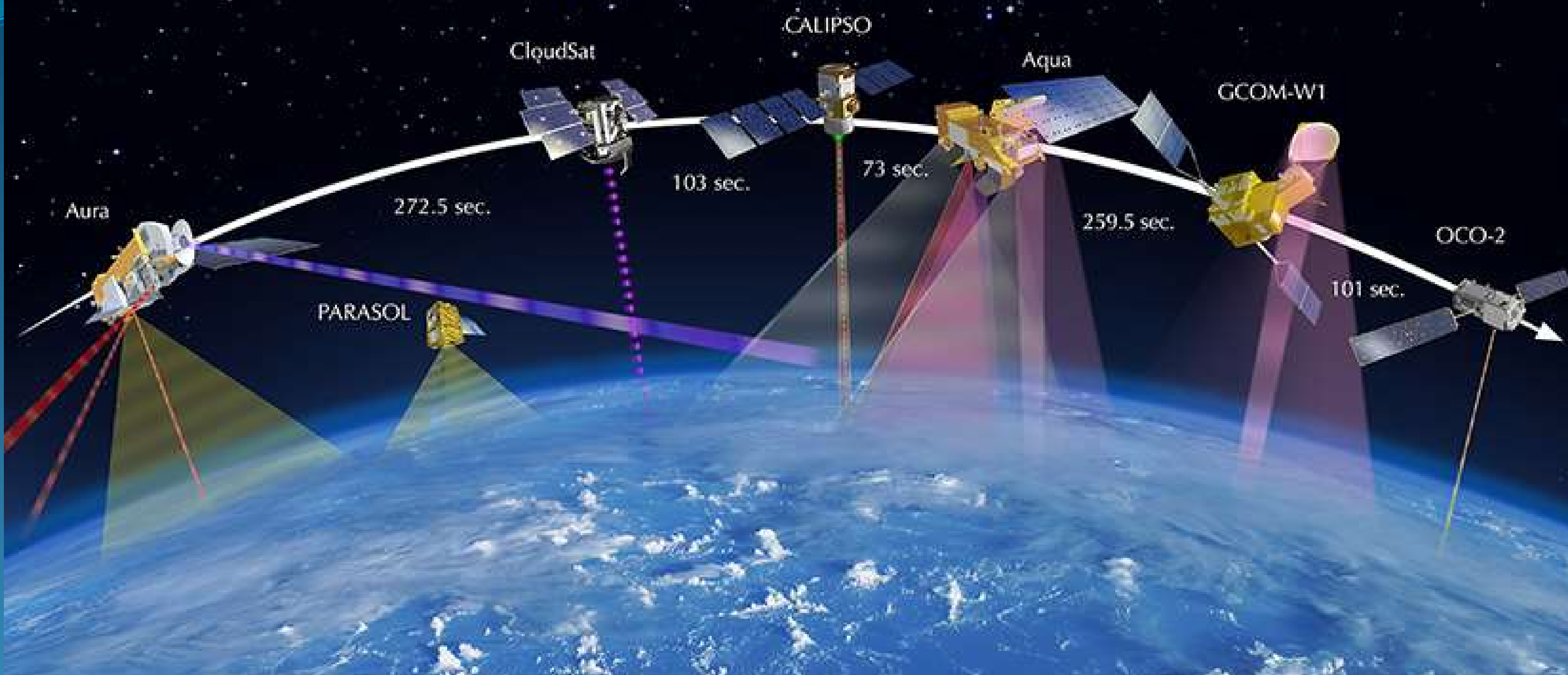
MET 611 – Satellite Data Applications



MODIS Aerosol C6 Improvements

Jennifer D. S. Griswold

Aerosols can travel a long way

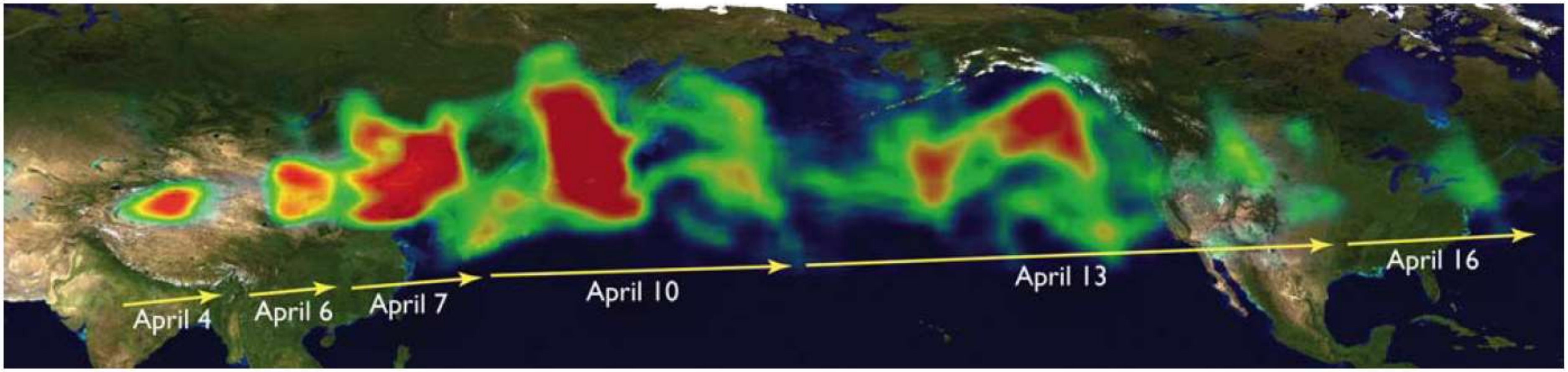


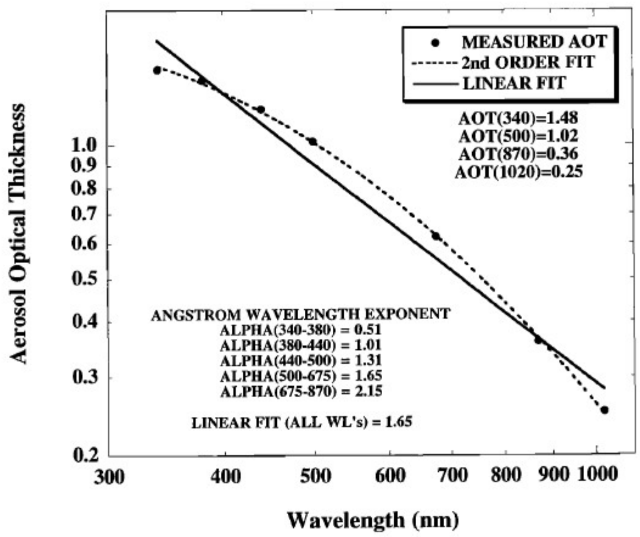
Fig. 1. Time series of TOMS AI composite in April 2001 showing the long-range transport of Asian dust across the Pacific reaching as far as the east coast of the U.S.

- Mineral dust from Taklimakan desert transported to North America
  - Hsu *et al., IEEE TGARS* (2006)
  - Renewed attention in Yu *et al., Science/Atmos. Res.,* (2012)

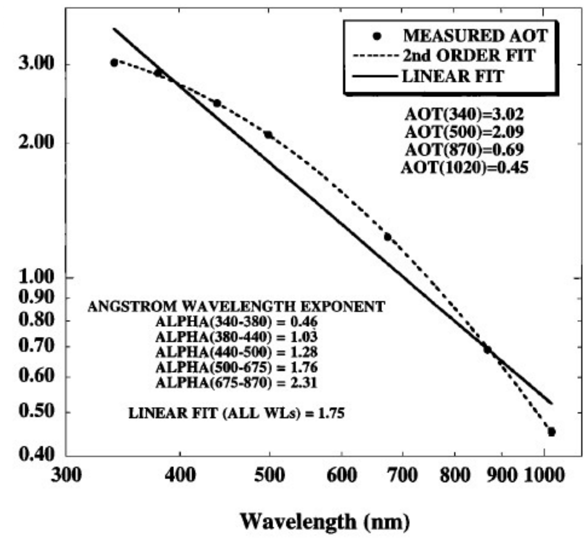
- We also see Asian pollution transported to North America, Saharan dust transported to the Amazon and Europe, African smoke transported to South America, Asian dust to Europe, high-latitude smoke circling the world in both hemispheres, etc…

Aerosols and properties of interest: AE

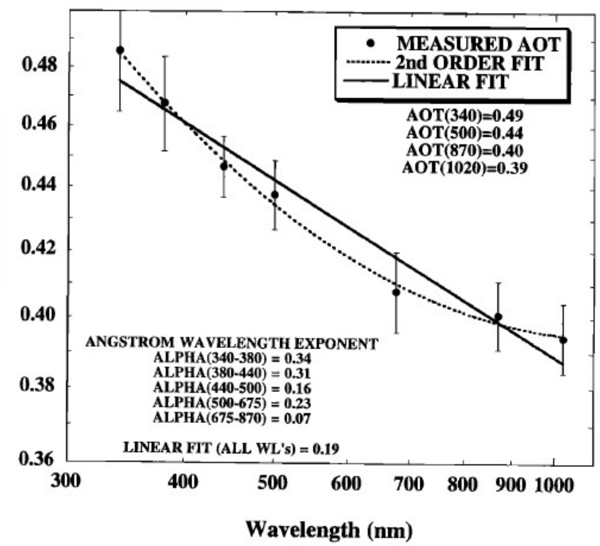
Urban aerosols (NASA GSFC, USA)



Smoke aerosols (Bolivia)



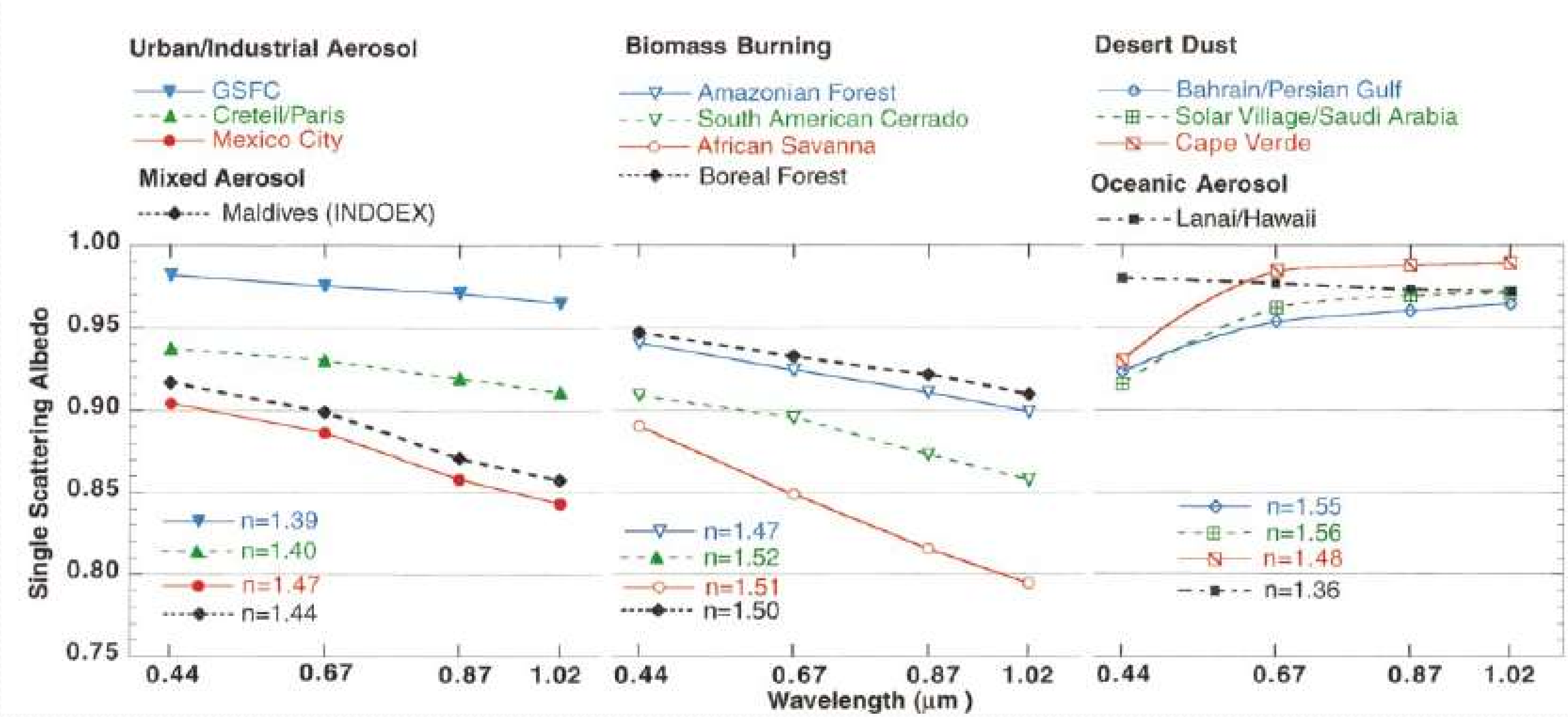
Mineral dust aerosols (Dalanzadgad, Mongolia)



From Eck *et al.*, JGR, 1999

- Ångström exponent (AE, α): spectral dependence of AOD
  - Values < 1 suggest optical dominance of coarse particles (e.g. dust)
  - Values > 1 suggest optical dominance of fine particles (e.g. smoke)
  - Depends on wavelength range used to calculate it

Aerosols and properties of interest: SSA



From Dubovik *et al.*, JAS, 2002

- Single Scattering Albedo (SSA) : measure of light absorption by aerosols
  - SSA = 0: Pure absorbing aerosols (never encountered)
  - SSA = 1: Pure scattering aerosols
  - Typical range ~0.8 (some industrial/smoke) - 0.99 ('clean' continental, marine aerosols)
  - Also has wavelength dependence

Aerosol algorithm REVIEW

The 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

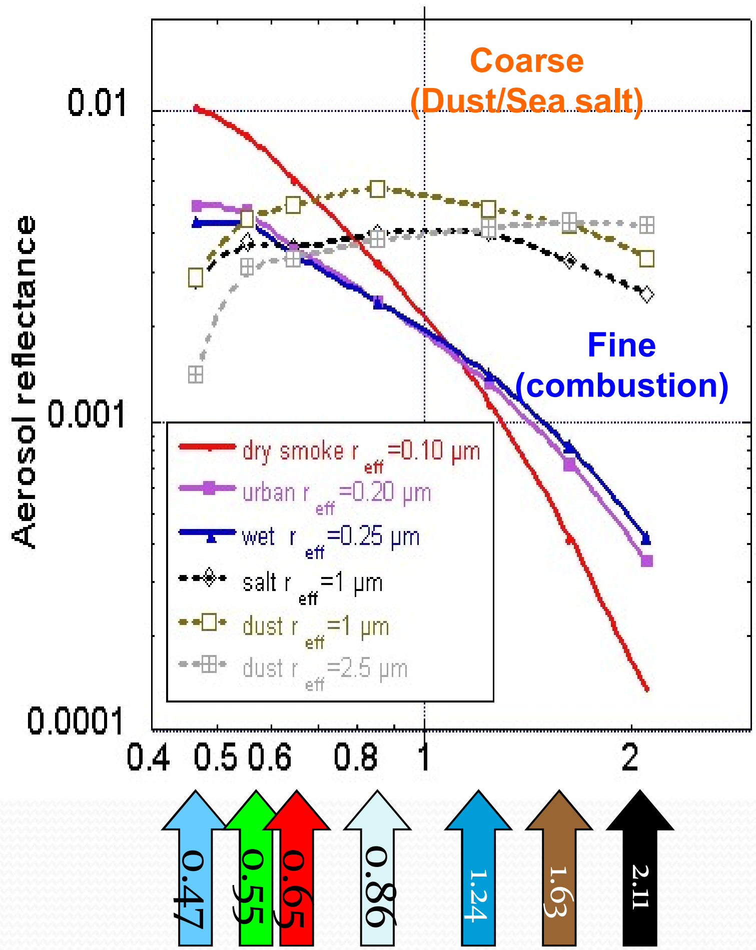
3. Deciding whether over "land" or "ocean"

4. Separating signal (aerosol) from noise (clouds, surface inhomogeneities, instrument issues, etc), includes "cloud masking"

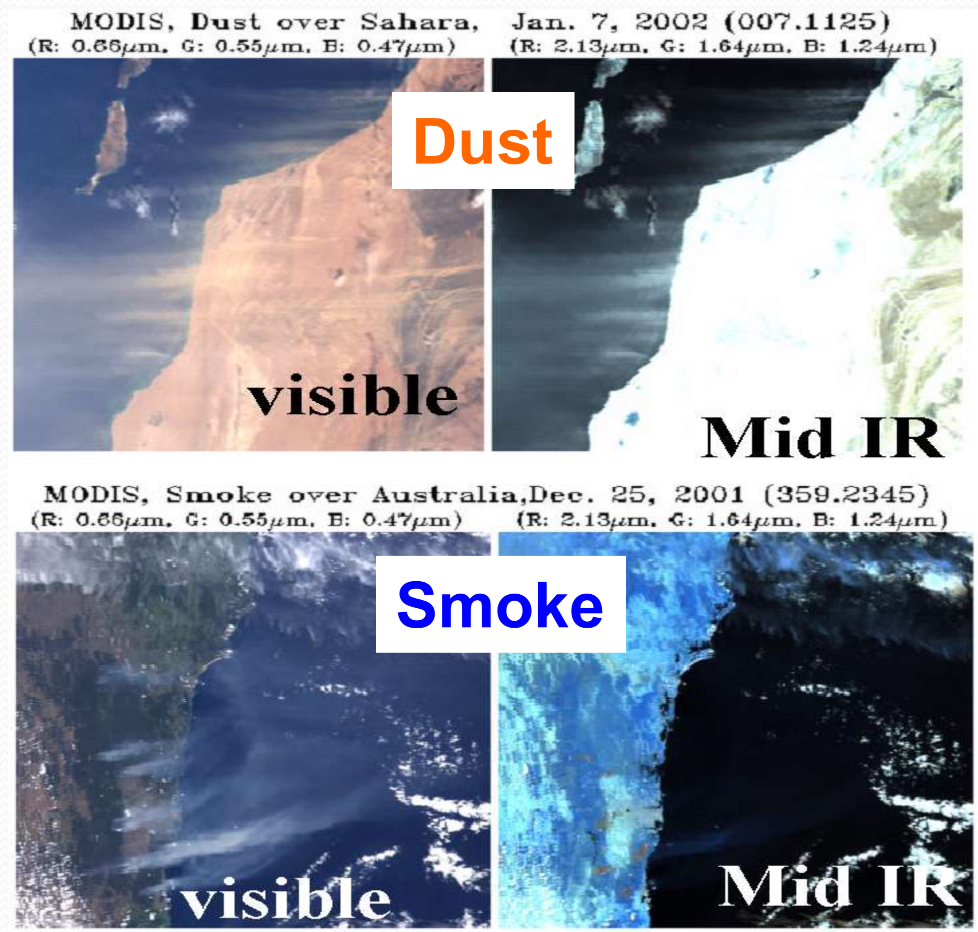
5. Correctly interpreting the signal to AOD and aerosol size. "the retrieval"

