Recent progress in the NASA 'e-Deep Blue' algorithm for remote sensing of aerosol optical properties

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With acknowledgements to many others: MODIS Characterization Support Team, AERONET, MODIS Dark Target group, Ocean Biology Processing Group

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Overview

- Deep Blue basics
- SeaWiFS, 1997-2010
- MODIS Terra/Aqua, 2000/2002+
  - ‘Merged’ Deep Blue/Dark Target land & ocean dataset
- VIIRS, 2011+

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

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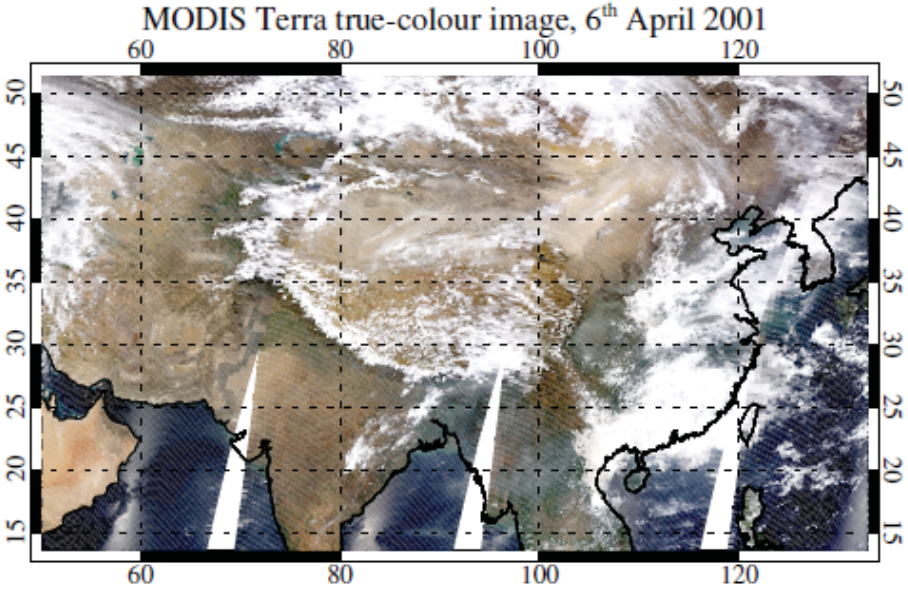
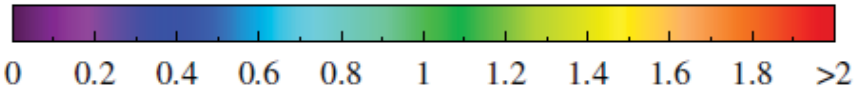
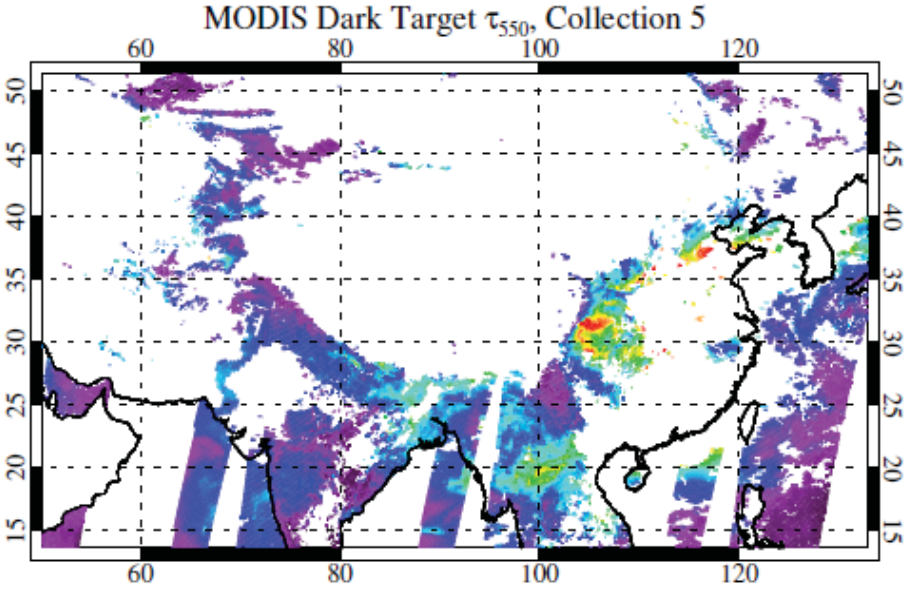
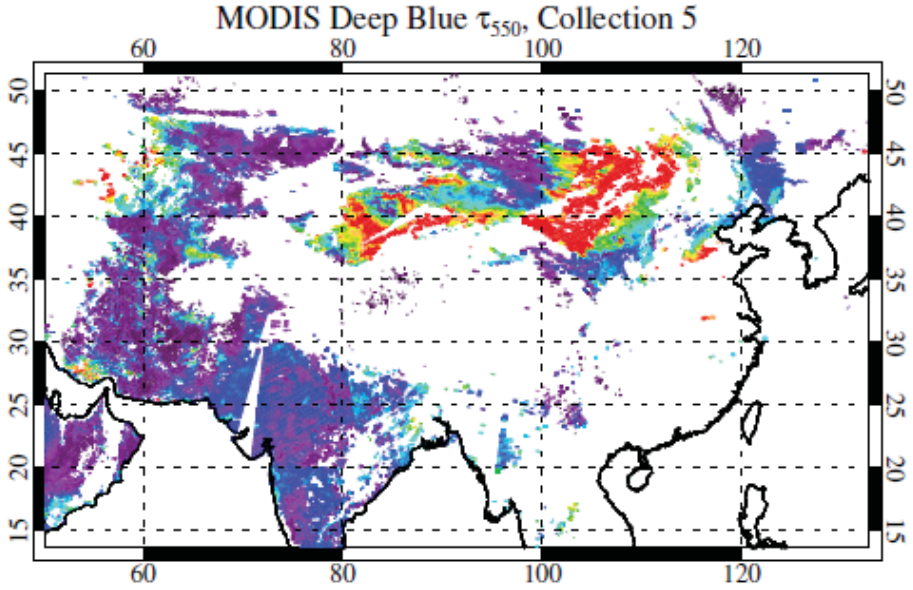
Deep Blue: original motivation



- MODIS 'Dark Target' AOD algorithm does not retrieve over bright surfaces
- These are important aerosol source regions
- Deep Blue initially filled in some gaps
  - Now, it does more than that: extended/enhanced **e-Deep Blue**







Deep Blue: key concepts

- Often, better surface/aerosol contrast in the violet/blue (~400-490 nm) than longer wavelengths
  - Prescribe surface reflectance
  - Retrieve AOD independently at several wavelengths
- **Advantages:**
  - Avoids regional/seasonal artefacts arising from e.g. global surface models
  - Applicable to many sensors
- **Disadvantages:**
  - Departures from expected surface cover can lead to artefacts in instantaneous data
  - Cannot directly back out e.g. aerosol effective radius or mass

