Recent advances in the ‘Deep Blue’ aerosol optical depth retrieval algorithm: SeaWiFS, MODIS, and VIIRS

A. M. Sayer
on behalf of N. Christina Hsu & team:

C. Bettenhausen, R. Gautam, R. Hansell, J. Huang, M. J. Jeong, J. Lee, R. Limbacher, A. M. Sayer, C. Seftor, J. Warner

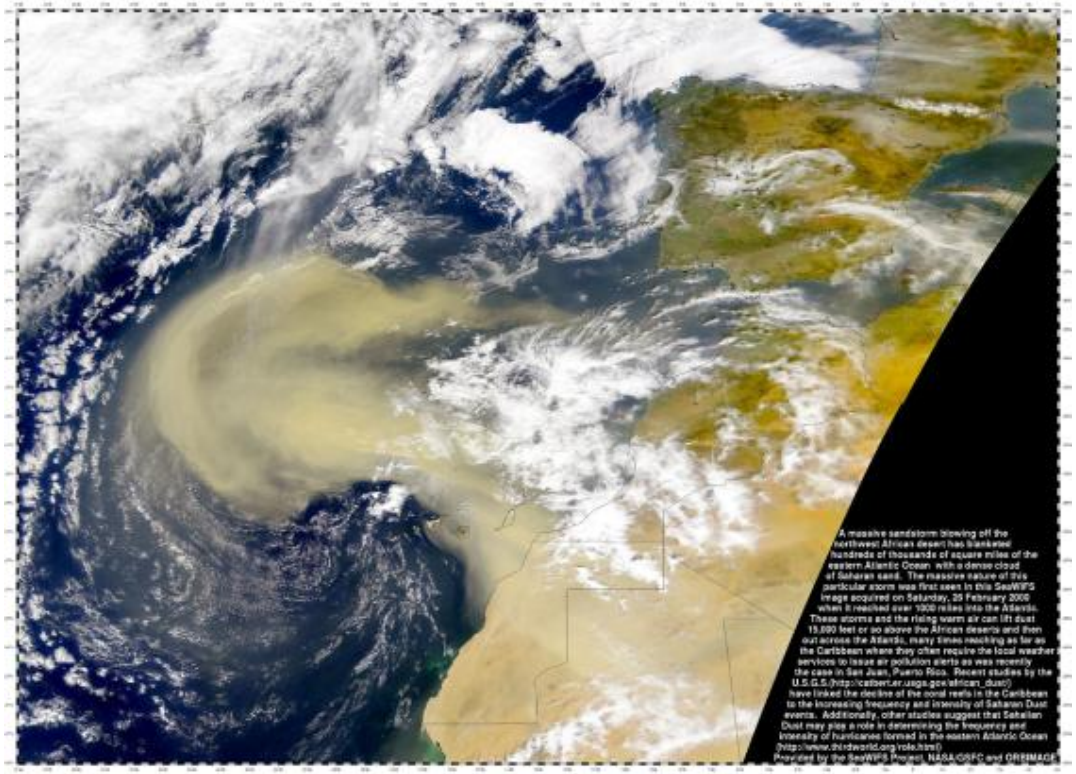
andrew.sayer@nasa.gov

Outline

- What is Deep Blue?
- SeaWiFS – our new dataset
- MODIS – the forthcoming Collection 6 (C6)
- VIIRS – future application

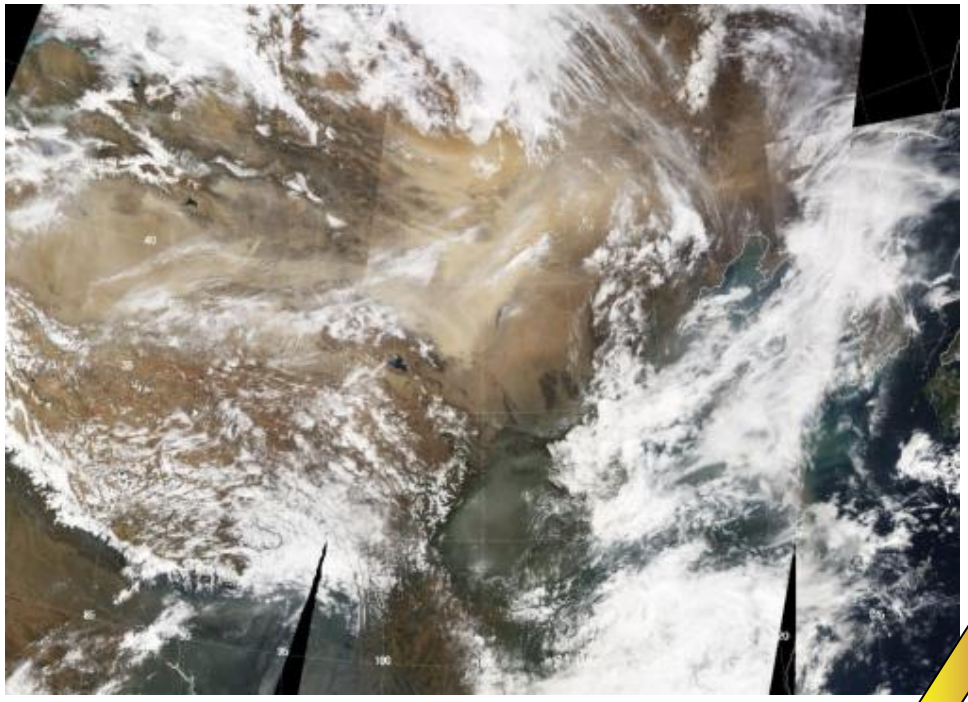
What is Deep Blue?

- Aerosol remote sensing over deserts in the visible/near-IR is difficult due to low contrast between the surface and atmosphere
  - The MODIS operational land AOD retrieval algorithm (Dark Target) lacks coverage over bright arid surfaces (e.g. deserts), because its surface reflectance assumptions become inappropriate
  - Deep Blue (Hsu *et al.*, *TGARS*, 2004, 2006), introduced in Collection 5, fills in some of these gaps
- Contrast is increased, ameliorating these difficulties, in other spectral regions:
  - UV
  - 'Deep Blue'
  - Thermal IR
  - Or through multiangle imaging, polarisation
- Initial application was to MODIS; now also applied to SeaWiFS and will be applied to NPP-VIIRS



Saharan dust storm over Africa and the Atlantic, observed by SeaWiFS
Image courtesy of the SeaWiFS project

