Recent developments in 'Deep Blue' satellite aerosol data products from NASA GSFC

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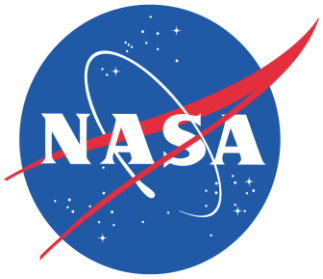

Overview

- Deep Blue key concepts
- Our datasets
  - The past: SeaWiFS, 1997-2010
  - The present: MODIS Terra/Aqua, 2000/2002+
  - The (near) future: VIIRS, 2011+

Images from NASA Earth Observatory, http://earthobservatory.nasa.gov/Features/Aerosols/

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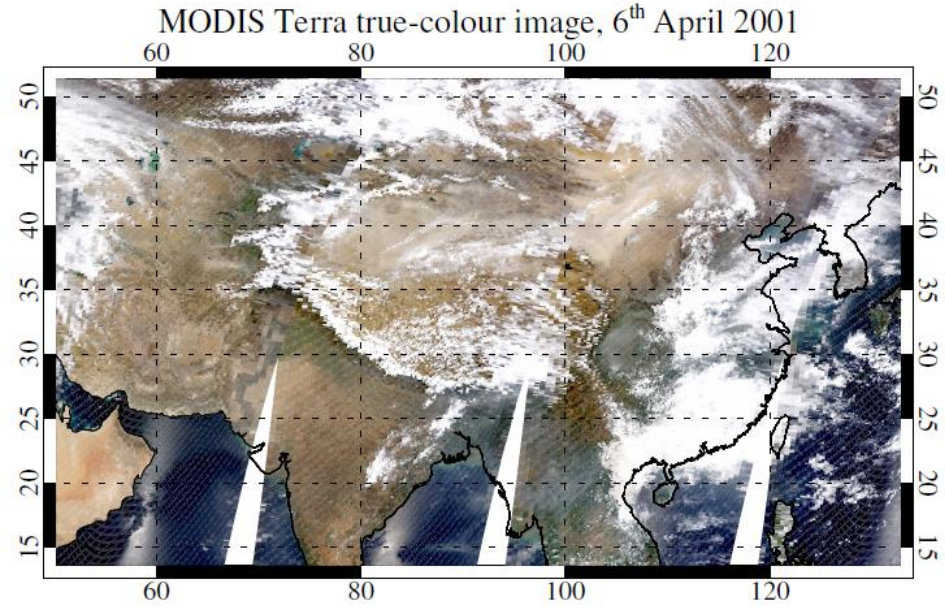
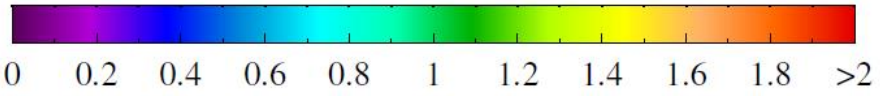
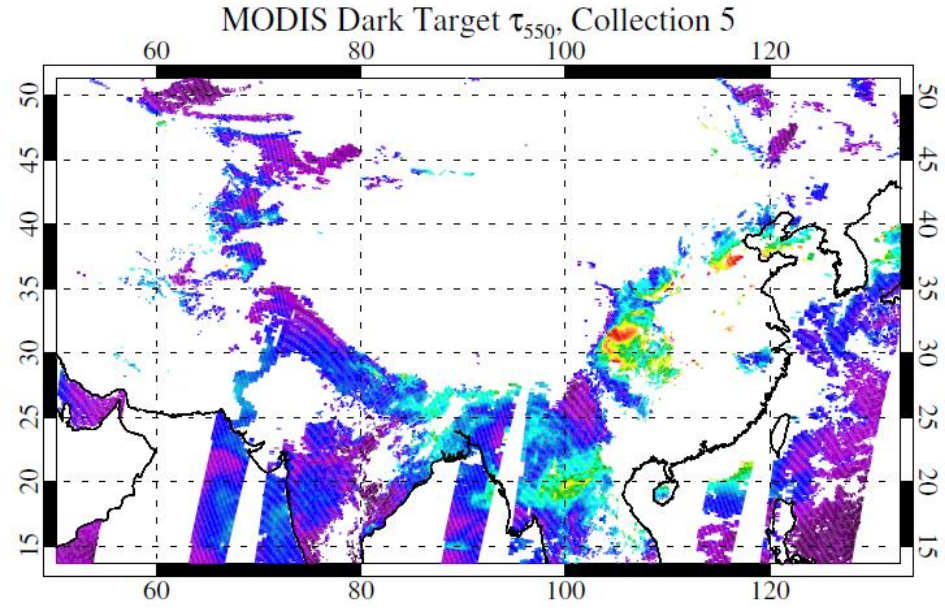
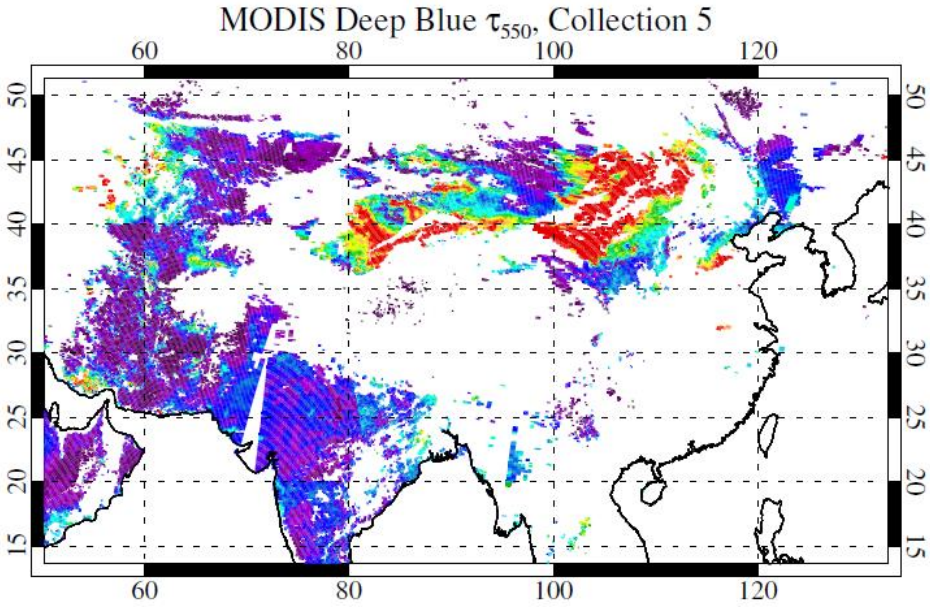
Deep Blue: original motivation



- MODIS '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)