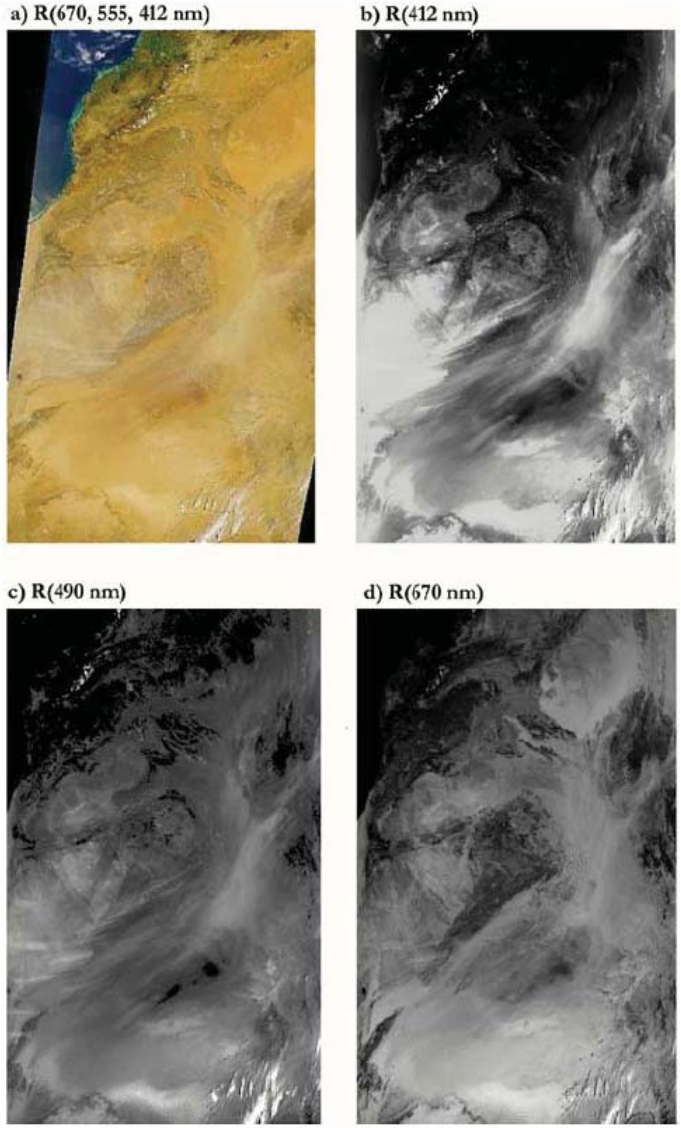
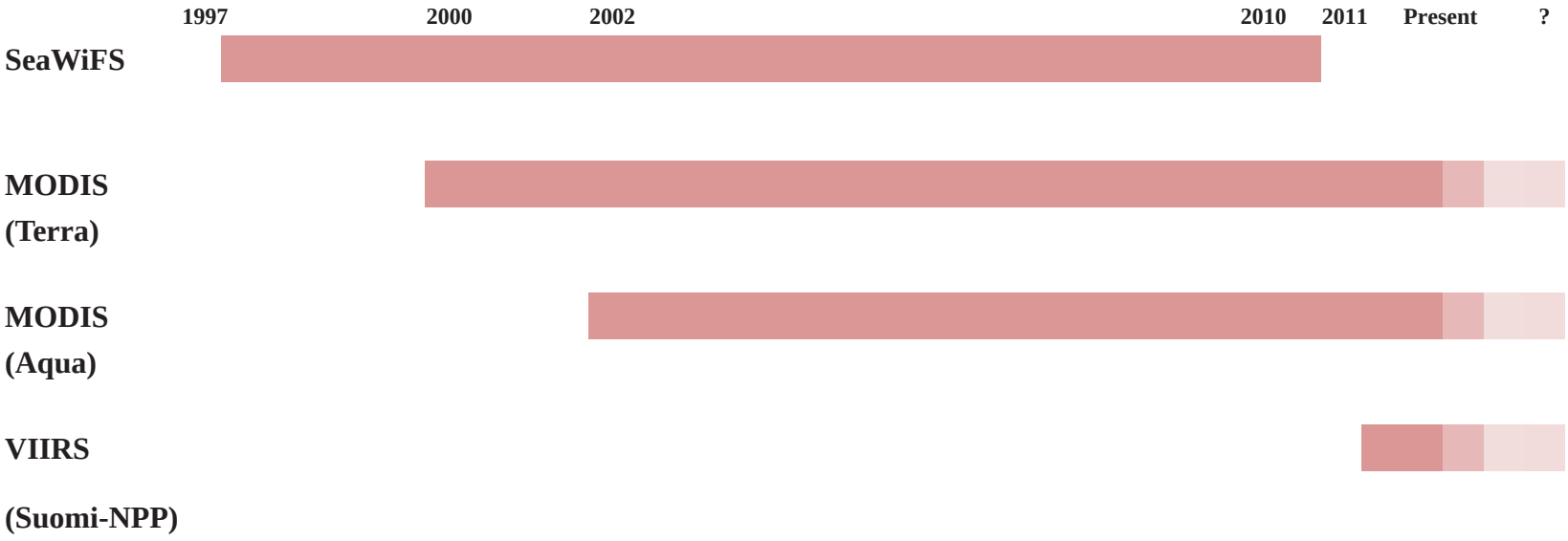


Fig. 2. SeaWiFS images over northeast Africa on February 10, 2001. The dynamical ranges of the grayscale used in (b)–(d) are individually adjusted to optimize the appearance of atmospheric features against the background surfaces.

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

Sensors Deep Blue has been applied to



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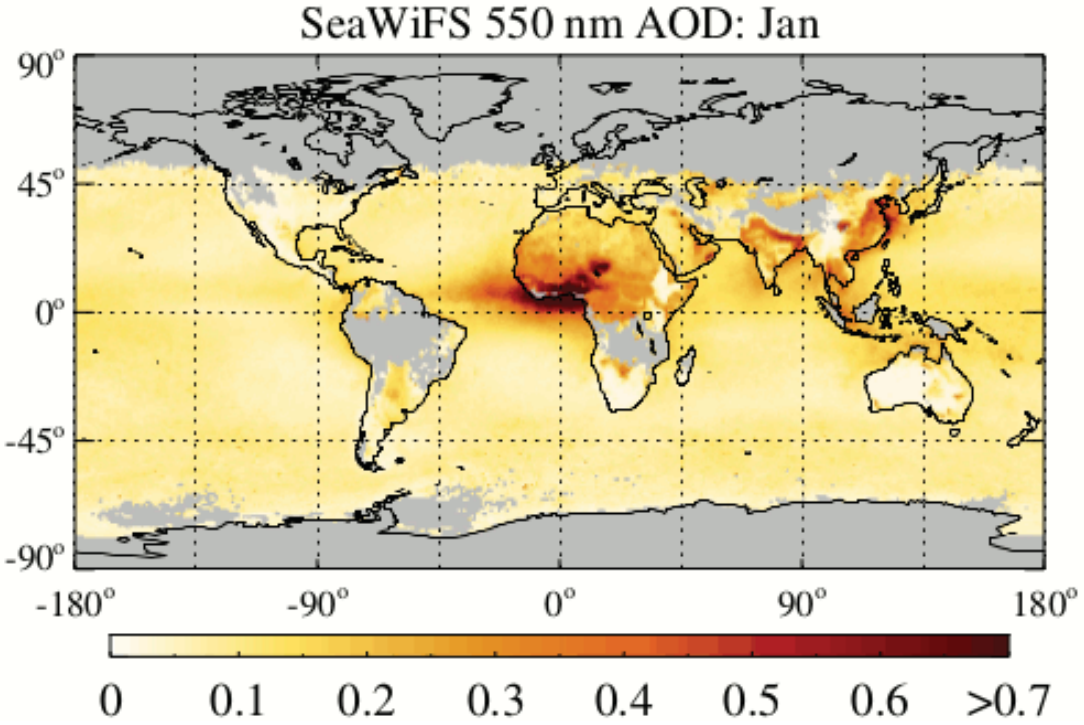
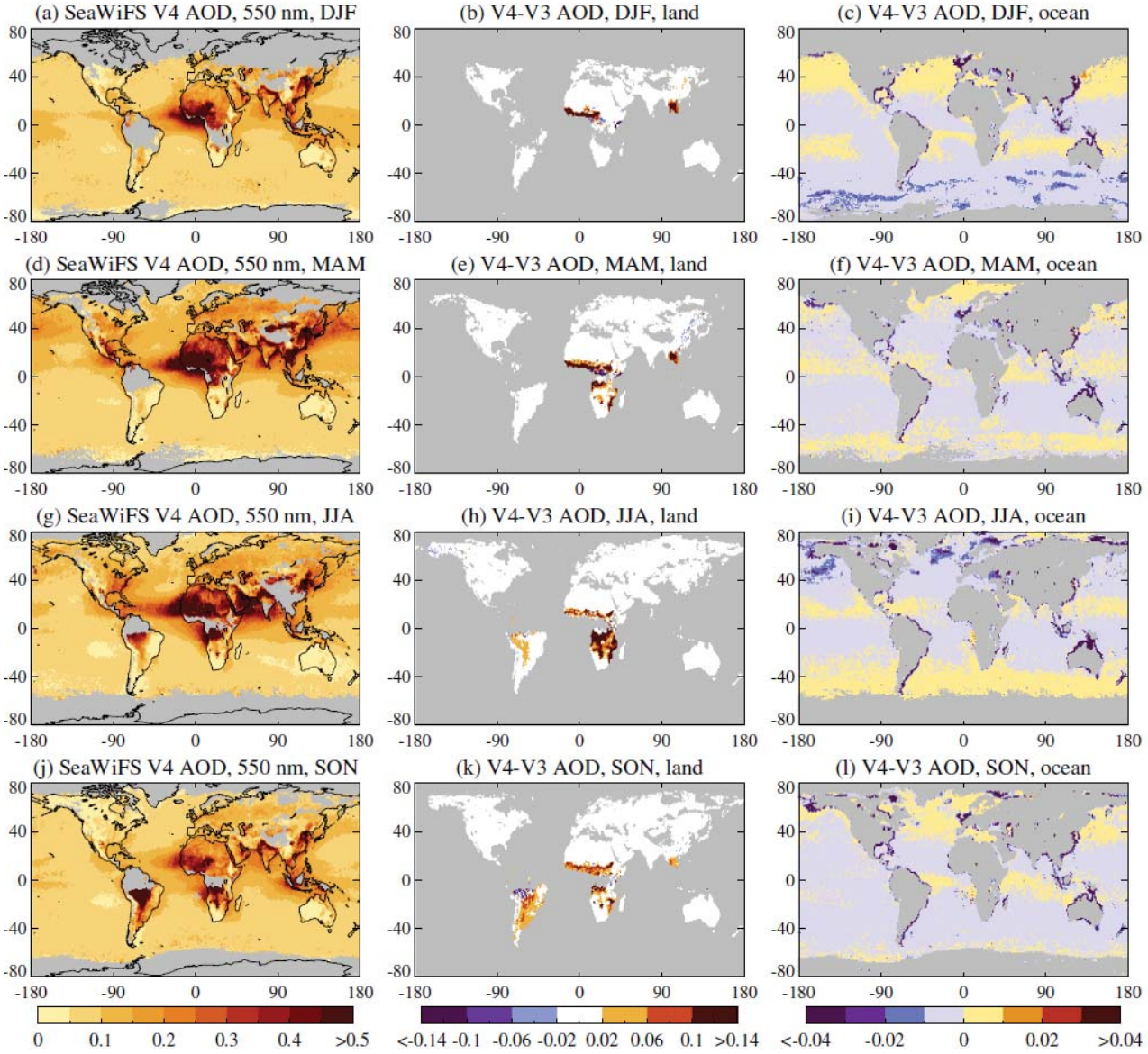
SeaWiFS version 4