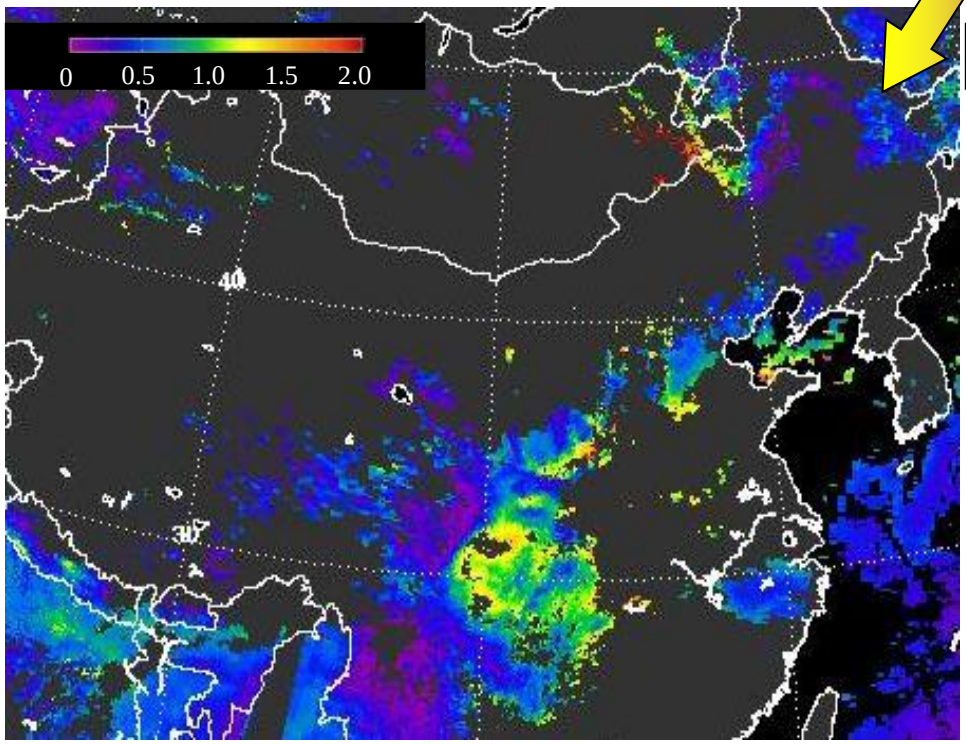
Dust storm: 6th April 2001

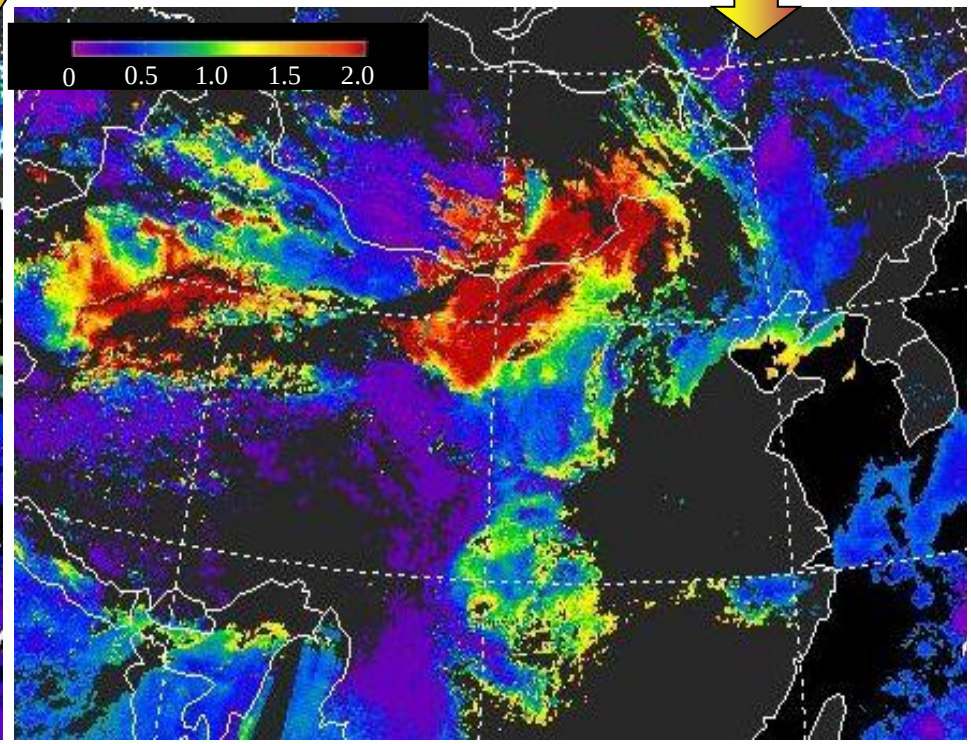


MODIS *Red*-*Green*-*Blue* composite

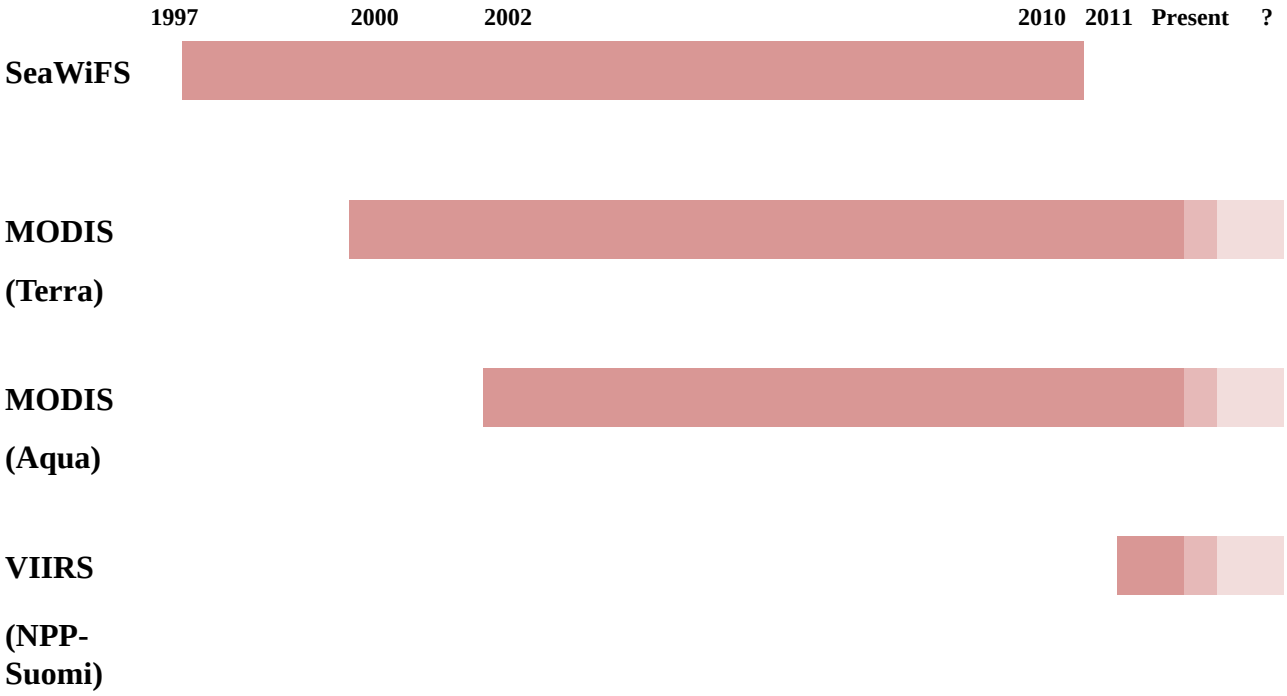
MODIS *Dark Target* AOD

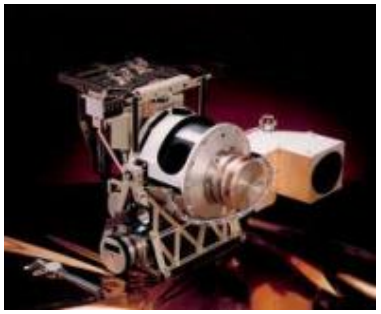
MODIS *Deep Blue AOD*

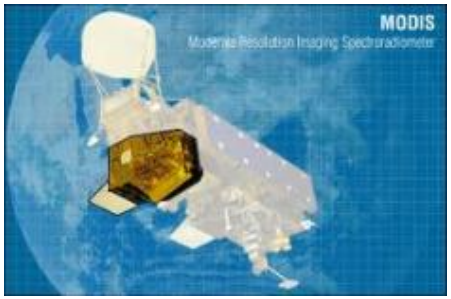


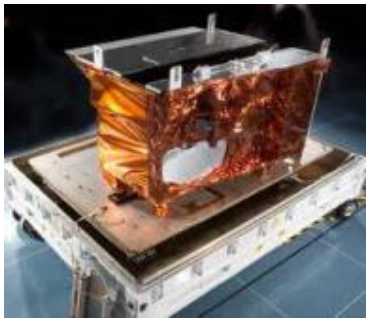


US Deep Blue sensors: past, present, and near future









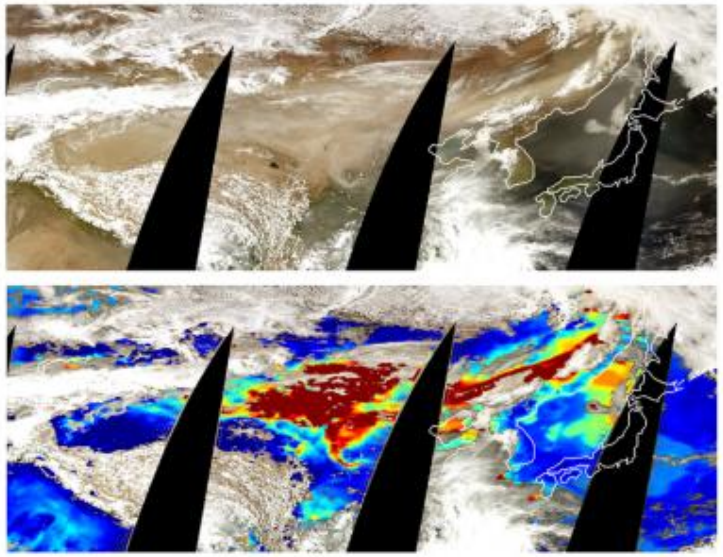
- Non-US sensors too:
  - MERIS (Envisat), 2002-2012
  - GOCI, 2010+

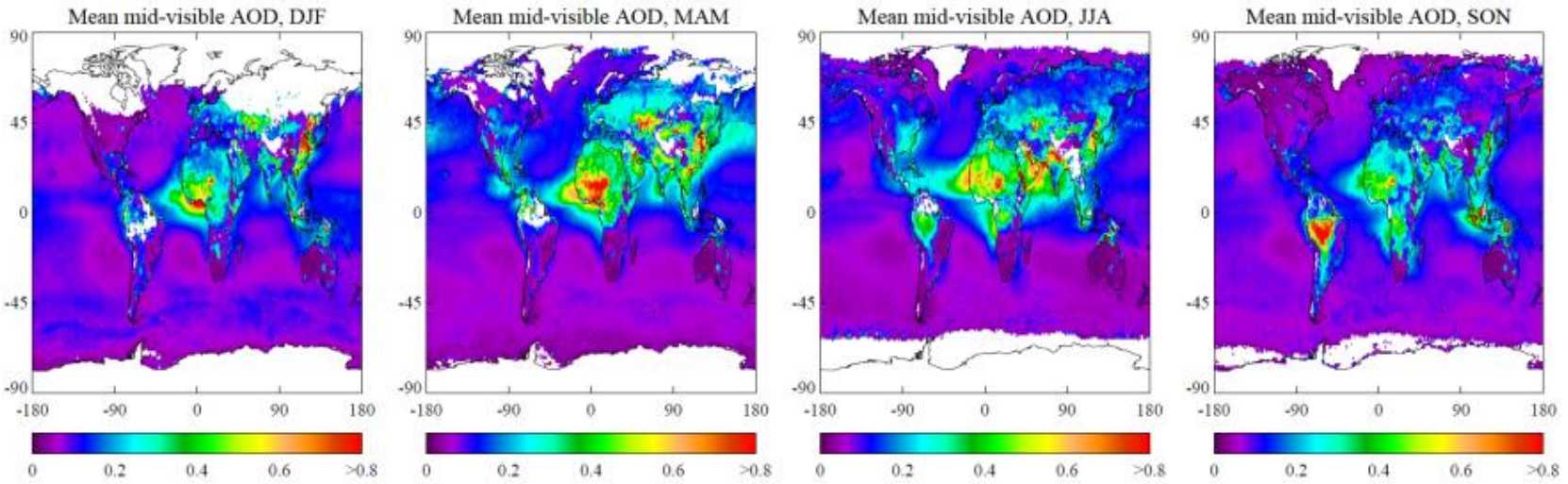
Images courtesy of SeaWiFS/MODIS projects and Raytheon

Sea-viewing Wide Field-of-view Sensor (SeaWiFS)