6. Assigning quality assurance, reporting retrieved, derived, and diagnostic products. "the post-process"

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



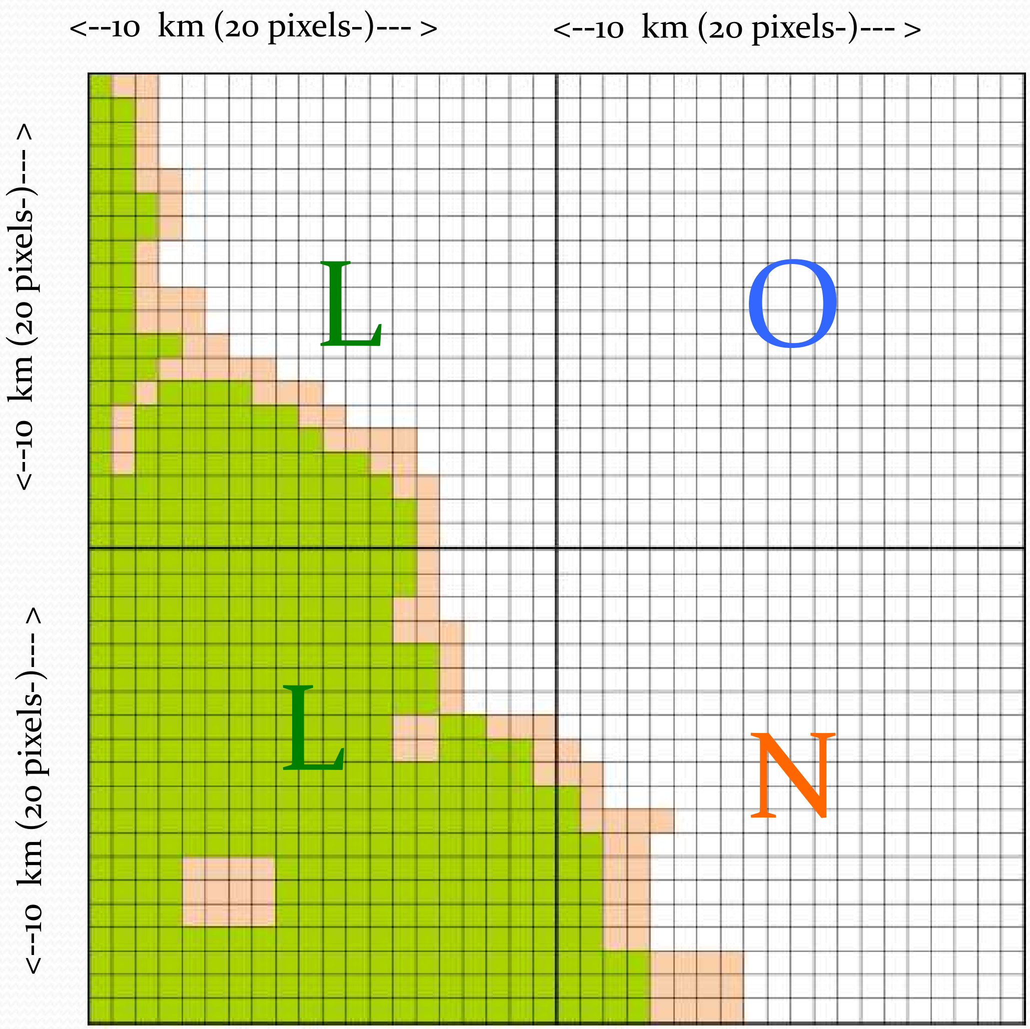
MODIS “Channels”
Used for DT aerosol



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

Y. Kaufman, D. Tanré

Some Basics About the Grid Boxes



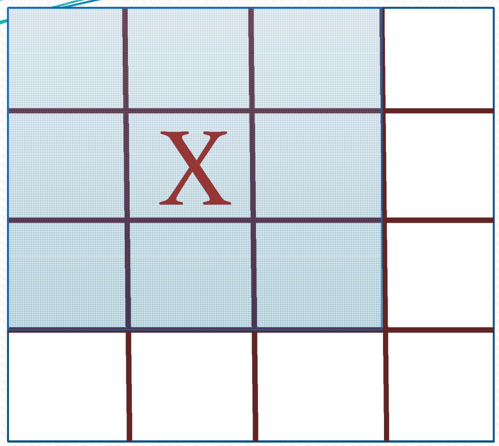
- Uses calibrated L1B reflectance data at primarily 500 m resolution.
- **Splits up the granule into 20x20 boxes** (~10 km at nadir).
- Corrects for "gas absorption" in each pixel (H_2O, O_3, CO_2).
- Decides whether pixel is "land" or "ocean"
  - If "all" pixels are ocean (white) then try Ocean retrieval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

Cloud Masking

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

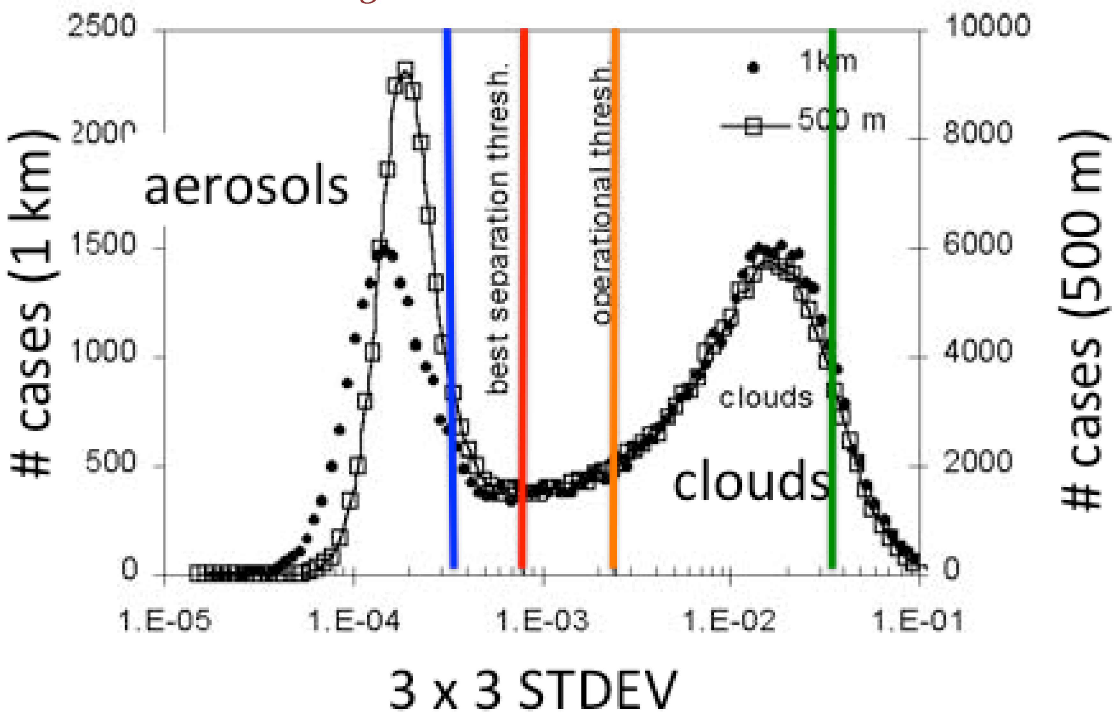
- Spatial Variability Tests (clouds appear bumpy)
- Visible channel brightness (clouds appear bright)
- Visible channel gradients (aerosols appear “colored”)
- Cirrus Cloud Removal (high clouds obscure water vapor)
- IR tests: (clouds are colder than the surface)

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).

aerosols tend to be homogeneous and clouds are fractal



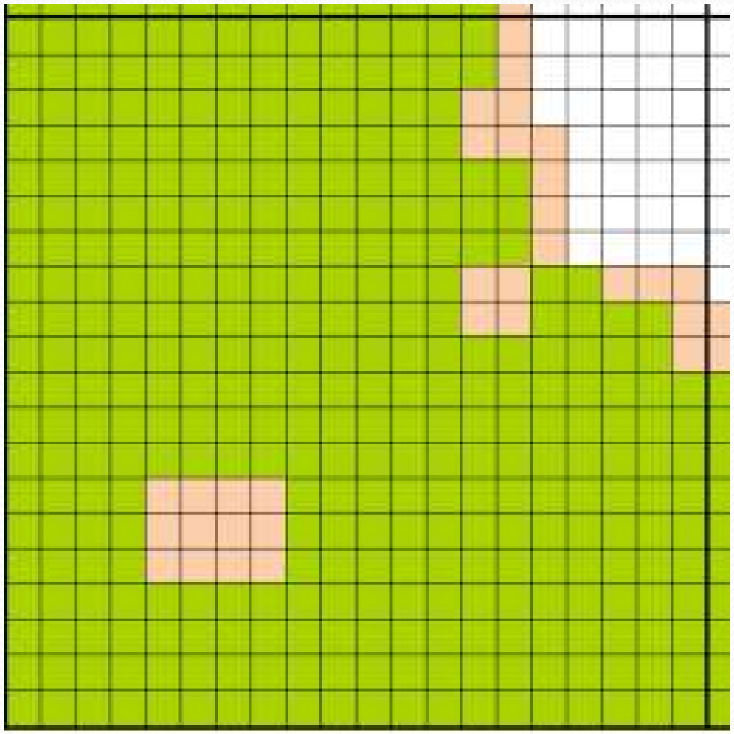
If the STDEV > threshold THEN the center pixel is cloudy

For C6: Slight changes for thresholds and formulas

Martins et al., (2002)

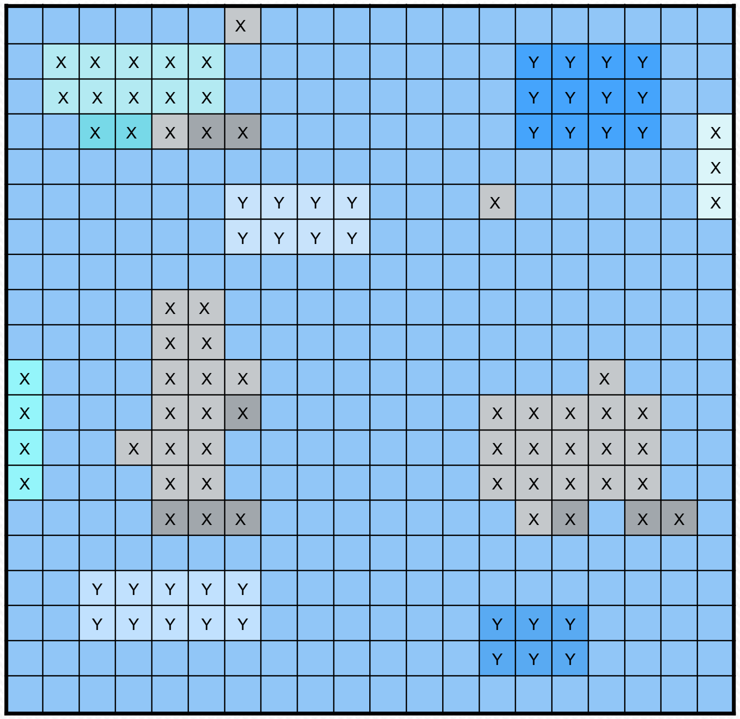
Land Retrieval: Review

- 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)



Ocean Retrieval: Review

- 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)