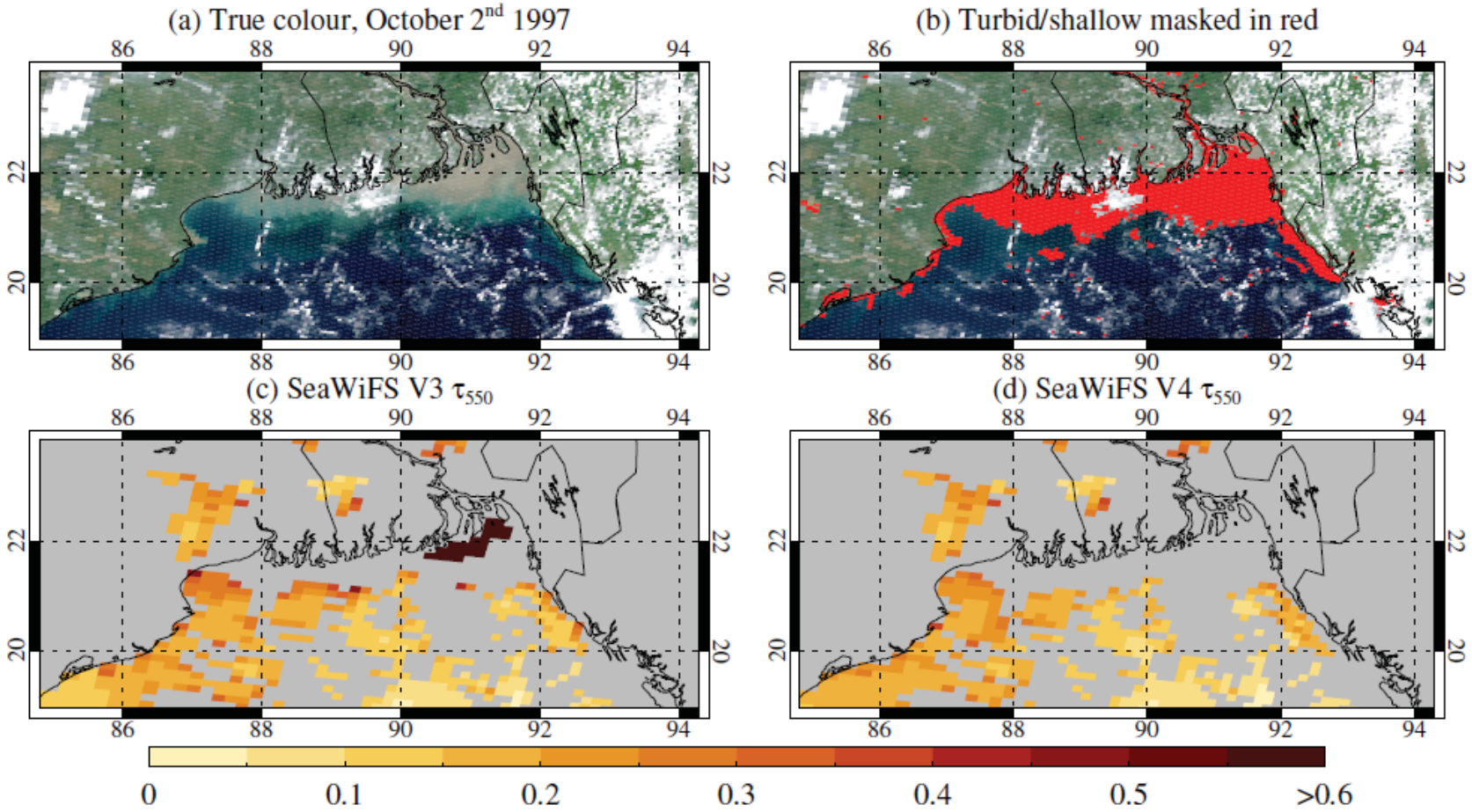
- Minor changes from Version 3 dataset
  - Land: some regional surface/aerosol model changes
  - Water: improved shallow/turbid pixel identification
- 550 nm AOD uncertainty:
  - Land: ~0.05+20%
  - Ocean: ~0.03+15%

Aspect	Comments
Time series	SeaStar satellite (1997-2010, a few gaps)
Coverage	Daytime cloud-free snow-free land Daytime cloud-free ice-free non-turbid water
Data products	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 13.5 x 13.5 km resolution ~1,500 km swath
Level 3	0.5° and 1°; daily and monthly resolution
Data access	Distributed by GES DISC Level 3 visualisation through Giovanni

