box the Land Algorithm is used.
- The MOD35 cloud mask product is used to determine if each pixel is land or ocean. However this MOD35 is based on MOD03, which is further based on a global land/sea mask.
- That land/sea mask was changed!

Upshot: no "global" change, but big local changes. Also new retrievals over inland water bodies.

Cloud Masking

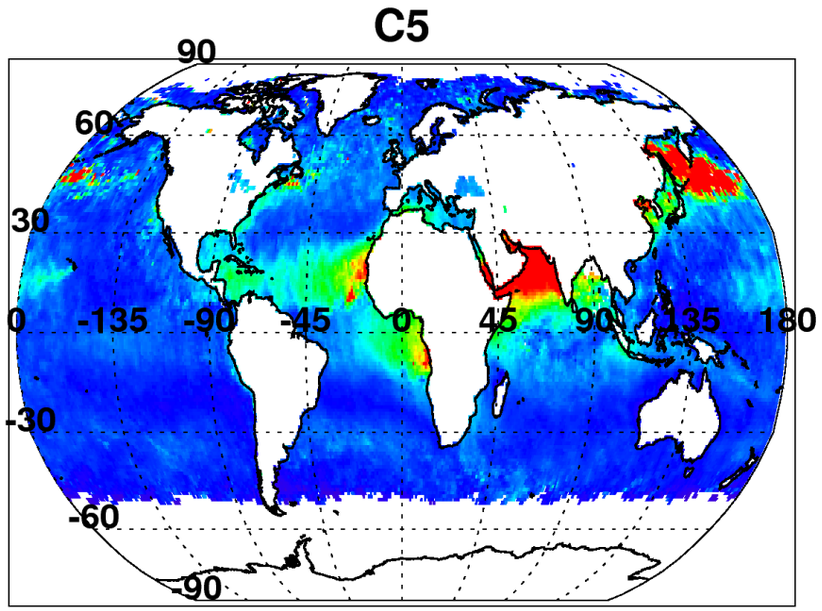
There are many "tests" for clouds in the MODIS scene.

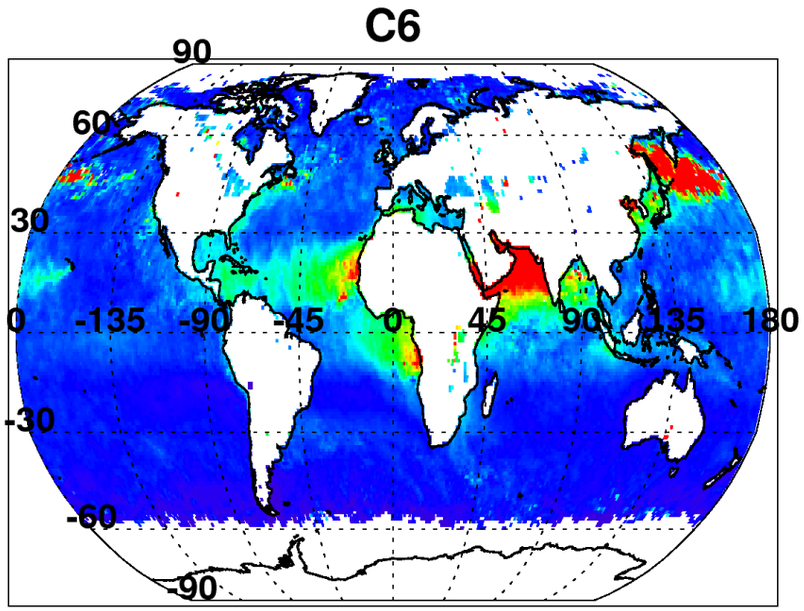
- Spatial Variability Tests (clouds appear bumpy)
- Visible channel brightness (clouds appear bright)
- Visible channel gradients (aerosols appear "colored")
- Cirrus Cloud Removal (high clouds obscure water vapor)
- IR tests: (clouds are colder than the surface)



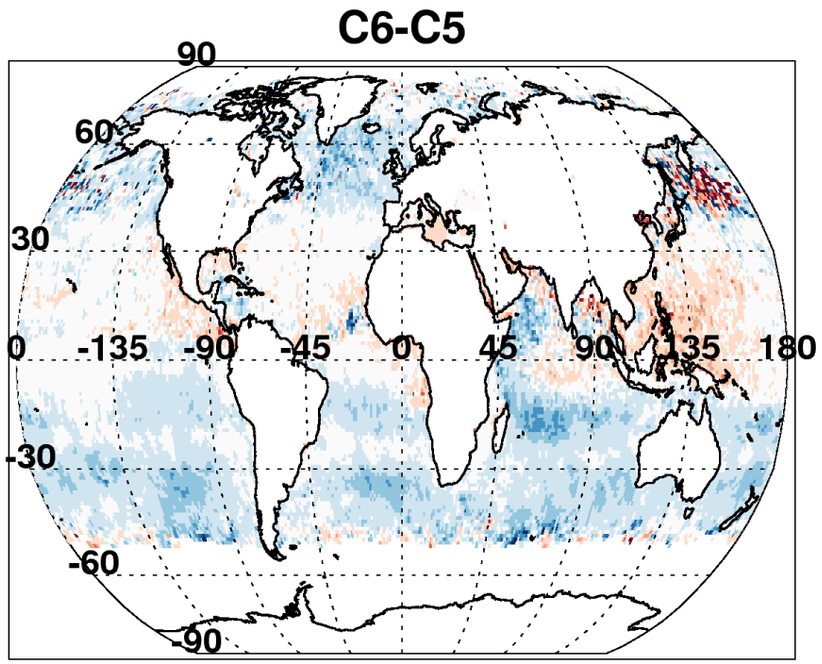
Upshot: no "global" change, but big local changes. Especially big over Asia, and tropical cirrus regions.

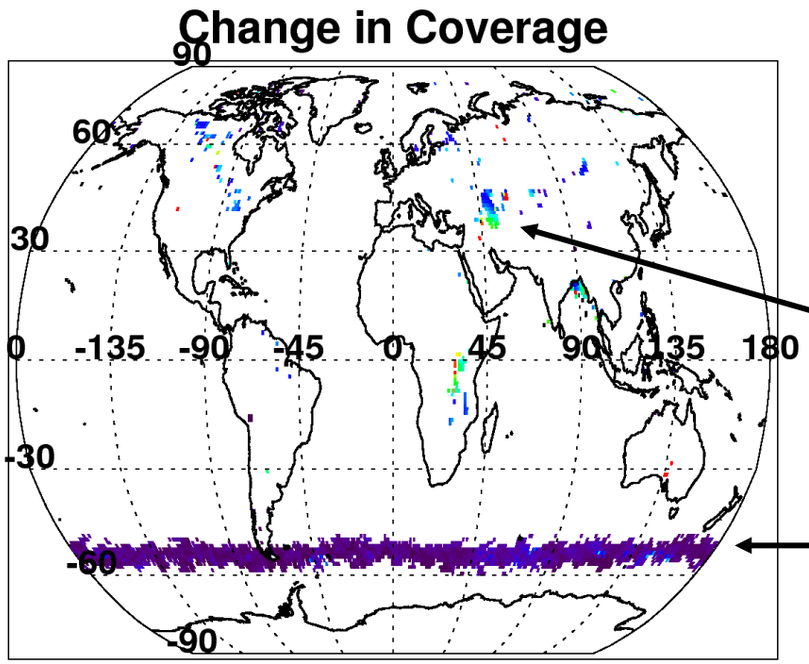
Dark target over ocean
Overall changes to products (Aqua, Jul 2008)



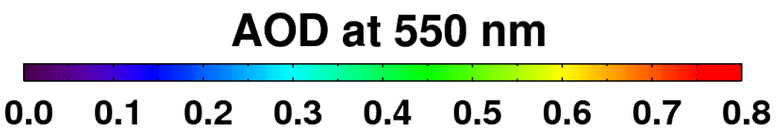


- Overall decrease of AOD in mid-latitudes
- Strong decrease in "roaring 40s" (even stronger in other months)
- Overall increase in tropics



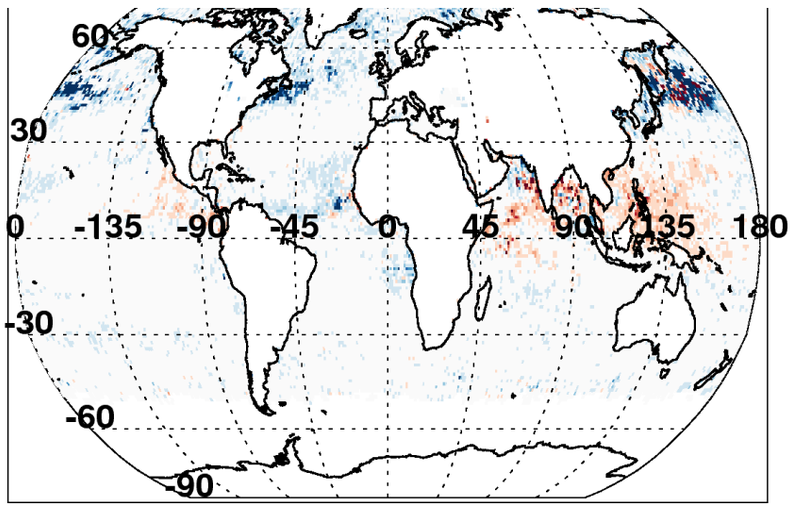


- "New" coverage over inland lakes
- Increase in coverage toward poles

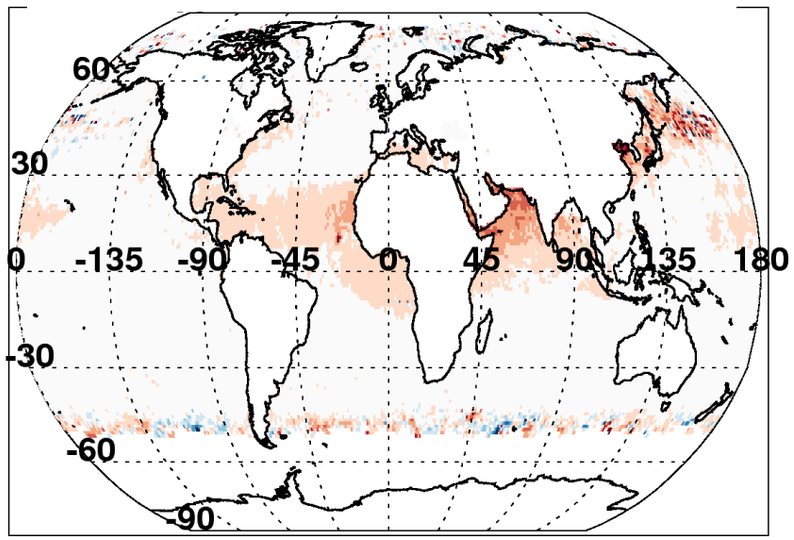


C6-C5 ocean: Due to many incremental changes (Aqua, July 2008)

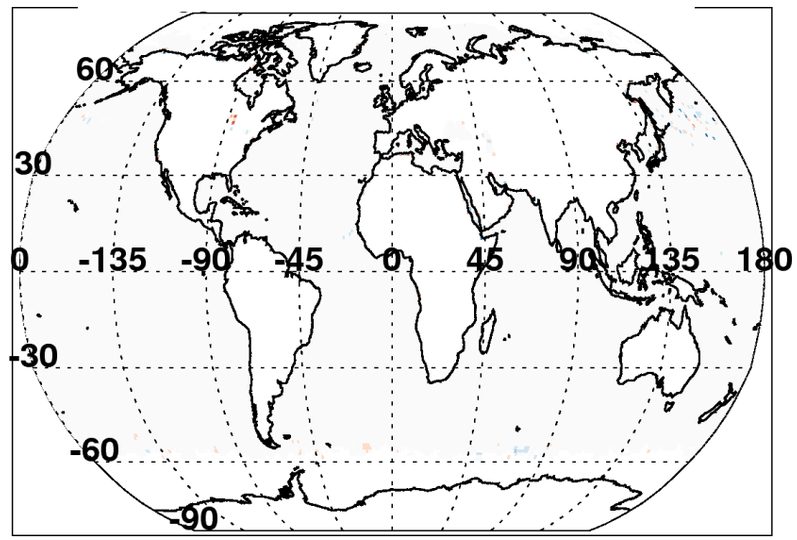
New reflectance, geo-location inputs, Wisconsin cloud mask