Deep Blue: key concepts

- Often, darker surface and stronger aerosol signal in the blue than at longer wavelengths
- Prescribed empirical surface reflectance database
  - Geometric & NDVI-dependence (dynamic); input from AERONET and surface type
- Retrieve AOD independently at several wavelengths
  - Use these to identify aerosol 'type' for moderate and high AOD
- **Advantages:**
  - Avoids regional artefacts 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 (blue bands are useful but not necessarily needed)
- **Disadvantages:**
  - Drastic departures from expected surface cover type can lead to artefacts
  - Not a physical inversion so cannot directly back out e.g. effective radius or mass loading

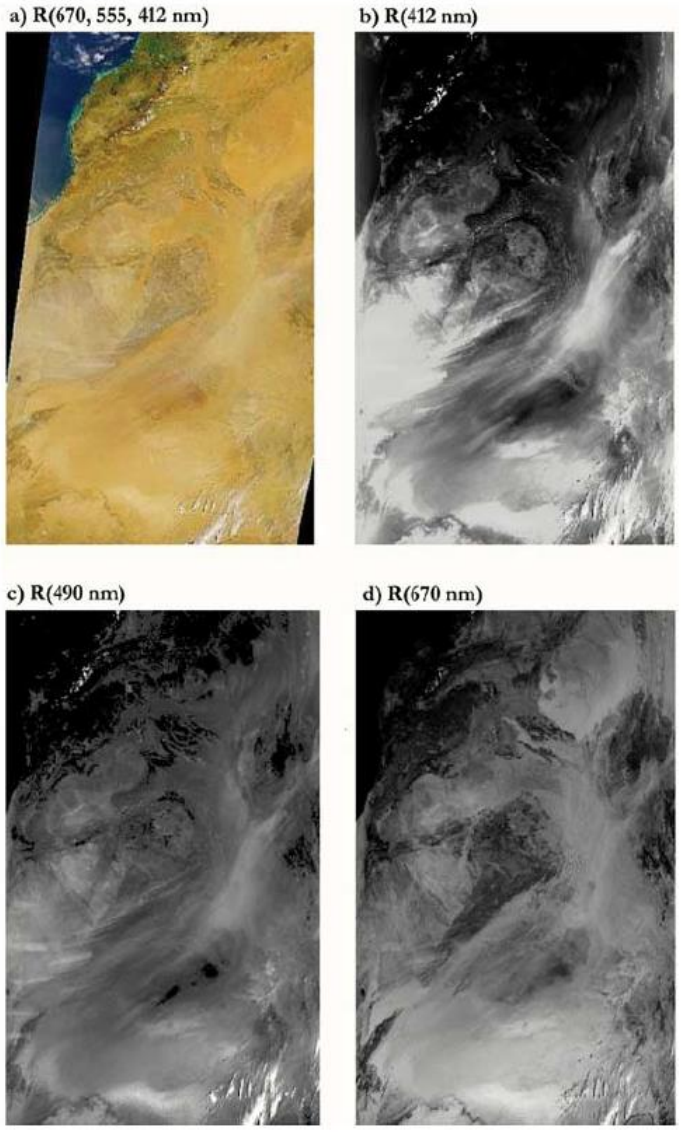
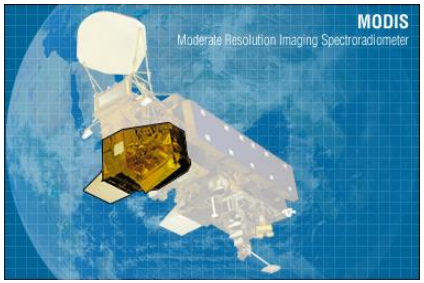


Fig. 2. SeaWiFS images over northeast Africa on February 10, 2001. The dynamical ranges of the grayscale used in (b)–(d) are individually adjusted to optimize the appearance of atmospheric features against the background surfaces.

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



MODIS vs. SeaWiFS Deep Blue

Dataset	MODIS (Collection 6, C6)	SeaWiFS (Version 4, V4)
Time series	MODIS Terra (2000 onwards) MODIS Aqua (2002 onwards)	SeaStar satellite (1997-2010, a few gaps)
Coverage	Cloud-free snow-free land only	Cloud-free snow-free land Cloud-free ice-free non-turbid water
Data products	Main product is AOD at 550 nm Also AOD at 412/470/670 nm, Ångström exponent, and SSA (for heavy dust)	Main product is AOD at 550 nm Land: also AOD at 412/490/670 nm, Ångström exponent, and SSA (for heavy dust) Water: also AOD at 510/670/865 nm, Ångström exponent, fine mode fractional volume
Level 2	Nominal 10 x 10 km resolution ~2,330 km swath	Nominal 13.5 x 13.5 km resolution ~1,500 km swath
Level 3	1°; daily, 8-day, and monthly resolution	0.5° and 1°; daily and monthly resolution
Data access	Distributed by MODIS LAADS Level 3 visualisation through Giovanni	Distributed by GES DISC Level 3 visualisation through Giovanni

- See Hsu *et al.* (2004, 2006, 2013); Sayer *et al.* (2012a,b, 2013)