SeaWiFS V4-V3 differences

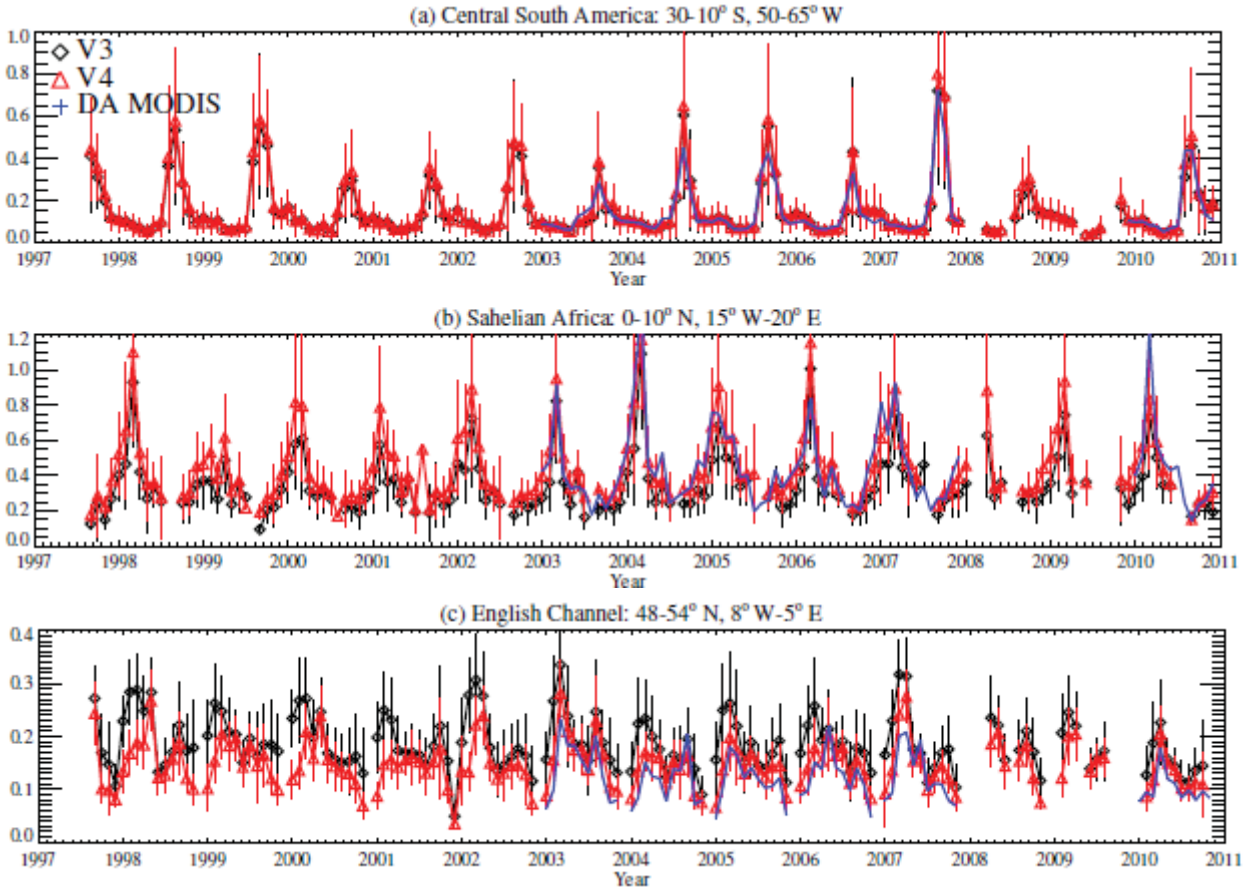


SeaWiFS V4-V3 differences



- Improved shallow/turbid water detection removes artefacts, mainly in coastal areas
  - Example shown for Bay of Bengal
  - Note V3 did manage to identify and remove some turbid water!
- Features are semi-persistent regionally, but not always on a per-pixel basis

SeaWiFS V4-V3 differences



South America Amazon

Sahel

English Channel (La Manche)

- Changes make physical sense and improve time series consistency with Data Assimilation (DA) grade MODIS product from NRL
- Comparison against AERONET modestly improved

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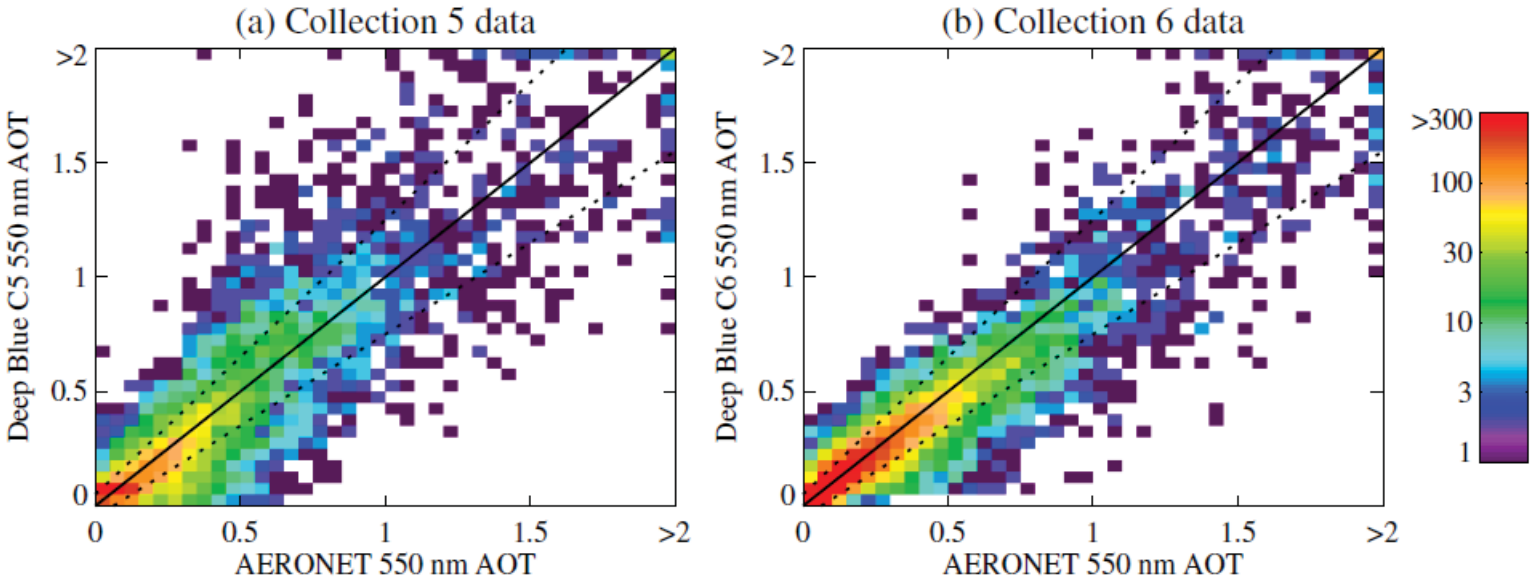
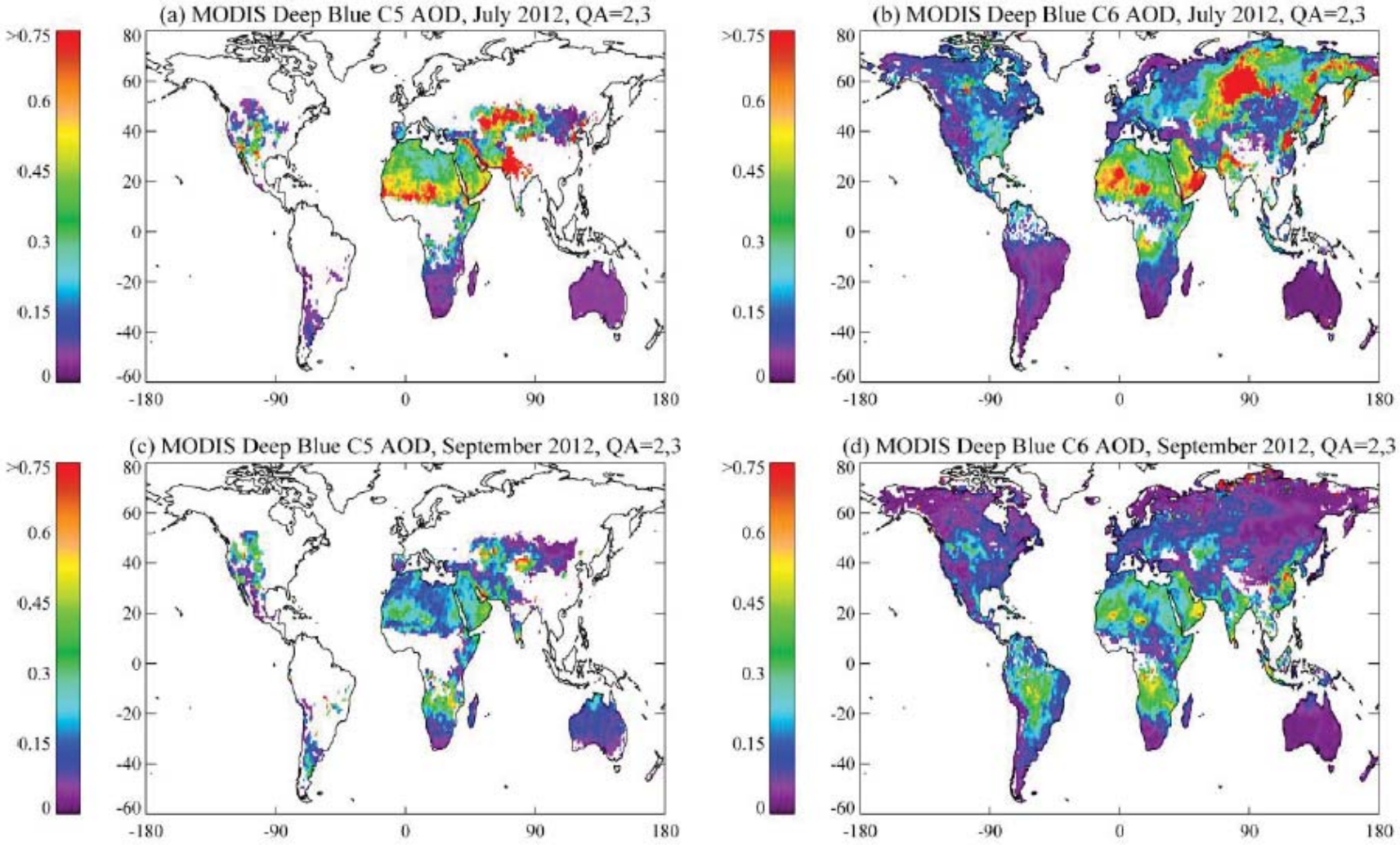
MODIS C6: main developments