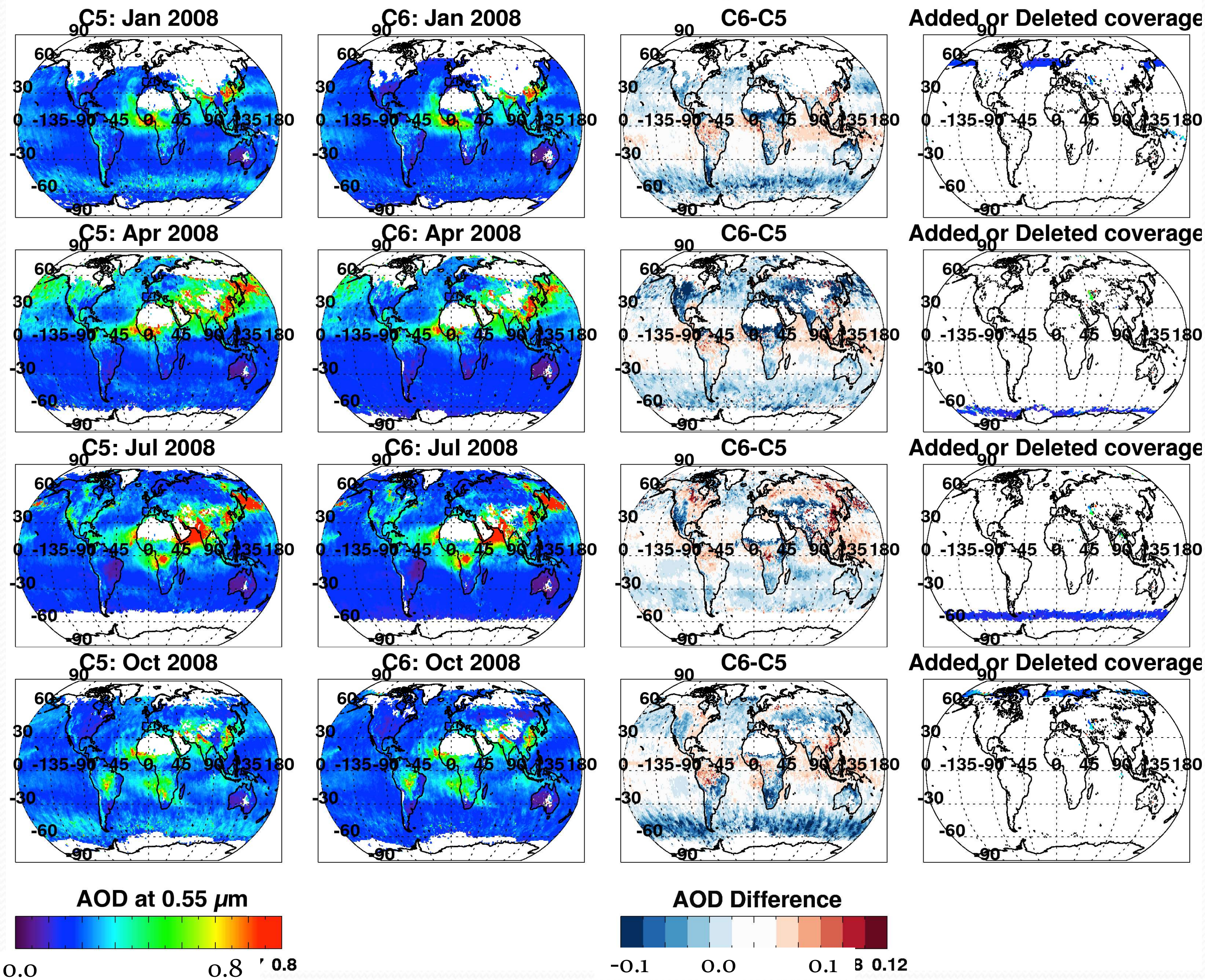
Overall changes (C6 vs C5): Aqua, 2008

Jan

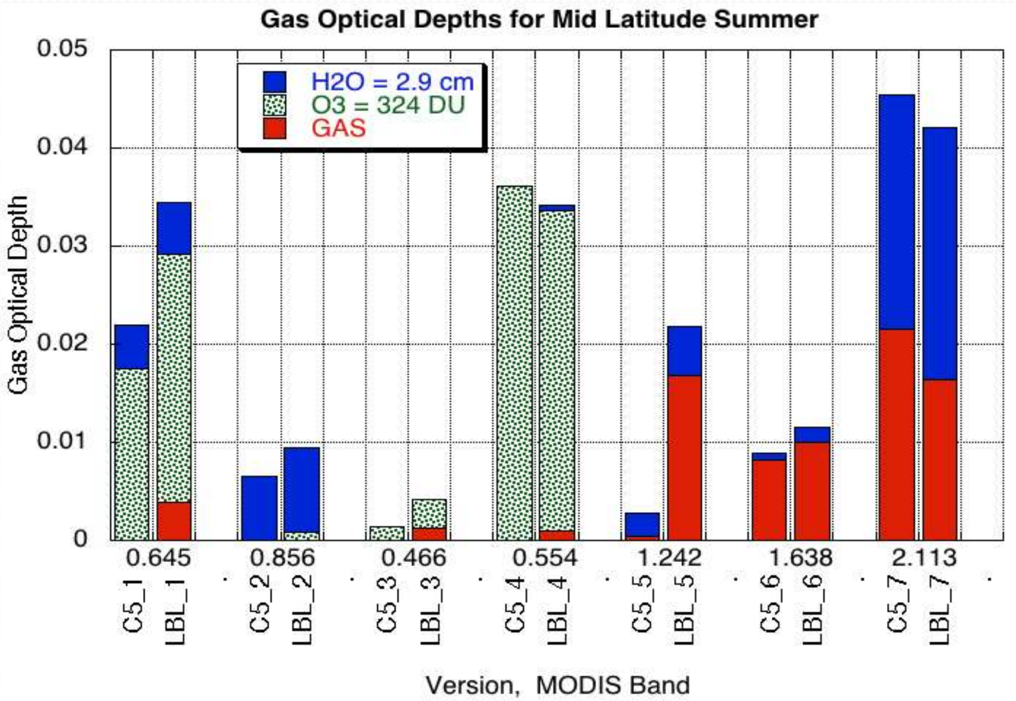
Apr

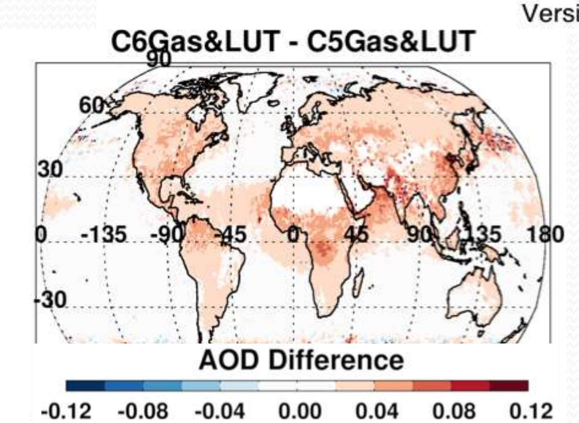
Jul

Oct



Correction for gas absorption and Rayleigh optical depth





Upshot: global AOD increased by 0.02

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

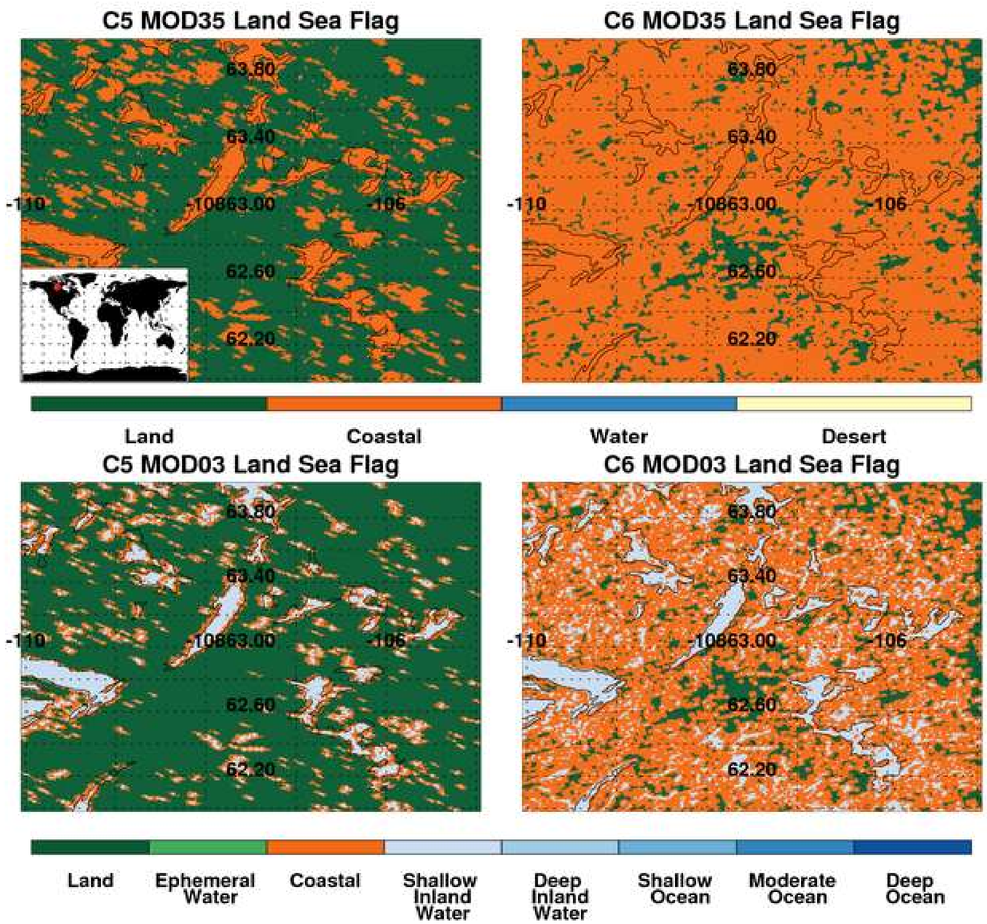
Absorption of these gases varies by wavelength! And can be up to optical depths of 0.05!

Must account for this accurately!

For C6:

- Uses modern Radiative Transfer code to account for gas absorption
- Recalculates center wavelengths and Rayleigh optical depths

Land/Sea Flag Land or Ocean?



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

- 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.
- Essentially, the land/sea mask was changed!

Deep Blue: Review

- Often, darker surface and stronger aerosol signal in the violet/blue (~400-490 nm) than at longer wavelengths
  - Prescribe surface reflectance
  - Retrieve AOD independently at several wavelengths

- **Advantages:**
  - Avoids regional artifacts arising from e.g. global prescription of surface reflectance ratios
  - Avoids requirement for auxiliary data (so can run in near real-time)
  - Can be applied to many sensors

- **Disadvantages:**
  - Drastic departures from expected surface cover type can lead to localized artefacts
  - Can't directly calculate aerosol effective radius, volume etc

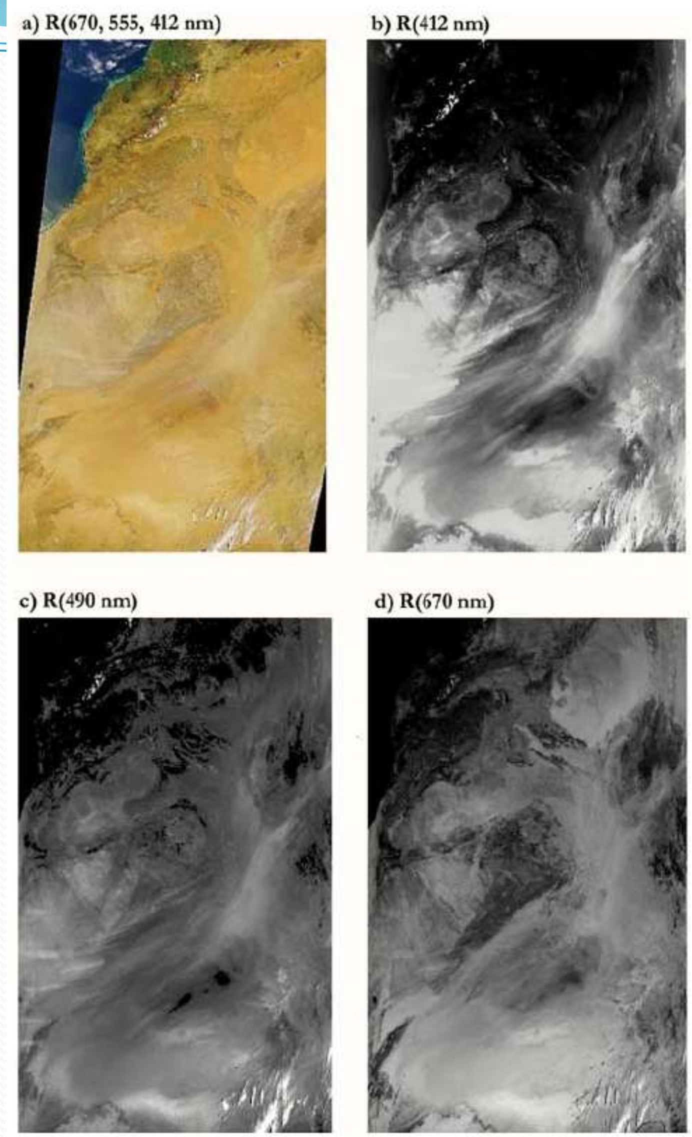
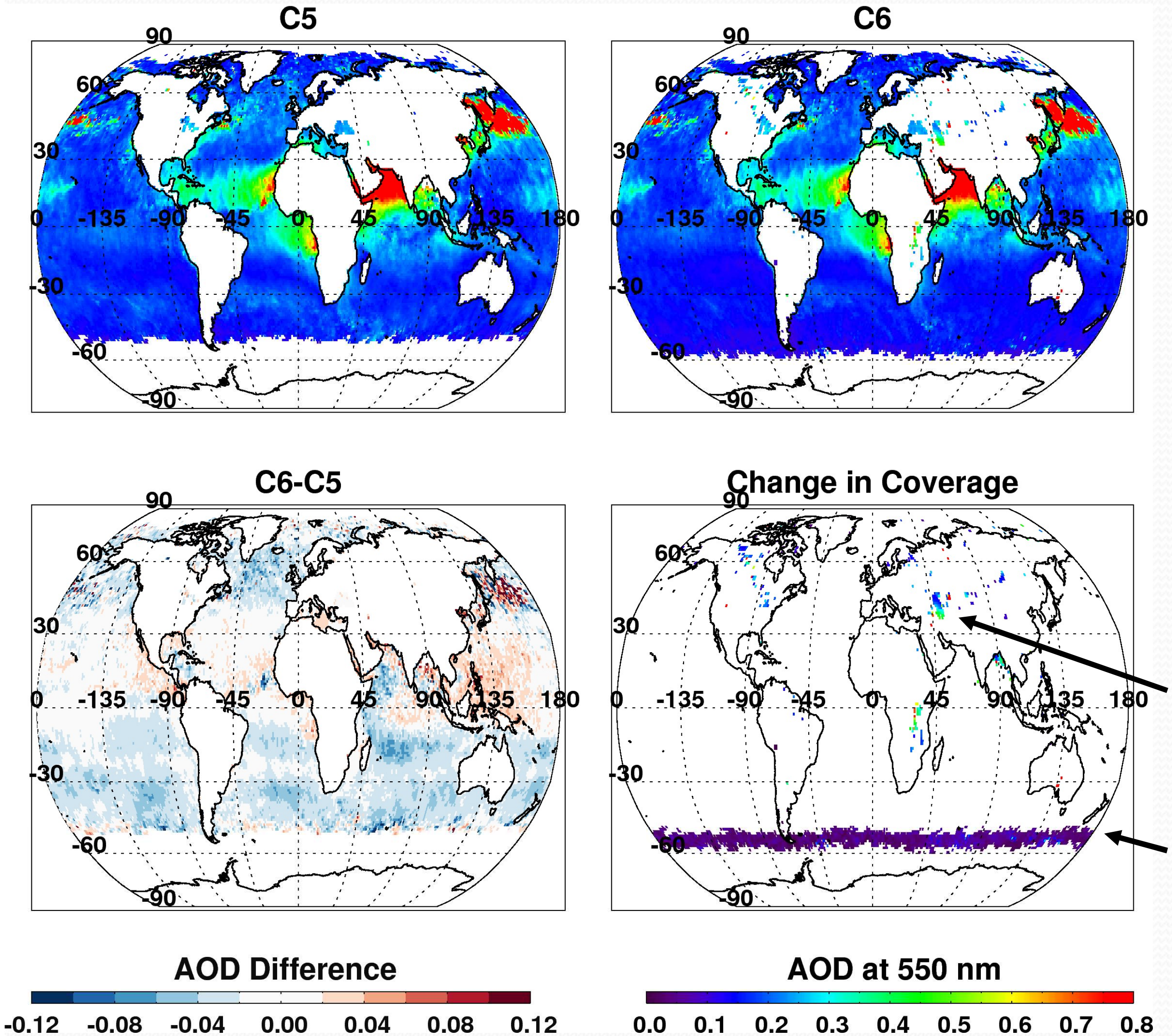


Fig. 2. SeaWiFS images over northeast Africa on February 10, 2001. The dynamical ranges of the grayscale used in (b)–(d) are individually adjusted to optimize the appearance of atmospheric features against the background surfaces.

Figure from Hsu *et al.*, *IEEE TGARS* (2004)

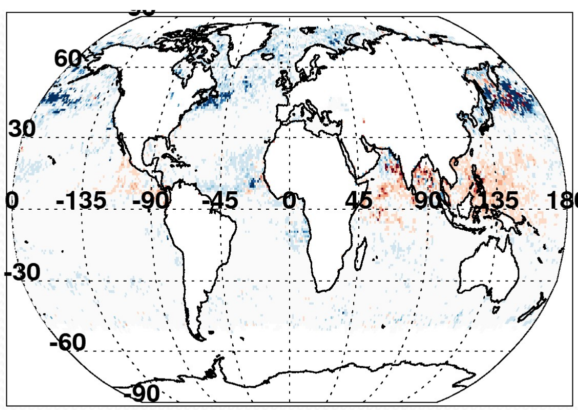
Dark target over ocean - overall changes to products (Aqua, Jul 2008)



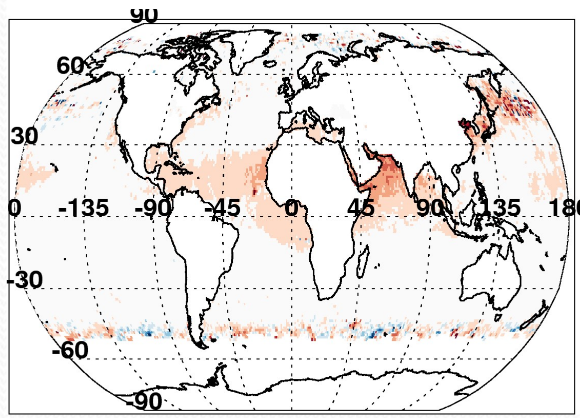
- Overall **decrease** of AOD in **mid-latitudes**
- Strong **decrease in "roaring 40s"** (even stronger in other months)
- Overall **increase in tropics**
- **"New" coverage over inland lakes**
- **Increase in coverage toward poles**

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

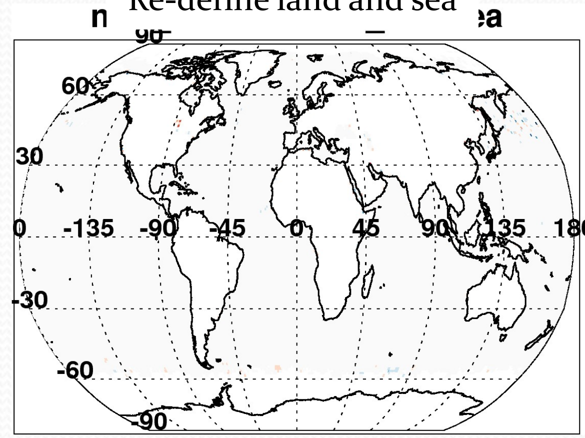
New reflectance, geo-location inputs, Wisconsin cloud mask