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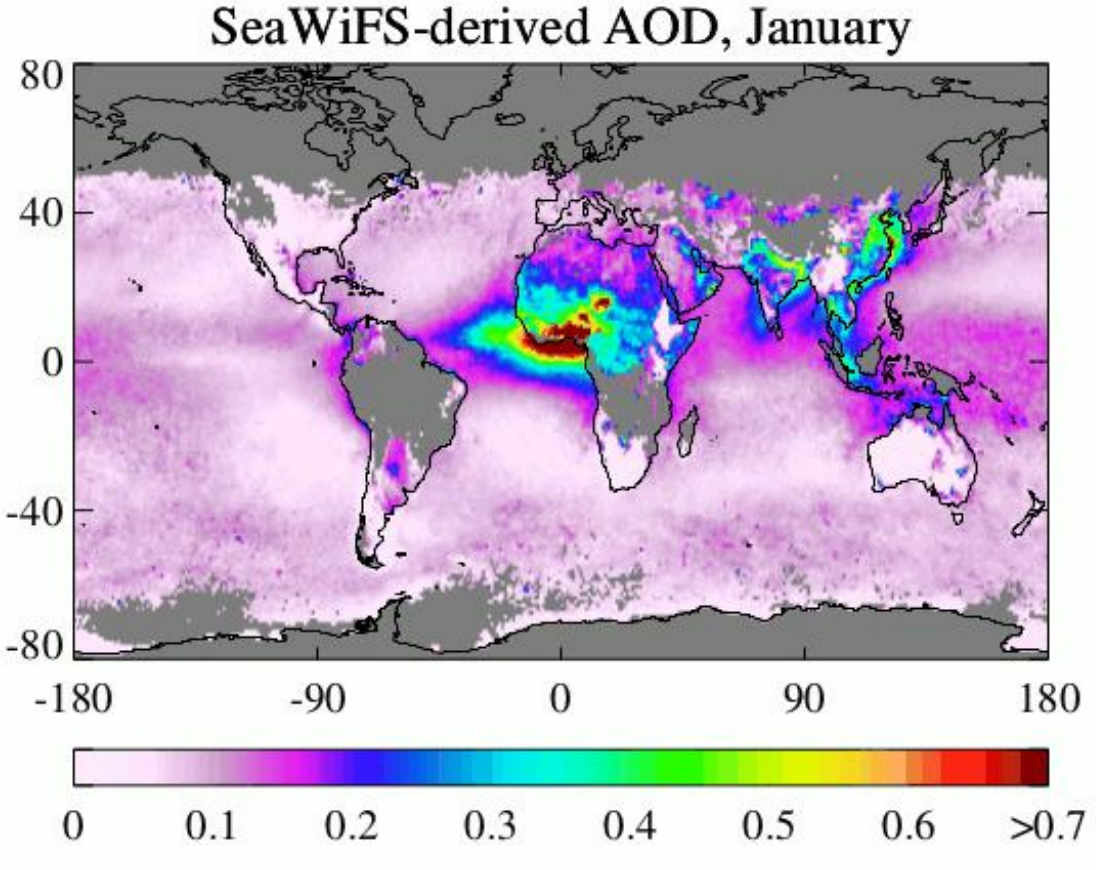
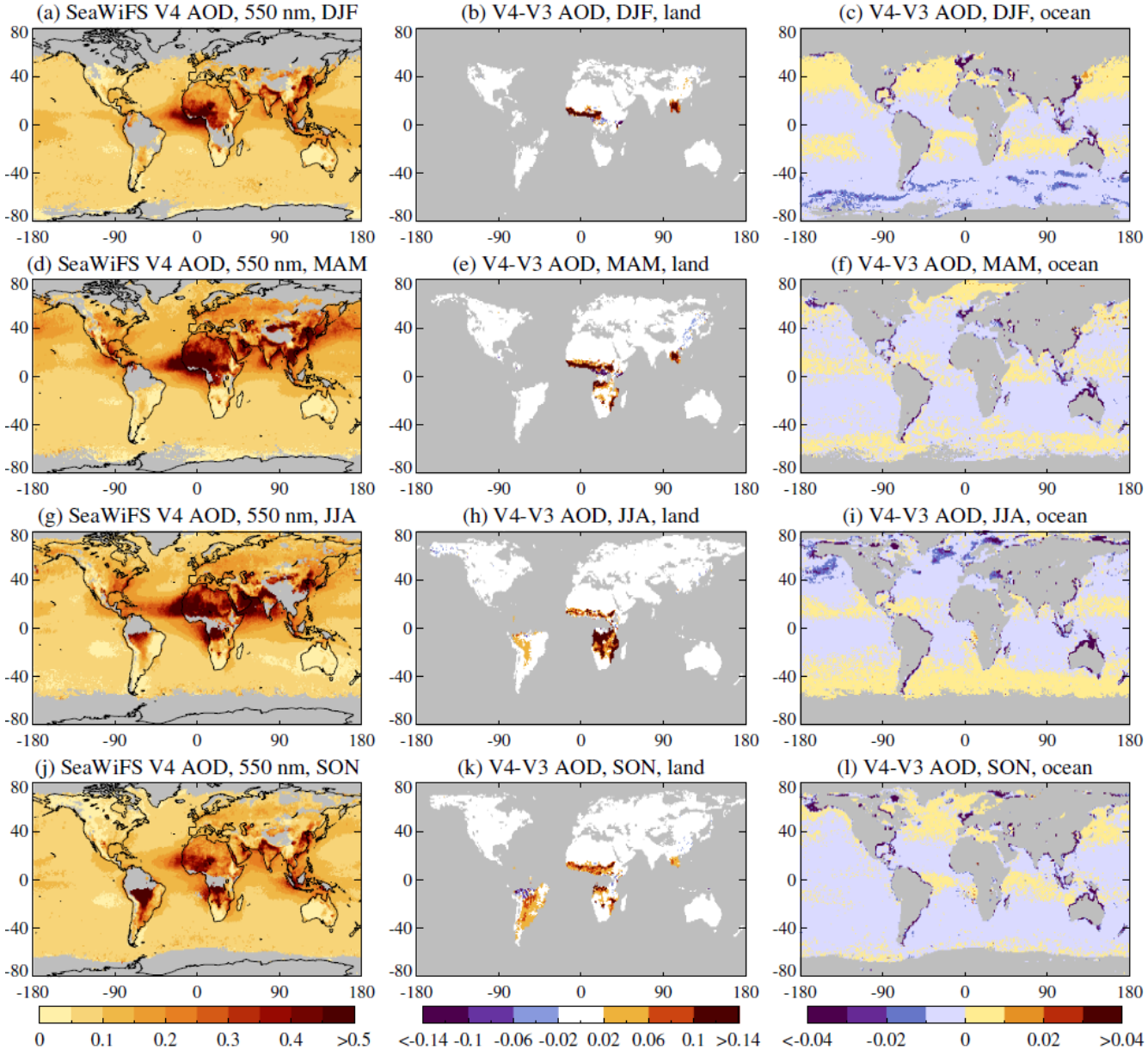
SeaWiFS V4: main developments

- Sea-viewing Wide Field-of view Sensor (SeaWiFS)
- Retrievals over water:
  - Absolute expected AOD error (EE) ~0.03+15%
  - Improved turbid water detection
  - Fixed a coding error
  - Note the ocean algorithm is a multispectral inversion technique, not the same as land Deep Blue
- Retrievals over land:
  - Absolute expected AOD error (EE) ~0.05+20%
  - Updated aerosol model selection in some regions, to address some previously-identified biases

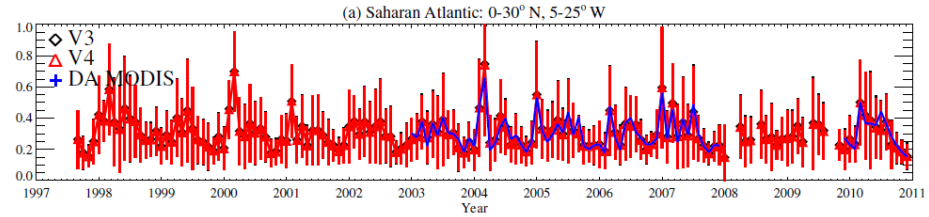


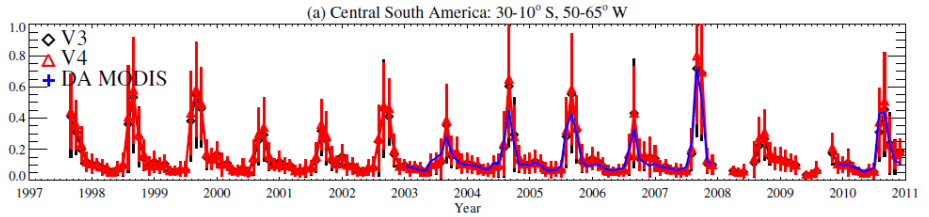
SeaWiFS V4: seasonal differences

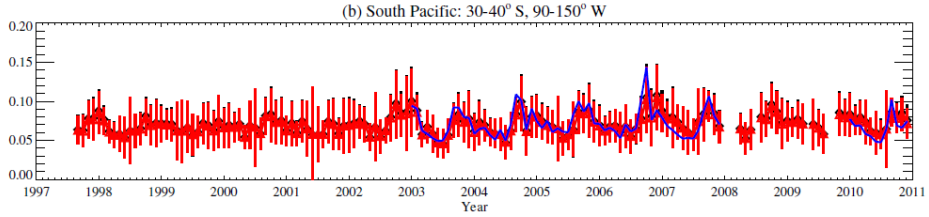
- **Over ocean**, outside of coastal regions, the AOD change is generally <0.01 in magnitude
  - In coastal regions, AOD decreases can be <-0.05
- **Over land**, many regions are unchanged; most biomass burning source regions have higher AOD due to use of more absorbing models