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



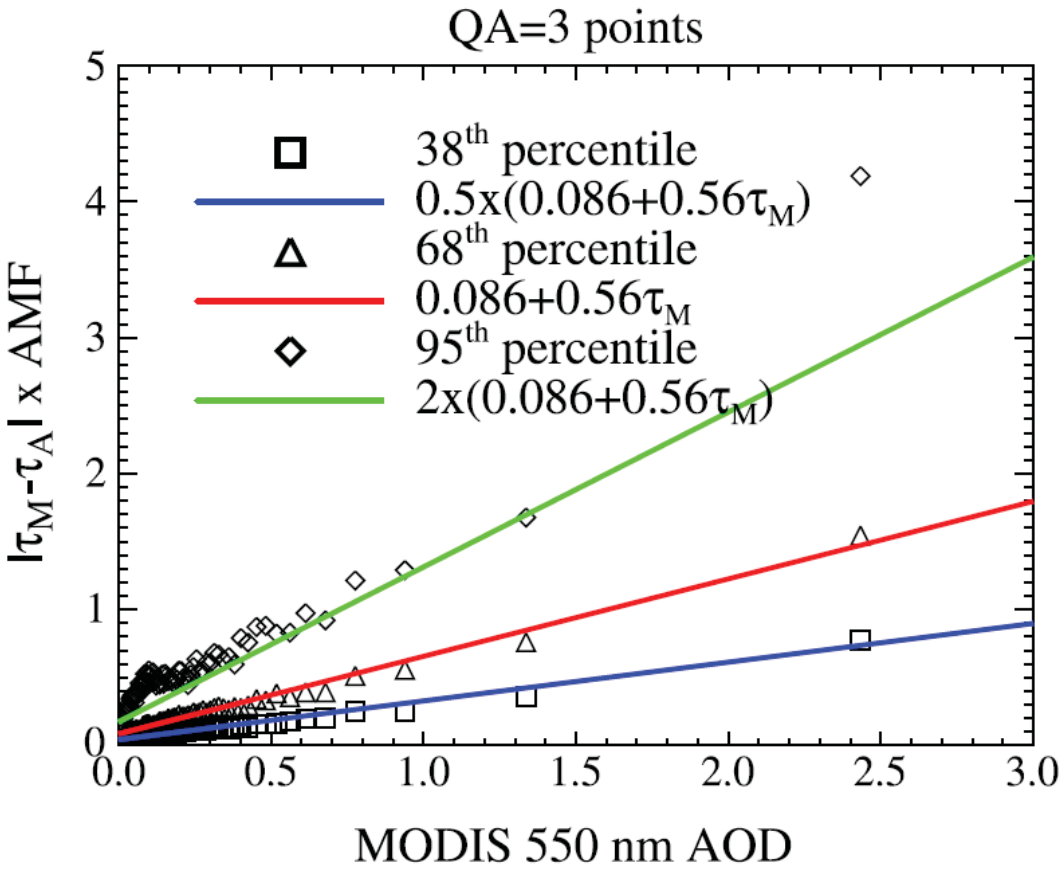
- Collection 6 refinements to Deep Blue:
  1. Extended coverage to include vegetated surfaces as well as bright land
  2. Improved surface reflectance models
  3. Improved aerosol optical models
  4. Improved cloud screening
  5. Simplified quality assurance (QA) flags and QA-filtered AOD SDS included
  6. Radiometric calibration improvements
  7. AOD uncertainty estimates for every retrieval

MODIS C6: extended spatial coverage

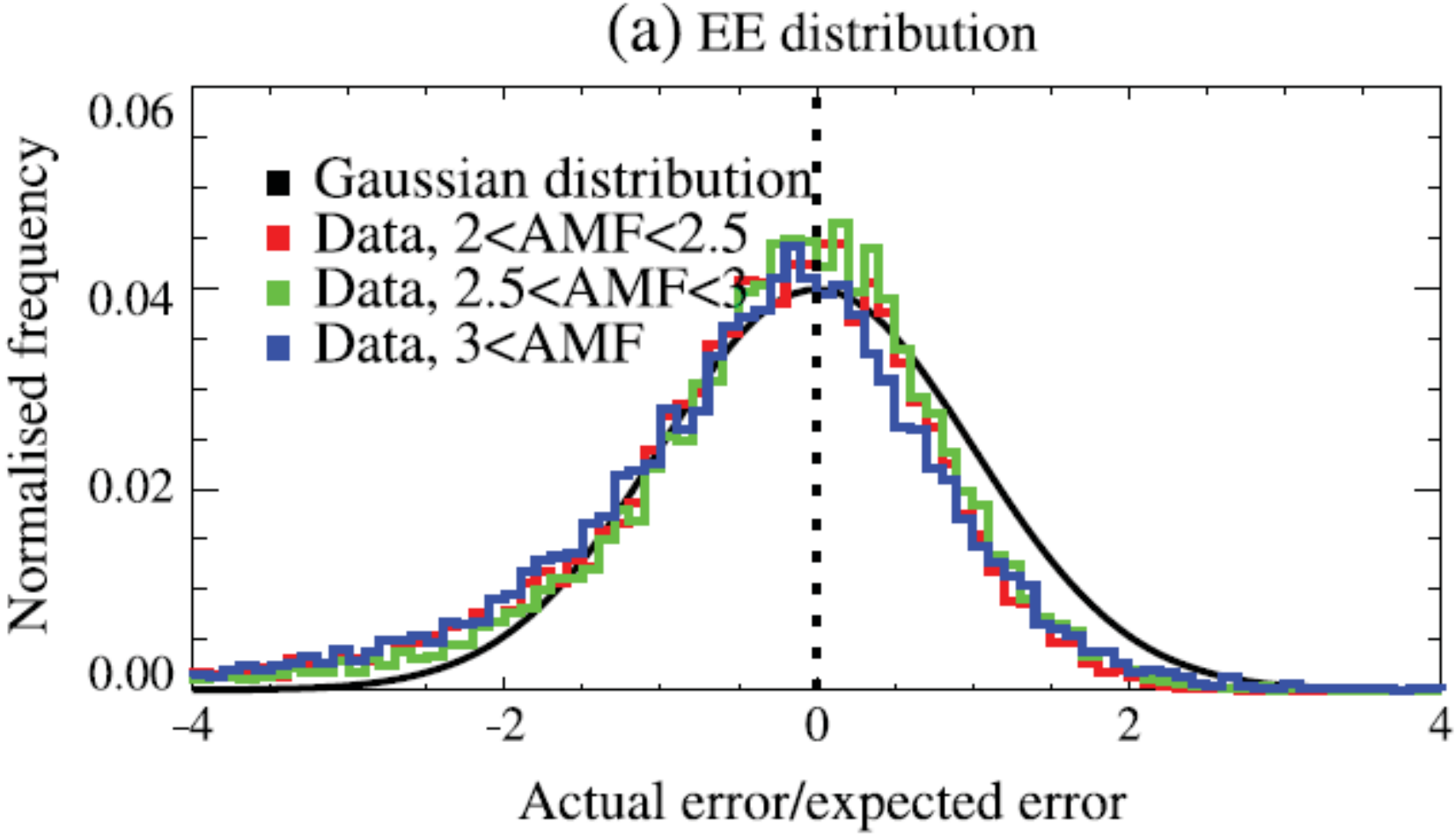


Retrieval-level uncertainty estimates

- Provided within level 2 MOD/MYD04 files
- Depend on AOD, QA flag, and geometric air mass factor (AMF)
- Prognostic (defined relative to retrieved AOD, not AERONET AOD)
- For Aqua, QA=3:
  - Expected error +/- (0.086+0.56*AOD)/AMF
  - Median AMF=2.8, leads to typical expected error +/- (0.03+0.2*AOD)
- Similar for QA=2, larger for QA=1