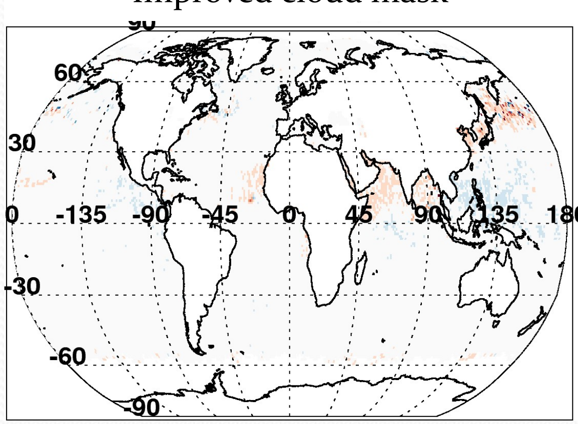
Updated radiative transfer



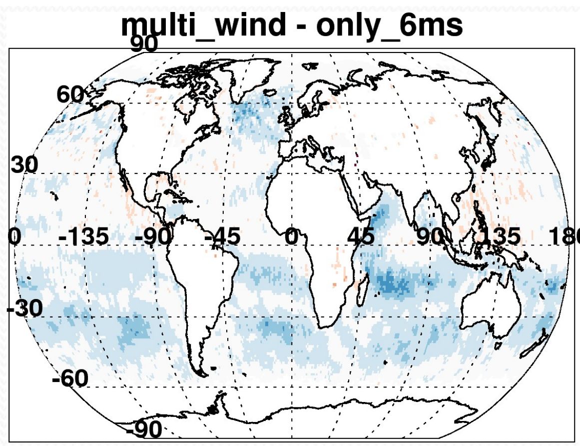
Re-define land and sea

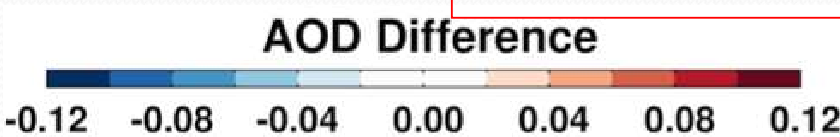


Improved cloud mask



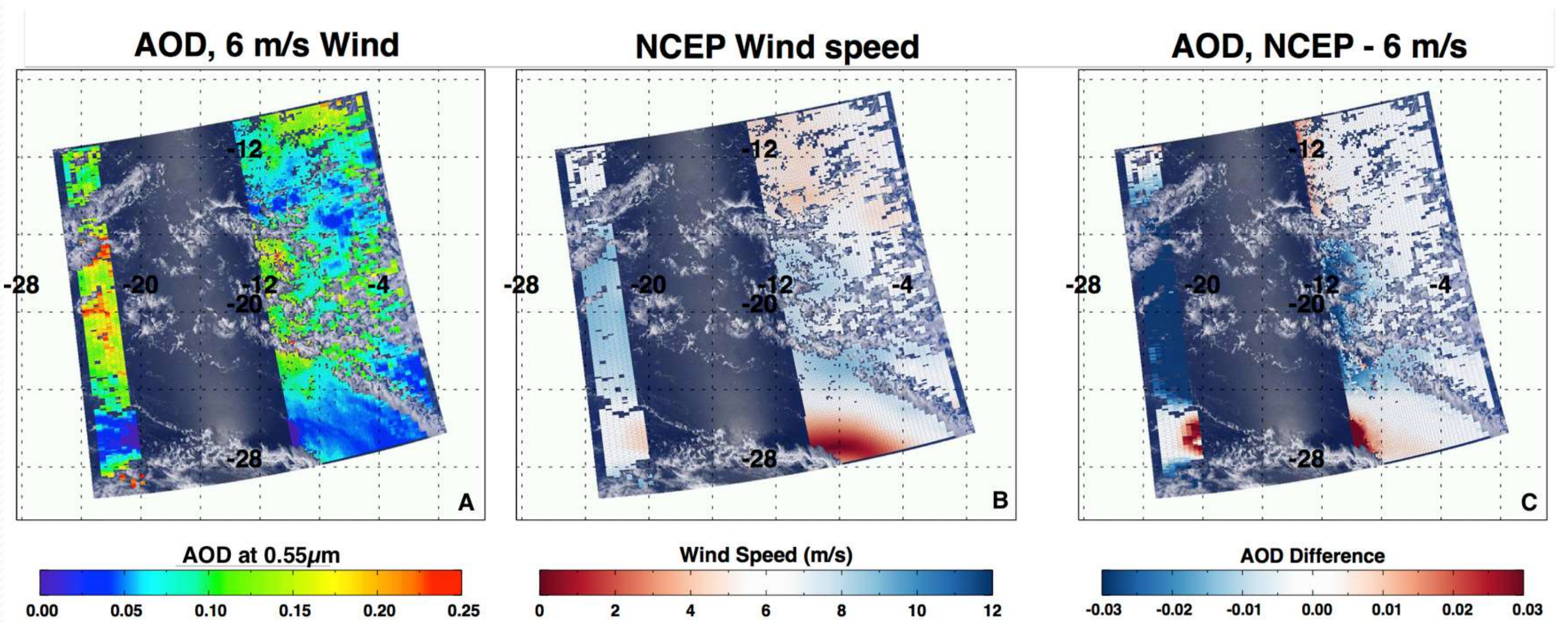
Account for wind speed impact on surface

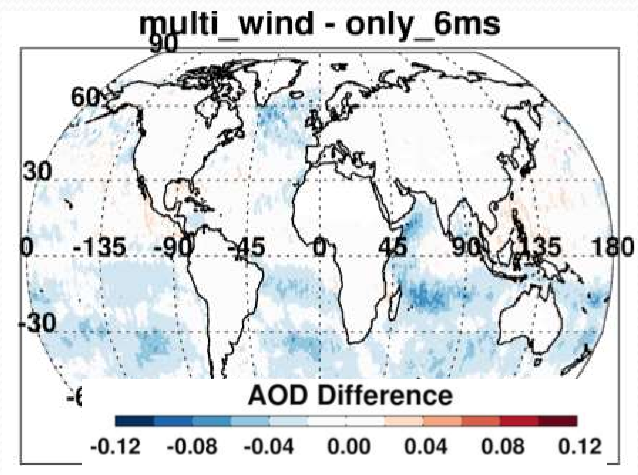




- Also changed **"Quality Assurance"** Filtering
- Changed aerosol definitions of **land and sea**

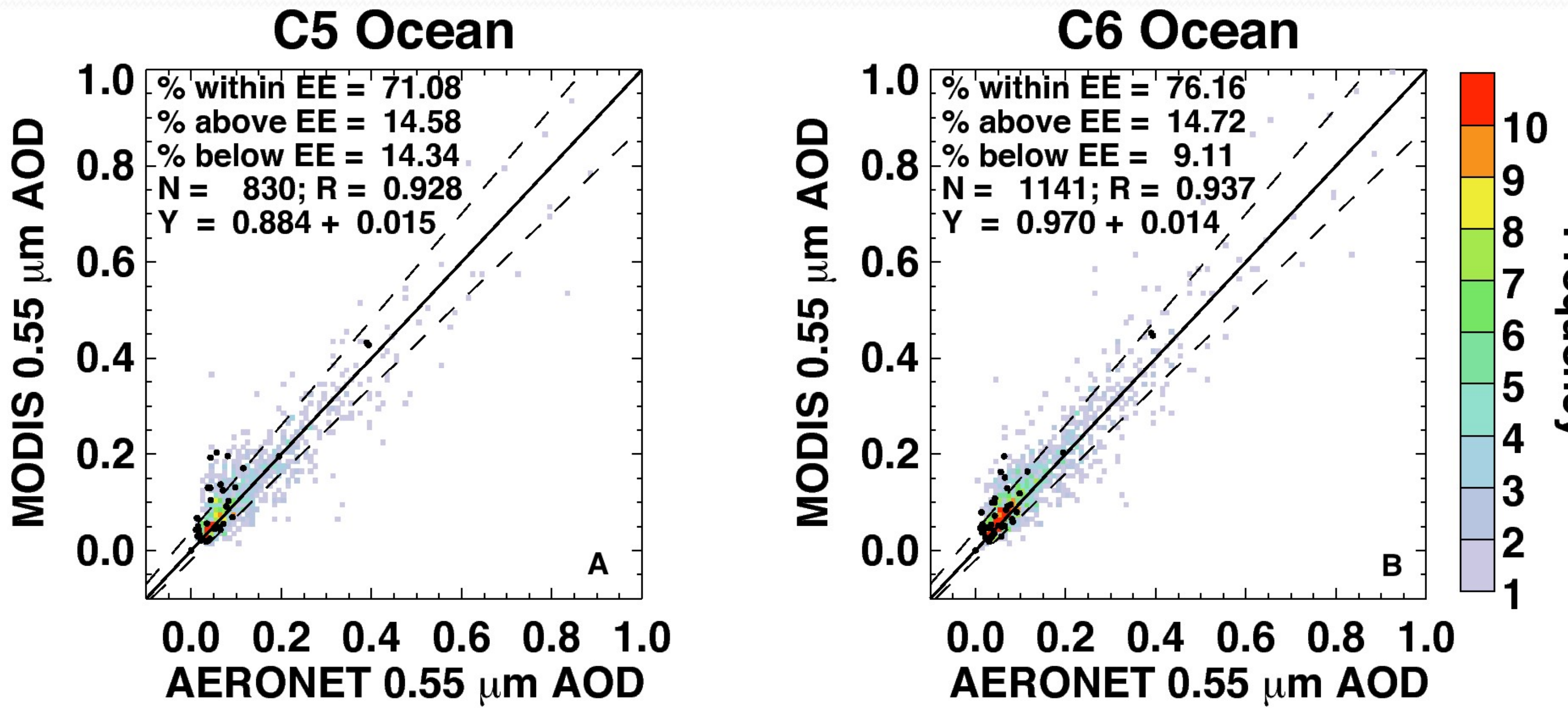
Over ocean: Wind speed dependence





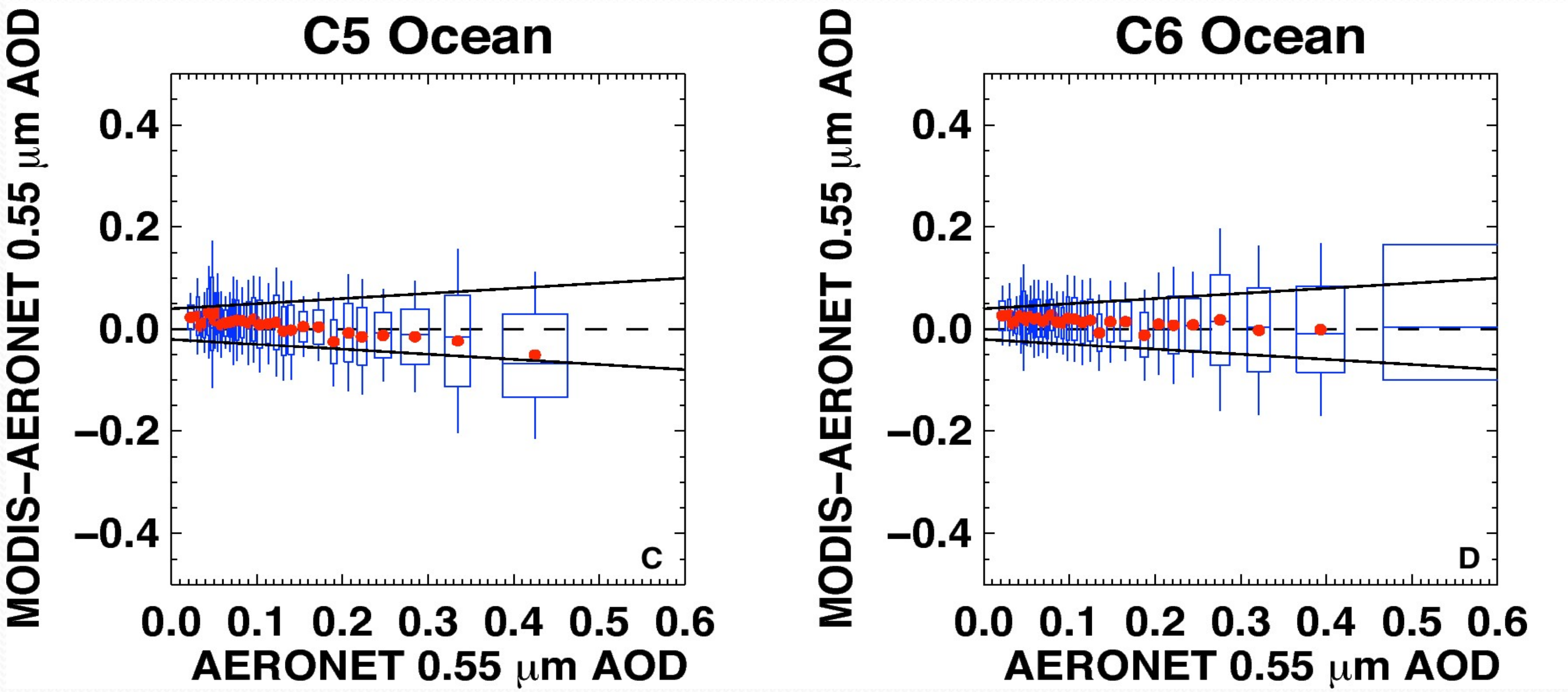
- Upshot: reduced AOD by 0.01 over all ocean
- Especially important in Southern Hemisphere

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.

Validation available for all years of Aqua data

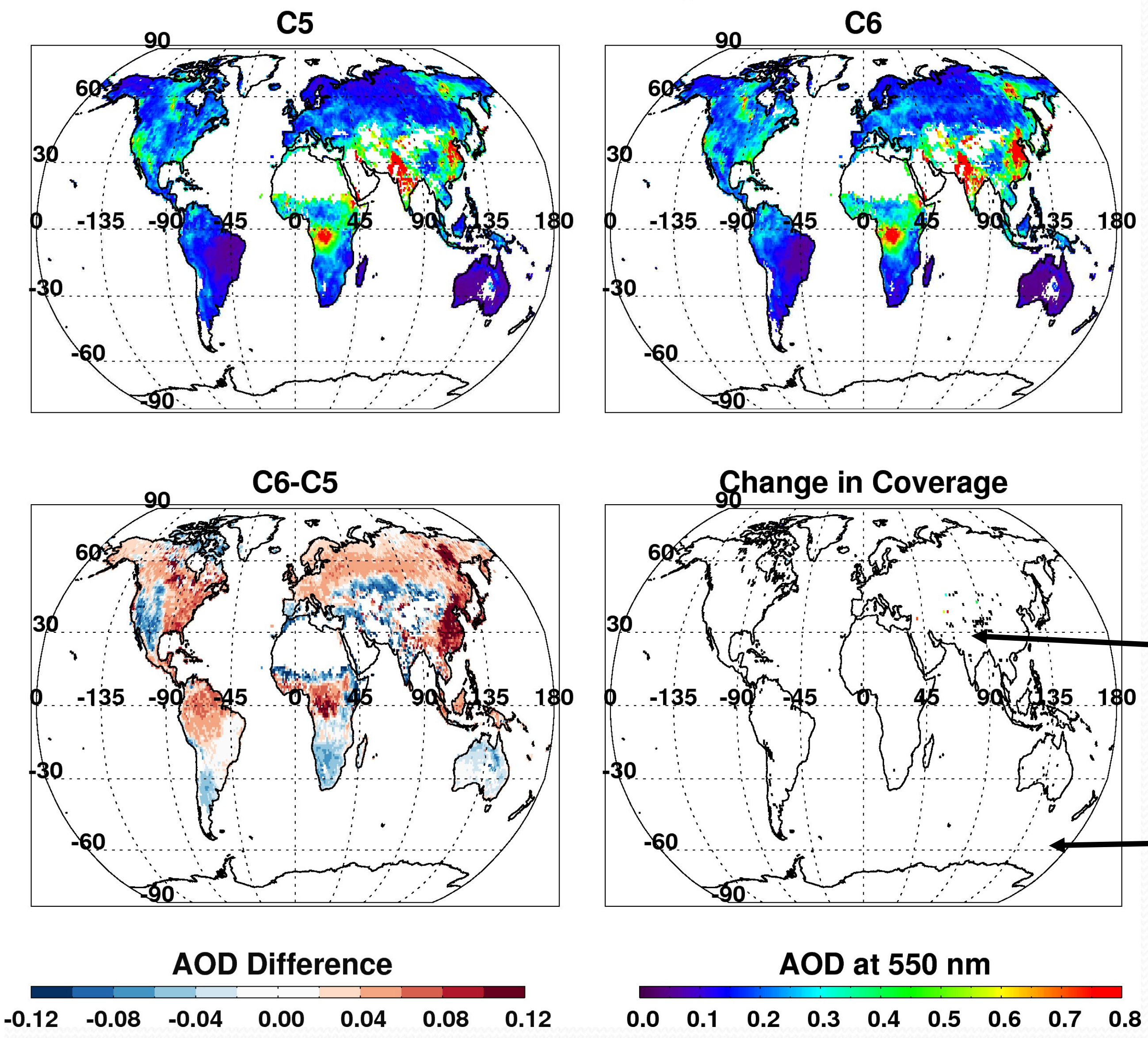
SDSs over ocean

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").

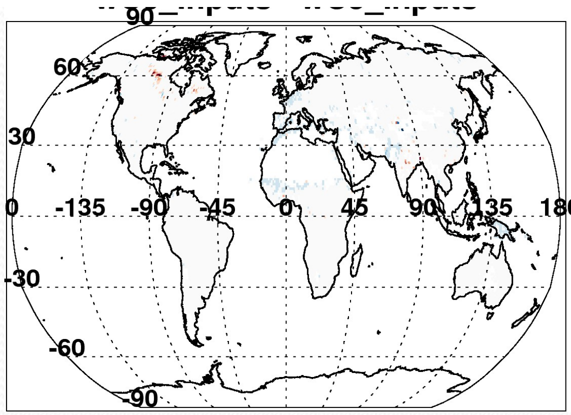
Dark target over land - overall changes to products (Aqua, Jul 2008)



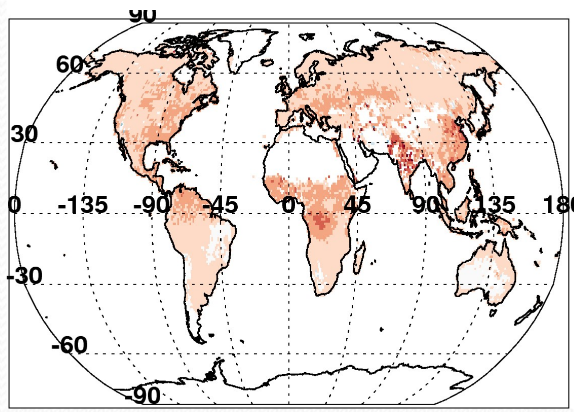
- Overall **decrease** of AOD in **semi-arid**
- Overall **increase** over **vegetation**
- **Strong increase over Eastern Asia**
- **Slight change in coverage here and there**