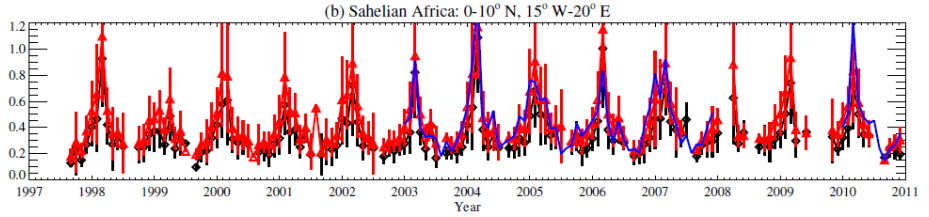


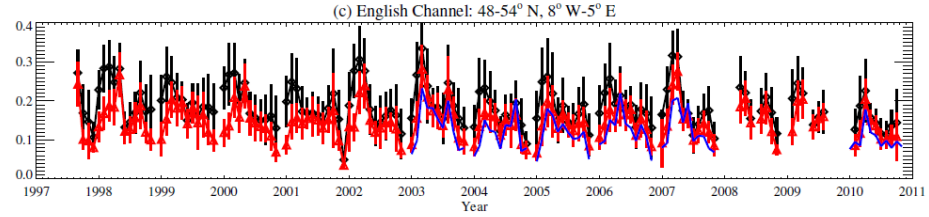
SeaWiFS V4: regional time series

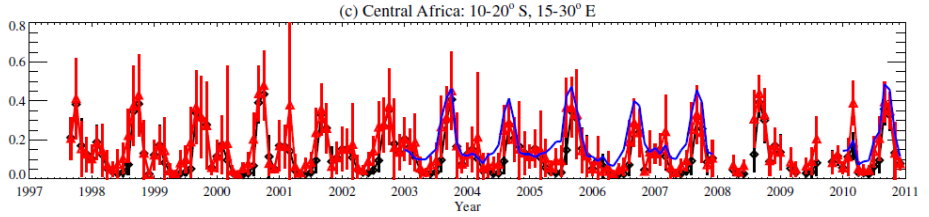


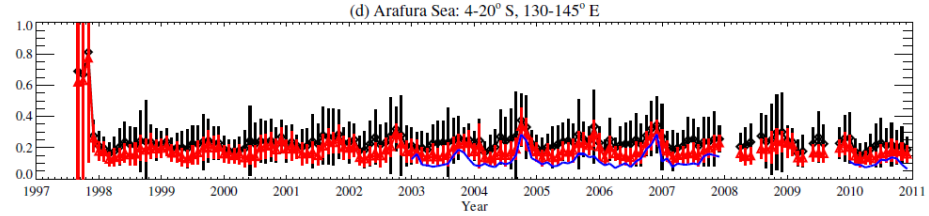


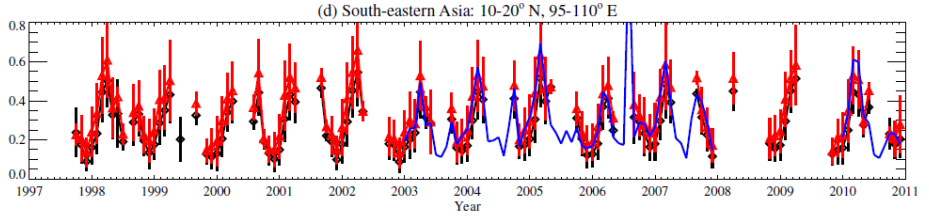












- Compare **SeaWiFS V3**, **SeaWiFS V4**, and data-assimilation **(DA) grade MODIS** (NRL/UND; Reid, Zhang, Hyer, Shi *et al.*) time series
- Overall, changes bring SeaWiFS closer in line with DA-MODIS
  - But both versions were, in our view, pretty good