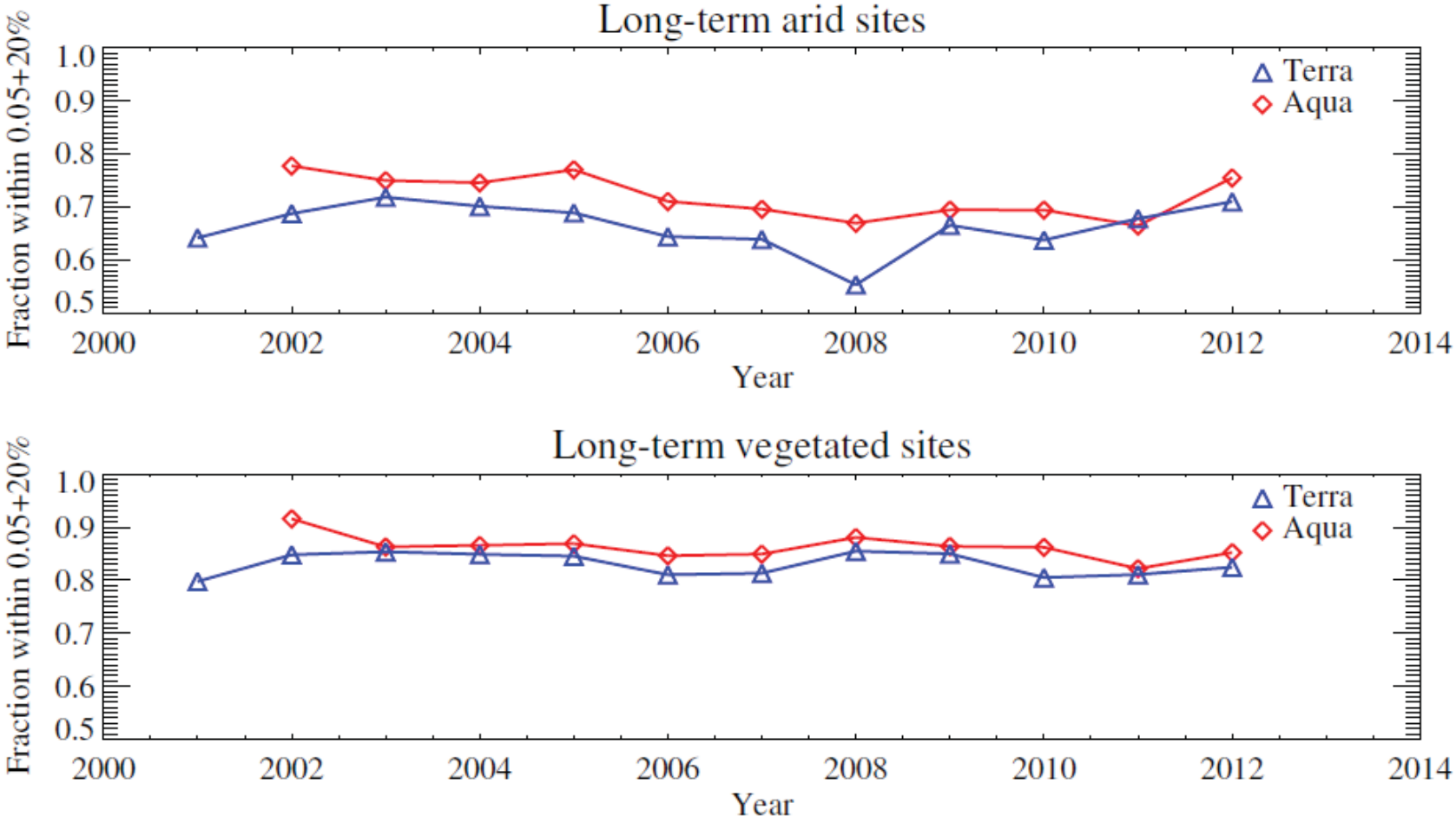


Error histograms are nearly* zero-centered Gaussian



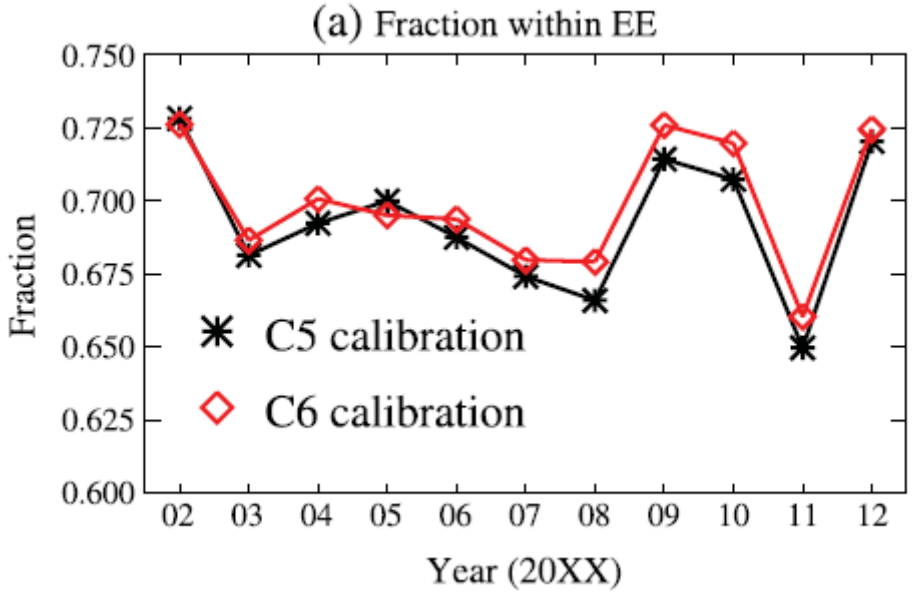
*not perfectly – scope for future refinement

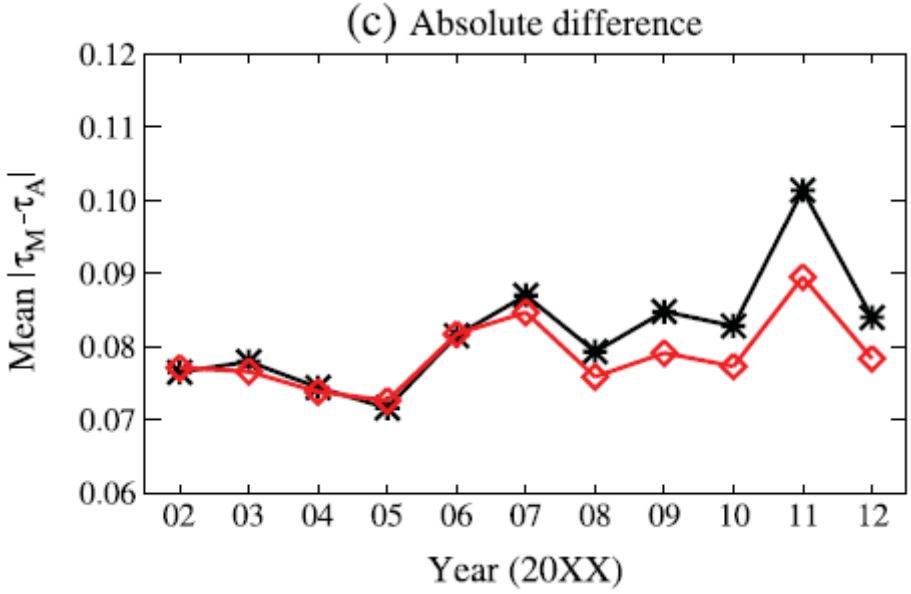
What about Terra?

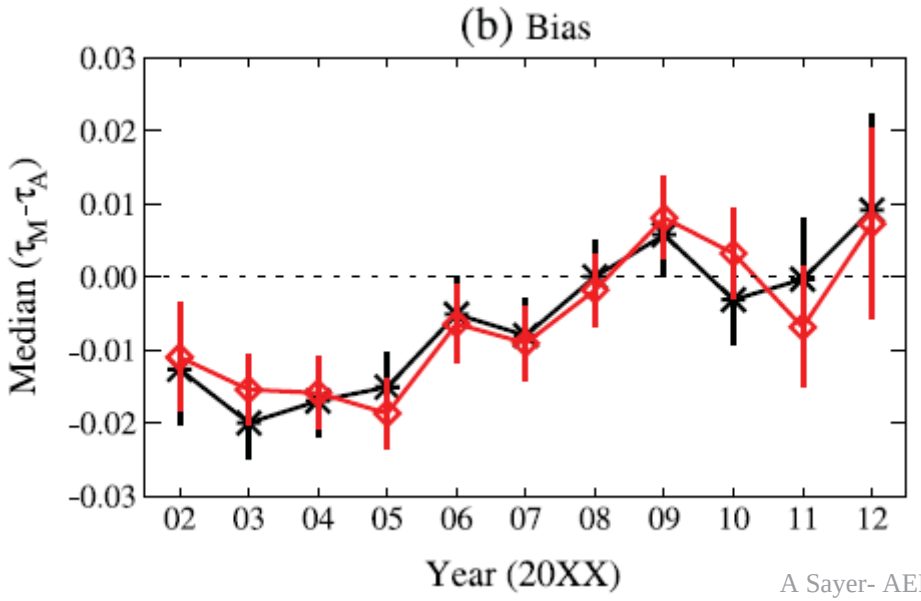


- Reprocessing handled by MODAPS, should be soon (this year)
  - In-house testing suggests Deep Blue Terra performance appears similar to, but slightly poorer than, Aqua
  - Both show good temporal stability