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

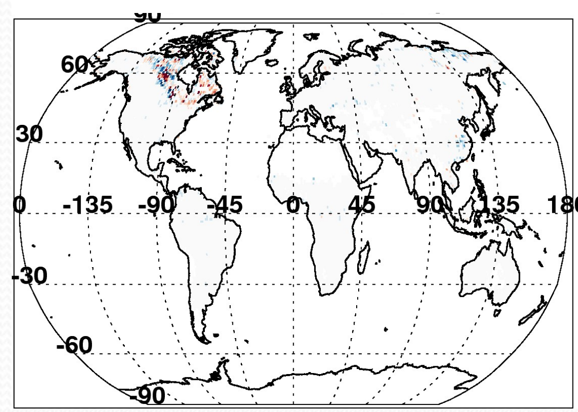
New reflectance and geo-location inputs



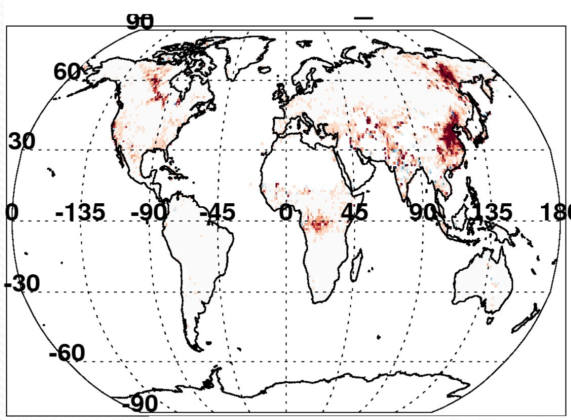
Updated radiative transfer



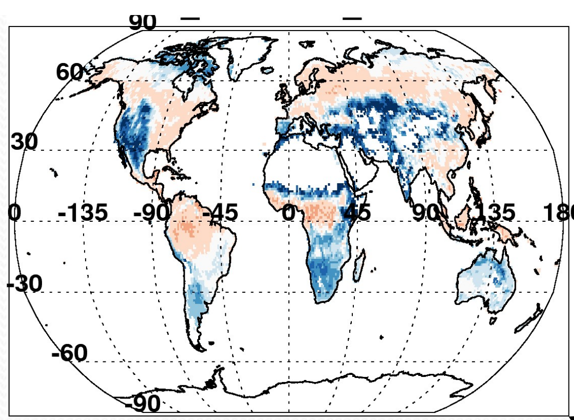
Re-define land and sea

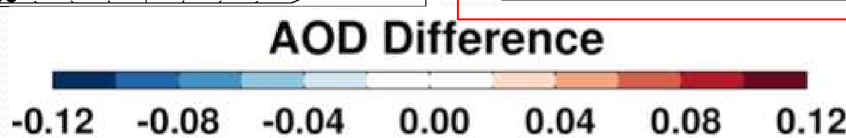


Improved cloud mask to detect smoke



Fixed surface reflectance dependence on TOA NDVI

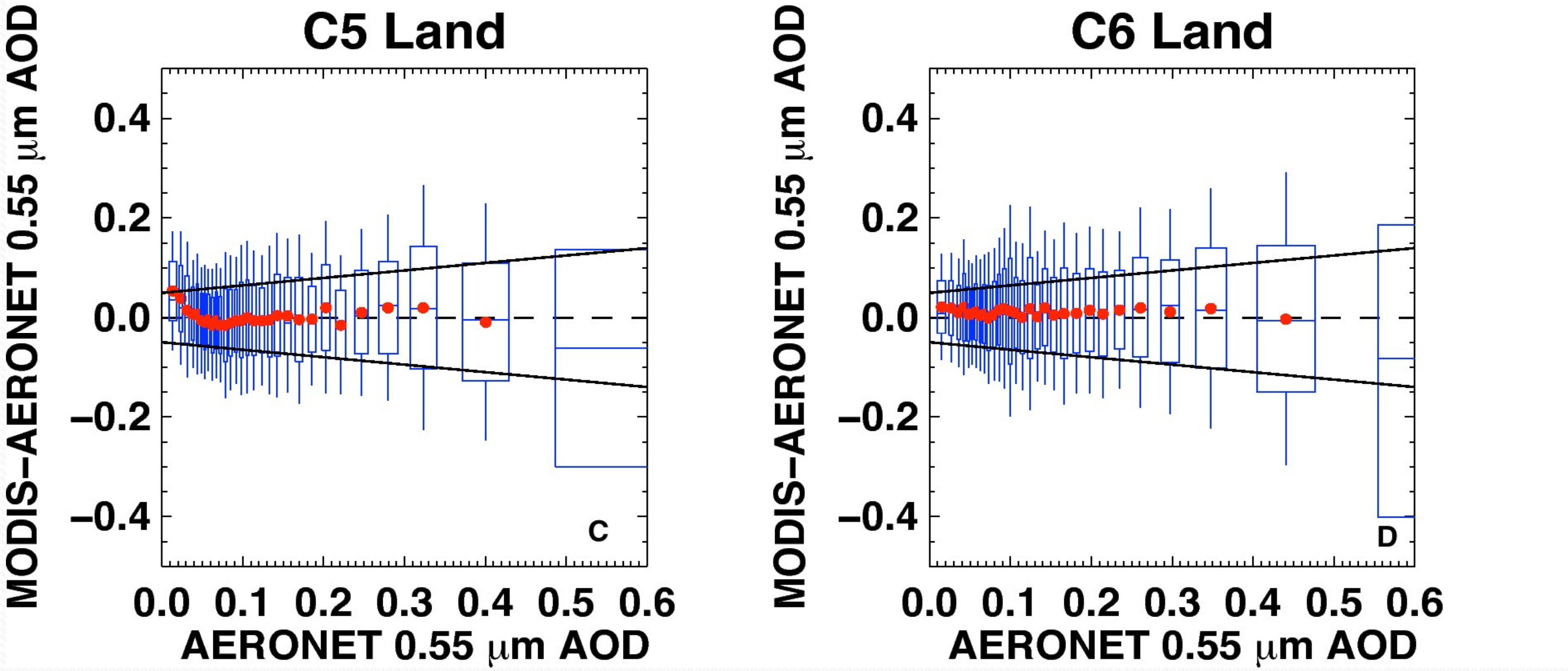




- Also changed **"Quality Assurance"** Filtering
- Changed aerosol definitions of **land and sea**

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, there are 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

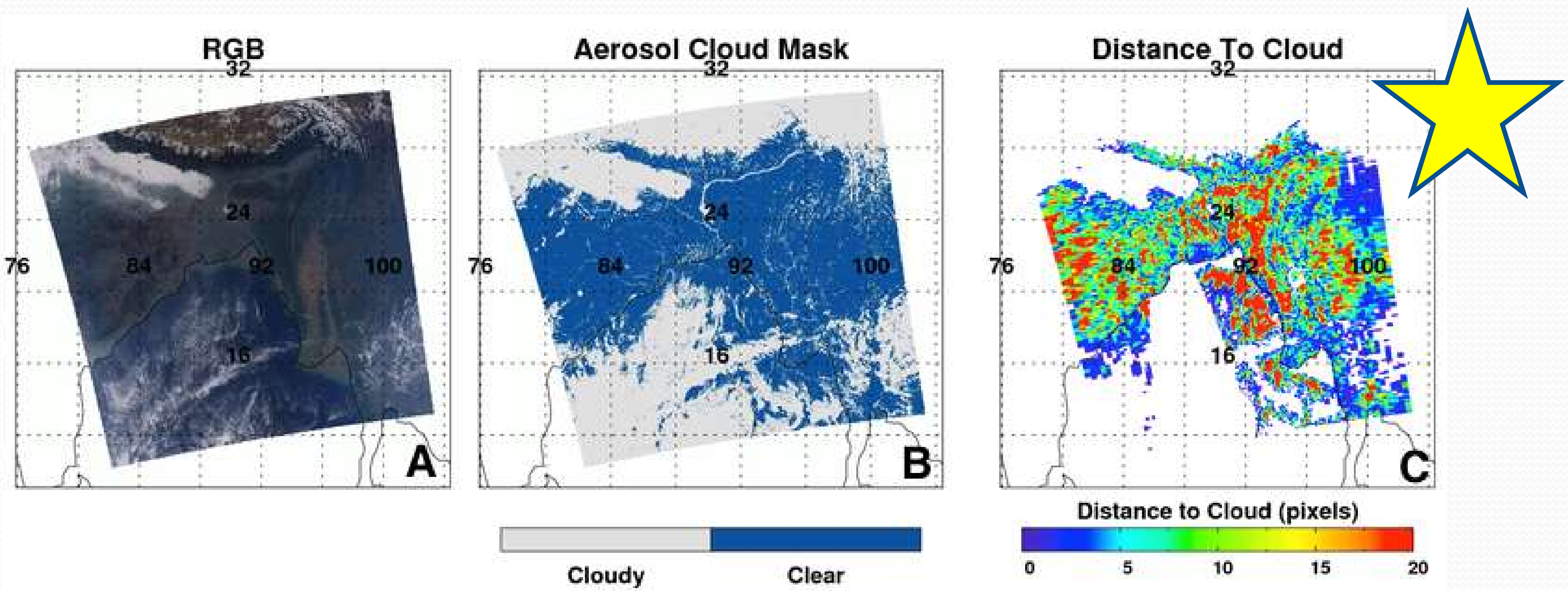
X, Y refers to a 2-dimensional array along/across the swath (at a particular wavelength λ). Some parameters have a third dimension. A dimension of "#λ" refers to # wavelengths. # = 3a: 0.47, 0.55 and 0.65 μm. # = 3b: 0.47, 0.55 and 2.11 μm. # = 4: 0.47, 0.55, 0.65 and 2.11 μm. # = 7: 0.47, 0.55, 0.65, 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

- "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).

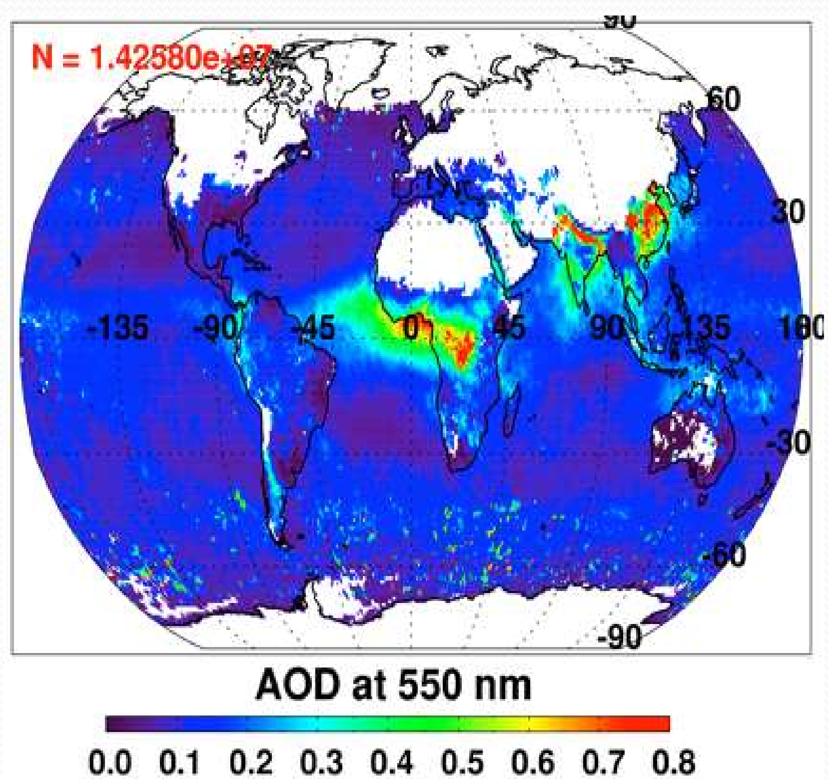
What else for C6 Level 2?

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

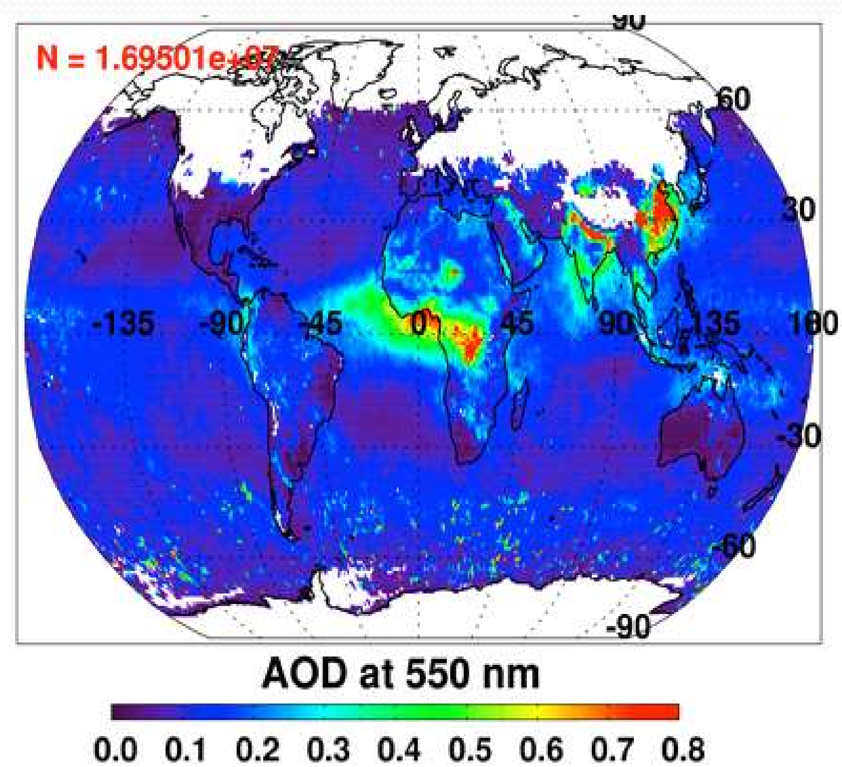


Deep Blue/Dark Target Merge:

Dark Target AOD



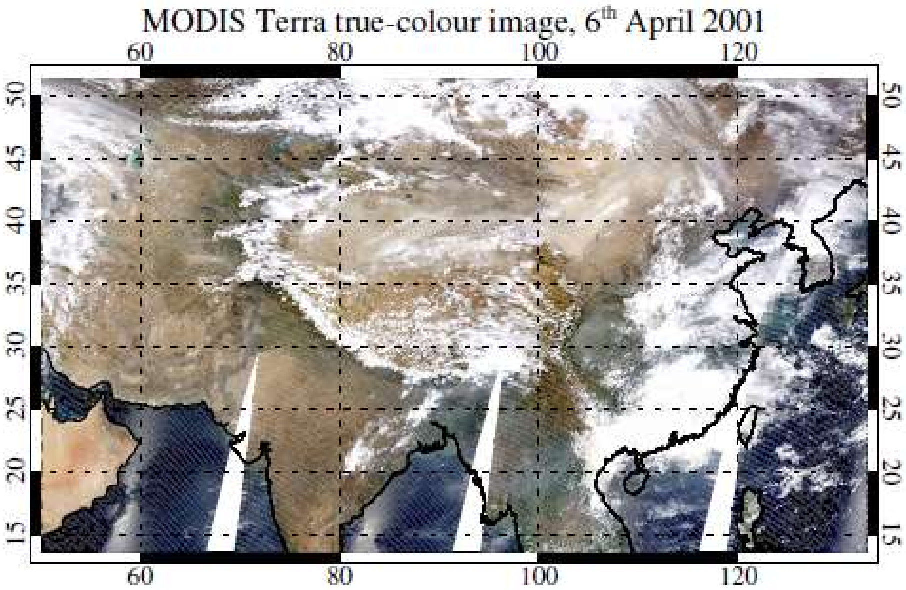
DeepDark AOD



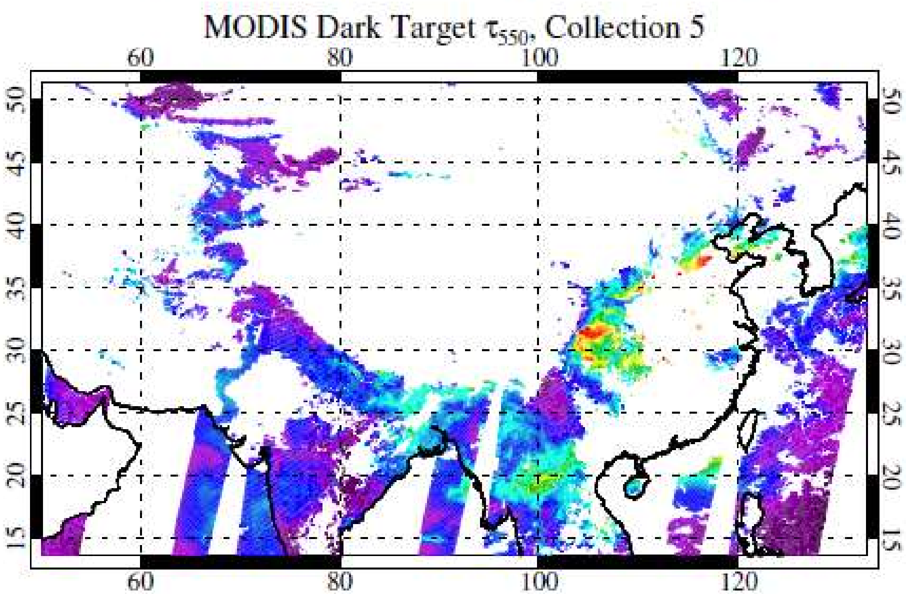
Merging deep blue & dark target produces best global coverage

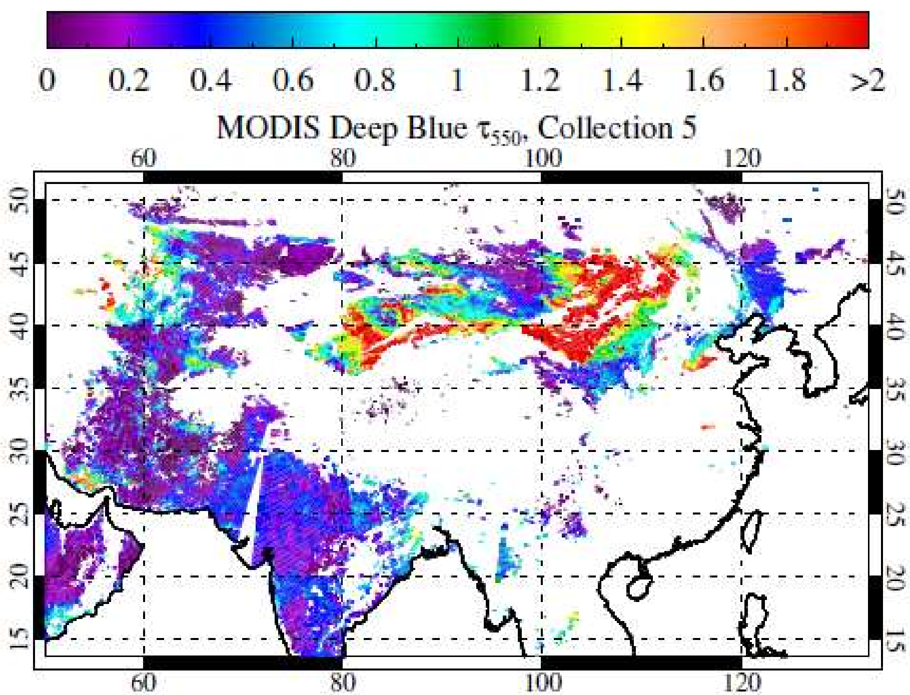
- Deep blue is land-only; need dark target for oceans
- Deep blue introduces coverage over Australian outback, Sahara desert and Arabian peninsula
- Still no coverage over snow (see: most of Northern Hemisphere).