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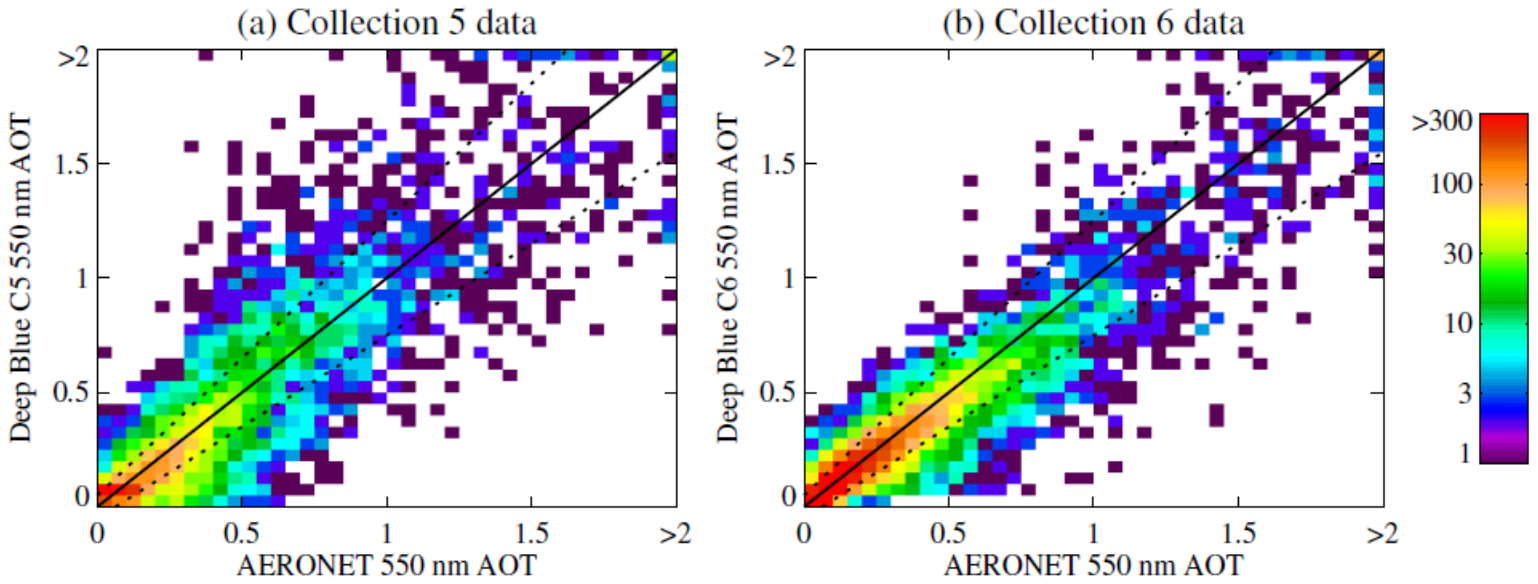
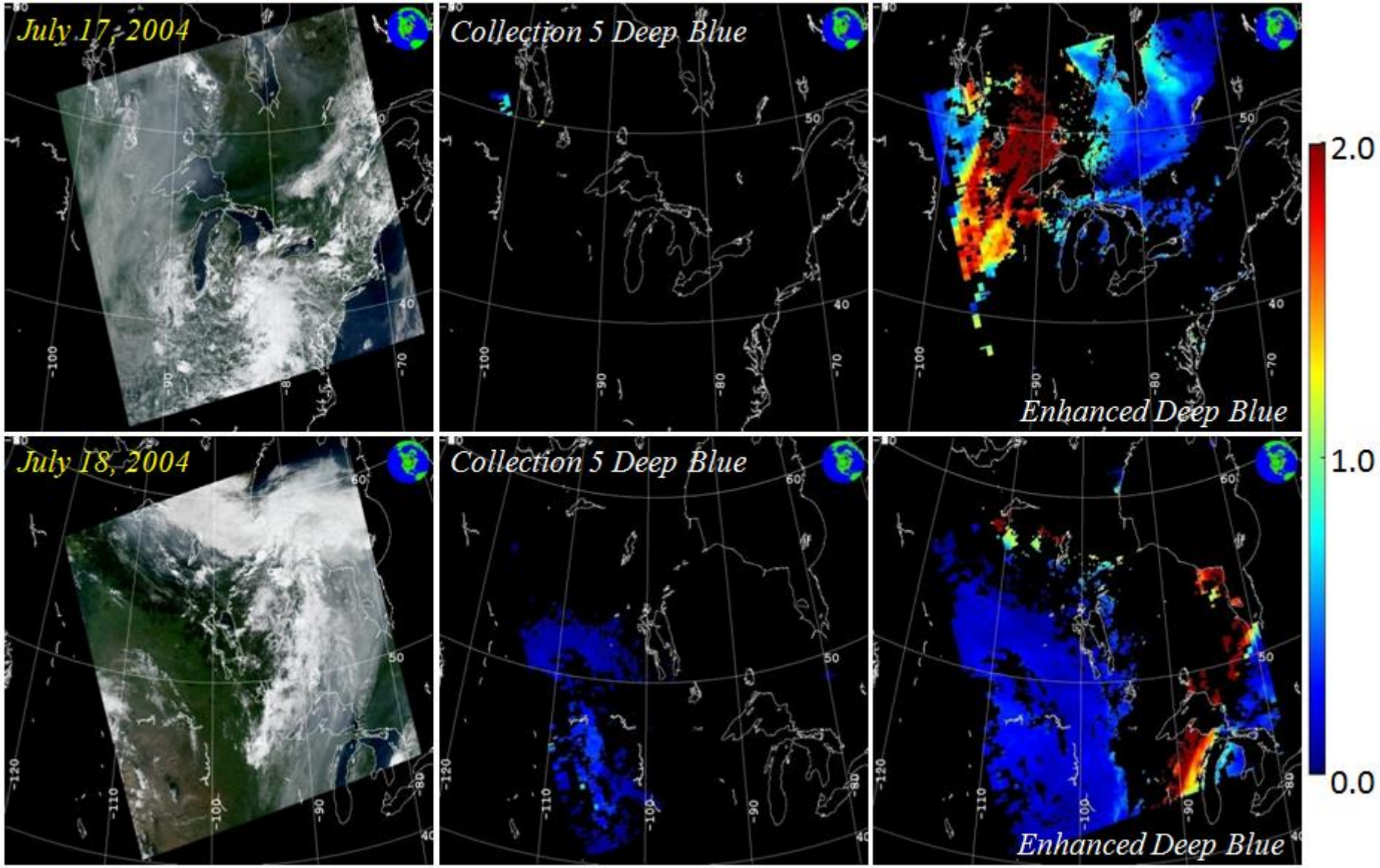
MODIS C6: main developments

- Described by Hsu *et al.*, *J. Geophys. Res.* (2013)
  - Summary: more retrievals, better retrievals



- Collection 6 refinements to Deep Blue:
  1. Extended coverage to vegetated surfaces, as well as bright land
  2. Improved surface reflectance models
  3. Improved aerosol optical models
  4. Improved cloud screening
  5. Simplified quality assurance (QA) flags
  6. Radiometric calibration improvements