Importance of calibration stability







- Use C6 algorithm with C5 and C6 level 1 data
  - Use of C6 level 1 data results in better agreement with AERONET
  - Both versions have 0.01-0.02 change in bias over the mission; not sure if related to calibration or a coincidence of sampling
- This is for Aqua – Terra calibration improvements are larger

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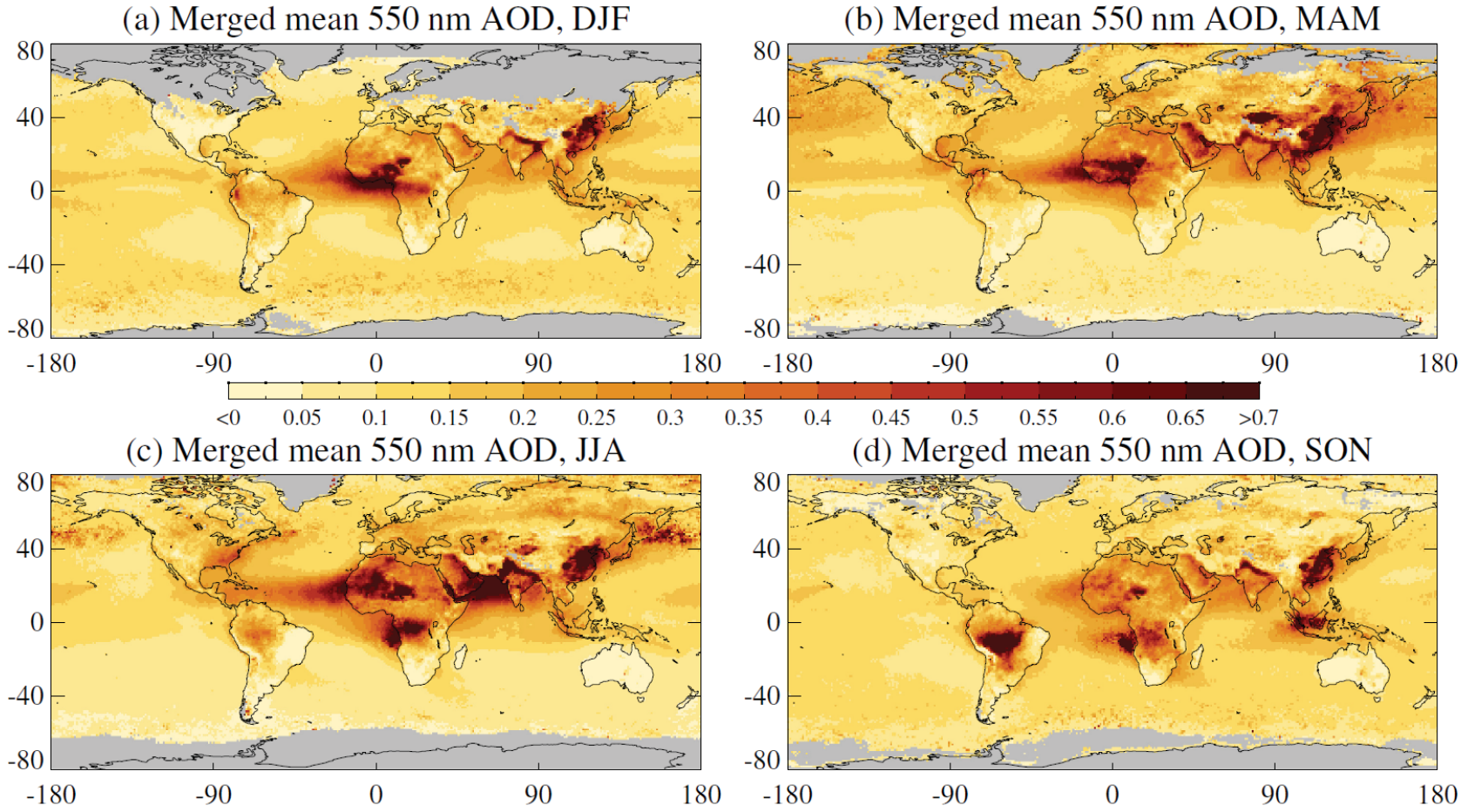
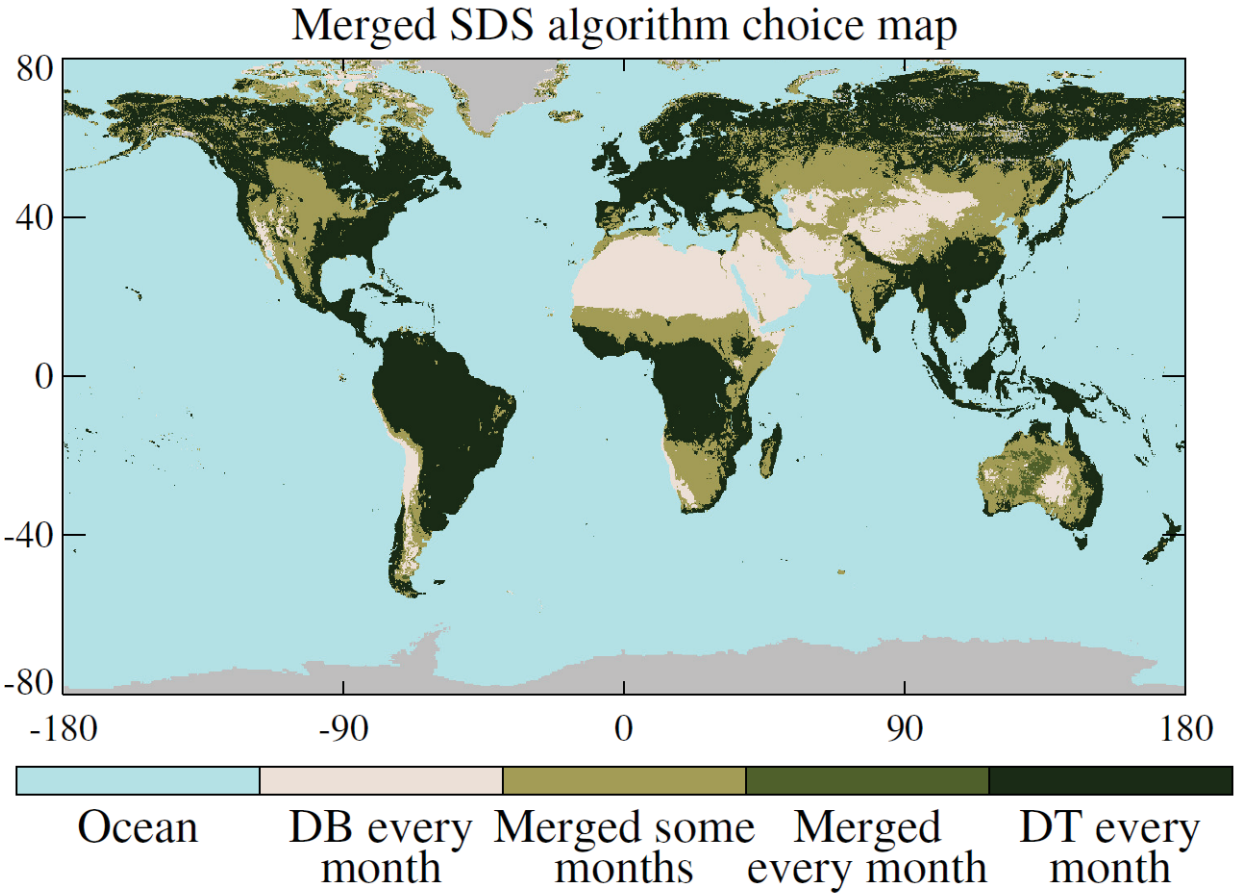
What is the ‘merged’ MODIS dataset?