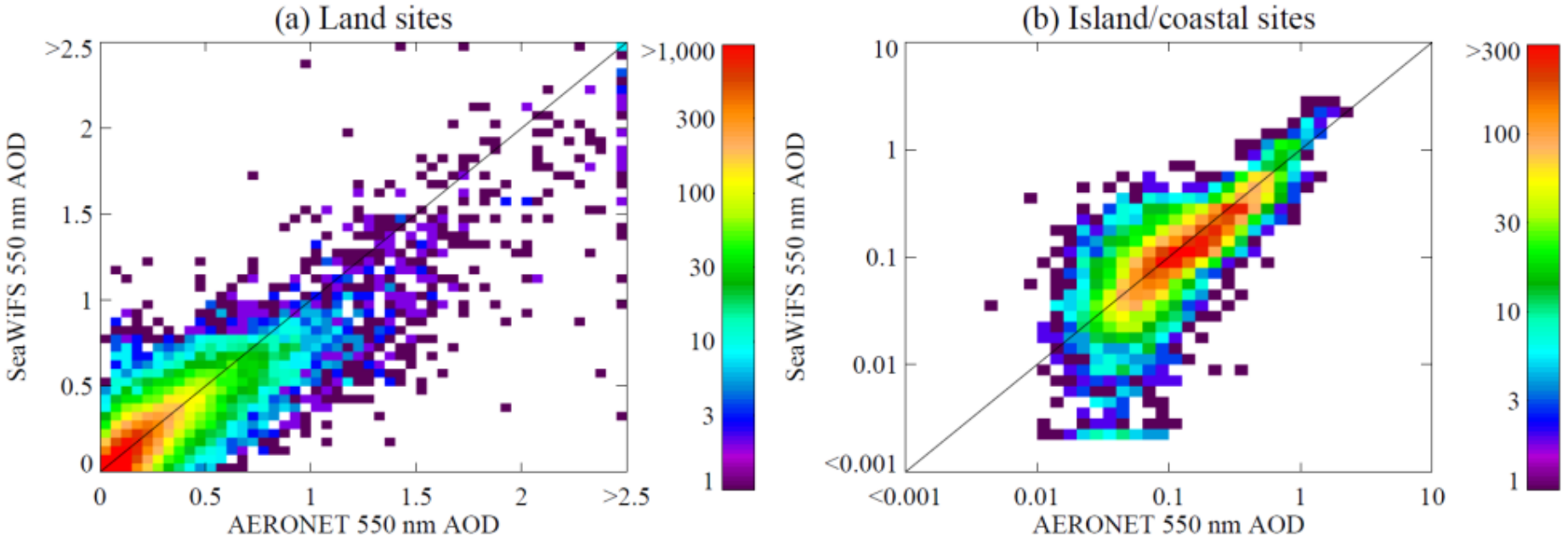
DATA: http://disc.sci.gsfc.nasa.gov/dust/data-holdings
GIOVANNI: http://disc.sci.gsfc.nasa.gov/giovanni/overview/index.html

- Covers Sept 1997 – Dec 2010, with a few gaps
- Data free from GES DISC
  - HDF5 format
  - Level 2 (orbit) at 14.5 km nominal resolution
  - Level 3 (daily/monthly) at 1 degree and half degree
- Coverage over vegetated and arid land, and ocean
  - Land: based on Deep Blue MODIS heritage (Hsu *et al.*, *TGARS*, 2004, 2006; Sayer *et al.*, *AMTD*, 2012)
  - Ocean: Sayer *et al.*, *JGR*, 2012



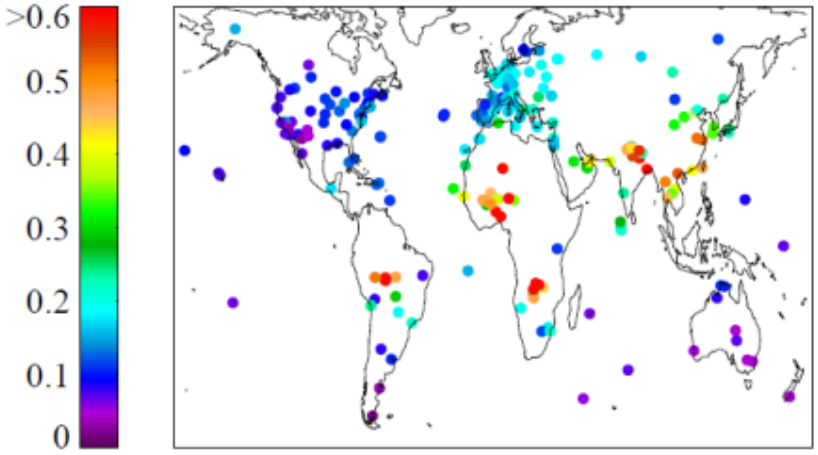


SeaWiFS validation with AERONET

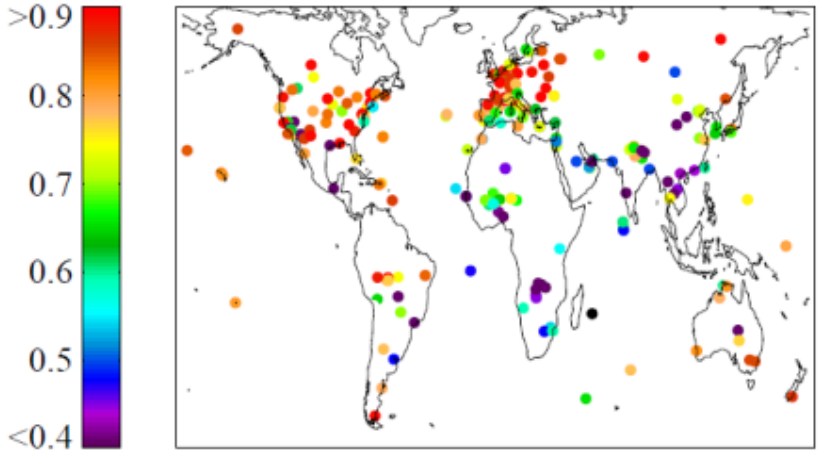


- AERONET validation results are comparable to other modern satellite datasets
- Define an ‘expected error’ (one-sigma absolute uncertainty confidence envelope):
  - 0.05+20% at 550 nm over land (Sayer *et al.*, *AMTD*, 2012)
  - 0.03+15% at 550 nm over ocean (Sayer *et al.*, *JGR*, 2012)
- We have looked at spectral AOD, not just 550 nm

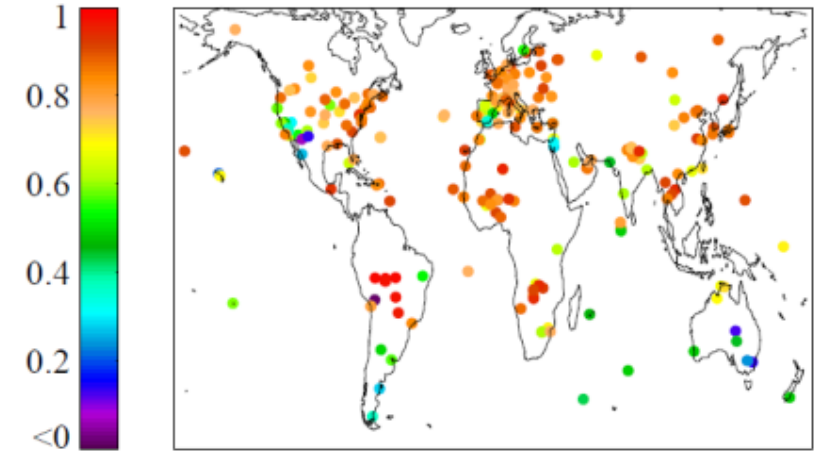
(a) Mean AERONET 550 nm AOD



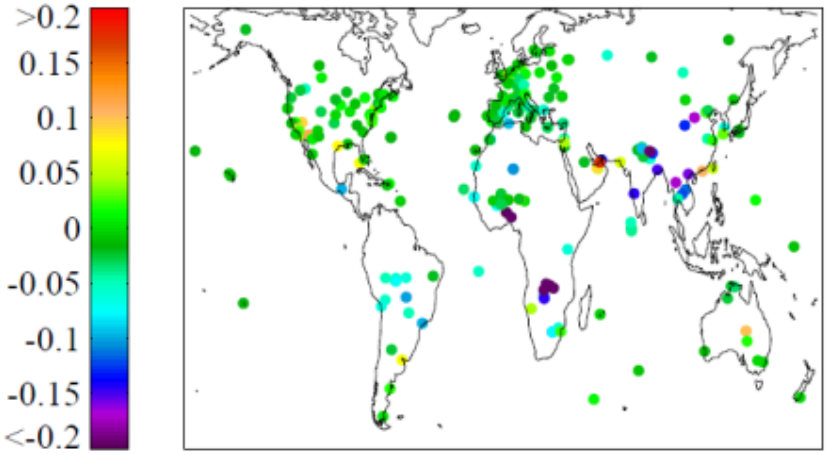
(b) Fraction within expected error, 550 nm