MODIS C6: extended spatial coverage



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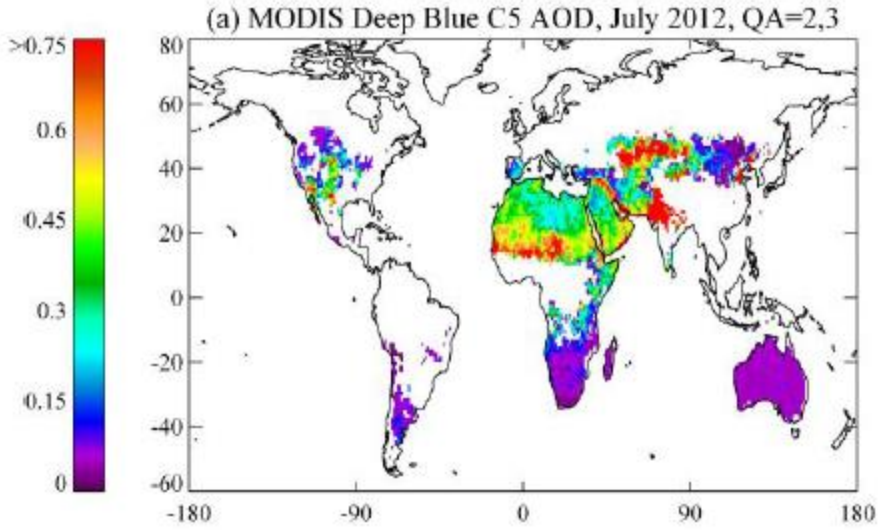
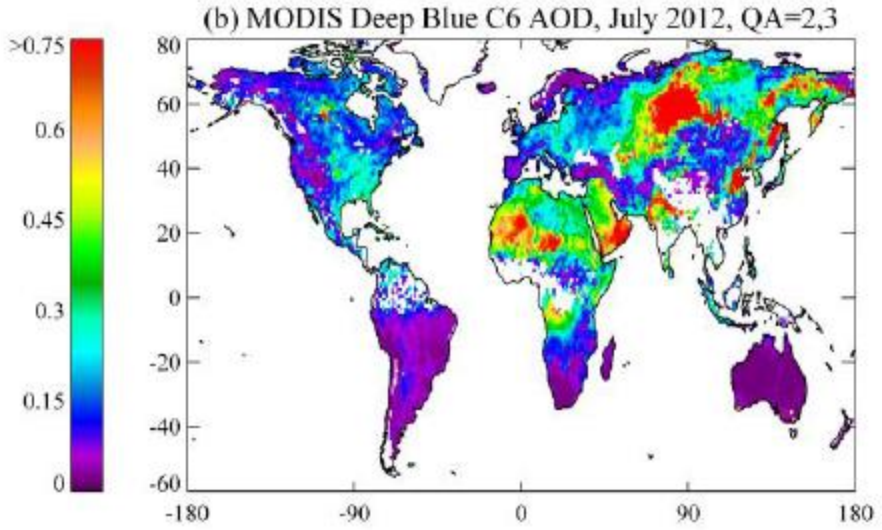
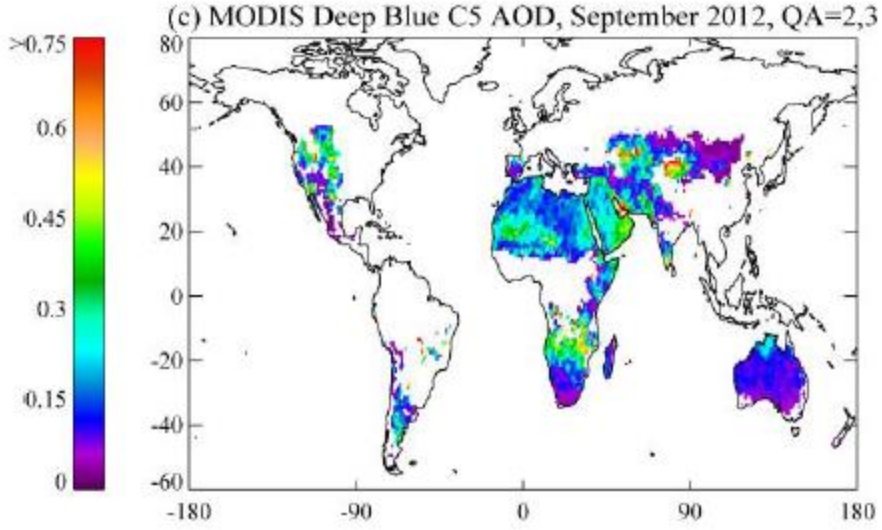
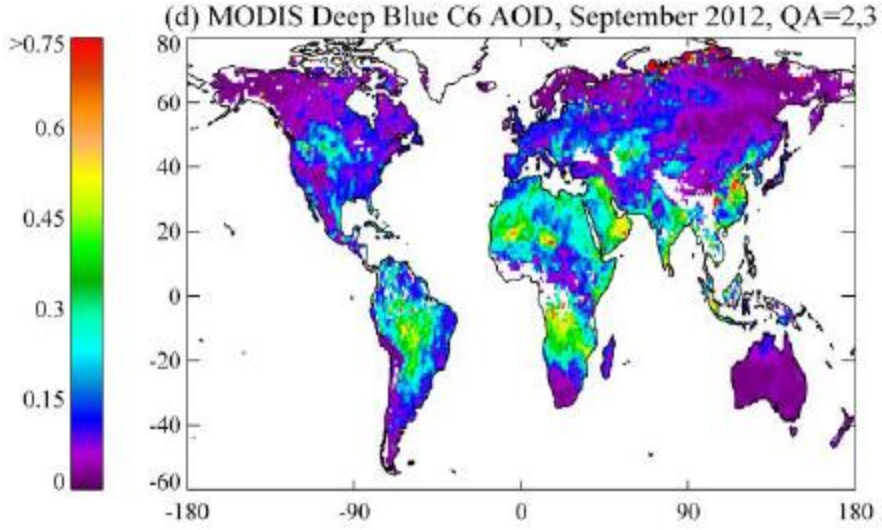
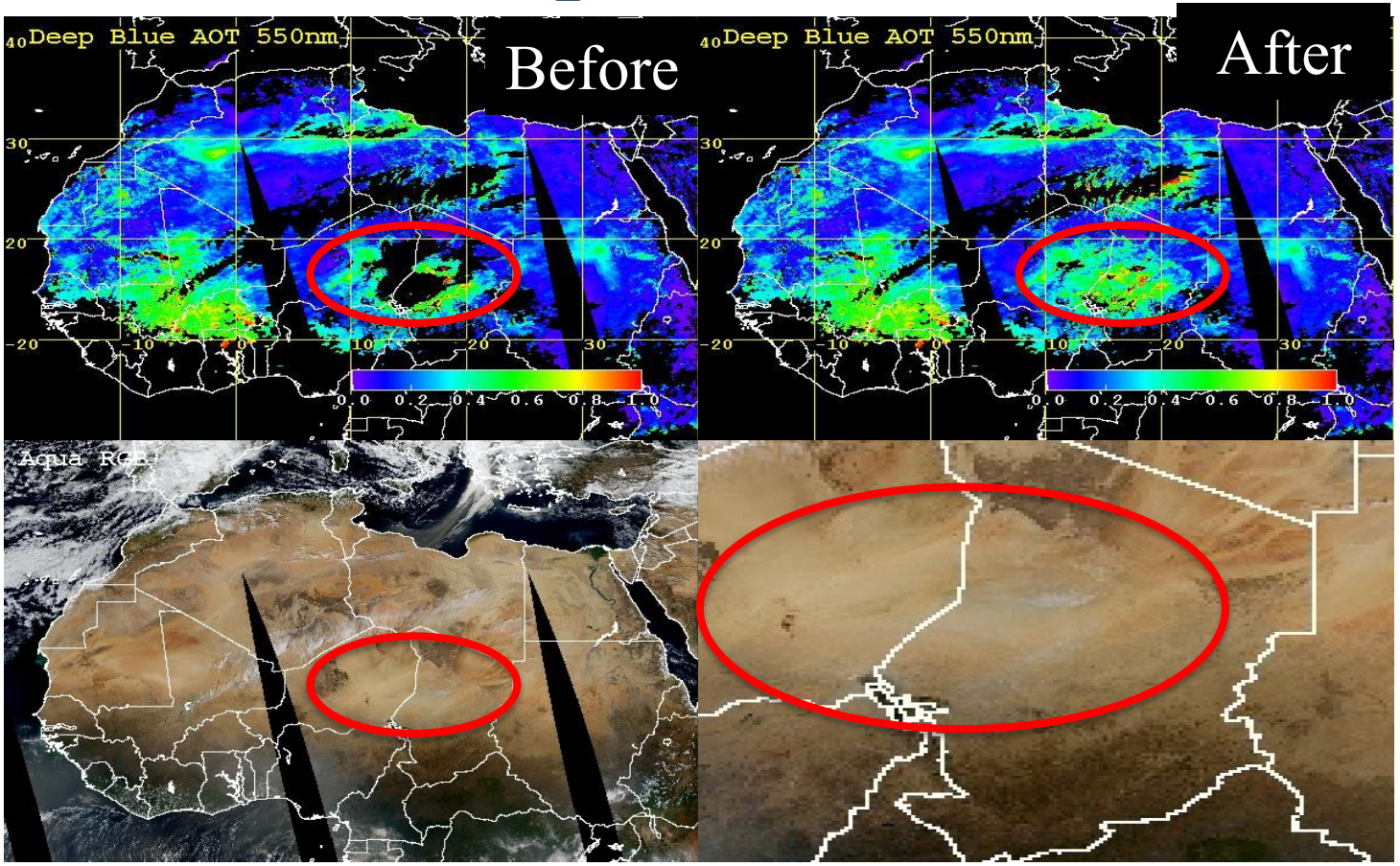