Deep Blue: original motivation

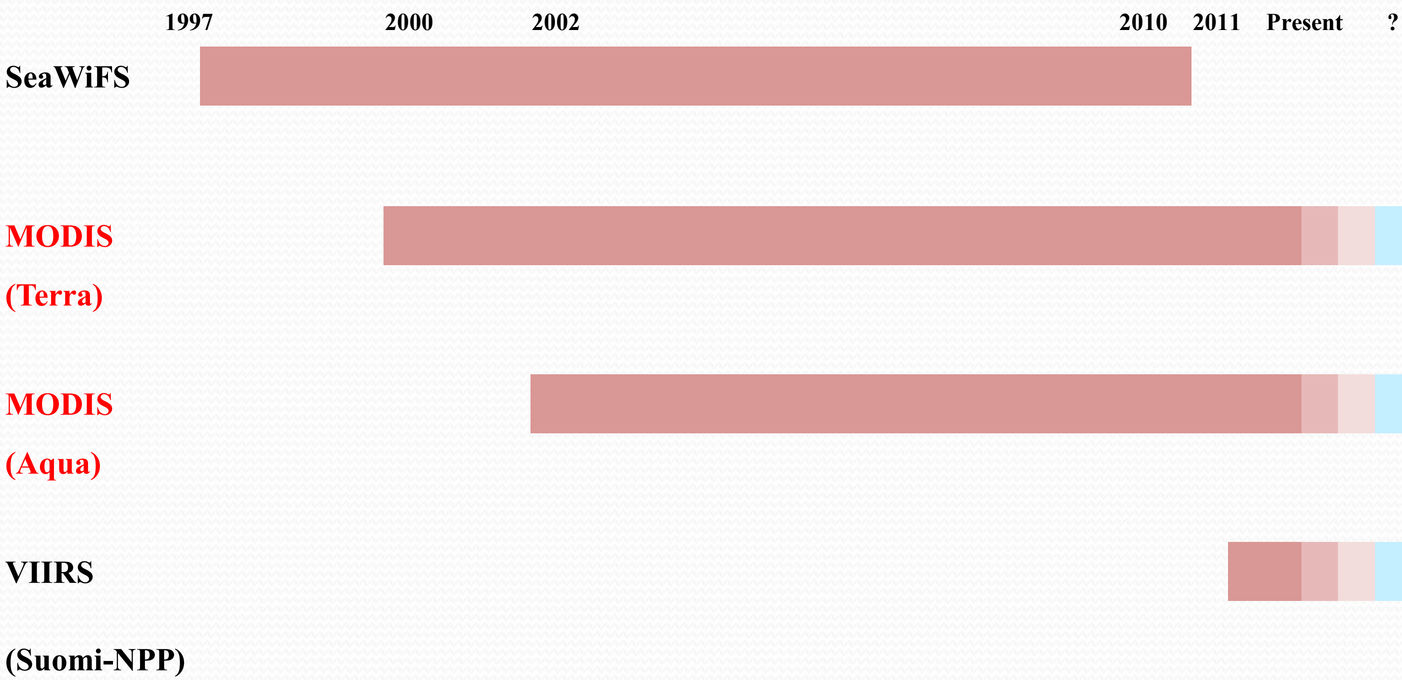


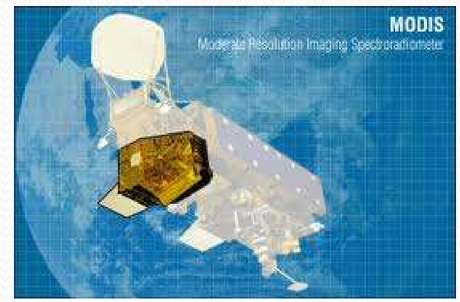
- ‘Dark Target’ AOD algorithm does not retrieve over bright surfaces
  - Violates algorithmic assumptions
- These are important aerosol sources, especially mineral dust
- Deep Blue filled in some gaps
  - (Now, it does more than that)

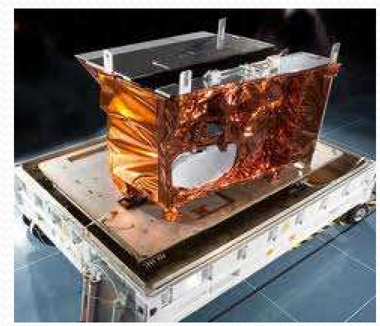




Sensors Deep Blue has been applied to

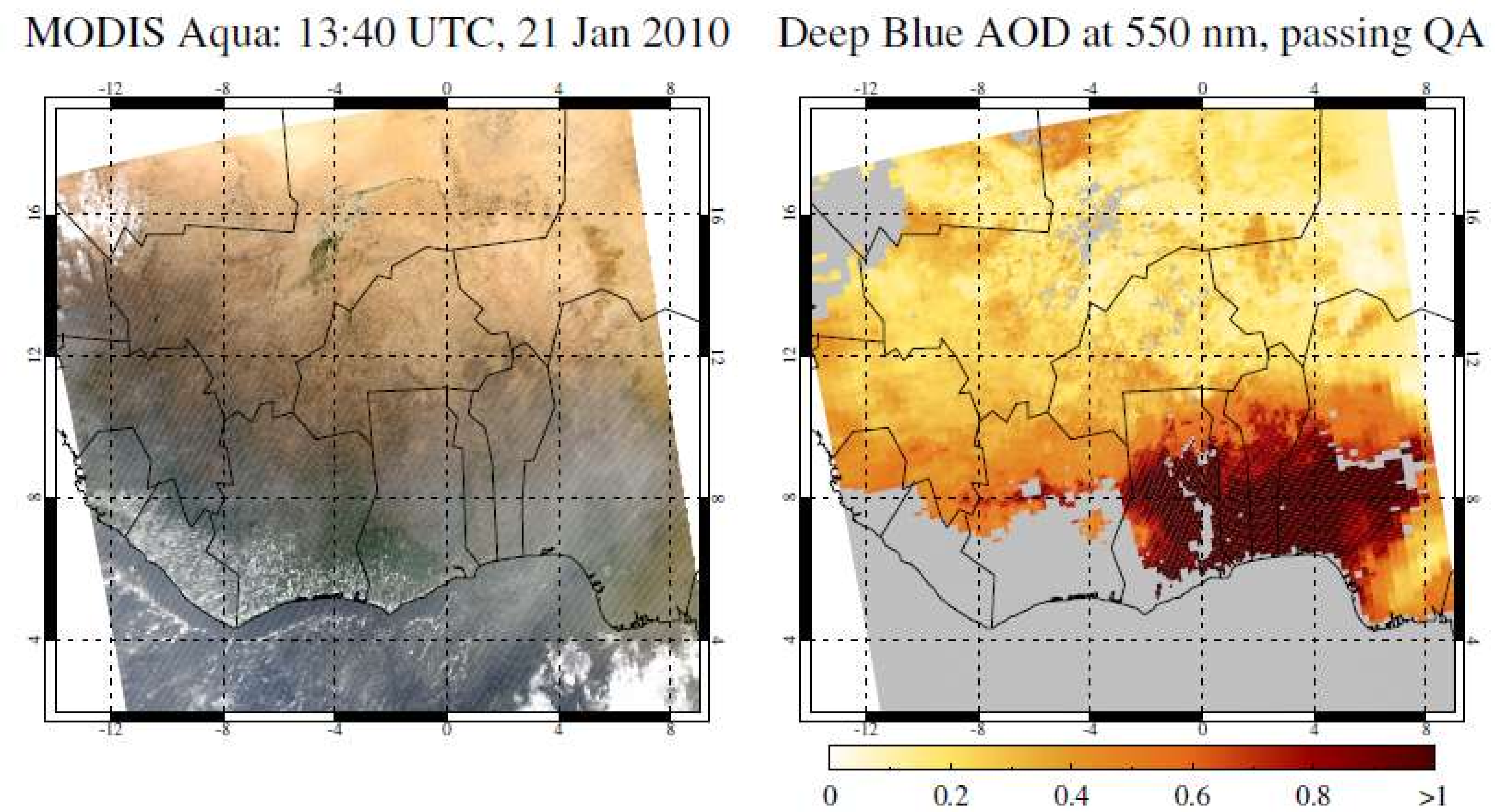






Images courtesy of SeaWiFS/MODIS projects and Raytheon

Example Level 2 data



- Science Data Set (SDS) names relevant for most users:
  - Deep_Blue_Aerosol_Optical_Depth_550_Land_Best_Estimate
    - This has our quality filters applied, i.e. any retrieval not set to the fill value (-9.999) should be usable
    - For the bulk of applications, quality assurance (QA) filters should be used
  - Latitude
  - Longitude
- Example granule shown here: *MYD021KM.A2010021.1340.006.2012064111514.hdf*

Example Level 2 data

AE (useful in high AOD)

Algorithm flag (indicates surface reflectance method)

QA flag (required if not using prefiltered SDS)

AOD uncertainty estimate (new for C6!)

Table 5. List of SDS Names for MODIS Collection 6 Deep Blue Aerosol Products

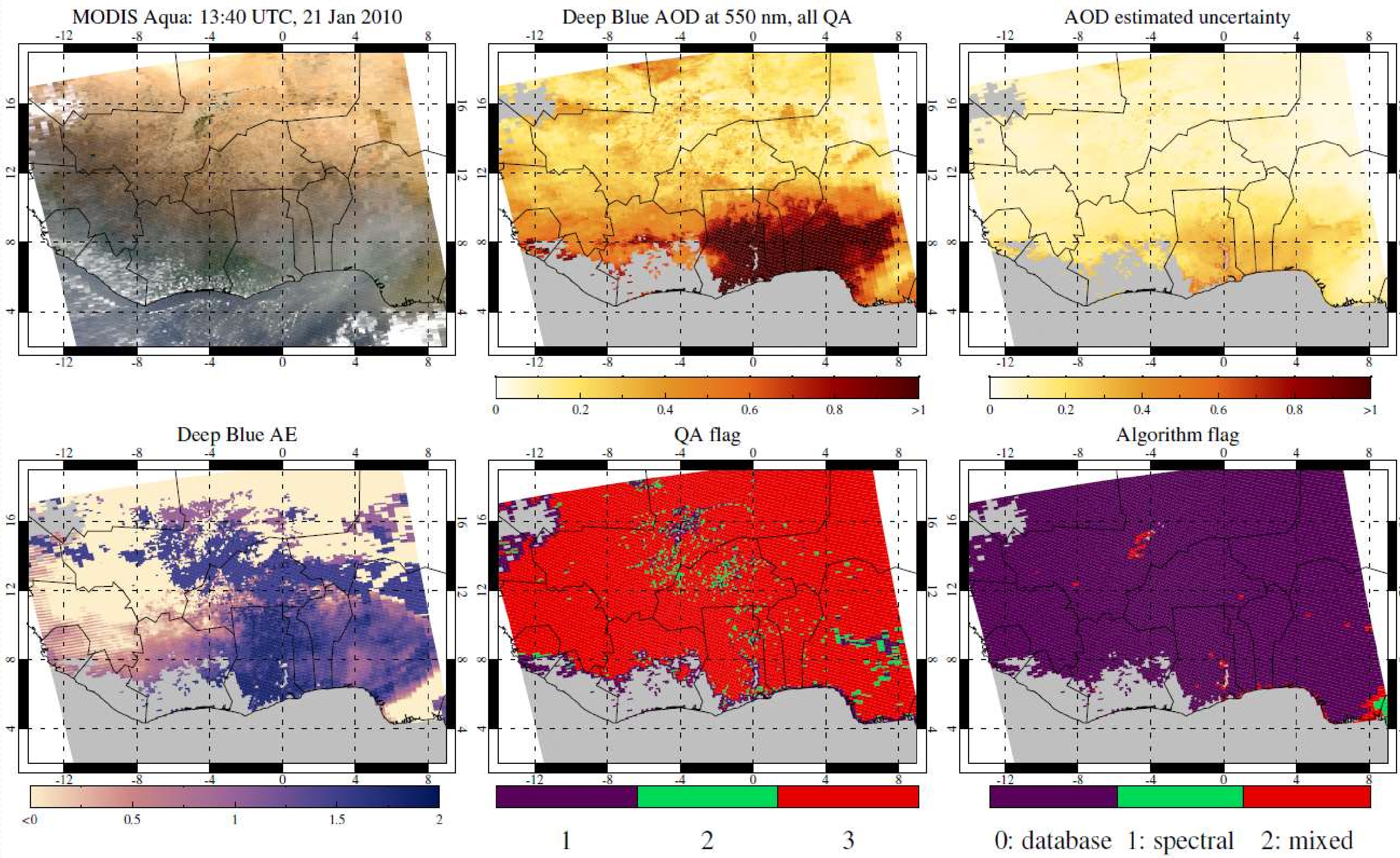
Name	Dimensions[a]	Description
Deep_Blue_Angstrom_Exponent_Land	[Cell_Along_Swath, Cell_Across_Swath]	Angstrom Exponent Over Land.
Deep_Blue_Aerosol_Optical_Depth_550_ Land	[Cell_Along_Swath, Cell_Across_Swath]	Aerosol Optical Depth at 550 nm Over Land.
Deep_Blue_Aerosol_Optical_Depth_550_ Land_Best_Estimate	[Cell_Along_Swath, Cell_Across_Swath]	Aerosol Optical Depth at 550 nm Over Land Filtered by Quality (*QA* = 2,3 only).
Deep_Blue_Aerosol_Optical_Depth_550_ Land_STD	[Cell_Along_Swath, Cell_Across_Swath]	Standard Deviation of Individual Pixel-Level Aerosol Optical Depth at 550 nm per Cell.
Deep_Blue_Algorithm_Flag_Land	[Cell_Along_Swath, Cell_Across_Swath]	Flag Indicating the Path Taken Through the Algorithm.
Deep_Blue_Aerosol_Optical_Depth_550_ Land_QA_Flag	[Cell_Along_Swath, Cell_Across_Swath]	Quality Assurance Flag for Aerosol Optical Depth at 550 nm.
Deep_Blue_Aerosol_Optical_Depth_550_ Land_Estimated_Uncertainty	[Cell_Along_Swath, Cell_Across_Swath]	Estimated Uncertainty in Aerosol Optical Depth at 550 nm.
Deep_Blue_Cloud_Fraction_Land	[Cell_Along_Swath, Cell_Across_Swath]	Fraction of Pixels per Cell Where Retrieval was not Attempted.
Deep_Blue_Number_Pixels_Used_550_ Land	[Cell_Along_Swath, Cell_Across_Swath]	Number of Aerosol Property Retrievals Performed per Cell.
Deep_Blue_Spectral_Aerosol_Optical_ Depth_Land	[Num_DeepBlue_Wavelengths, Cell_Along_Swath, Cell_Across_Swath]	Retrieved Aerosol Optical Depth Over Land at 412, 470, and 650 nm.
Deep_Blue_Spectral_Single_Scattering_ Albedo_Land	[Num_DeepBlue_Wavelengths, Cell_Along_Swath, Cell_Across_Swath]	Single-Scattering Albedo Over Land at 412, 470, and 650 nm.
Deep_Blue_Spectral_Surface_Reflectance_Land	[Num_DeepBlue_Wavelengths, Cell_Along_Swath, Cell_Across_Swath]	Surface Reflectance Used in Aerosol Retrieval Over Land for 412, 470, and 650 nm.
Deep_Blue_Spectral_TOA_Reflectance_ Land	[Num_DeepBlue_Wavelengths, Cell_Along_Swath, Cell_Across_Swath]	Top-of-Atmosphere Reflectance at 412, 470, and 650 nm.

[a]Cell_Along_Swath = number of cells in the along-track direction. Cell_Across_Swath = number of cells across the swath. Num_DeepBlue_Wavelengths = number of bands reported by the Deep Blue products, currently has a value of 3 (412, 470, and 650 nm).