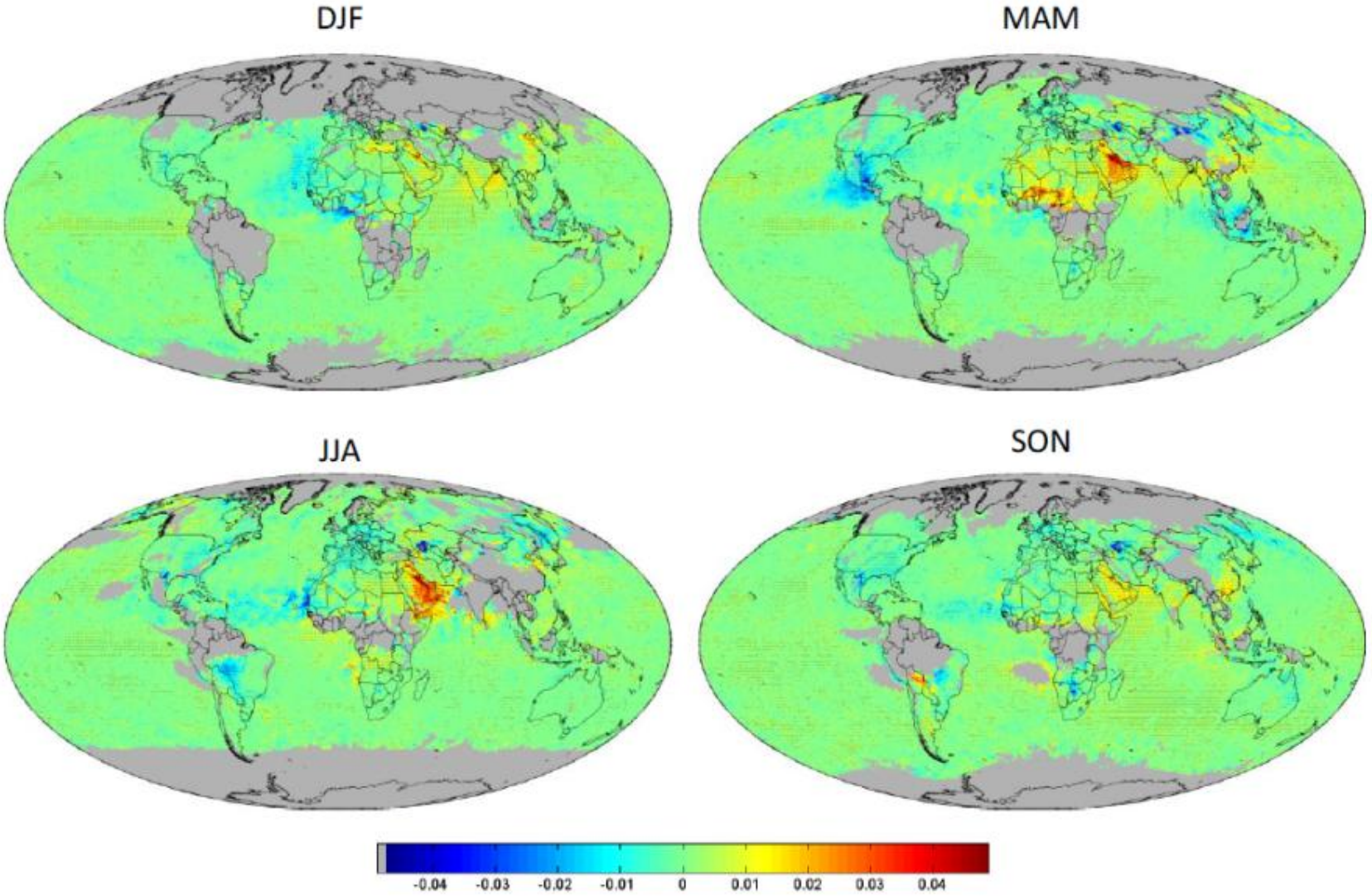
(c) Correlation coefficient, 550 nm



(d) Median bias, 550 nm



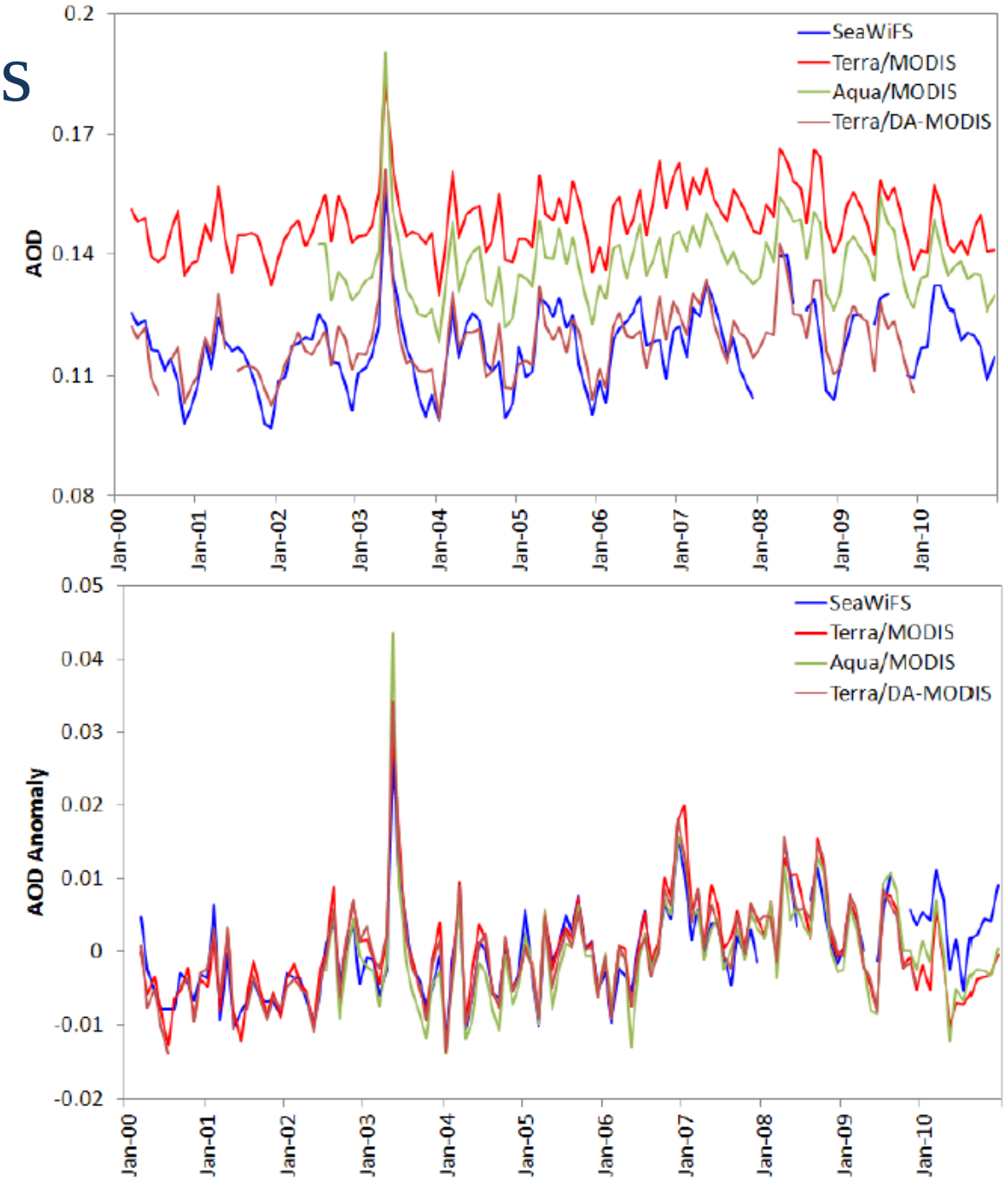
Looking at ‘trends’ (or rather ‘changes’) in AOD



- Linear trends in deseasonalised 550 nm AOD (Hsu *et al.*, *ACPD*, 2012)

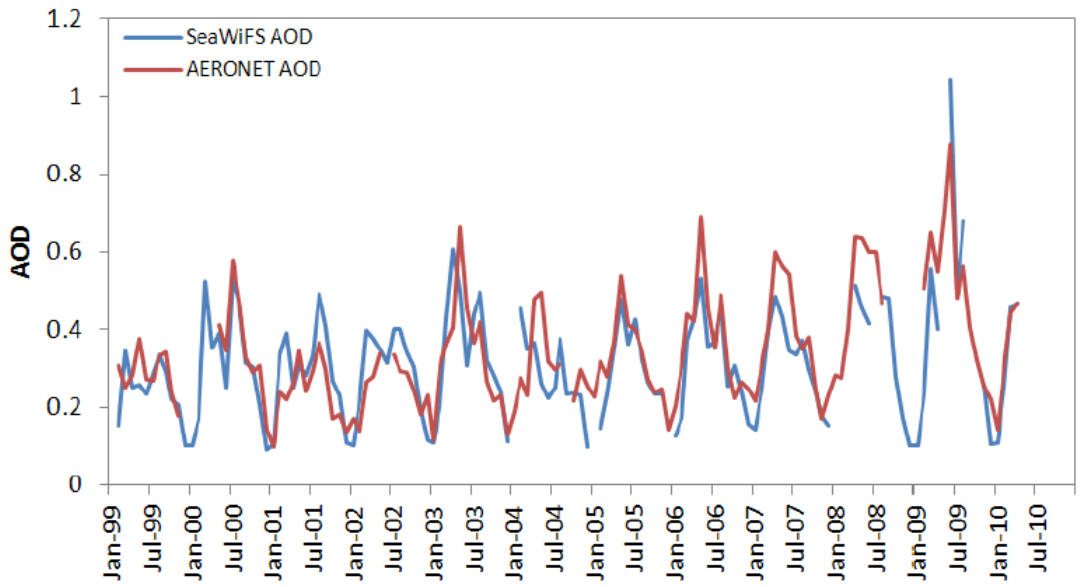
Ocean time series

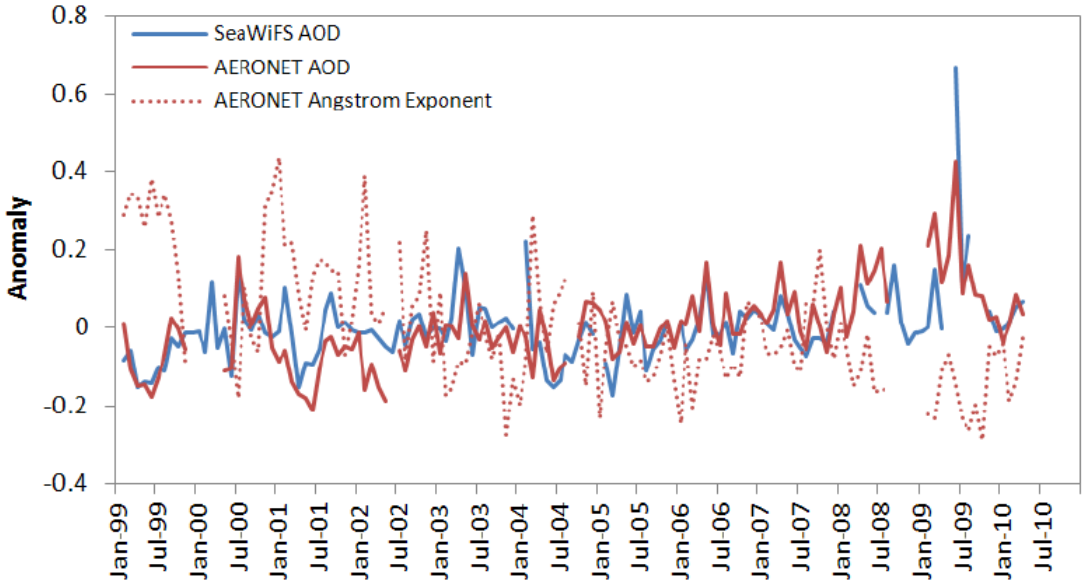
- Over ocean, even though AOD from different sensors is offset, the time series of monthly anomalies line up very closely
- Linear trend in AOD is negligible
- AOD in a given month and year is quite strongly influenced by strong outflow events and meteorology (e.g. ENSO)
  - We need a longer time series to be able to disentangle real changes in aerosol emissions/transport from the background variance
- But the sensors are at least consistent in tracking change…



Changes in AOD at Solar Village?