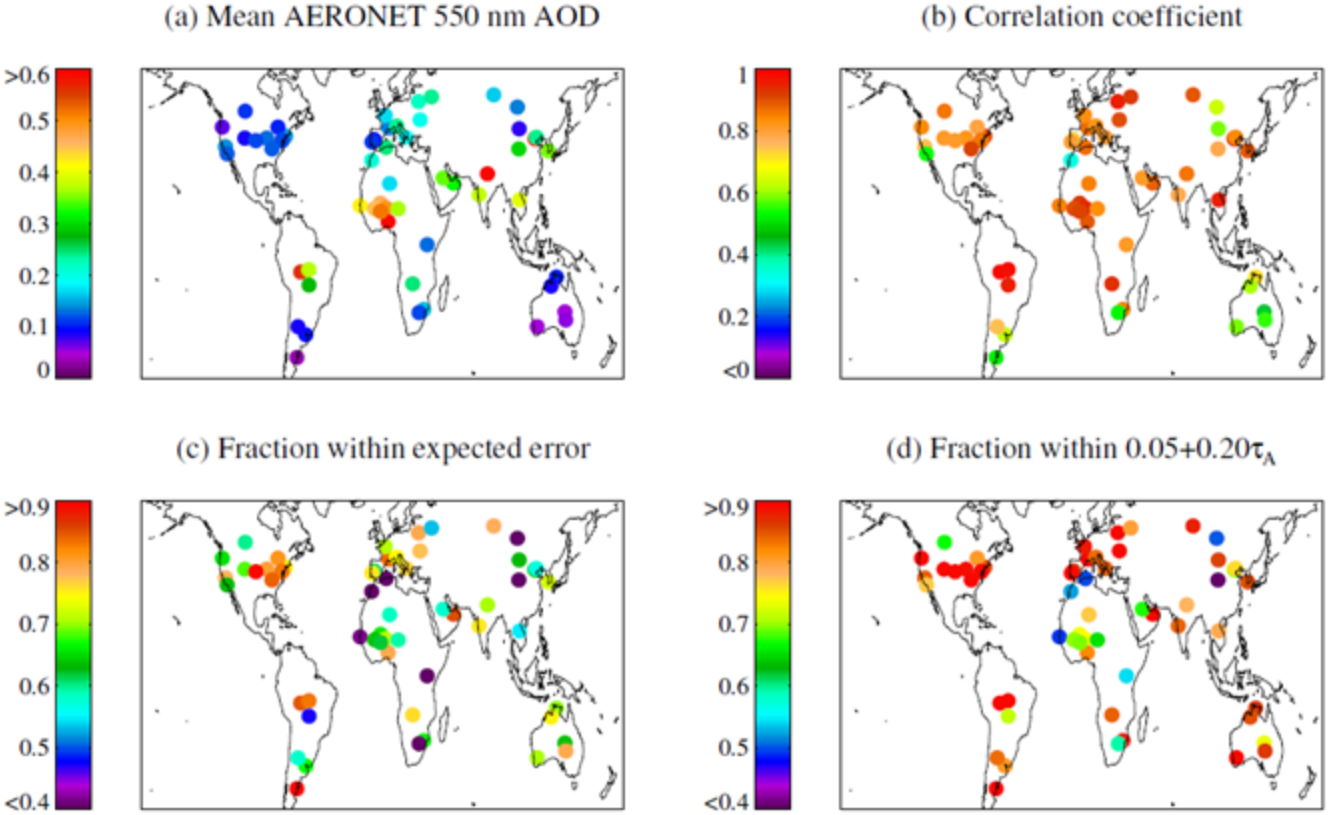


MODIS C6: improved cloud screening



- 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
  - Fix in C6 typically gives more high-AOD events
- Missed clouds also decreased through refinement of other cloud tests and QA flags

Deep Blue C6 AOD validation



- Validated MODIS Aqua data against AERONET at 60 sites
- One-sigma absolute uncertainty estimates provided for each retrieval within the C6 dataset
  - Typical absolute expected error (EE) ~0.03+20%
- Performance poorer for spatially heterogeneous sites, and complex aerosol mixtures
- For sites where both C5 and C6 perform retrievals, C6 data have:
  - Better data volume (factor of ~2) and correlation with AERONET (0.93 vs. 0.86)
  - Smaller errors (bias ~halved, RMS error decrease by ~30%)
- Sayer *et al.*, *J. Geophys. Res.* (2013)

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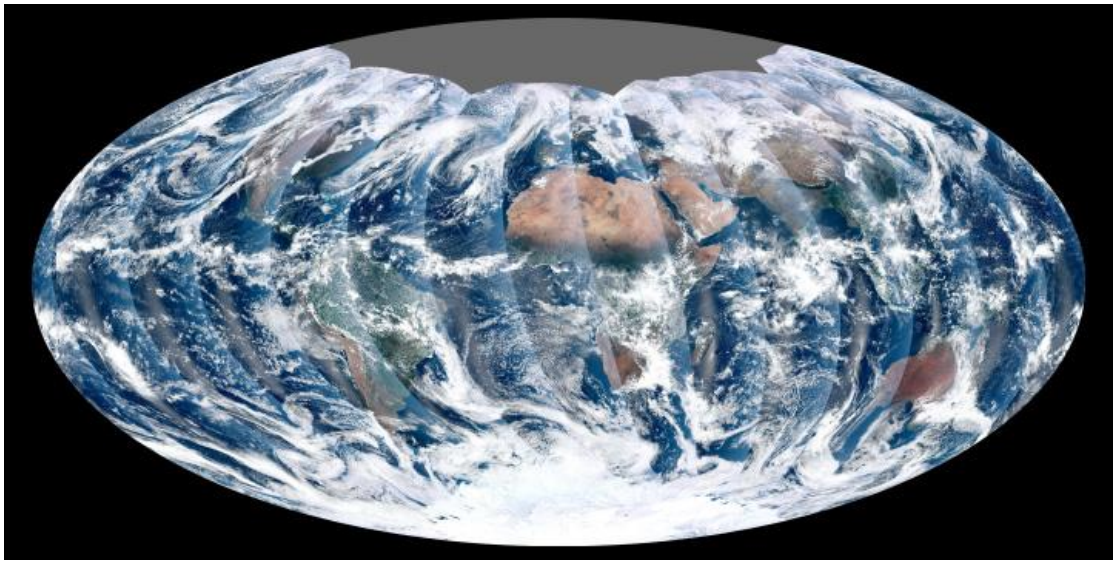
The (near) future: VIIRS