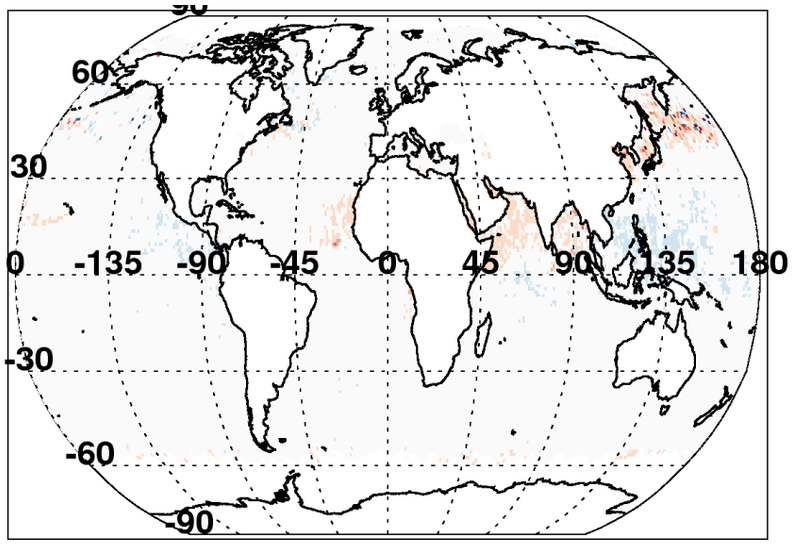
Updated radiative transfer



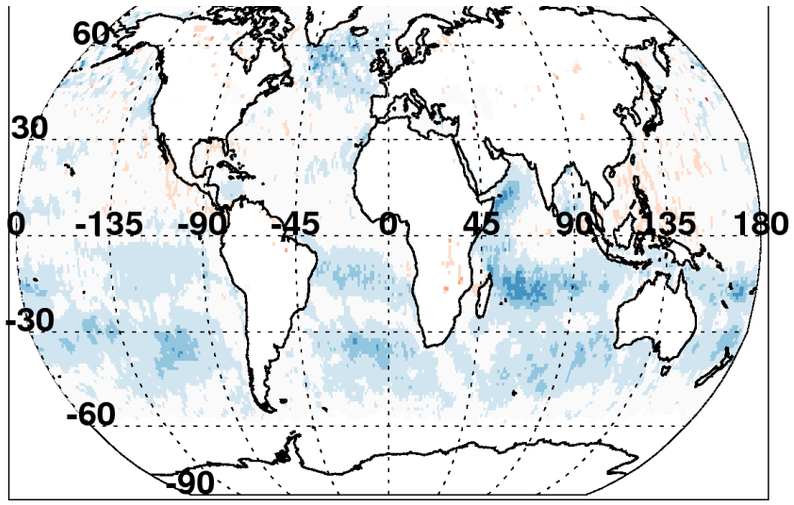
Re-define land and sea



Improved cloud mask



Account for wind speed impact on surface

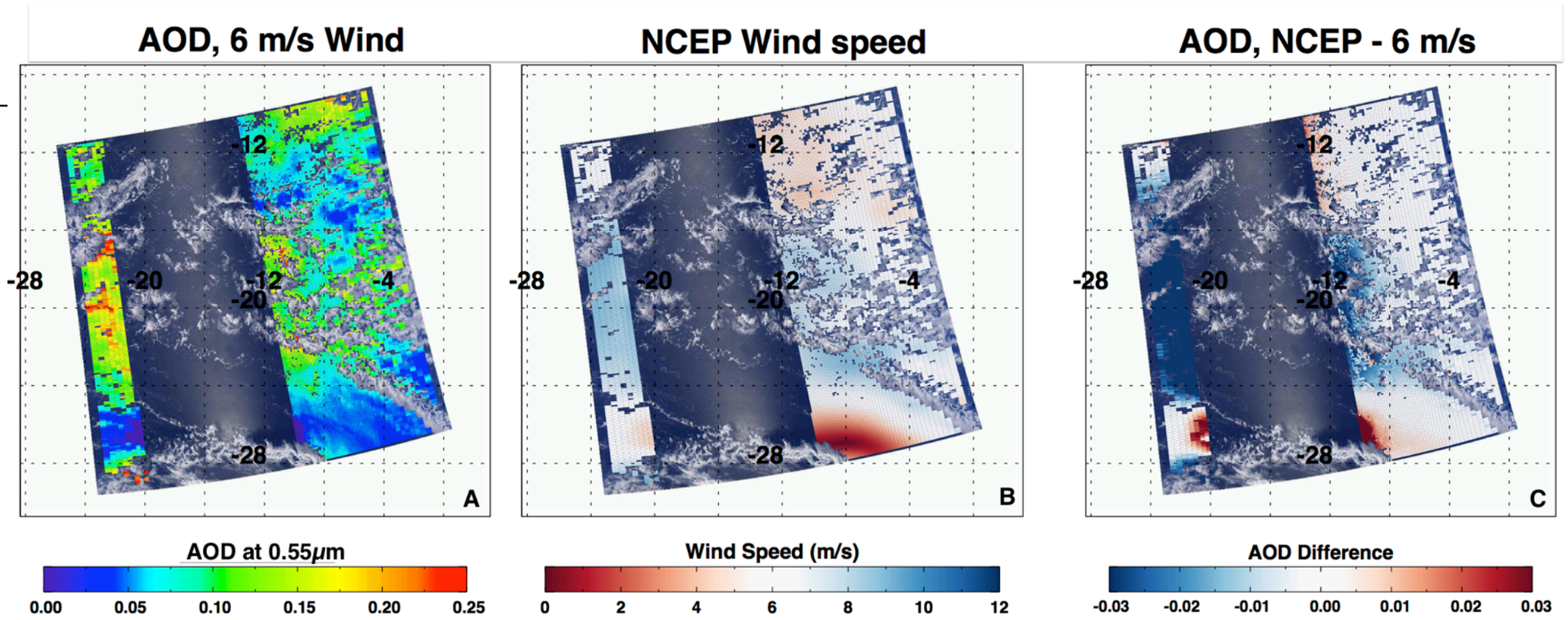


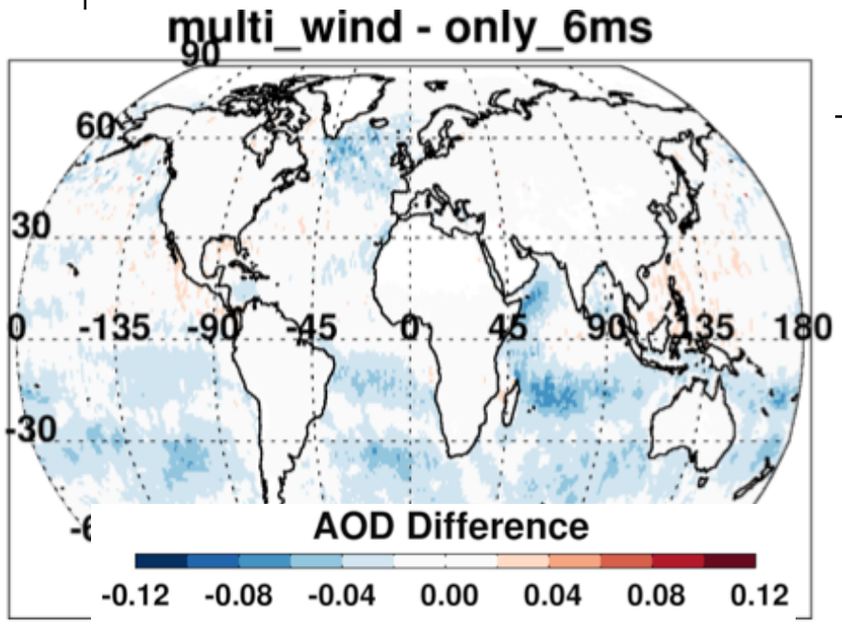
AOD Difference

-0.12 -0.08 -0.04 0.00 0.04 0.08 0.12

- Also changed "Quality Assurance" Filtering
- Changed aerosol definitions of land and sea
- Etc