- SeaWiFS identified positive trend in AOD over parts of the Arabian Peninsula
- AERONET site at Solar Village shows similar trend
  - AOD increasing, Ångström parameter decreasing: getting more dusty?
  - Mostly driven by spring and summer





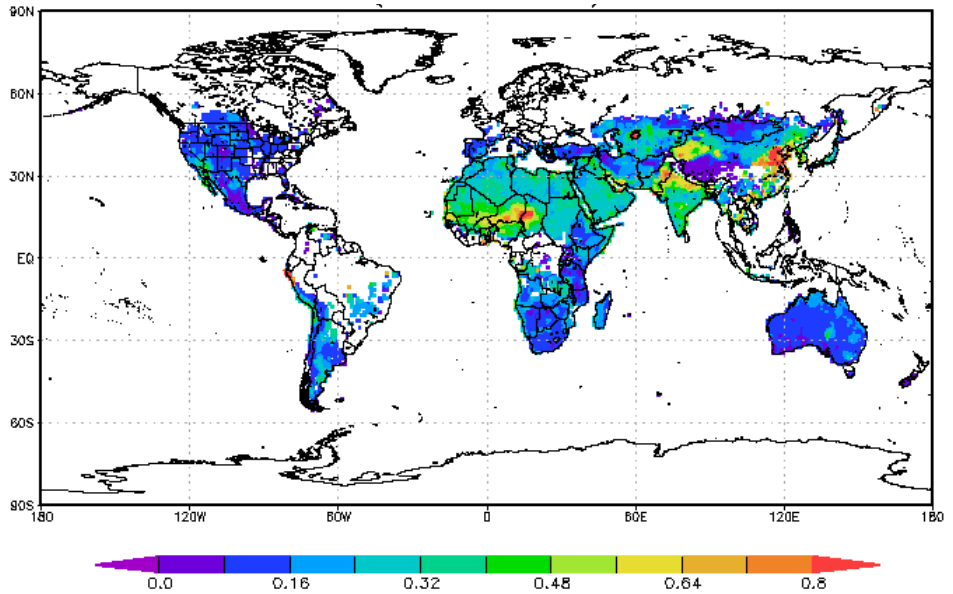
MODIS – C6 developments

- Collection 6 should become available later in 2012
- It will include various refinements to Deep Blue, chiefly:
  1. Extended coverage to vegetated surfaces, as well as bright land.
  2. Improved surface reflectance models.
  3. Improved aerosol microphysical models.
  4. Improved cloud screening (reduced false positive and false negatives).
  5. Simplified integer quality assurance (QA) flags (note bitwise will also still be present).
  6. Calibration improvements will mean that Deep Blue can be applied to the whole MODIS record (previously the Terra record ended in 2007).
  7. Merged Deep Blue – Dark Target aerosol SDS, to provide a more gap-free (aside from clouds and snow) product.

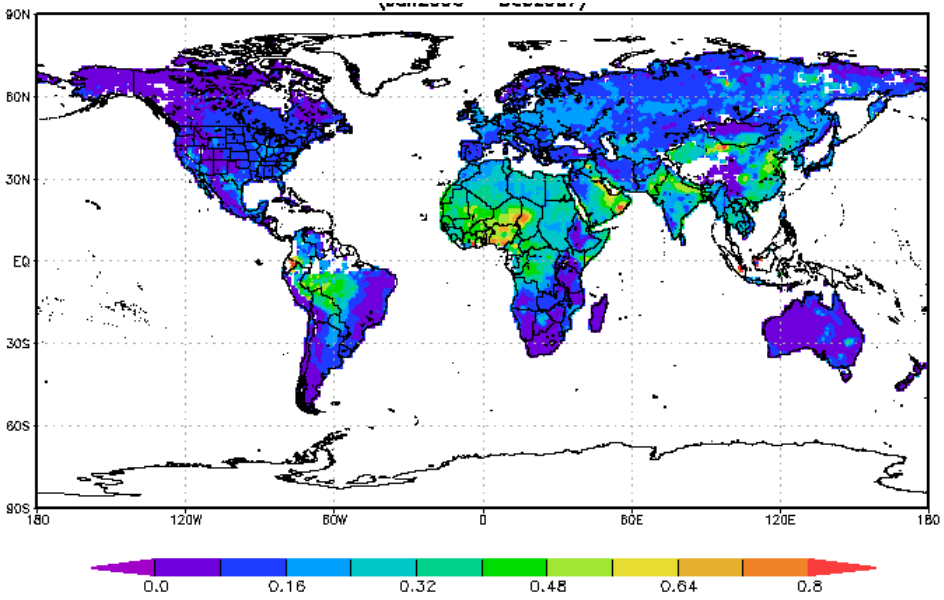
Extended spatial coverage

- We are applying ‘Deep Blue’ over all non-snow land surfaces
  - Upper right: coverage of MODIS Deep Blue for Aqua Collection 5.1
  - Lower right: coverage of MODIS Dark Target and ocean for Aqua Collection 5.1
  - Bottom left: over-land coverage of SeaWiFS Deep Blue (from Giovanni); MODIS Collection 6 Deep Blue coverage should match this
- All images from Giovanni monthly instances

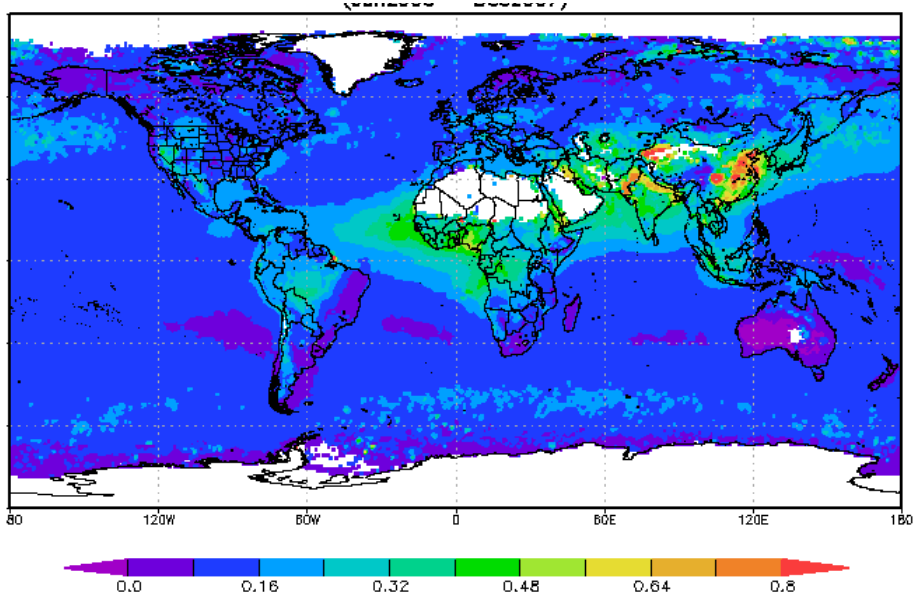
MODIS Deep Blue C5



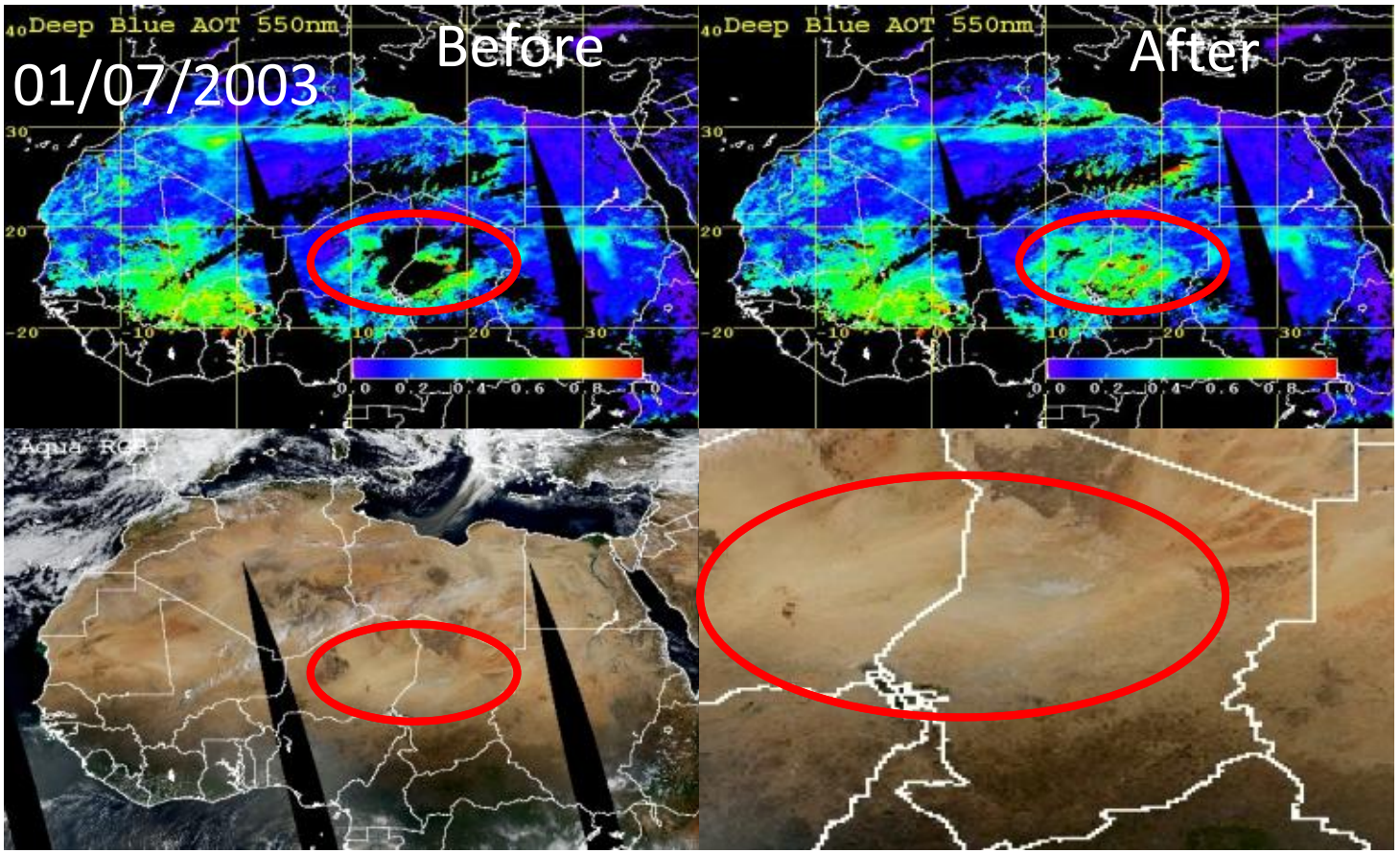
SeaWiFS Deep Blue, expected MODIS Deep Blue C6