First VIIRS global image: 24th November 2011, courtesy of NASA NPP team

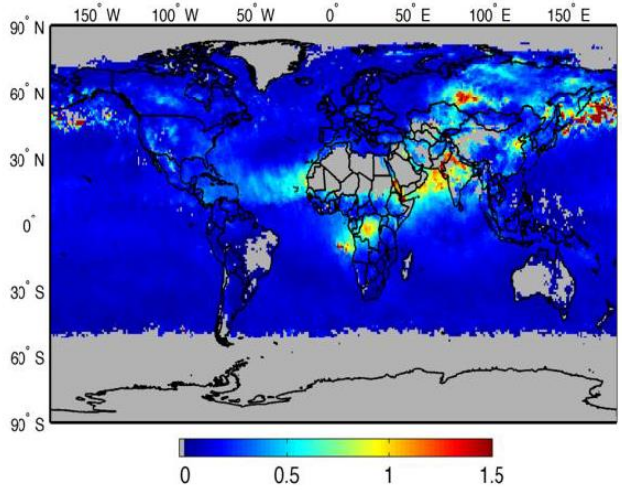
- Visible Infrared Imaging Radiometer Suite (VIIRS) launched on Suomi-NPP in late 2011
- Similar to MODIS (for aerosol purposes), but:
  - 3,000 km swath width (no gap between orbits)
  - 'Bowtie effect' (pixel size increase across swath) much smaller than in MODIS
  - 750 m pixel size
- Current available products are distributed by NOAA, for operational purposes
  - NASA has recently put out a call for proposals to 'continue the EOS heritage'

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.)

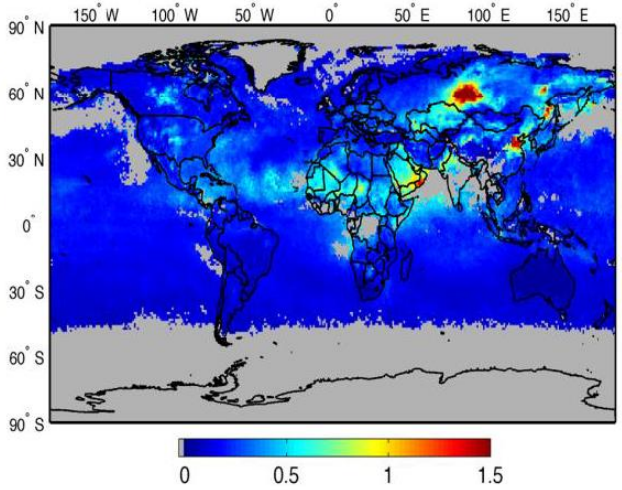
Figure 1. High level VIIRS Flight Unit 1 and Flight Unit 2 instrument characteristics with photo of FU1 being integrated onto the NPP spacecraft at Ball Aerospace. Photo courtesy Ball Aerospace.

VIIRS first steps

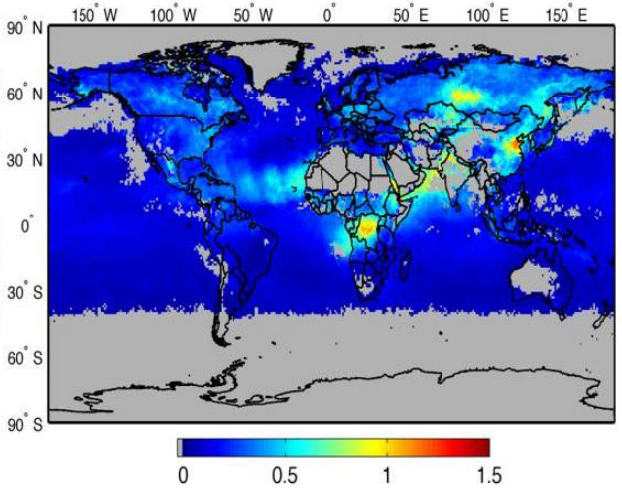
MODIS Aqua (C5), Dark Target/ocean



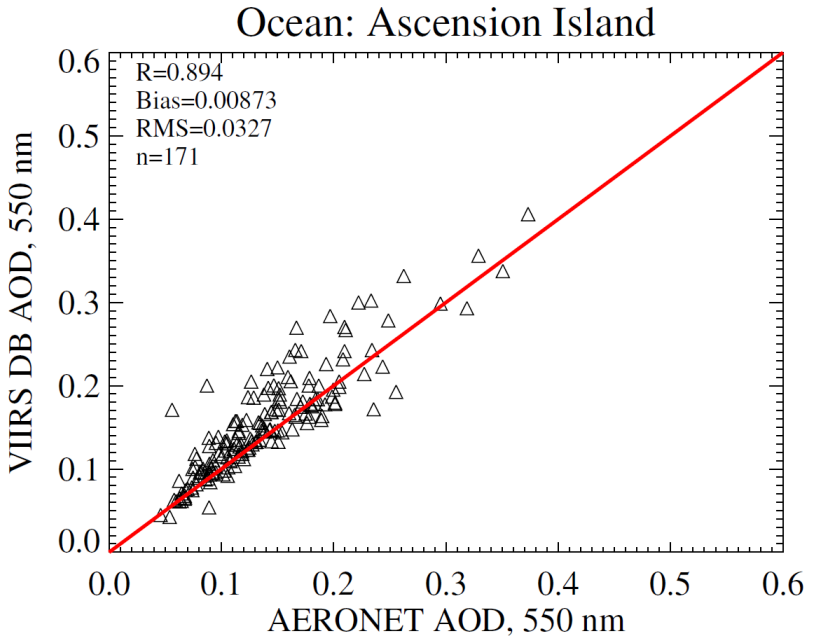
VIIRS, Deep Blue/our ocean



VIIRS, NOAA algorithms



- Developing Deep Blue and an ocean algorithm for VIIRS
  - Examples (above) shown for July 2012
  - Preliminary, but looks reasonable
  - First validation for Ascension Island (right) is promising



Summary

- New (or imminent) 'Deep Blue' datasets
  - MODIS Collection 6
    - Uncertainty ~0.03+20% over land
    - See http://modis-atmos.gsfc.nasa.gov
  - SeaWiFS Version 4
    - Uncertainty ~0.05+20% over land, ~0.03+15% over ocean
    - See http://disc.gsfc.nasa.gov
  - VIIRS algorithm in development
- Please use the data, ask questions and give comments, and tell us when you find something exciting/odd
  - We are happy to help you read the data, and use it appropriately
  - It's nice to hear from users ☺

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