Table from Hsu *et al.*, *JGR* (2013)

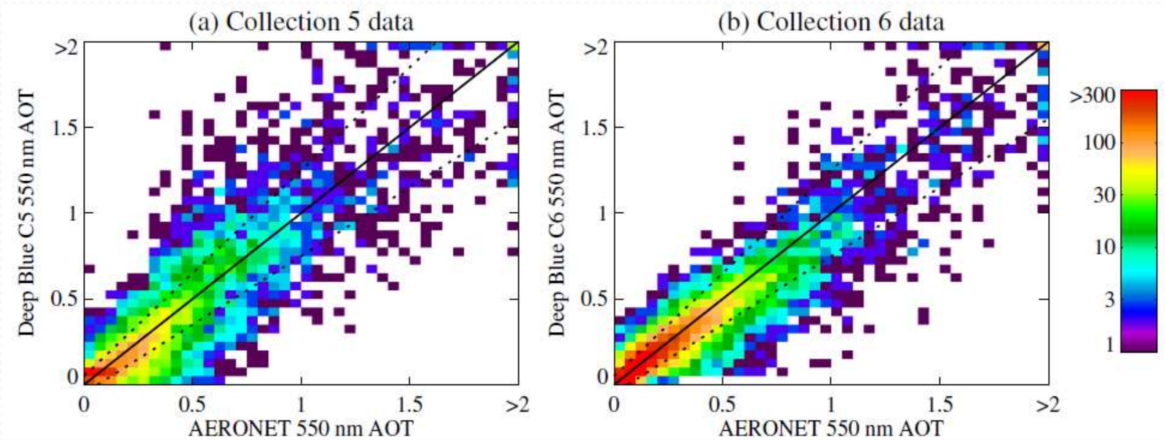
- Other stuff included in files but not listed above:
  - Diagnostic information (e.g. geometry, land/sea mask)
  - Dark Target and ocean aerosol data
  - Deep Blue/Dark Target 'merged' SDS

Example Level 2 data



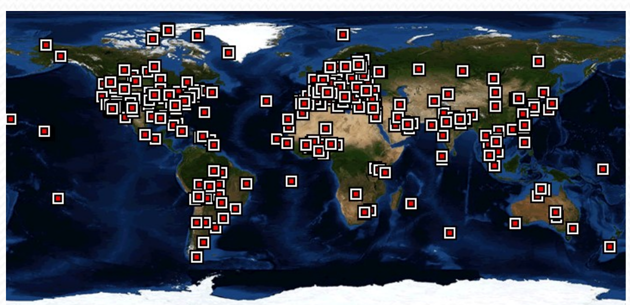
e-Deep Blue: main developments in C6

- Described by Hsu *et al.*, *JGR* (2013); Sayer *et al.*, *JGR* (2013)
  - Enhanced Deep Blue (e-Deep Blue)
  - Summary: more retrievals, better retrievals



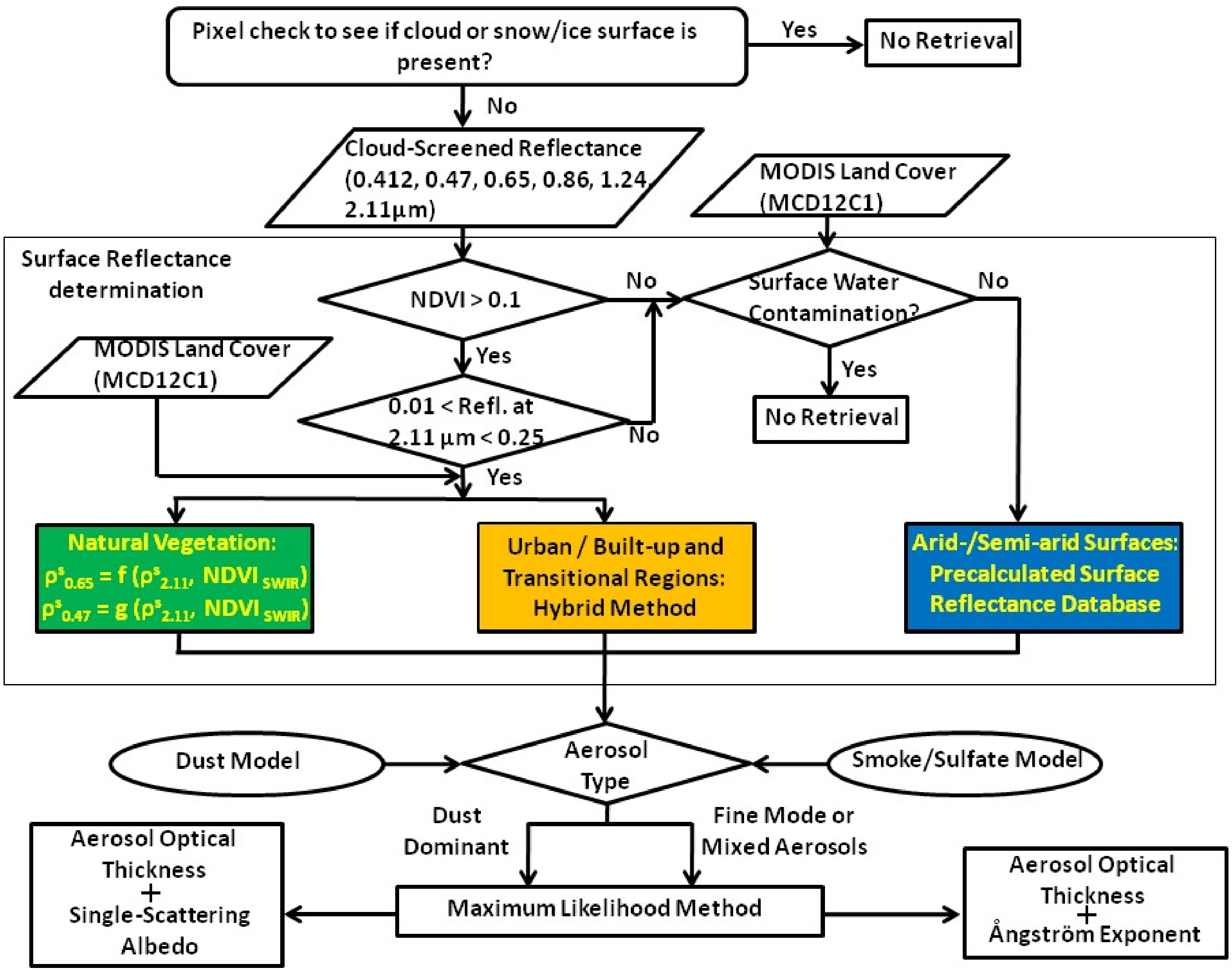
Refinements to e-Deep Blue in MODIS Collection 6:

- Extended coverage to vegetated surfaces, as well as bright land
- Improved surface reflectance models
- Improved aerosol optical models
- Improved cloud screening
- Simplified quality assurance (QA) flag reading
- Radiometric calibration improvements



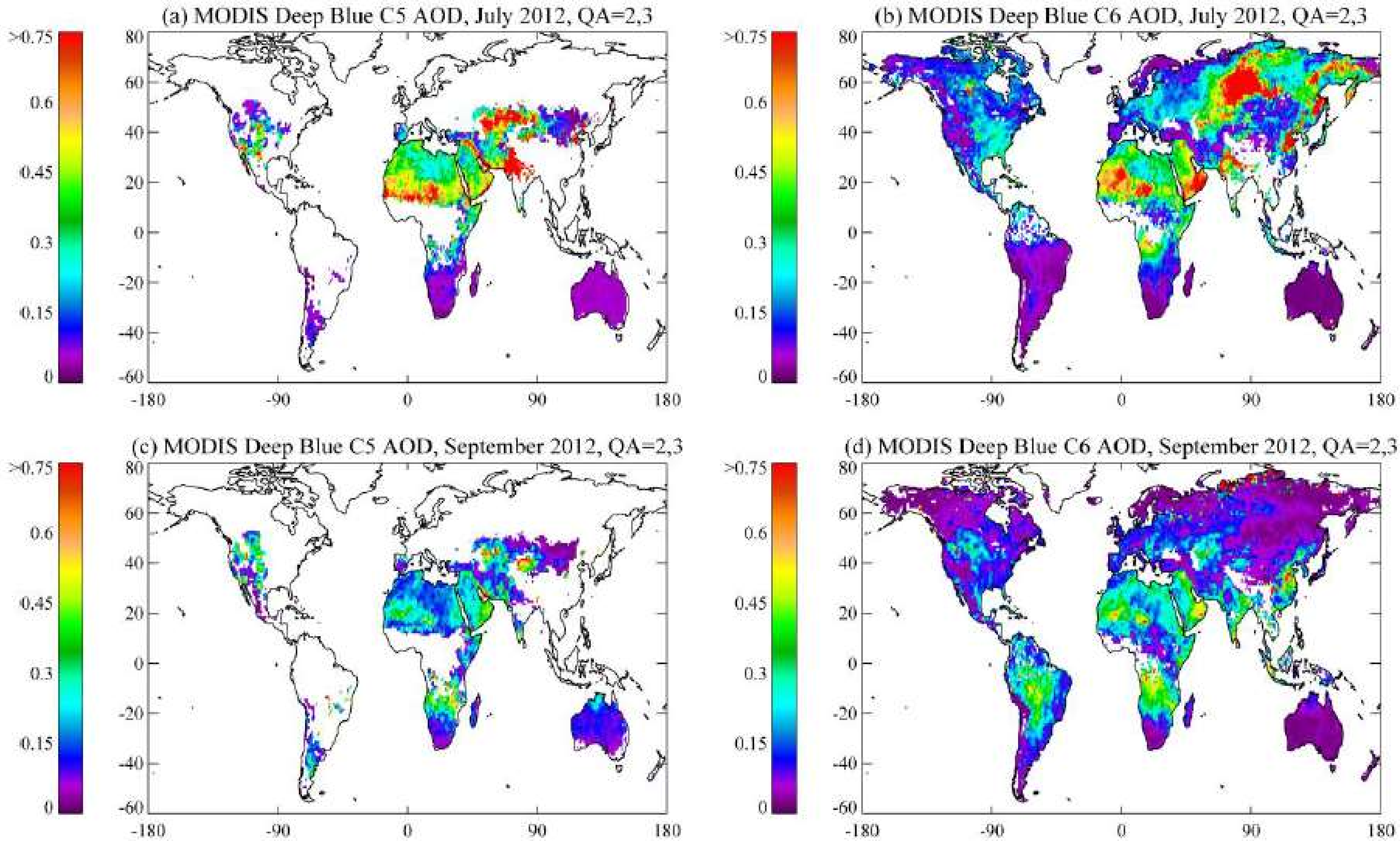
Images from NASA AERONET page, http://aeronet.gsfc.nasa.gov/

e-Deep Blue: C6 flow chart



- Described by Hsu *et al.*, *JGR* (2013)

MODIS C6: extended spatial coverage



MODIS C6: improved cloud screening

MODIS RGB image over northern Africa on March 7, 2006

MODIS C5 Deep Blue AOD

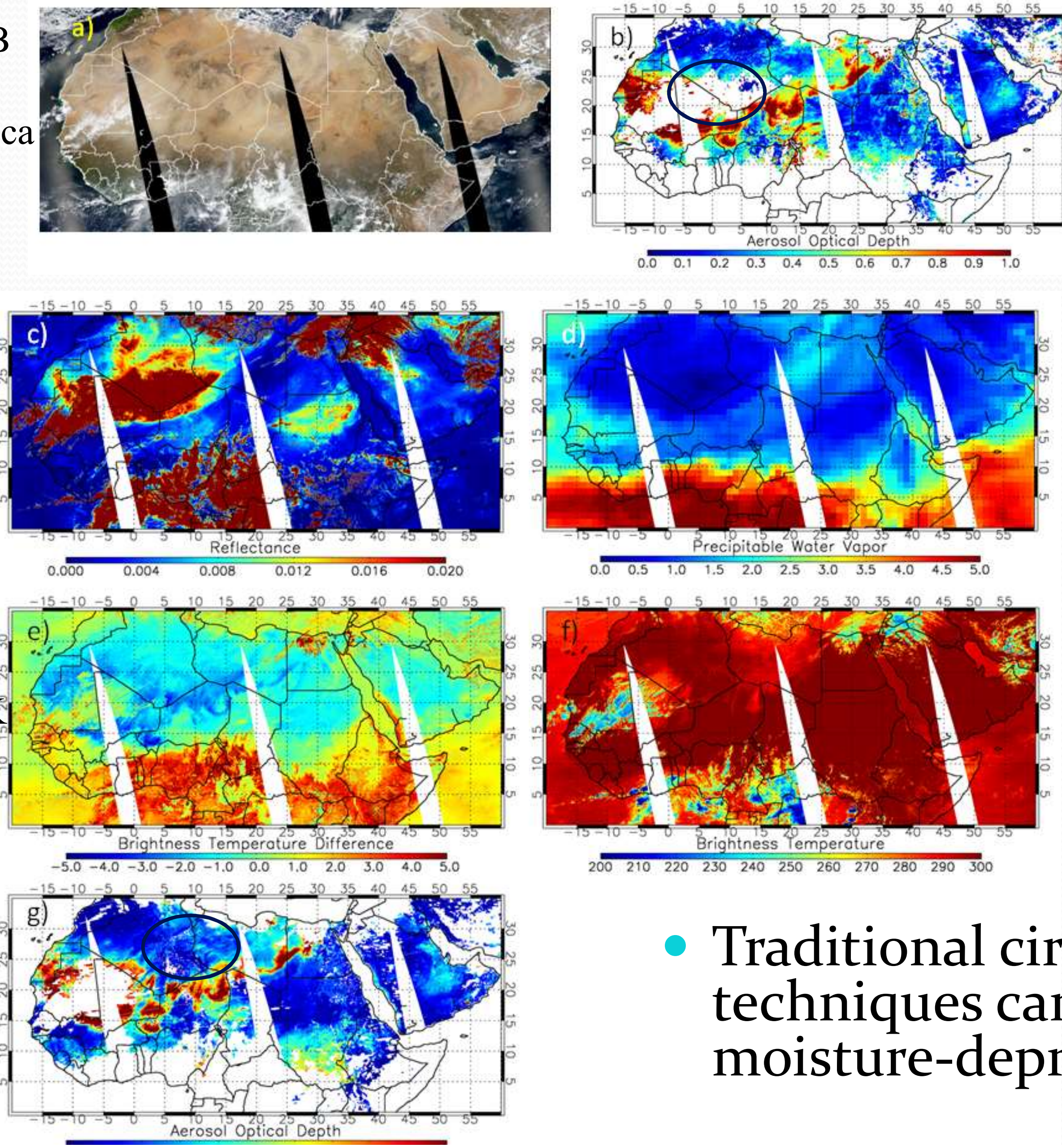
TOA Reflectance at 1.38 μm

Precipitable water vapor, cm

BTD, 11-12 μm, K

Brightness temperature at 11 μm, K

MODIS C6 Deep Blue AOD



- Traditional cirrus detection techniques can fail over moisture-deprived regions

Summary

- e-Deep Blue provides aerosol data at ~10 km spatial resolution over vegetated, urban, and arid land surfaces, in near real time, suitable for quantitative use in scientific applications
  - Primary data product AOD at 550 nm
  - Ångström exponent, SSA useful in some situations
  - Collection 6 has more and better retrievals than Collection 5

Links:

MODIS Atmospheres website: *modis-atmos.gsfc.nasa.gov*

NASA LAADS (data distribution) website: *ladsweb.nascom.nasa.gov*

MODIS Collection 6 on the NASA LAADS ftp server: *ladsweb.nascom.nasa.gov/allData/6/<product name>*

Key references:

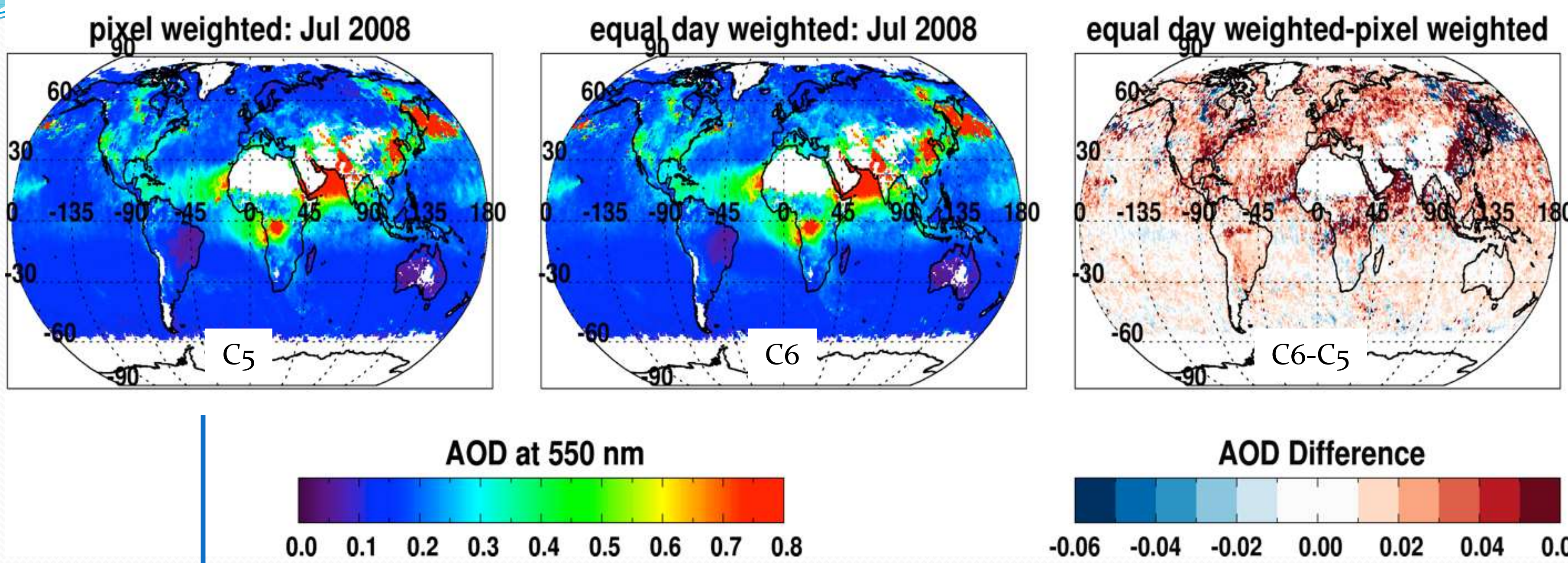
Hsu, N. C., S. C. Tsay, M. D. King, and J. R. Herman (2004), Aerosol properties over bright-reflecting source regions, *IEEE Trans. Geosci. Remote Sens.*, 42, 557–569