MODIS ocean/Dark Target C5

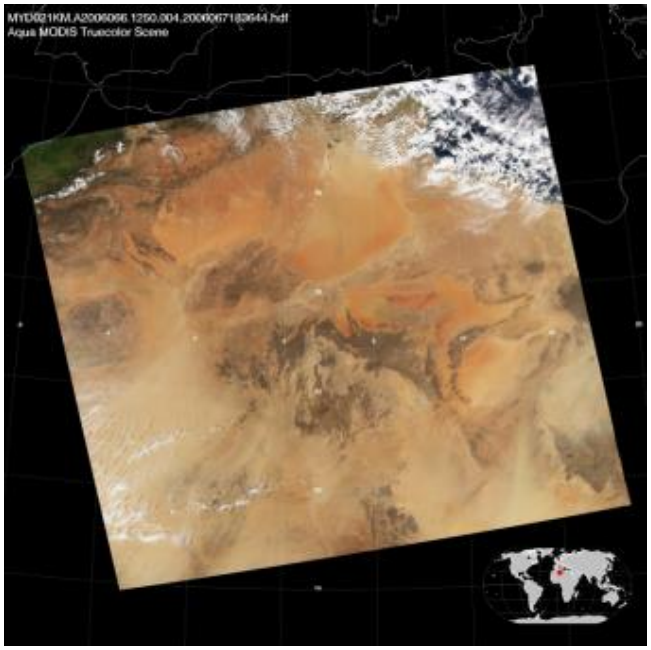


Cloud screening

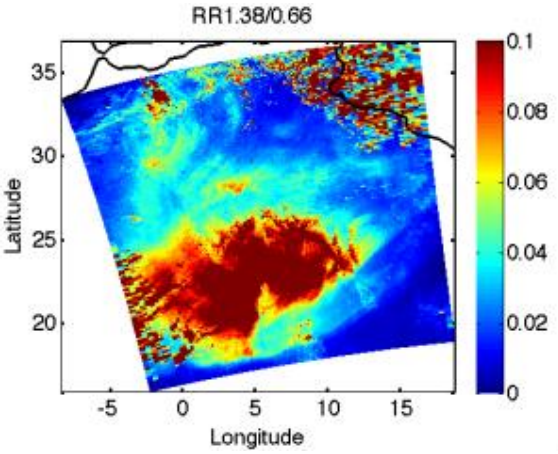


- In Collection 5, some cloud-free areas were flagged as cloudy by the 1.38 micron (cirrus/high cloud) test
  - Combination of high surface reflectance, aerosol, and low columnar water vapor
  - Developed several tests to reduce these false negatives: typically gives more high-AOD events
- False positives also decreased through refinement of other cloud tests and QA flags

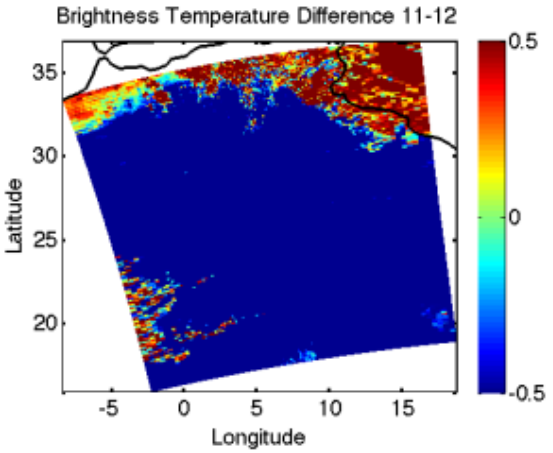
Thin Cirrus Over-Screening over the Sahara, March 7th 2006



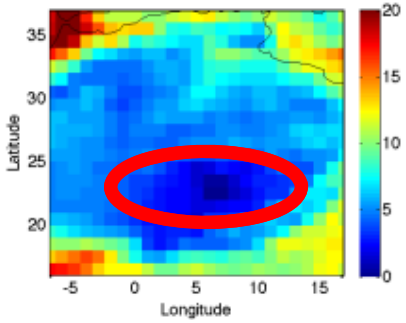
RR1.38/0.66



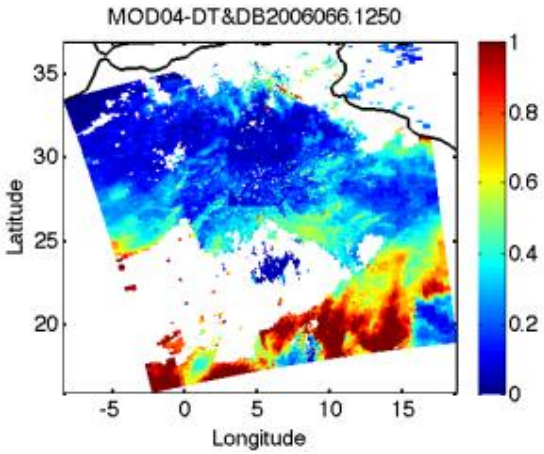
BTD11-12



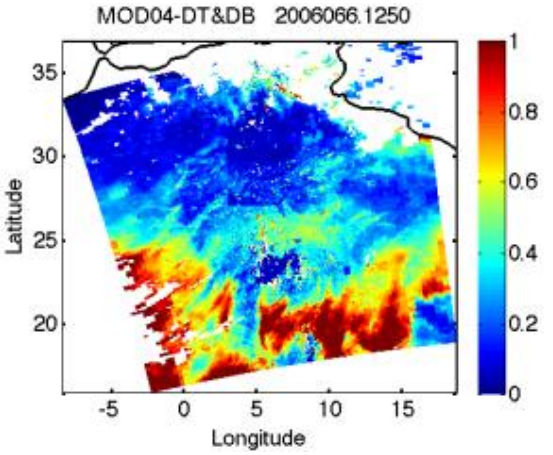
NCEP TPW (mm)



AOT C5.1

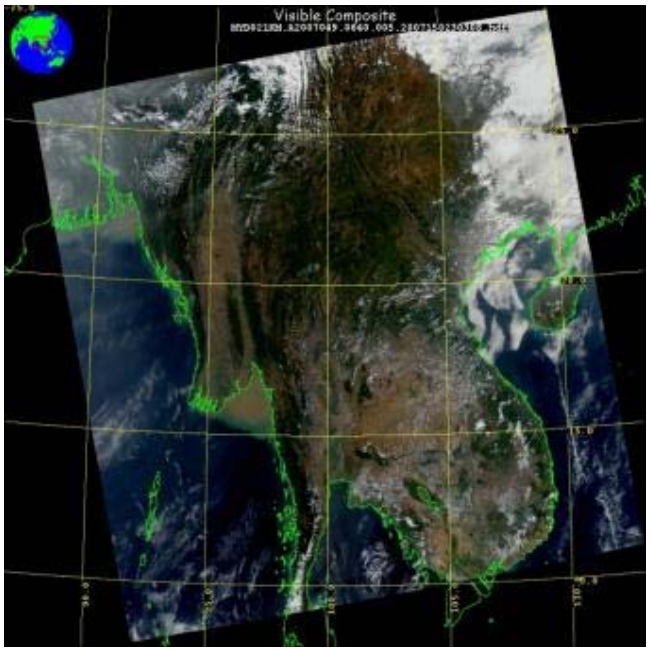


AOT C6

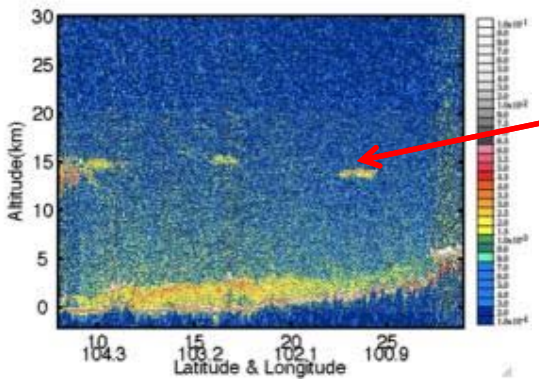


- Bright 1.38 micron reflectance caused cirrus test to be flagged.
- Low total precipitable water (TPW, <4 mm) in part of granule meant transmitted aerosol & surface reflectance was higher than expected
- Not apparent in thermal IR confirms cirrus unlikely
- Significant portion of dust plume regained, no adverse effect elsewhere