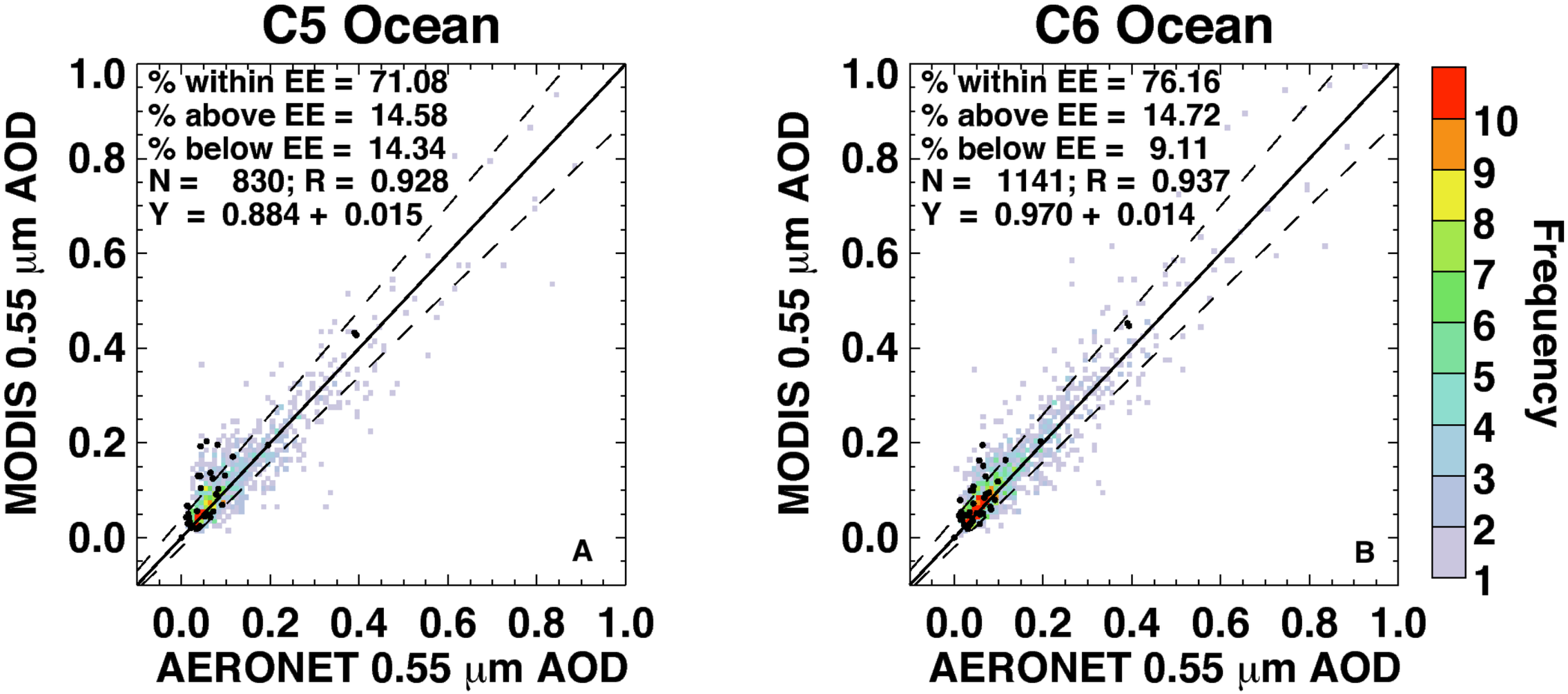
Over ocean: Wind speed dependence





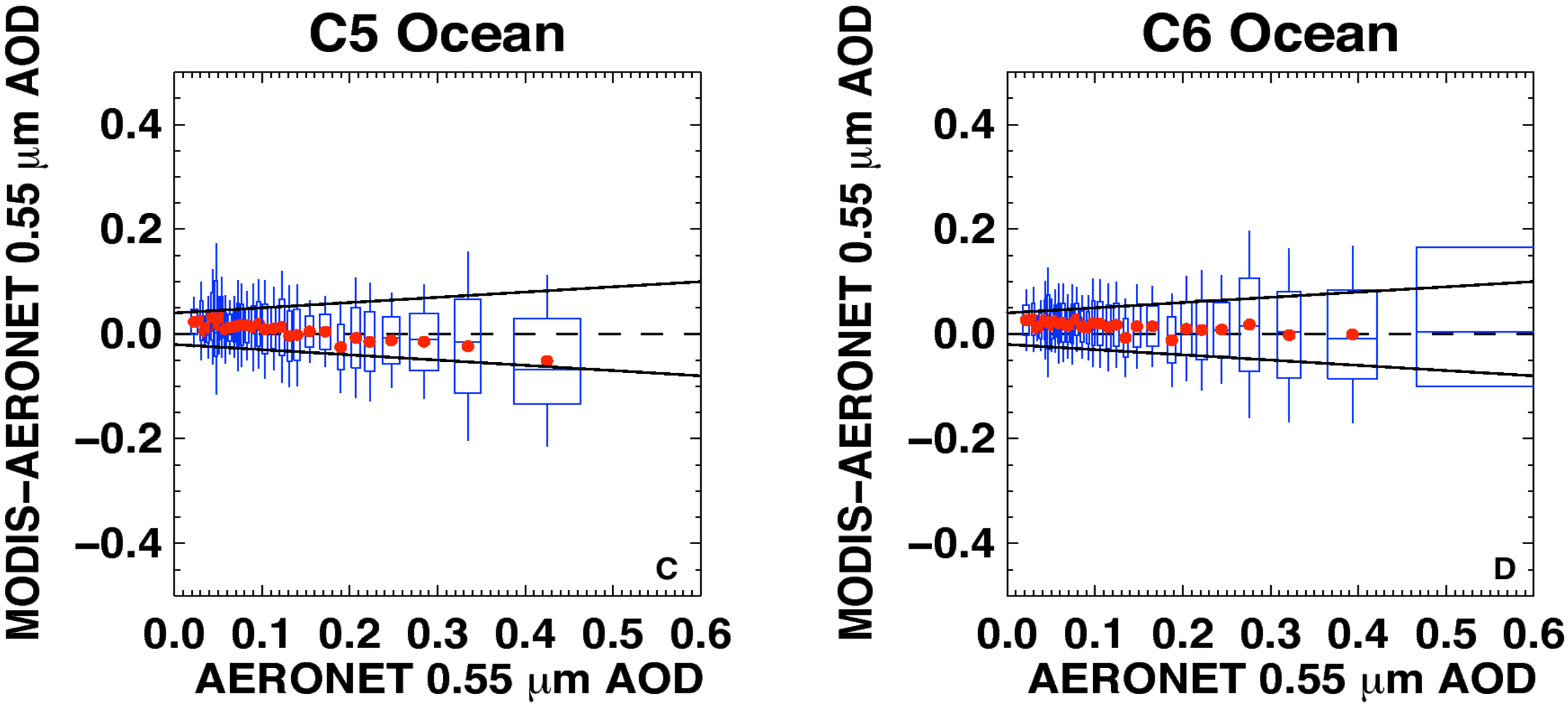
Upshot: reduced AOD by 0.01 over all ocean
Especially important in Southern Hemisphere

Comparison with AERONET and MAN



- Aqua for 8 months (Jan + July, 2003, 2008 and 2010; Apr + Oct 2008).
- Overall, not much change over ocean (slope, intercept, correlation)
- But 30% more valid points to compare with (1141 versus 830).
- AERONET are gray and colored, MAN are black dots

Better way to see MODIS improvement



- MODIS error (MODIS–AERONET) versus AERONET; zero “error” is dashed line
- Boxes represent middle 67% of each dataset, whiskers are middle 95% of MODIS-AERONET
- Solid lines are “expected error” (EE) envelope; note asymmetry (new definition for C6).
- Note that in C6, that the MODIS error is within EE for nearly all bins of AOD
- C5 EE = ±(0.03 + 5%). C6 EE = (-0.02 – 10%), (+0.04 + 10%))
- Less overall “bias” in C6.

We now have validation for all years of Aqua data

SDSs over ocean

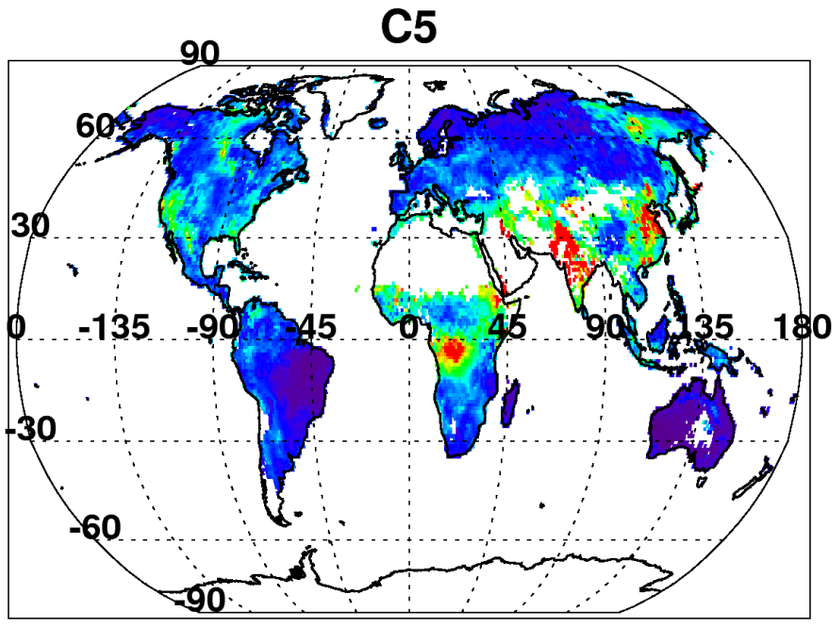
Table 3. C6 DT-ocean data products and changes from C51.

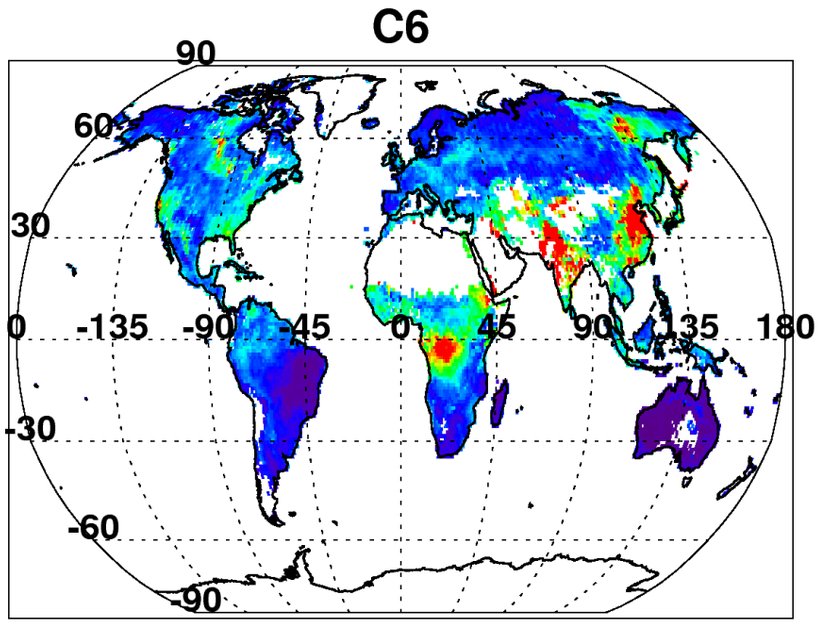
C6 SDS	C6 dimensions	Noted changes from C51 to C6
Effective_Optical_Depth_Average_Ocean	$X, Y, 7\lambda$	
Effective_Optical_Depth_Best_Ocean	$X, Y, 7\lambda$	
Optical_Depth_Ratio_Small_Ocean_0_55micron	$X, Y, 2S$	
Solution_Index_Ocean_Small	$X, Y, 2S$	
Solution_Index_Ocean_Large	$X, Y, 2S$	
Least_Squares_Error_Ocean	$X, Y, 2S$	
Effective_Radius_Ocean	$X, Y, 2S$	
Optical_Depth_Small_Best_Ocean	$X, Y, 7\lambda$	
Optical_Depth_Small_Average_Ocean	$X, Y, 7\lambda$	
Optical_Depth_Large_Best_Ocean	$X, Y, 7\lambda$	
Optical_Depth_Large_Average_Ocean	$X, Y, 7\lambda$	
Mass_Concentration_Ocean	$X, Y, 2S$	
Asymmetry_Factor_Best_Ocean	$X, Y, 7\lambda$	
Asymmetry_Factor_Average_Ocean	$X, Y, 7\lambda$	
Backscattering_Ratio_Best_Ocean	$X, Y, 7\lambda$	
Backscattering_Ratio_Average_Ocean	$X, Y, 7\lambda$	
Ångstrom_Exponent_1_Ocean (0.55/0.86 micron)	$X, Y, 2S$	
Angstrom_Exponent_2_Ocean (0.86/2.1 micron)	$X, Y, 2S$	
PSML003_Ocean	$X, Y, 2S$	Renamed from “Cloud_Condensation_Nuclei_Ocean”
Optical_Depth_by_models_Ocean	$X, Y, 9M$	
Aerosol_Cloud_Fraction_Ocean	X, Y	Renamed from “Cloud_Fraction_Ocean”
Number_Pixels_Used_Ocean	$X, Y, 10\lambda$	Separate tally for each of ten wavelength
Mean_Reflectance_Ocean	$X, Y, 10\lambda$	Added 3 wavelengths
STD_Reflectance_Ocean	$X, Y, 10\lambda$	Added 3 wavelengths
Quality_Assurance_Ocean	$X, Y, 5B$	
Wind_Speed_Ncep_Ocean	X, Y:	New diagnostic

X, Y refers to a 2-dimensional array along/across the swath (at a particular wavelength λ). Some parameters have a third dimension. A dimension of “#λ” refers to # wavelengths. # = 7: 0.47, 0.55, 0.65, 0.86, 1.24, 1.63 and 2.11 μm. # = 10: 0.47, 0.55, 0.65, 0.86, 1.24, 1.63, 2.11, 0.41, 0.44 and 0.76 μm. A dimension of “5B” refers to the number of bytes (5) of the QA Flags. A dimension of “9M” is number of modes (9). A dimension of “2S” is two solutions (“average” and “best”).

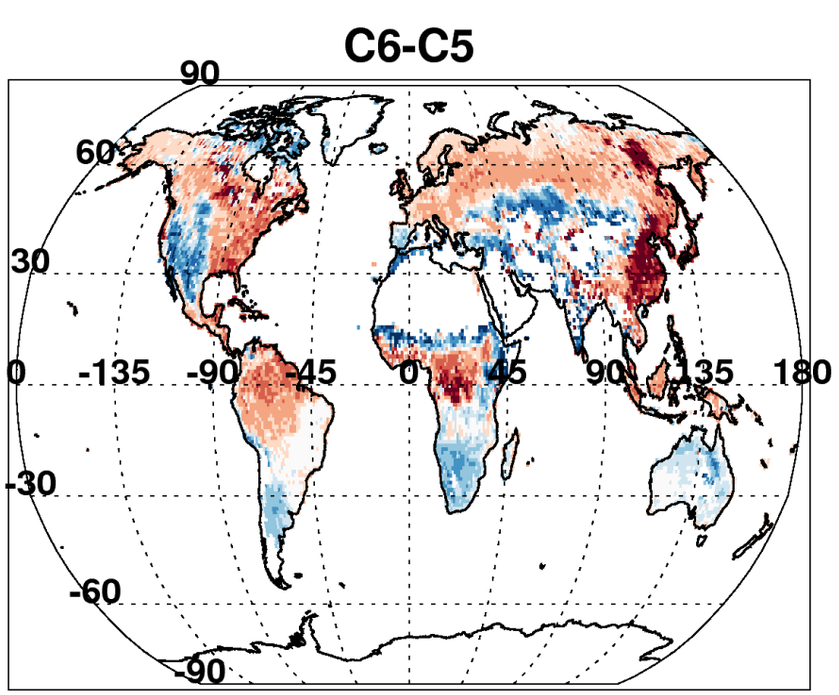
Aerosol over land

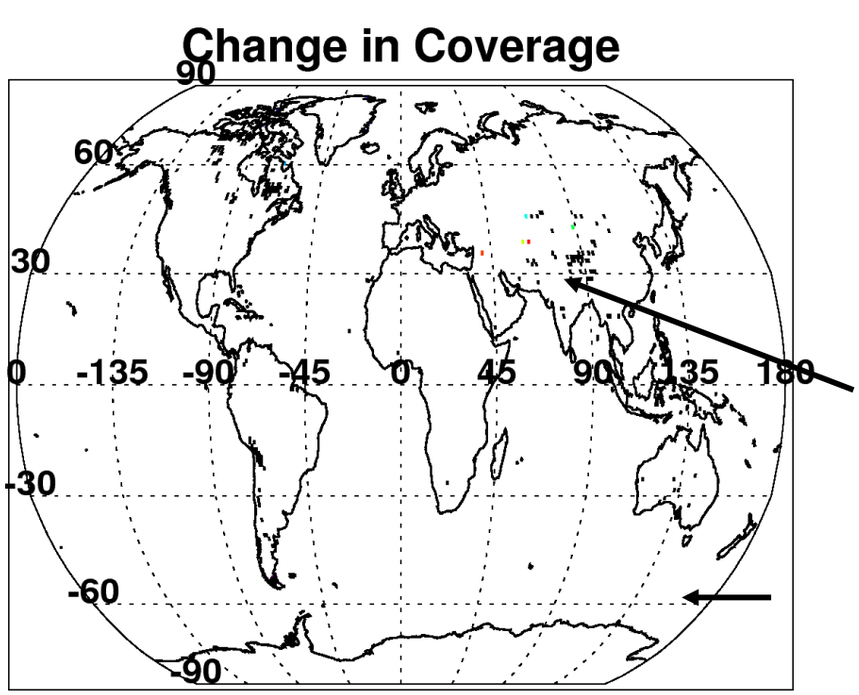
Dark target over land
Overall changes to products (Aqua, Jul 2008)