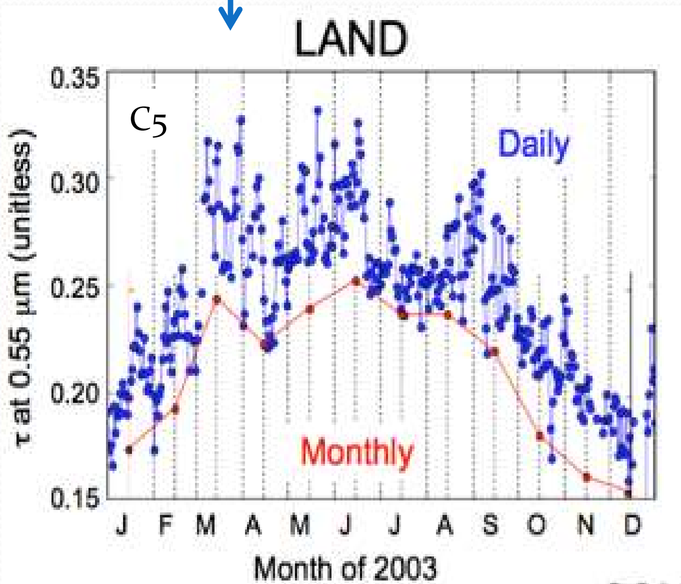
Hsu, N. C., S. C. Tsay, M. D. King, and J. R. Herman (2006), Deep blue retrievals of Asian aerosol properties during ACE-Asia, *IEEE Trans. Geosci. Remote Sens.*, 44, 3180–3195

Hsu, N. C., M.-J. Jeong, C. Bettenhausen, A. M. Sayer, R. Hansell, C. S. Seftor, J. Huang, and S.-C. Tsay (2013), Enhanced Deep Blue aerosol retrieval algorithm: The second generation, *J. Geophys. Res. Atmos.*, 118, 9296–9315, doi:10.1002/jgrd.50712

Sayer, A. M., N. C. Hsu, C. Bettenhausen, and M.-J. Jeong (2013), Validation and uncertainty estimates for MODIS Collection 6 "Deep Blue" aerosol data, *J. Geophys. Res. Atmos.*, 118, 7864–7872, doi:10.1002/jgrd.50600

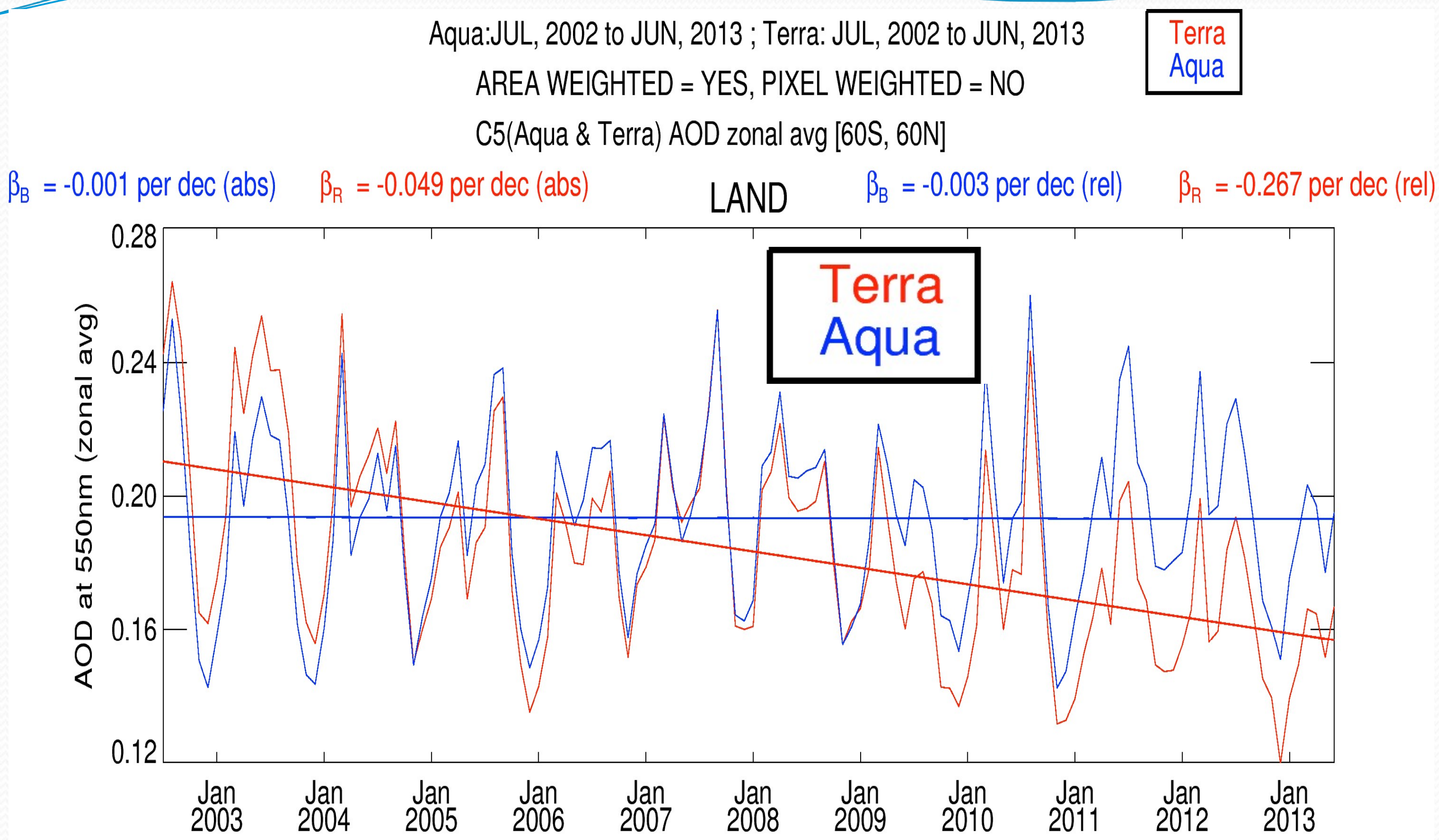
Changes to Level 3 (MxD08_M3)





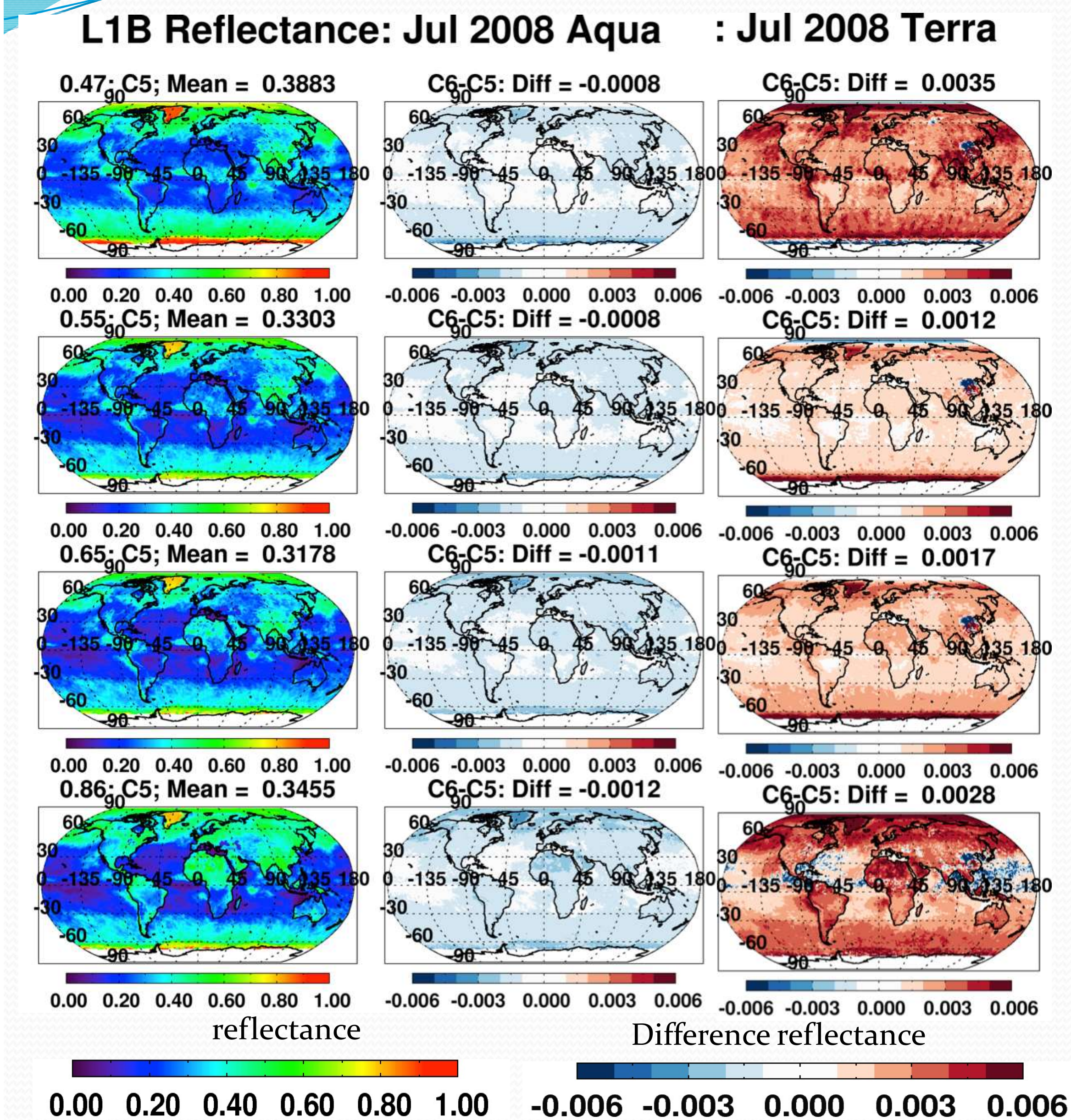
- In C5, averaging daily data did not look like monthly data (left, from Giovanni web application)
- C5 monthly was "pixel weighted". A day with 100 retrieved pixels was worth 10 times more than one with 10. It was clear-sky biased.
- C6 monthly is "equal day" weighted. If at least five pixels in a day,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

Trends in Collection 5



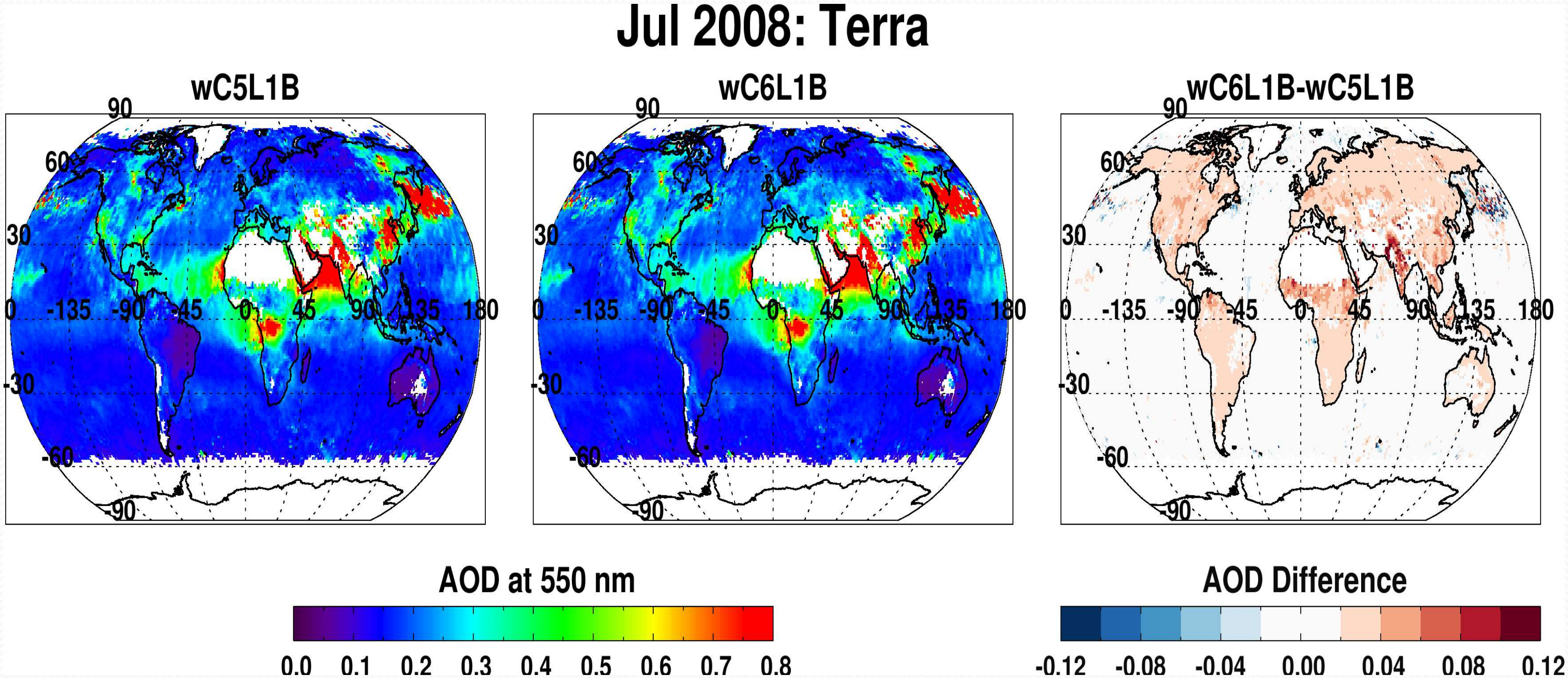
- Over land, Terra *decreases* (-0.04/decade), Aqua *constant*
- Terra / Aqua divergence is the same everywhere on the globe!
- In NH, observations are 1.5 hours apart, while SH are 4.5 hours
- So, probably not due to diurnal cycle of aerosol

Impact to “observed” reflectance



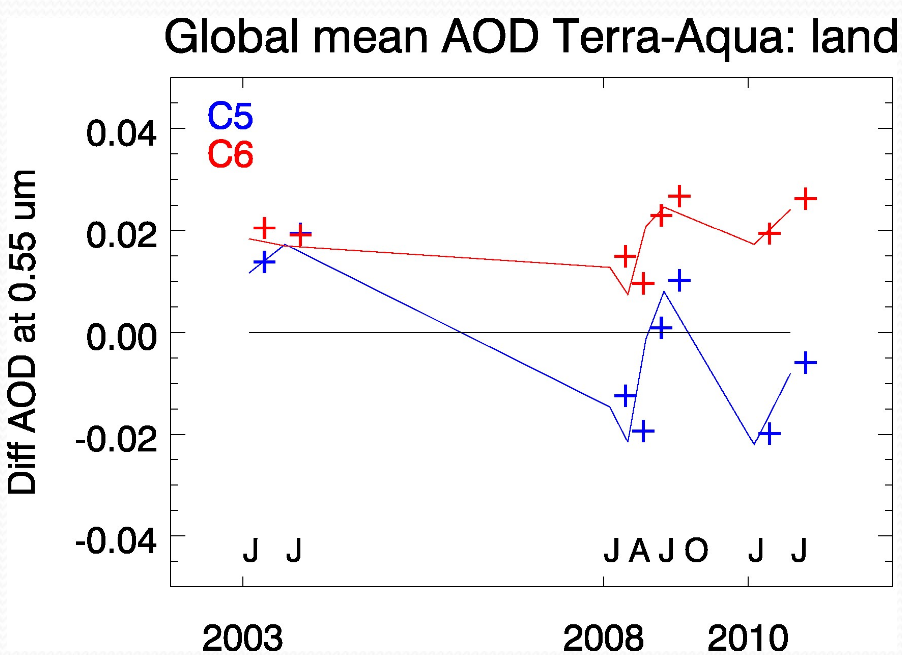
- “Global” Aqua changes in visible bands by -0.001 or less
- “Global” Terra changes in visible bands by +0.002 or more
- Overall Aqua changes are relatively stable, but Terra’s changes vary over time.

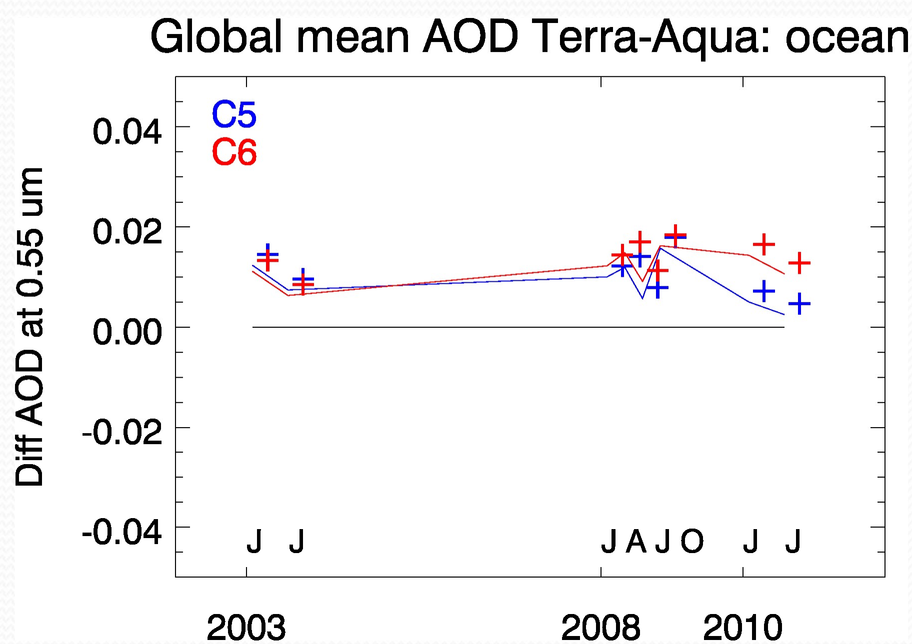
Impact of New Terra calibration



- 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!