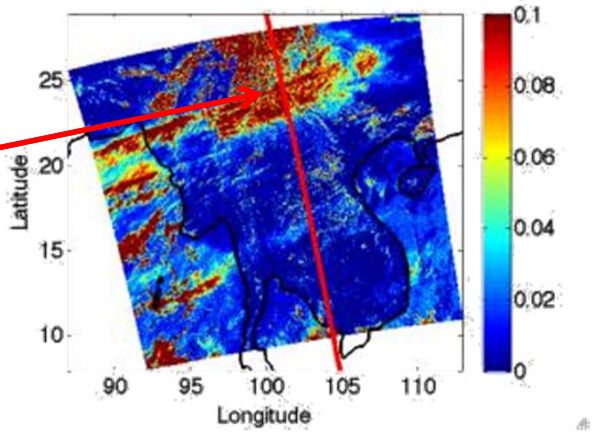
Thin Cirrus Under-Screening over Southeast Asia, February 18th 2002



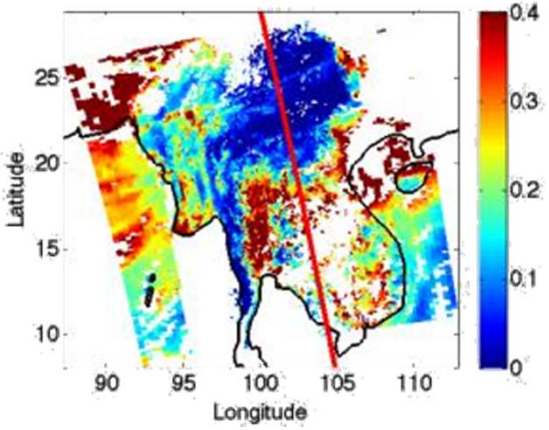
CALIOP TAB, 532 nm



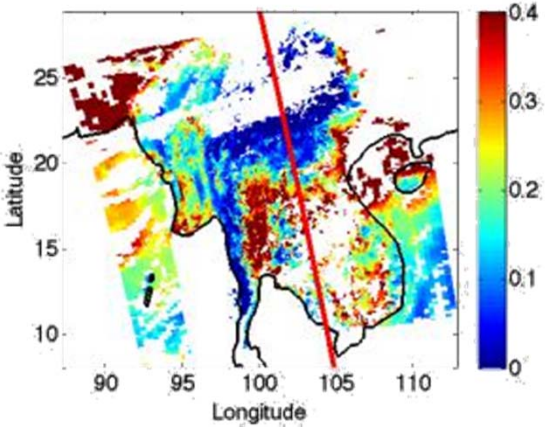
RR1.38/0.66



AOT C5.1



AOT C6

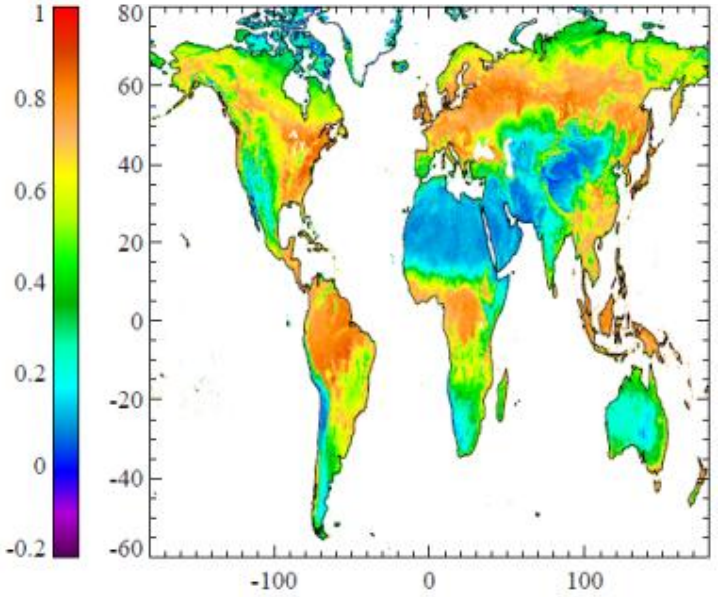


- Converse of previous case: undetected cirrus, visible in CALIOP, let to contamination of C5.1 retrieval
- New reflectance ratio and tests identify this, removing the retrievals from Collection 6
- Not found to introduce significant false negatives

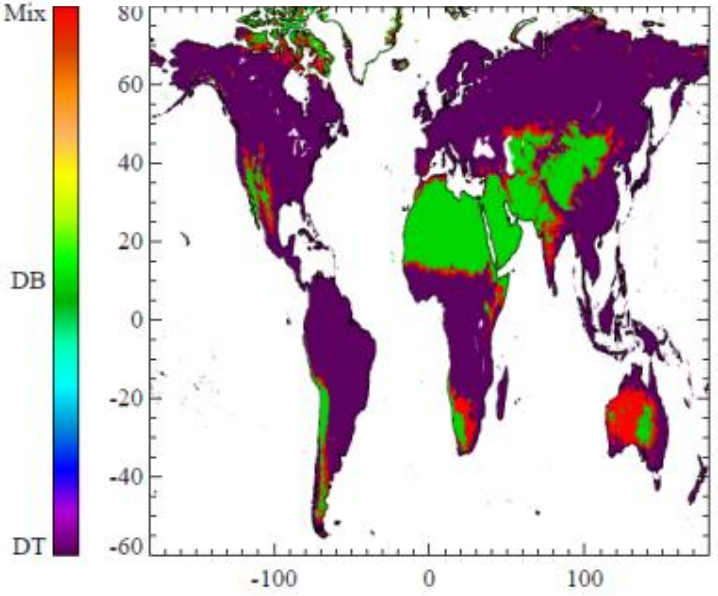
Merged Dark Target/ Deep Blue dataset

- C6 will include a dataset of merged 550 nm AOD from the Deep Blue and Dark Target algorithms.
- To minimize pixel-level discontinuities and for simplicity/clarity, pixels will be assigned to either algorithm based on climatological values of (atmospherically corrected) NDVI for each month
  - Only Deep Blue is available for bright barren surfaces, while Dark Target may be more reliable for greenest surfaces
  - Note ocean algorithm retrievals will also be included
  - Will be an interim ‘transition zone’ where retrievals will either be averaged (if the same QA) or that with higher QA flag chosen
- Example shown to the right for June