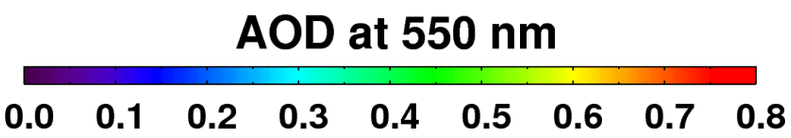


- Overall decrease of AOD in semi-arid
- Overall increase over vegetation
- Strong increase over Eastern Asia



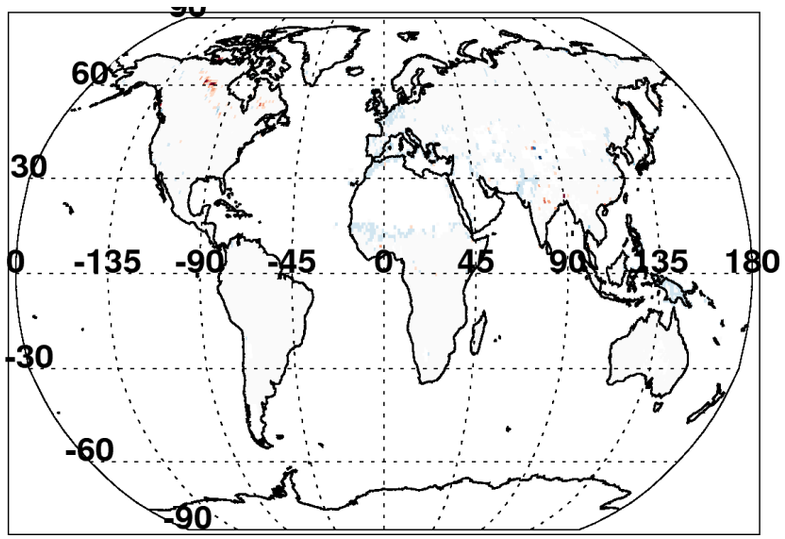


- Slight change in coverage here and there

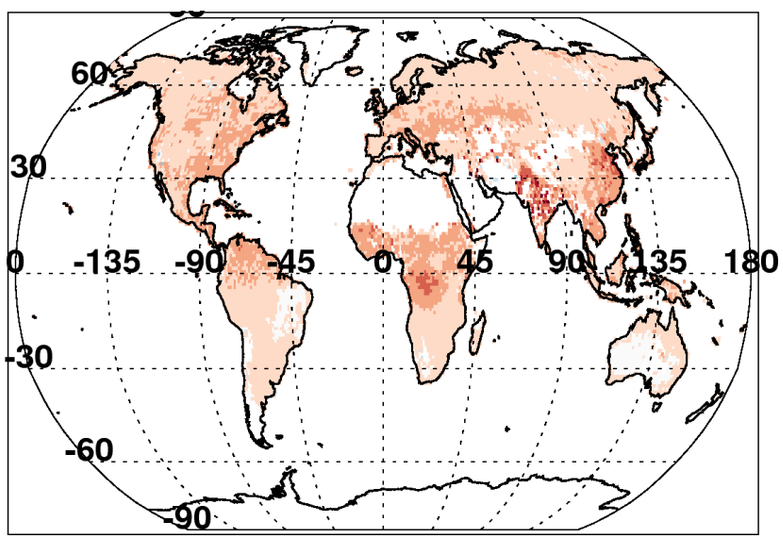


C6-C5 land: Due to many incremental changes (Aqua, July 2008)

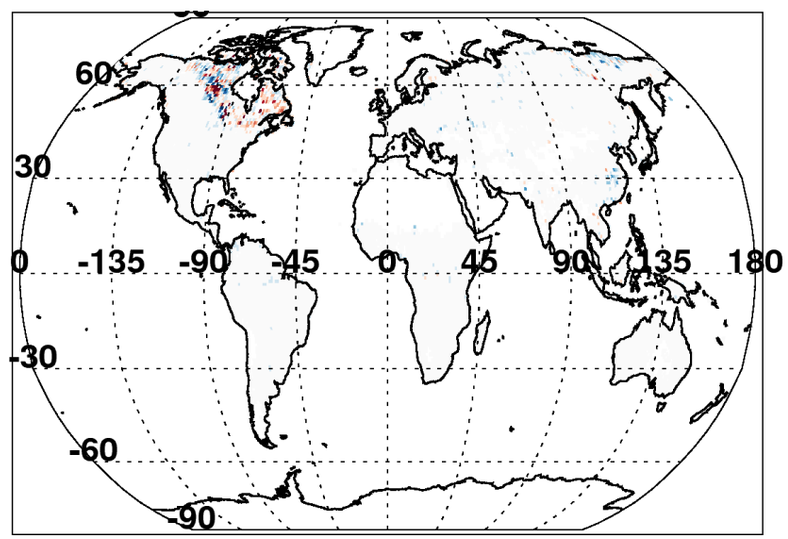
New reflectance and geo-location inputs



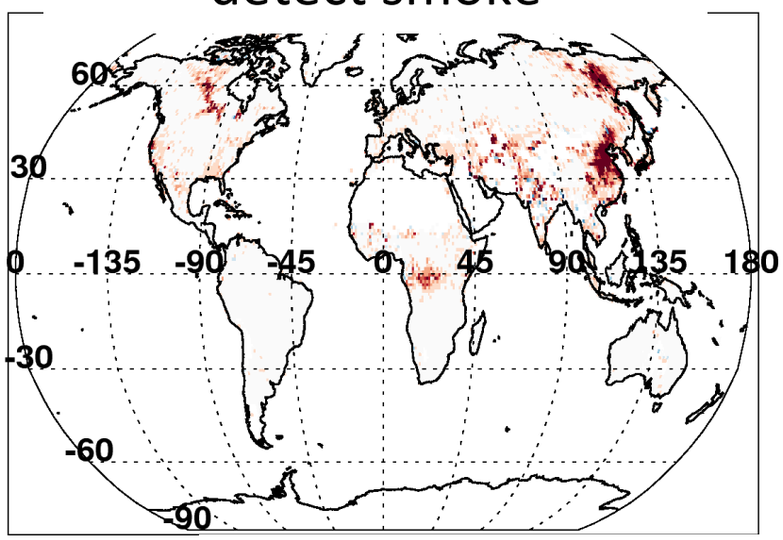
Updated radiative transfer



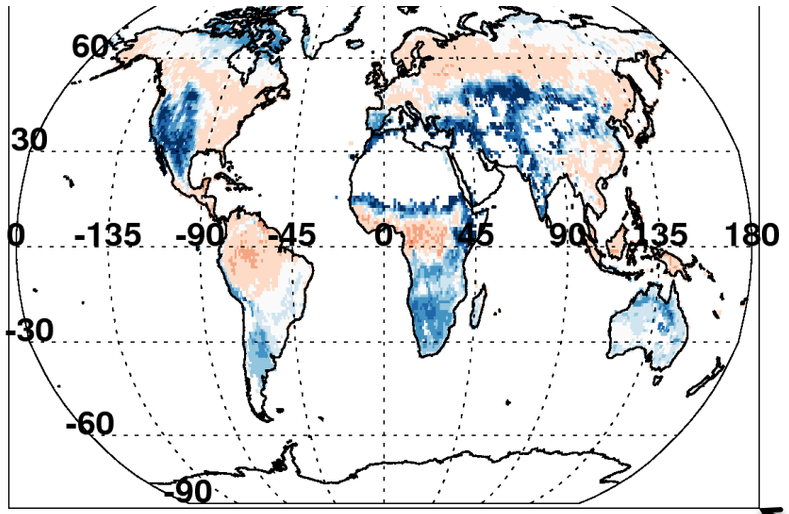
Re-define land and sea

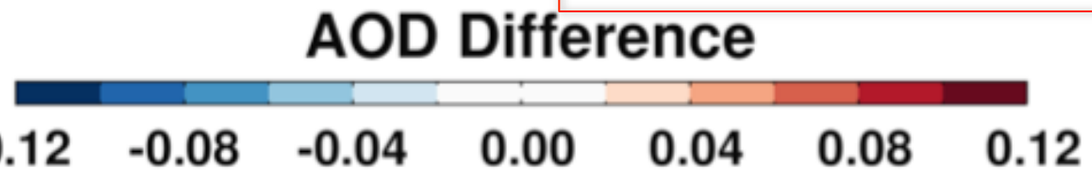


Improved cloud mask to detect smoke



Fixed surface reflectance dependence on TOA NDVI

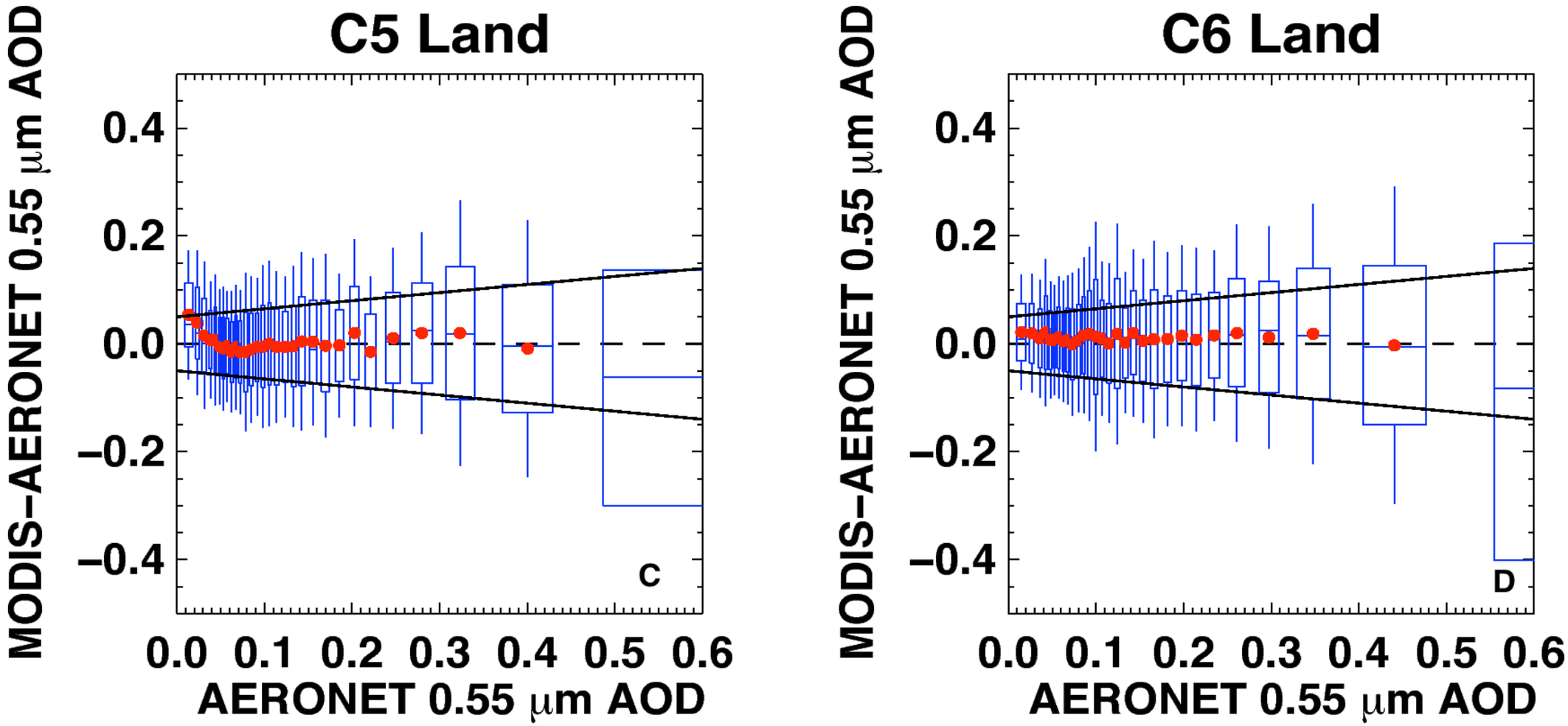




- Also changed "Quality Assurance" Filtering
- Changed aerosol definitions of land and sea
- Etc

This was a major bug!

Preliminary comparison with AERONET (8 months of Aqua data)



- MODIS error (MODIS–AERONET) versus AERONET; zero "error" is dashed line
- Boxes are middle 67% of dataset, whiskers are middle 95% of MODIS-AERONET
- Solid lines are "expected error" (EE) envelope; no asymmetry
- C6 MODIS error is within EE for nearly all bins of AOD (even at low values)
- C5 EE = ±(0.05 + 15%)). Keep definition for C6.