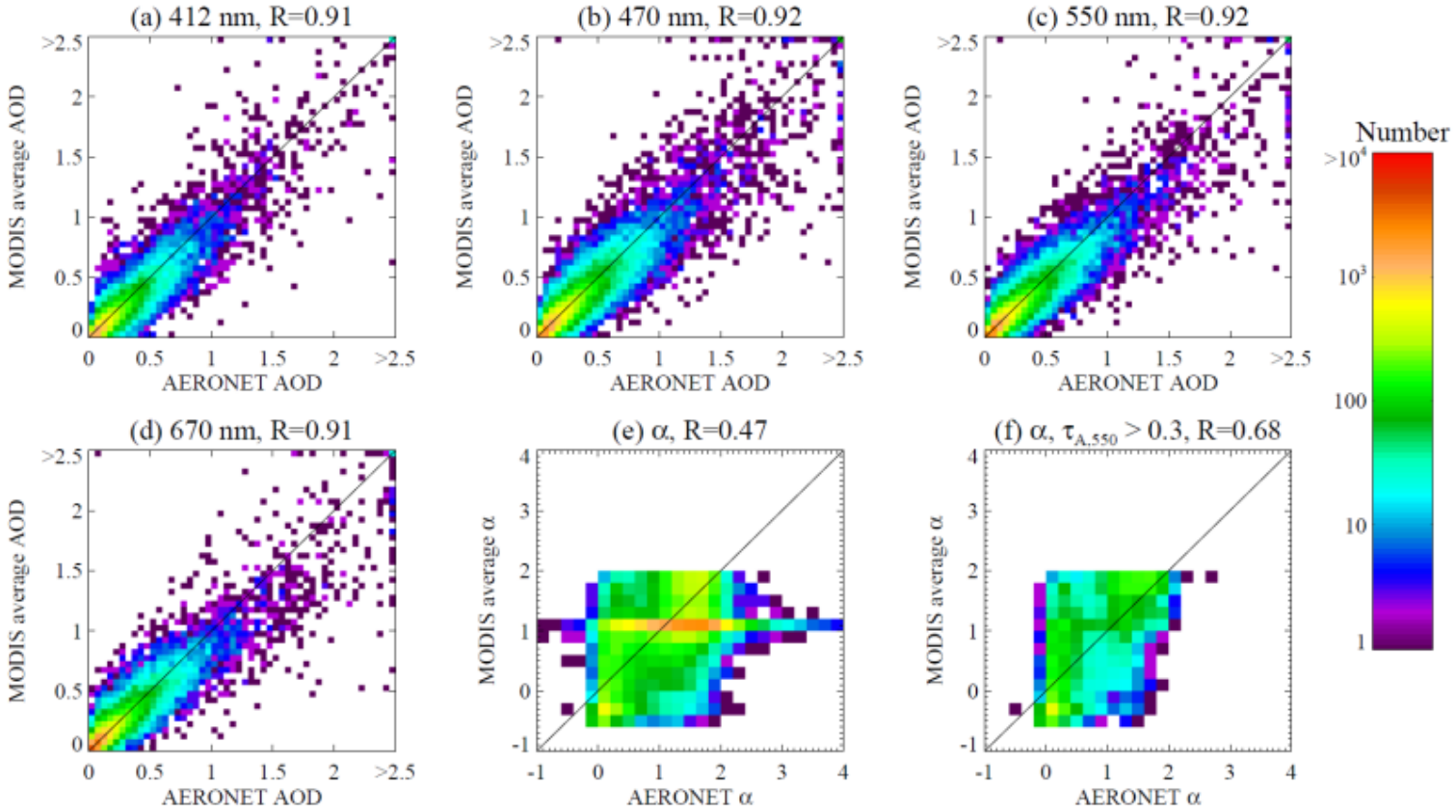
Multiannual mean NDVI, June



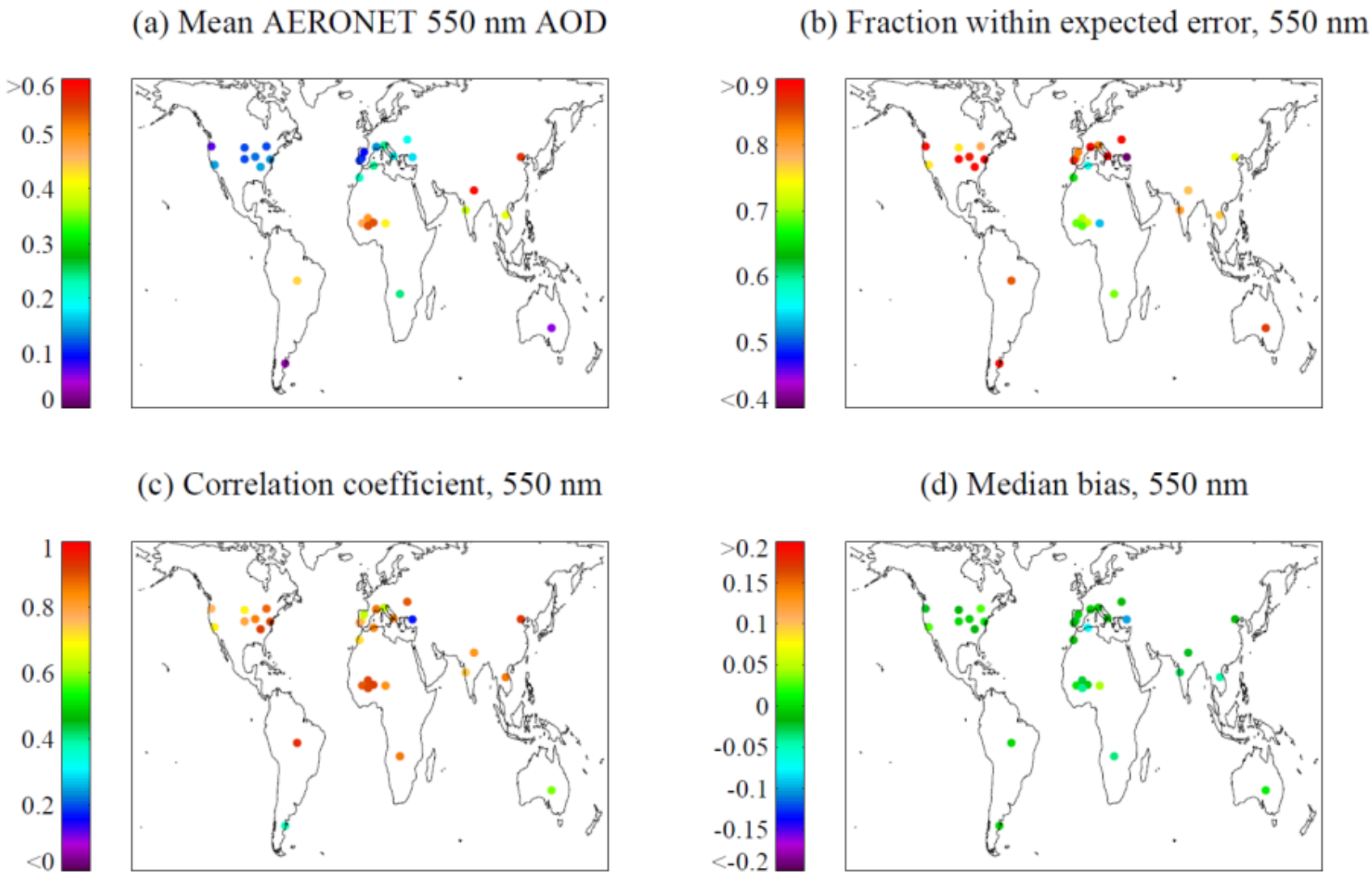
Dark Target **Deep Blue** **Merging zone**



Preliminary MODIS C6 validation



- QA flags are still being refined, but we have performed a preliminary validation against AERONET using MODIS Aqua
- Define one-sigma absolute expected error (EE) of 0.05+20% at each wavelength
- Current (albeit limited) testing suggests this goal is being achieved, although some regional variation in performance



- Generally, correlations are high: capture variability at individual sites well
- Most sites have 68% or more of matchups within expected error (the goal), and small biases

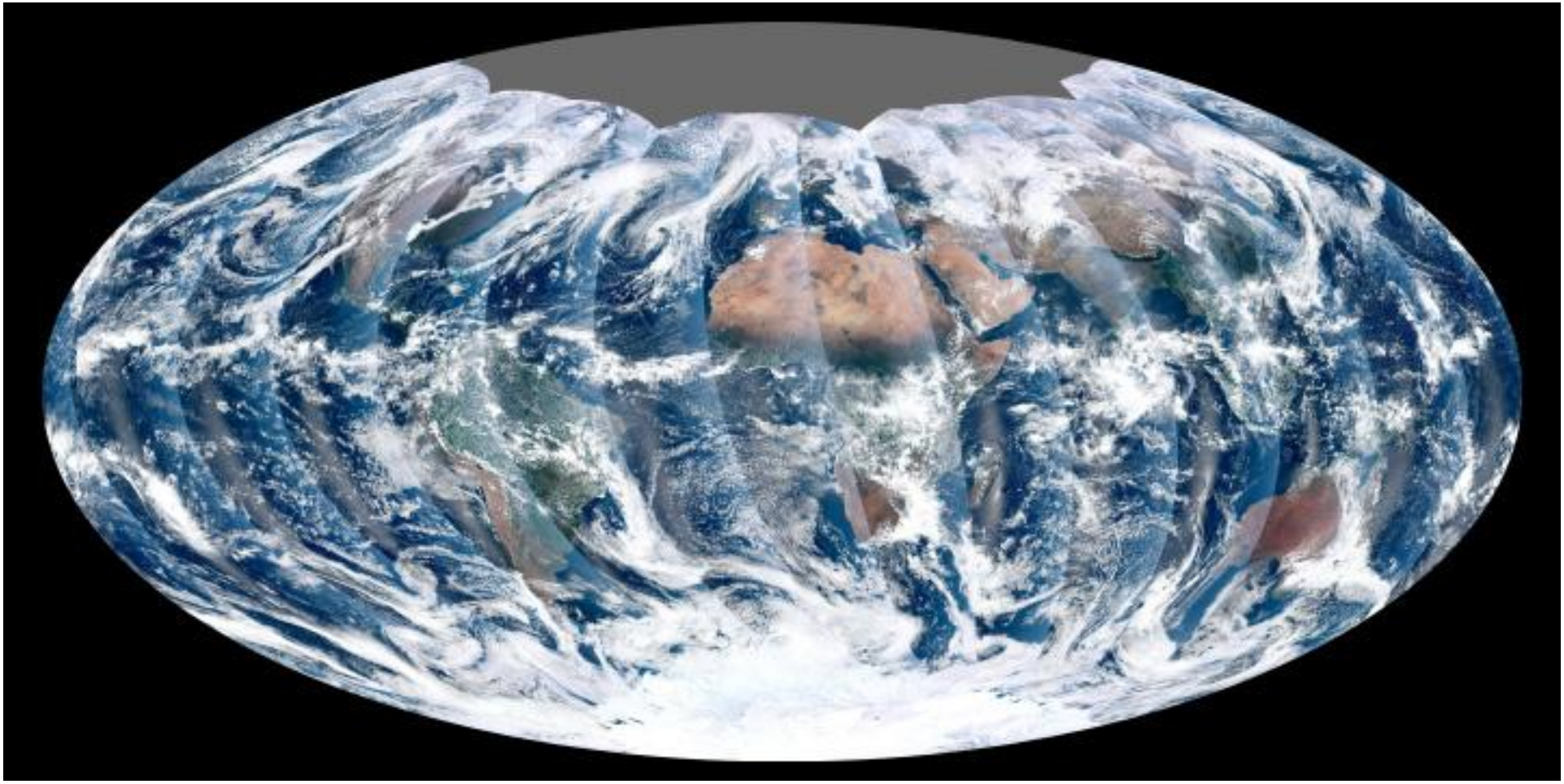
VIIRS – the present and near-future

- Launched October 2011 aboard Suomi-NPP, level 1 and other data products undergoing initial examination
- There will be a suite of operational products available in near real-time
  - No Deep Blue at present
- MODIS-like sensor (for Deep Blue purposes)
- Some differences:
  - 3,000 km swath width giving daily global coverage
  - Detector design means ‘bowtie effect’ (pixel size increase across swath) much smaller than in MODIS
  - 750 m pixel size

Flight Units 1 and 2 Instrument Specifications	
Orbit:	833 km polar sun-synchronous
Swath:	>3,000 km (±56 degrees about nadir)
Scanning:	Rotating telescope with dual-sided, half-angle mirror
Size:	135 x 148 x 89 cm^3
Spectral Coverage:	0.4 to 12.5 μm
Number of Bands:	
Visible/Near Infrared:	9, plus day/night band
Mid-wave Infrared:	8
Long-wave Infrared:	4
Resolution:	
Radiometric (16 bands):	0.742 km nadir, 1.6 km EOS
Imaging (5 bands):	0.371 km nadir, 0.8 km EOS
Day/Night Band:	0.742 km constant across scan
Mass:	270 kg
Power:	170 W
Data Rate:	8 Mbps (avg.) / 10.5 Mbps (max.)

Figure 1. High level VIIRS Flight Unit 1 and Flight Unit 2 instrument characteristics with photo of FU1 being integrated onto the NPP spacecraft at Ball Aerospace. Photo courtesy Ball Aerospace.

Thank you; any questions?



- FAQ:
  - First VIIRS global image: 24th November 2011, courtesy of NASA NPP team
  - Brightening at edge of swath is due to increased Rayleigh/aerosol scattering
  - Missing data at high northern latitudes as it is polar night