Note, we have 10+ years of validation now with Aqua

SDSs over land

Table 1. C6 DT-land data products and changes from C51.

C5 SDS	C6 SDS	C6 dimension	Noted changes from C5 to C6
Corrected_Optical_Depth_Land	Corrected_Optical_Depth_Land	X, Y, 3aλ	
Corrected_Optical_Depth_Land_wav2p1	Corrected_Optical_Depth_Land_wav2p1	X, Y: (at 2.11 μm)	
Optical_Depth_Ratio_Small_Land	Optical_Depth_Ratio_Small_Land	X, Y: (at 0.55 μm)	
Surface_Reflectance_Land	Surface_Reflectance_Land	X, Y, 3aλ	
Fitting_Error_Land	Fitting_Error_Land	X, Y: (at 0.65 μm)	
Quality_Assurance_Land	Quality_Assurance_Land	X, Y, 5B	
Aerosol_Type_Land	Aerosol_Type_Land	X, Y	
Angstrom_Exponent_Land			deleted
Mass_Concentration_Land	Mass_Concentration_Land	X, Y	
Optical_Depth_Small_Land		X, Y, 4λ	deleted
Mean_Reflectance_Land	Mean_Reflectance_Land	X, Y, 10λ	Added 3 wavelengths
STD_Reflectance_Land	STD_Reflectance_Land	X, Y, 10λ	Added 3 wavelengths
Cloud_Fraction_Land	Aerosol_Cloud_Fraction_Land	X, Y	Renamed
Number_Pixels_Used_Land	Number_Pixels_Used_Land	X, Y, 10λ	Separate tally each λ
Path_Radiance_Land			deleted
Error_Path_Radiance_Land			deleted
Critical_Reflectance_Land			deleted
Error_Crit_Reflectance_land			deleted
Error_Critical_Reflectance_Land			deleted
Quality_Weight_Path_Radiance_Land			deleted
Quality_Weight_Crit_Reflectance_Land			deleted
	Topographic_Altitude_Land	X, Y	New diagnostic

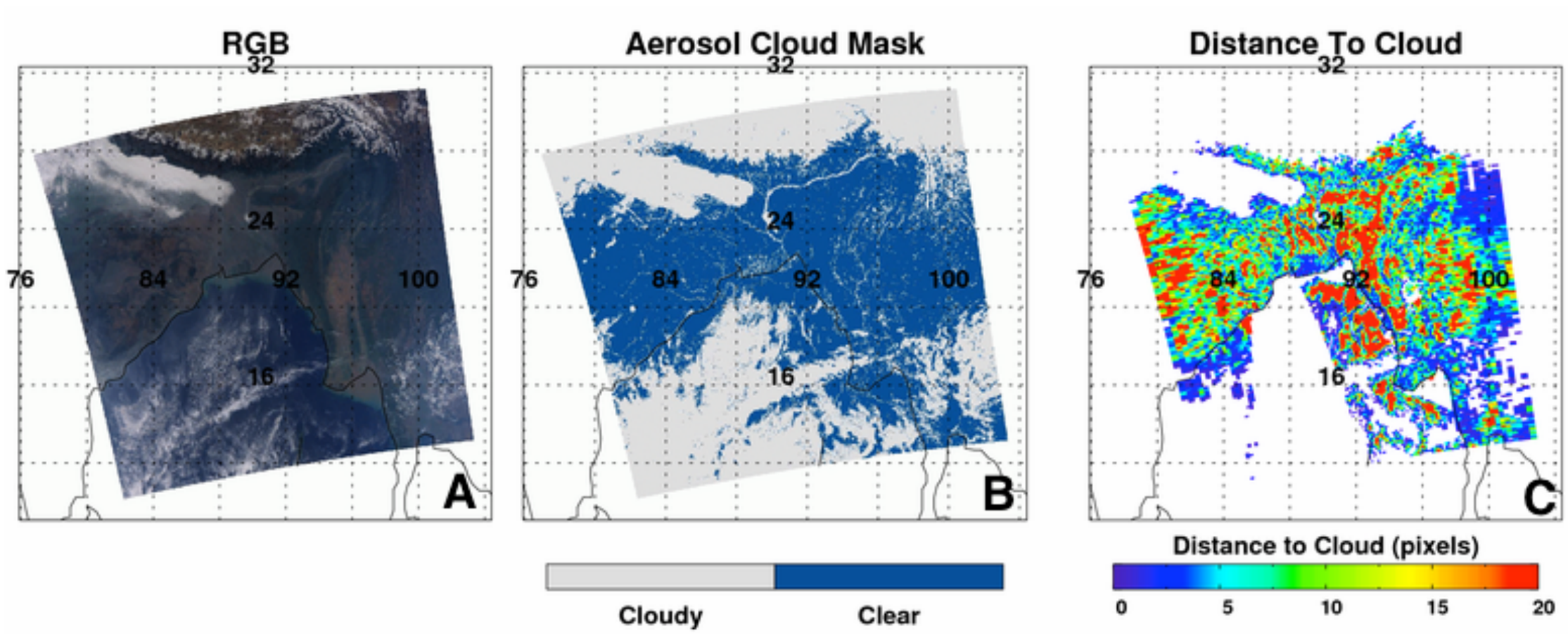
X, Y refers to a 2-dimensional array along/across the swath (at a particular wavelength λ). Some parameters have a third dimension. A dimension of "#λ" refers to # wavelengths. # = 3a: 0.47, 0.55 and 0.65 μm. # = 3b: 0.47, 0.55 and 2.11 μm. # = 4: 0.47, 0.55, 0.65 and 2.11 μm. # = 7: 0.47, 0.55, 0.65, 0.86, 1.24, 1.63 and 2.11 μm. # = 10: 0.47, 0.55, 0.65, 0.86, 1.24, 1.63, 2.11, 0.41, 0.44 and 0.76 μm. A dimension of "5B" refers to the number of bytes (5) of the QA Flags.

SDSs combined land/ocean

- We continue the idea of having “joint” SDSs that take the best of both land and ocean. There are two versions:
  - Image_Optical_Depth_Land_And_Ocean: populated for all pixels in which either land or ocean made a retrieval.
    - This is intended for imagery with fewer holes
  - Optical_Depth_Land_And_Ocean: populated for pixels that meet Quality Assurance criteria
    - This is intended for more scientific integrity
    - For land: QA = 3 (only)
    - For ocean: QA ≥ 1 (=1, 2 or 3).
  - Land_Sea_Flag: This new SDS integer describes whether retrieval over land or ocean (or neither).
  - Land_Ocean_Quality_Flag: This new SDS integer repeats the QA for land and ocean, but in an integer form (no decoding bits and bytes).

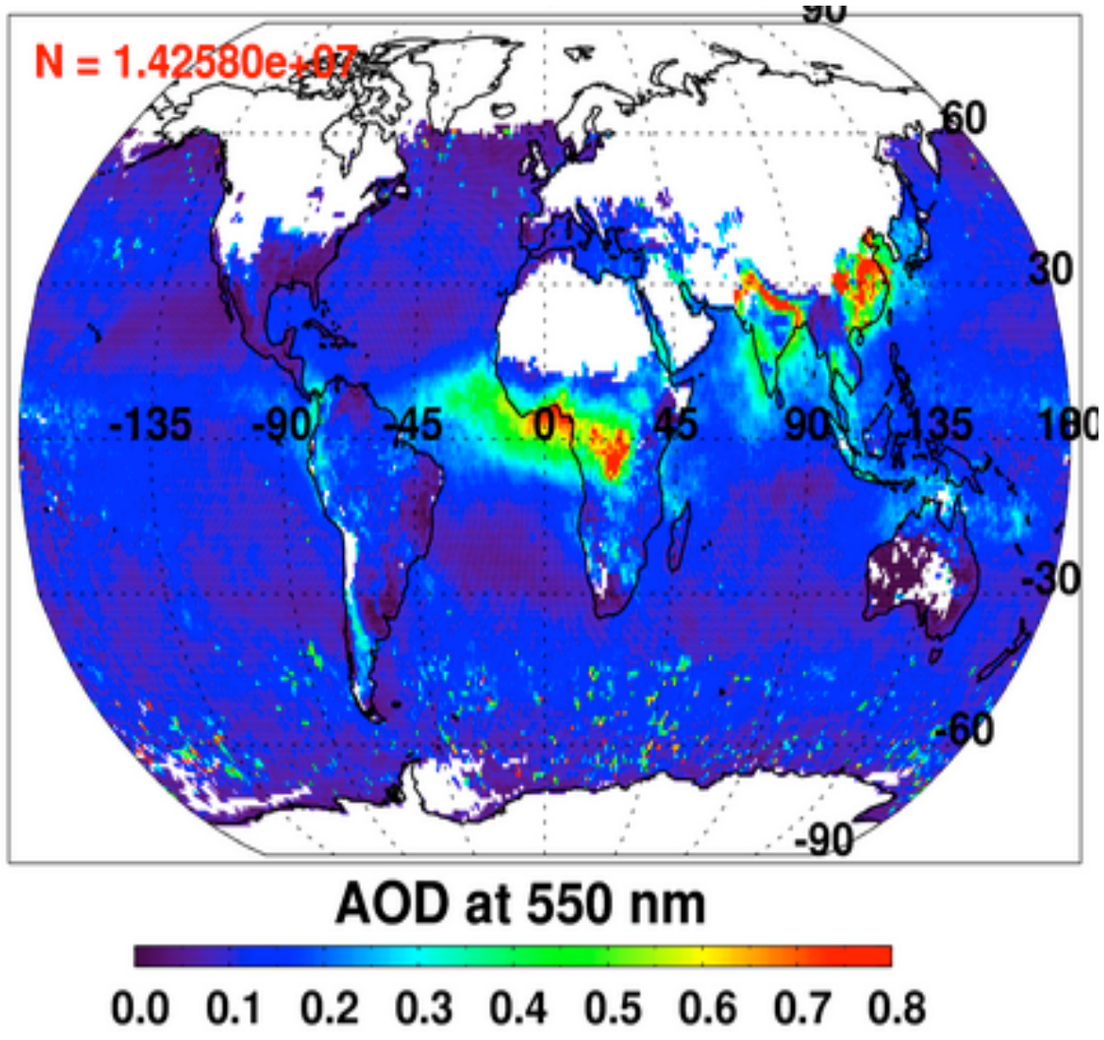
What else for C6 Level 2?

- Diagnostic SDSs (wind speed, topographic elevation, etc)
- “Cloud mask”, “distance to nearest cloud” (these are at native 500 m resolution).
- Changes to SDS names

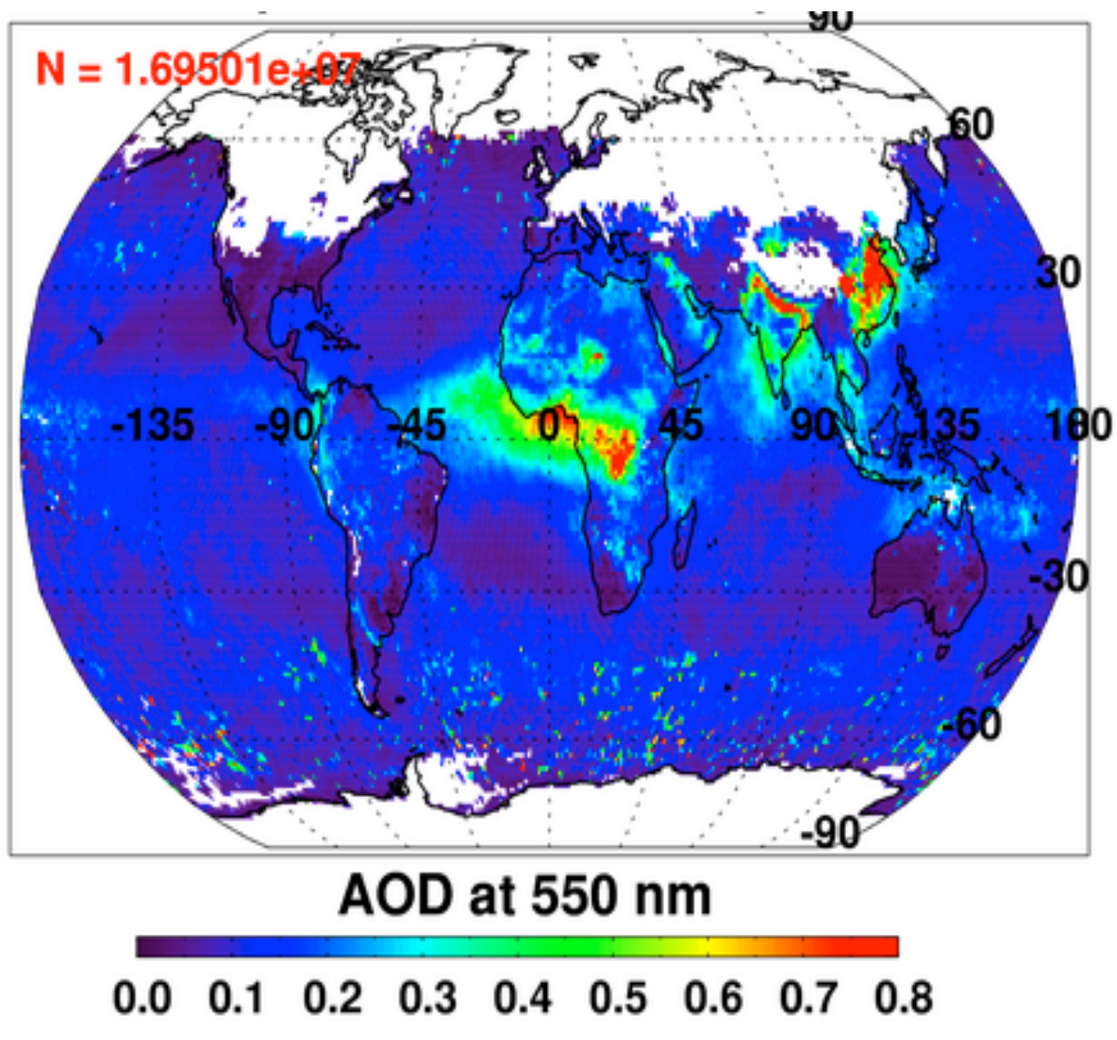


Deep Blue/Dark Target Merge:

Dark Target AOD



DeepDark AOD

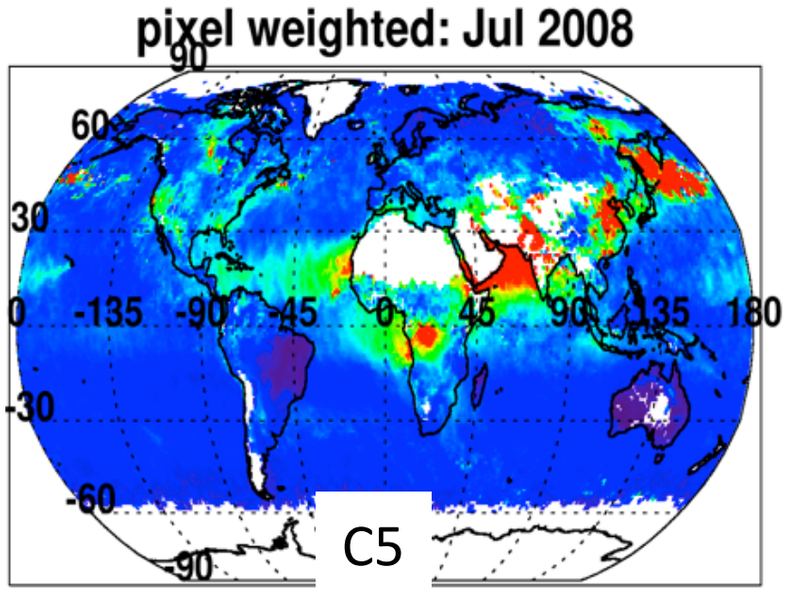


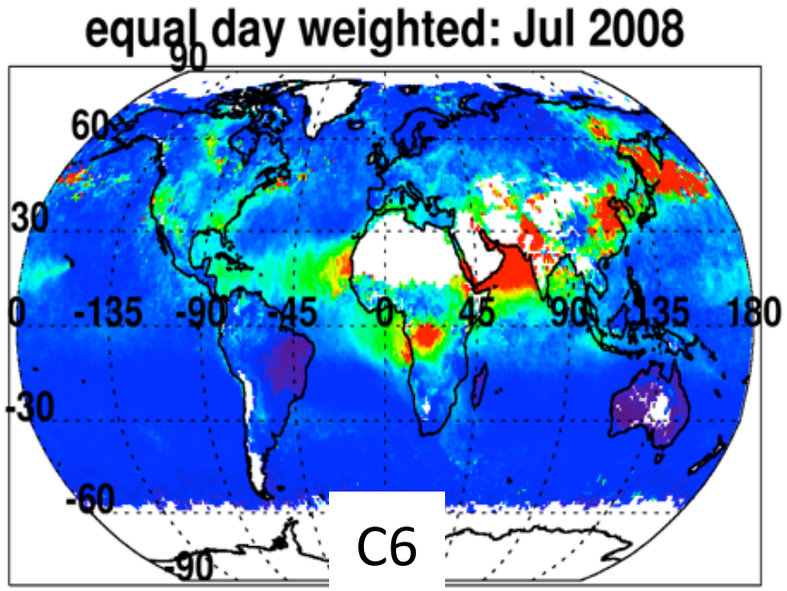
Merging deep blue & dark target produces best global coverage

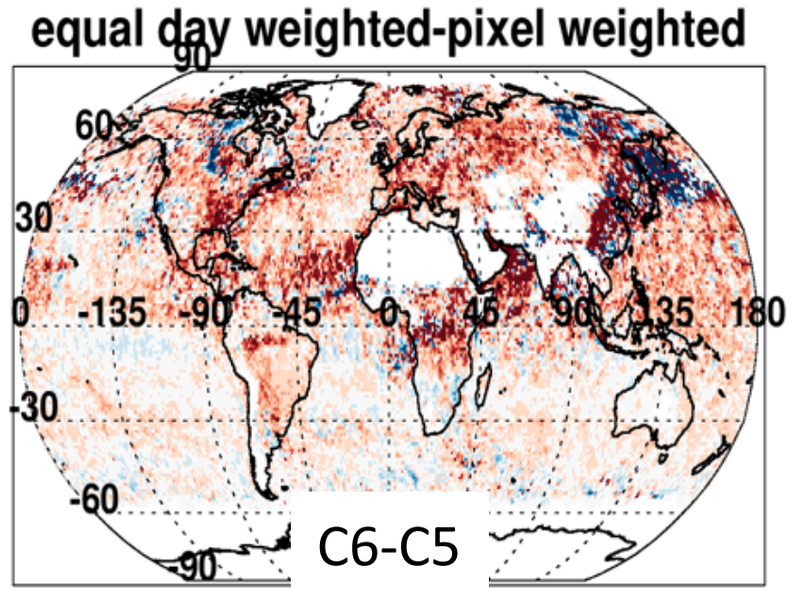
- **Deep blue is land-only; need dark target for oceans**
- **Deep blue introduces coverage over Australian outback, Sahara desert and Arabian peninsula**
- **Still no coverage over snow (see: most of Northern Hemisphere).**
- **LOOKS REASONABLE, Subject of next week's webinar?**

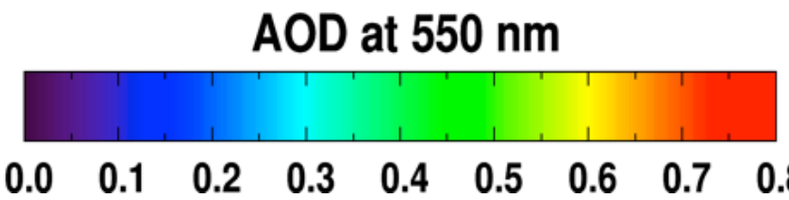
7. For Level 3

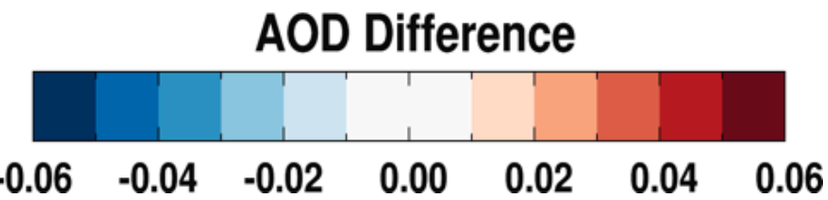
Changes to Level 3 (MxD08_M3)

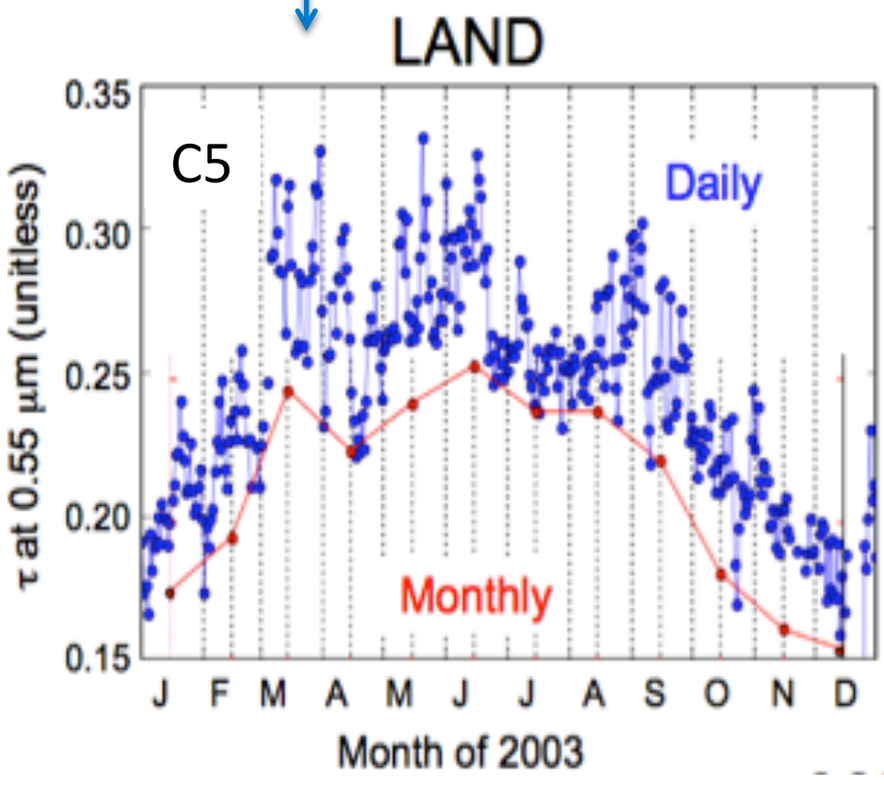












- In C5, averaging daily data did not look like monthly data (left, from Giovanni web application)
- C5 monthly was "pixel weighted". A day with 100 retrieved pixels was worth 10 times more than one with 10. It was clear-sky biased.
- C6 monthly is "equal day" weighted. If at least five pixels in a day, than that day counts.
- → Increases monthly mean AOD over land, and ocean. Less clear sky biased?

Changes to Level 3 (MxD08_M3)

Removed some SDSs that averaging makes no sense:

This is especially true of “intrinsic” aerosol parameters

- e.g., Angstrom exponent (AE), fine mode weighting (FMW)
- If a user wants to derive mean AE, they can use spectral AOD and calculate their own AE.

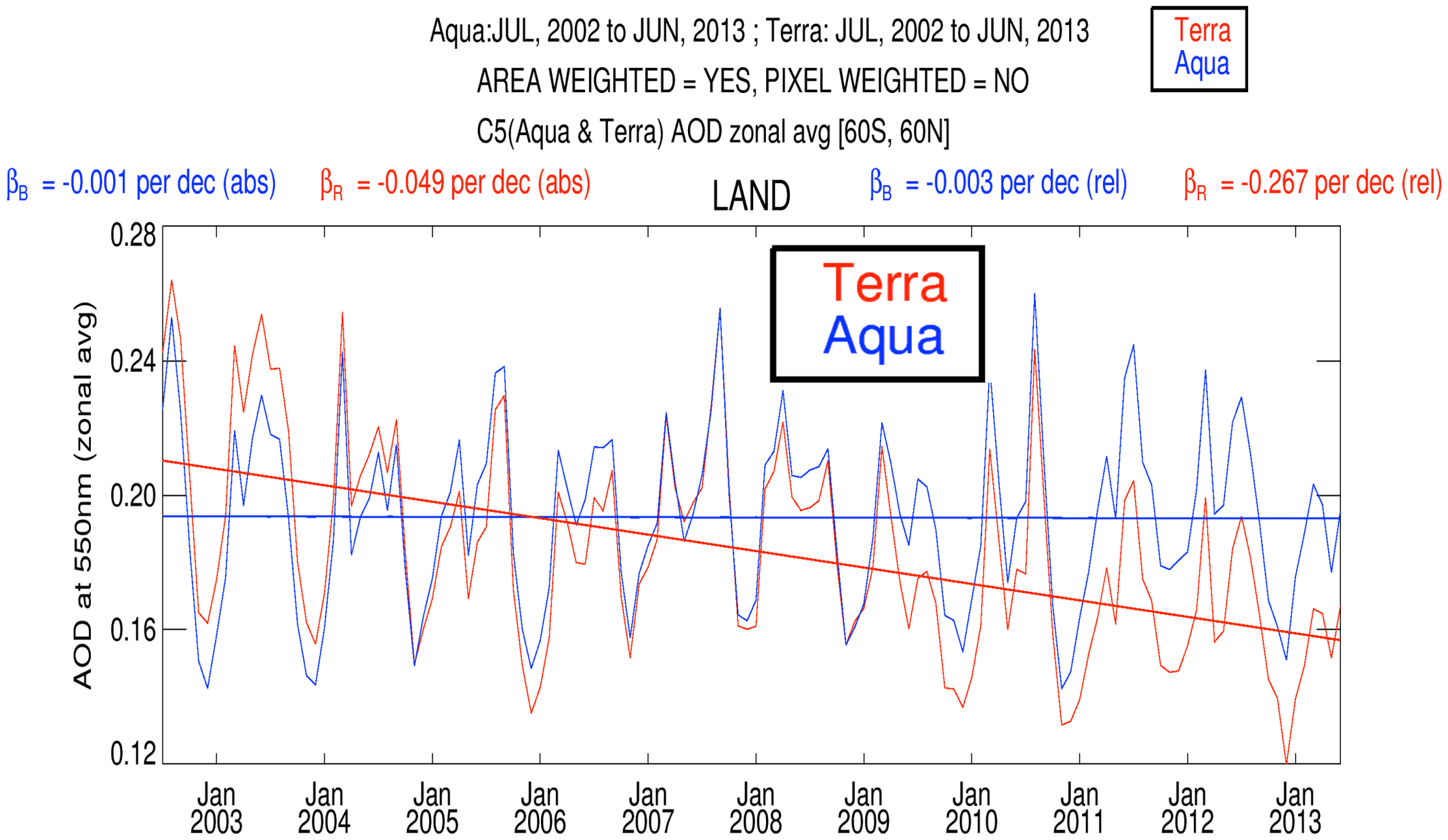
Added joint histograms for some SDSs

- e.g., Angstrom Exponent versus AOD.

8. Terra versus Aqua

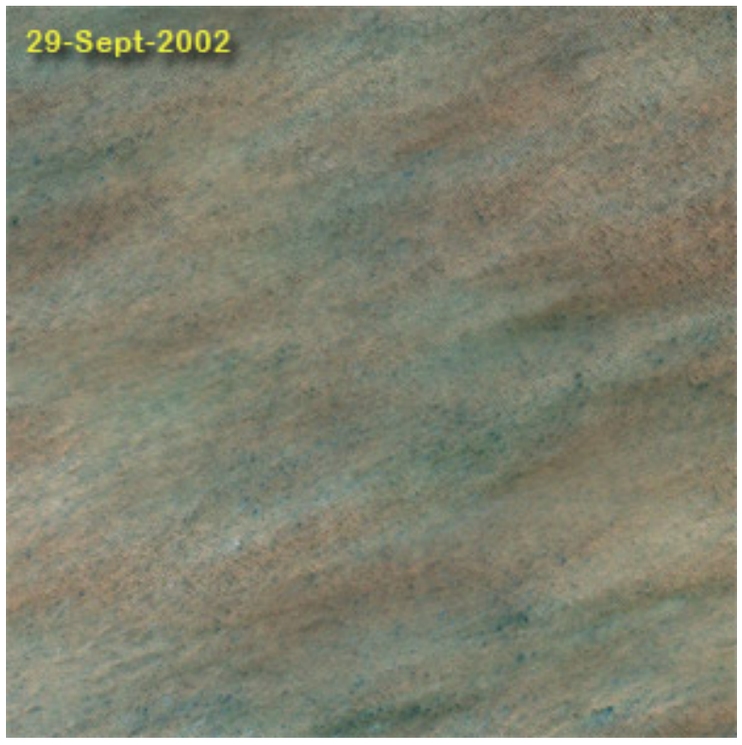
(also why Terra hasn't been produced yet)

Trends in Collection 5

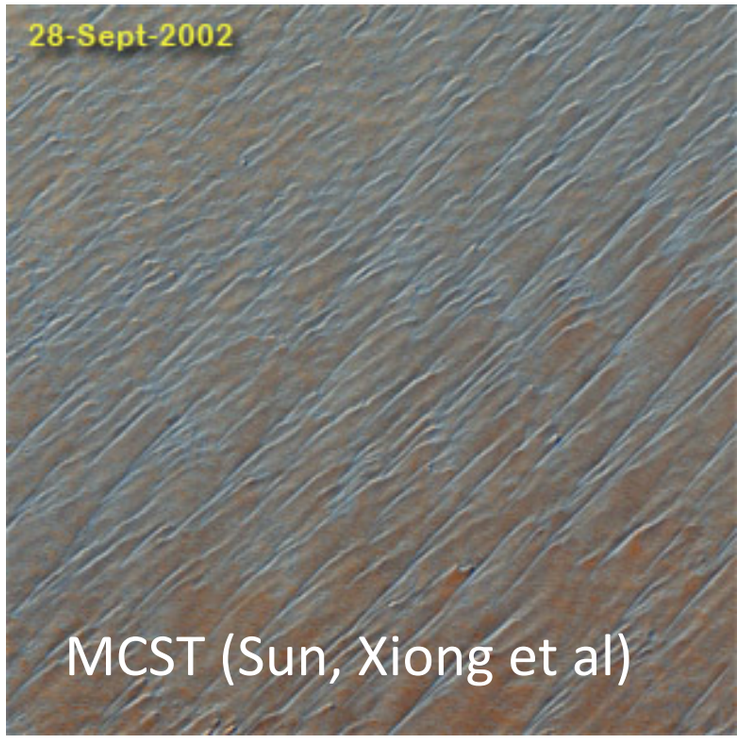


- Over land, Terra *decreases* (-0.04/decade), Aqua *constant*
- Terra / Aqua divergence is the same everywhere on the globe!
- In NH, observations are 1.5 hours apart, while SH are 4.5 hours
- So, probably not due to diurnal cycle of aerosol

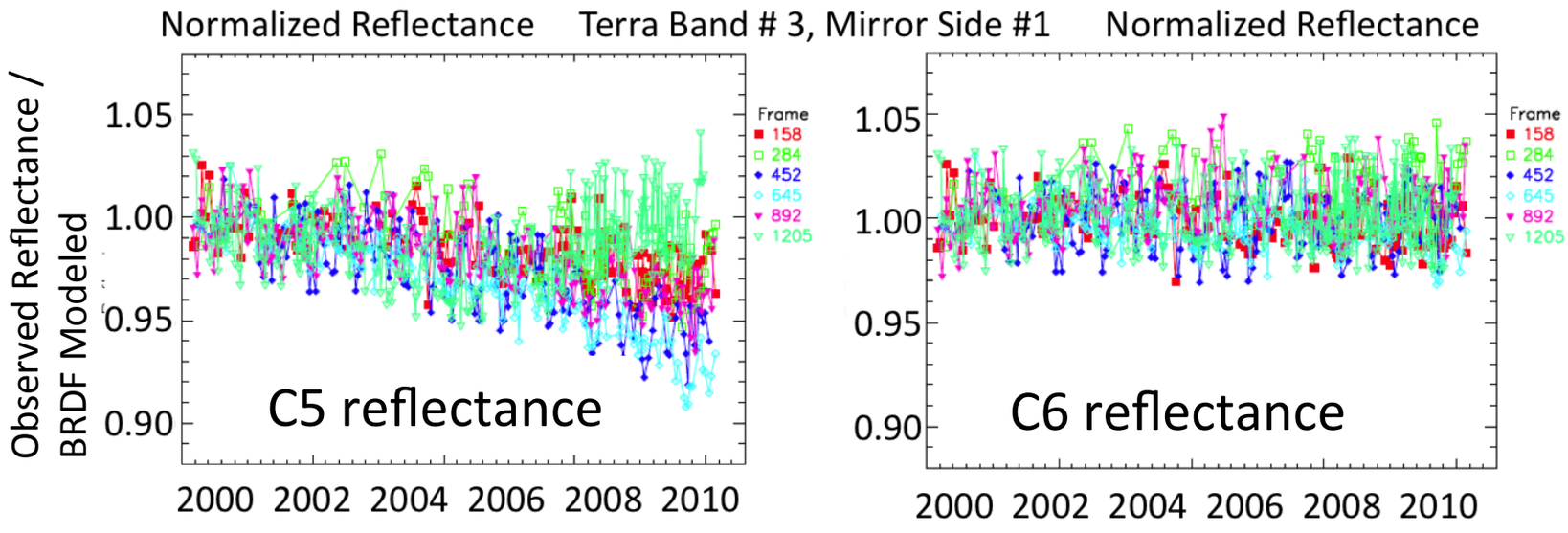
Why? MODIS reflectance over desert sites: C5



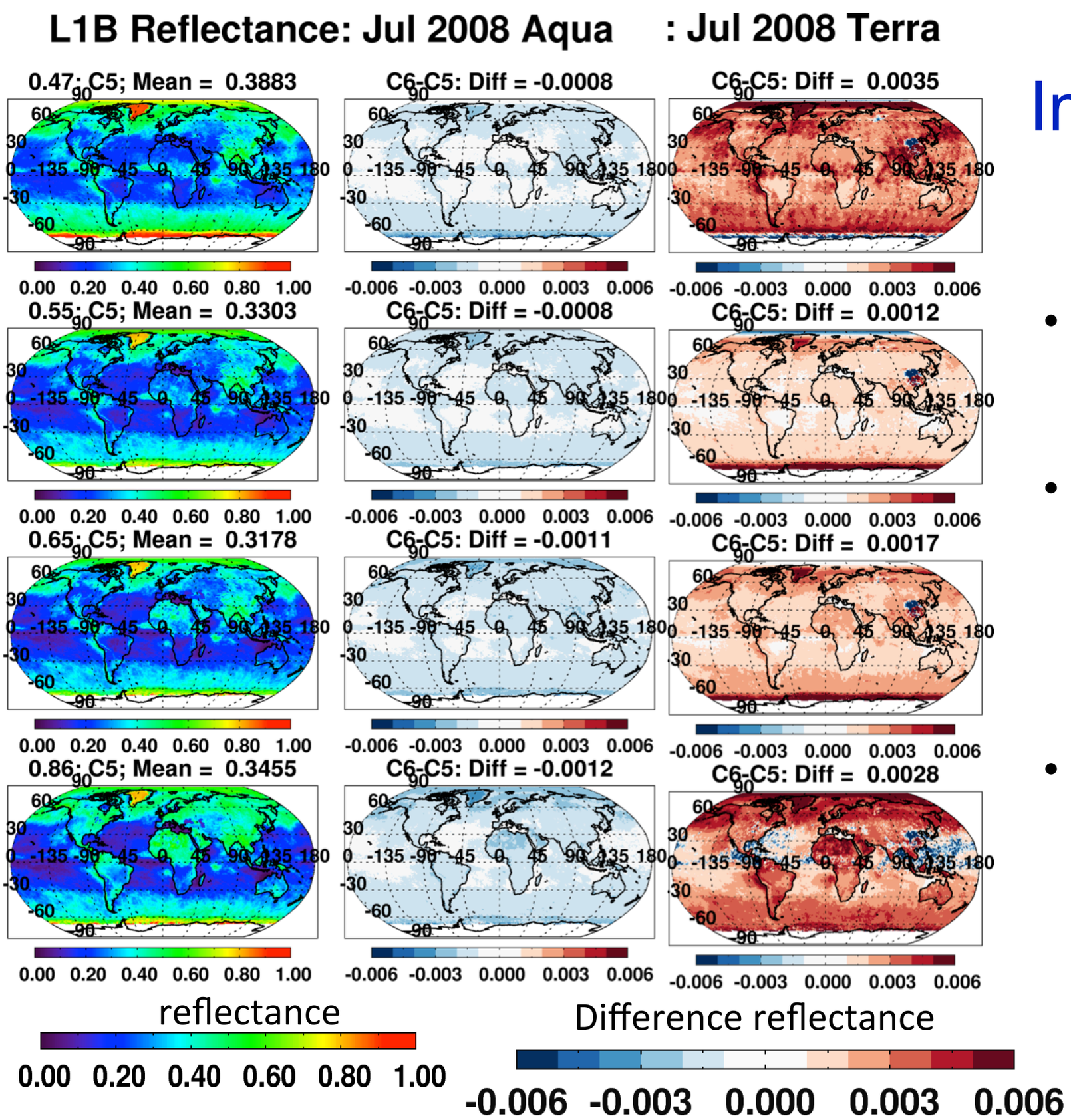
desert test sites



(1) Collect clear-sky MODIS data over desert sites
(2) Develop site-specific BRDF from first 3 years of mission
(3) MCST found that "observed" reflectance diverged from BRDF modeled reflectance over time



(4) Many bands were affected, but for DT aerosol, these included 0.47, 0.55, 0.65 and 0.86 μm bands.
(5) Terra much worse than Aqua
(6) MCST was able to "de-trend" the observations and
(7) Create a new L1B dataset for C6.

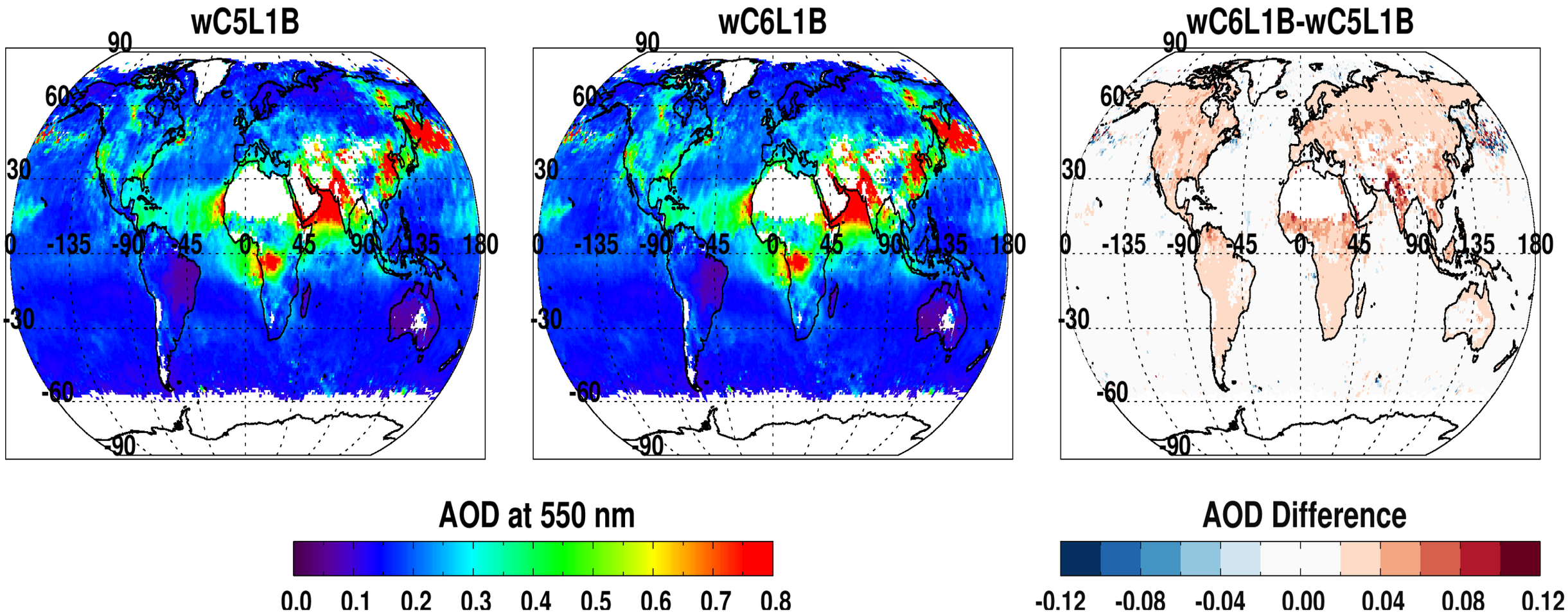


Impact to "observed" reflectance

- "Global" Aqua changes in visible bands by -0.001 or less
- "Global" Terra changes in visible bands by +0.002 or more

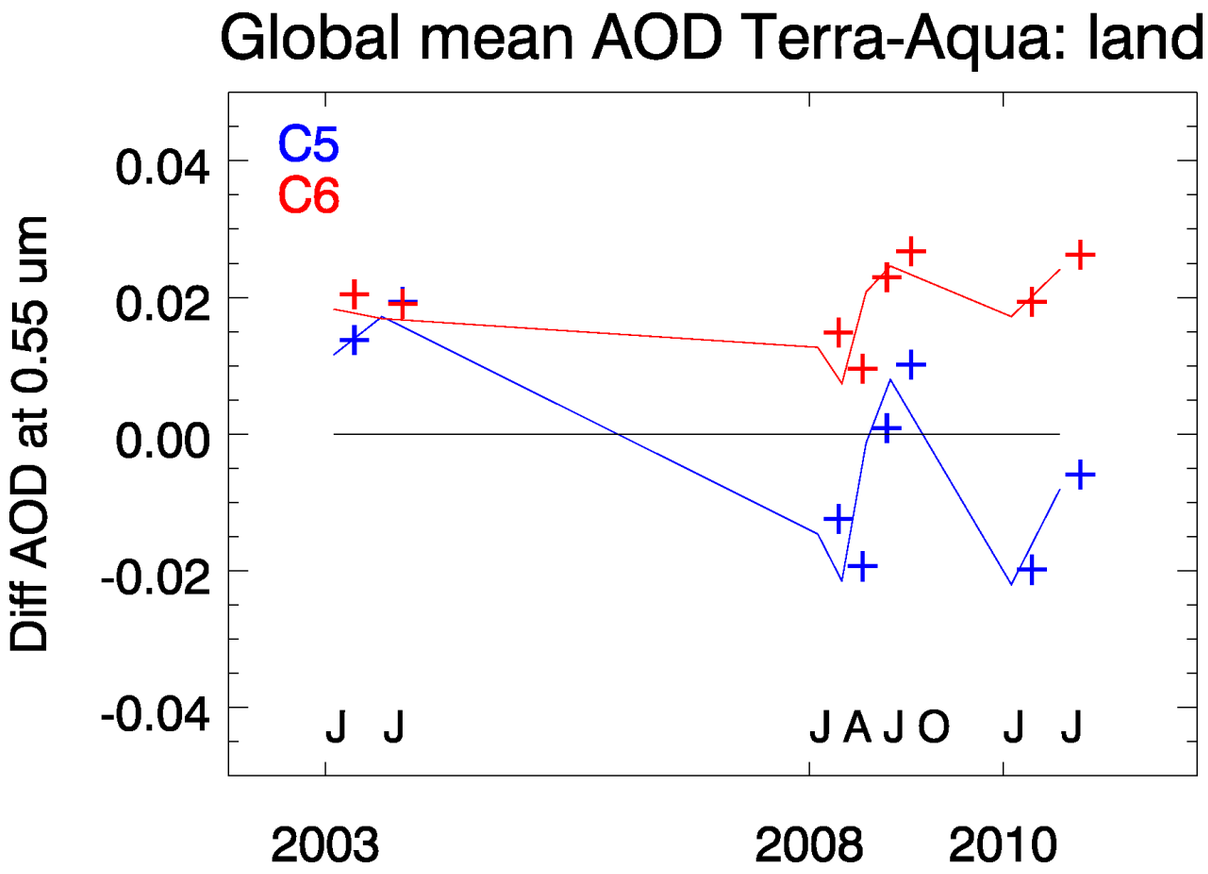
- Overall Aqua changes are relatively stable, but Terra's changes vary over time.

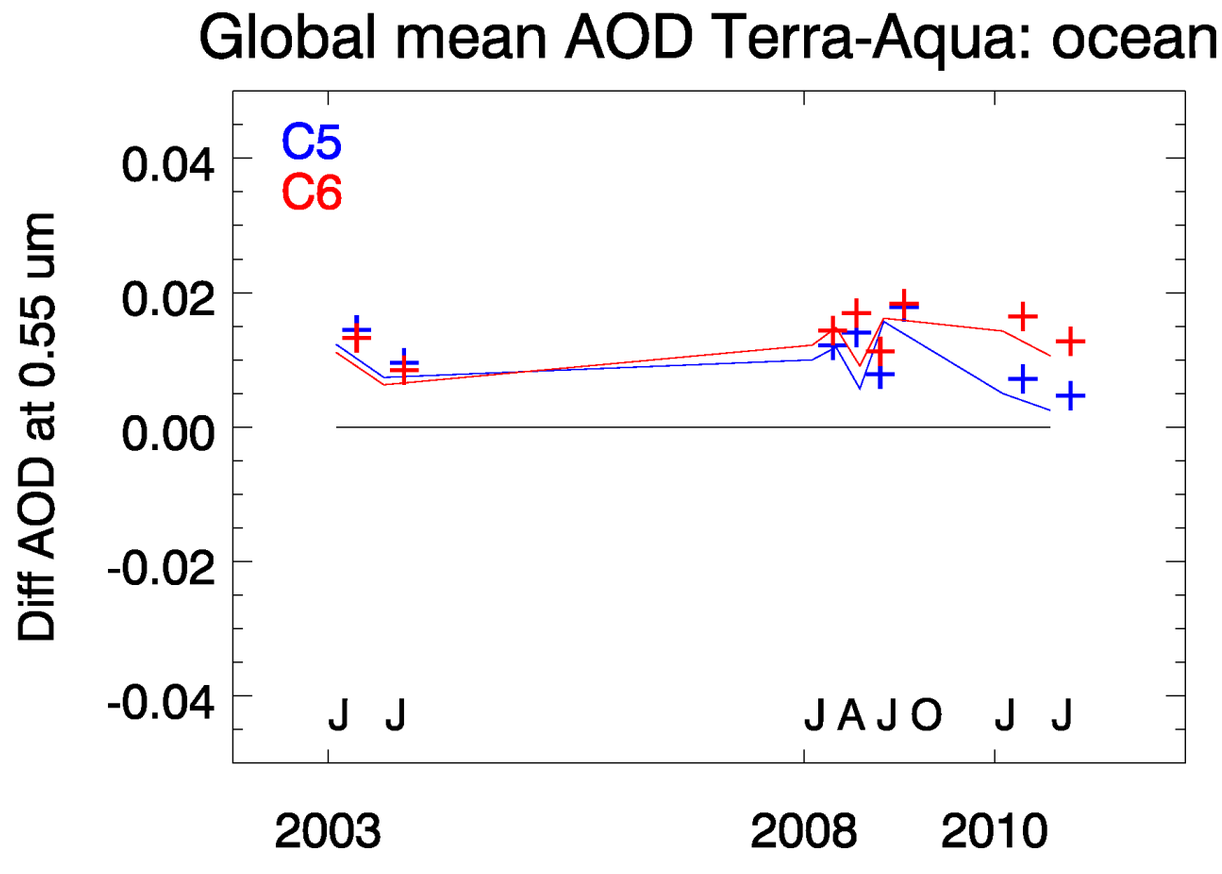
Impact of New Terra calibration



- Big changes to blue and red bands
- Biggest impacts over land
  - Global increase by 0.02 (for this particular month). 10% of global mean!
- Smaller impacts over ocean
  - Global increase by 0.004 (for this particular month)

Impact of new calibration on trend of Terra-Aqua AOD





- 8 months processed with same dark-target aerosol algorithms
- Terra now more "in sync" with Aqua time series
- **New calibration → Terra/Aqua divergence removed for C6!**
- (Terra-Aqua) offset remains 0.02 (land) and 0.015 (ocean)

Continuing MODIS Calibration Challenges

- VIS/NIR response vs. scan angle (**RVS**)
  - Band (detector) and mirror side dependent
- Large solar diffuser (SD) **degradation** at short wavelengths (esp. Terra)
  - Impact on radiometric uncertainty estimates
  - SWIR SD degradation not tracked by SDSM
- **Polarization** sensitivity changes found in Terra MODIS
  - Band (detector), RVS, and mirror side dependent
  - No noticeable change seen in Aqua to date
- **Aging** instruments
  - Undesirable features, unpredictable changes
- Which is why Terra has taken longer to reprocess. Get it right!

9. Summary

Summary (1)

- The MODIS dark-target (DT) aerosol retrieval is part of the "atmosphere" processing structure
- The DT retrieval is one of the two retrieval heritages within standard MxD04_L2 aerosol files (Deep Blue (DB) is doing webinar next week). I described some of the basics for DT.
- There are many updates for C6 algorithms which we described here, both over ocean and over land. I described how some of the changes impacted the retrieval.
- I noted changes in C6 product files, including new parameters (SDSs), changed SDSs and deleted SDSs
- Terra's degradation is a big deal, and MCST is providing new calibration and L1B data that will remove artificial trending in the L1B and our aerosol products for C6. There are continued challenges for calibration

Summary (2)

- MODIS-Aqua data are completely reprocessed for C6, and are available via LAADS.
- Terra data are undergoing final checks before being processed as C6.
- There will be aerosol webinars during the next few weeks, highlighting other changes within the aerosol product: including the improved Deep Blue (DB) data and the DB/DT merge data (within MxD04_L2), as well as new 3 KM resolution aerosol retrieval (MxD04_3K).

THANK YOU!!!!