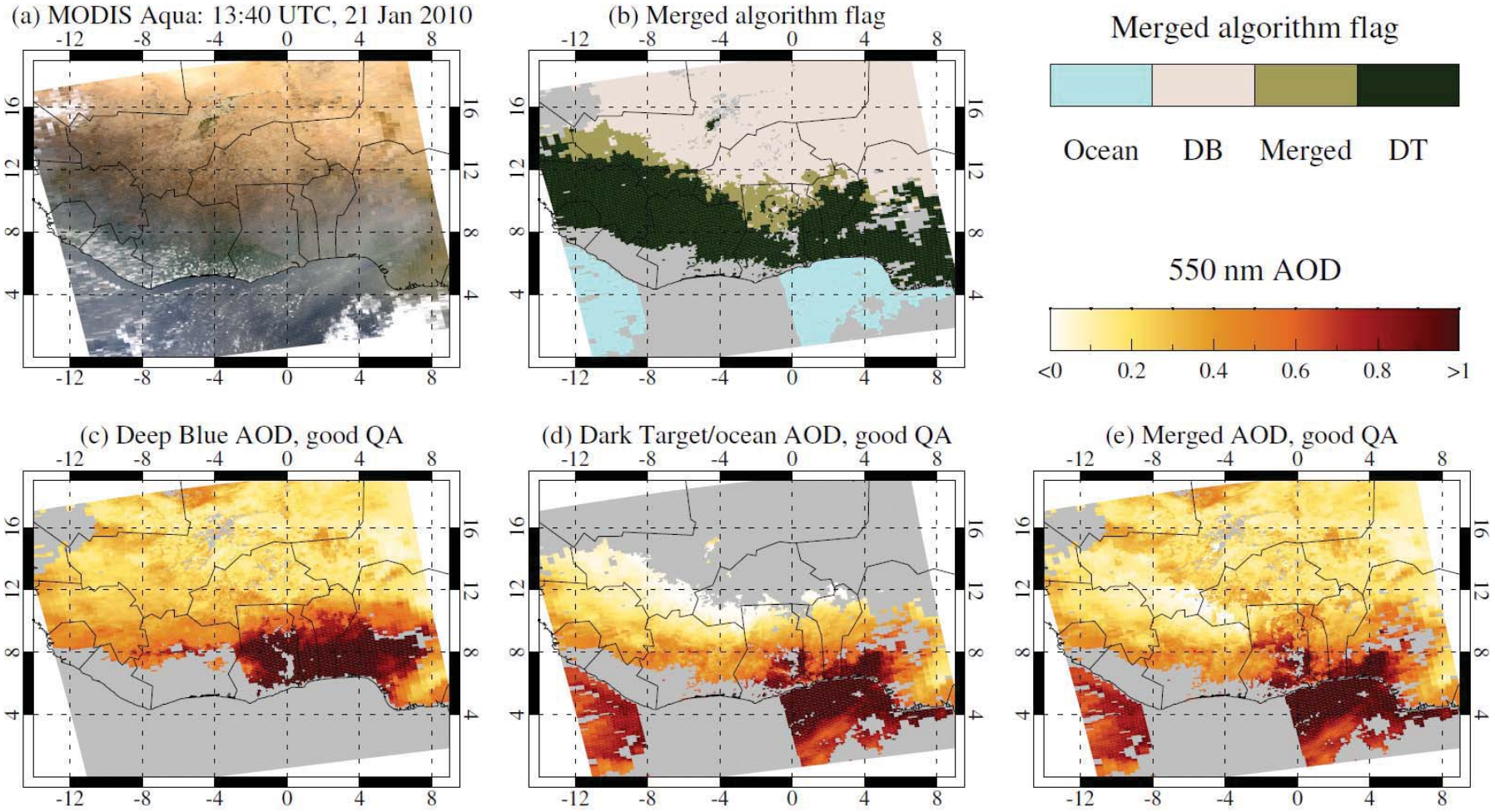
- Combination of Deep Blue and Dark Target group land/ocean algorithms to provide a more spatially-complete dataset
- Seasonal mean of daily mean AOD from the ‘merged’ SDS, 2006-2008

How is merging done?

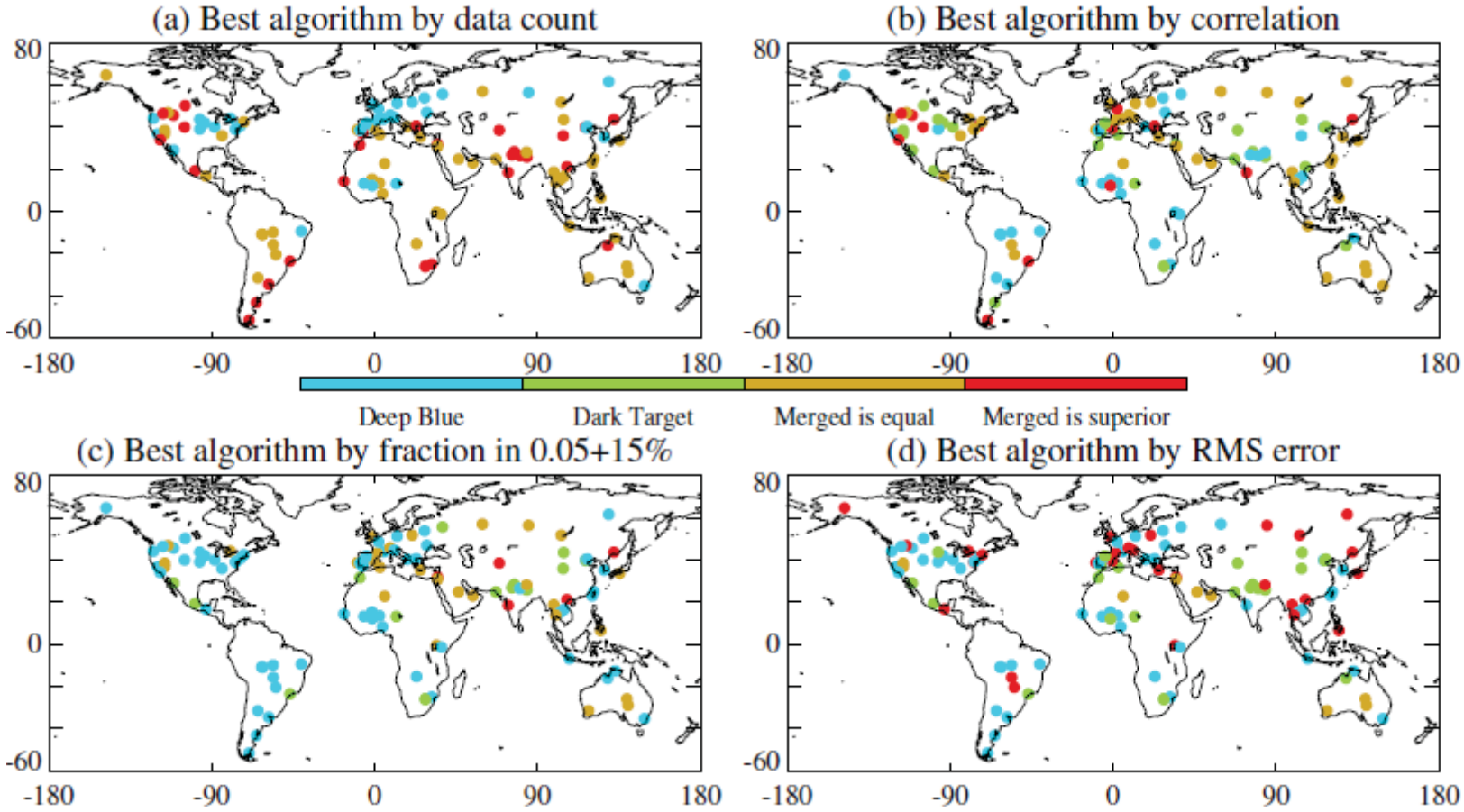
- This is a first attempt
- 12 monthly climatologies of NDVI used to assign retrievals over land:
  - NDVI < 0.2: Deep Blue
  - NDVI > 0.3: Dark Target
  - Otherwise: pick the algorithm with higher QA value, else average if both QA=3
- Ocean algorithm used over water
- Only contains retrievals passing QA checks



What does merging look like?



So… what should I use?



- Shown ‘Best algorithm’ vs. AERONET by different metrics
- Usage recommendations depend on your application and comfort level with the data
- No single algorithm is better than the others by all metrics, or for all regions/seasons
- Paper in review at JGR on this topic (and more general Deep Blue/Dark Targer comparison)

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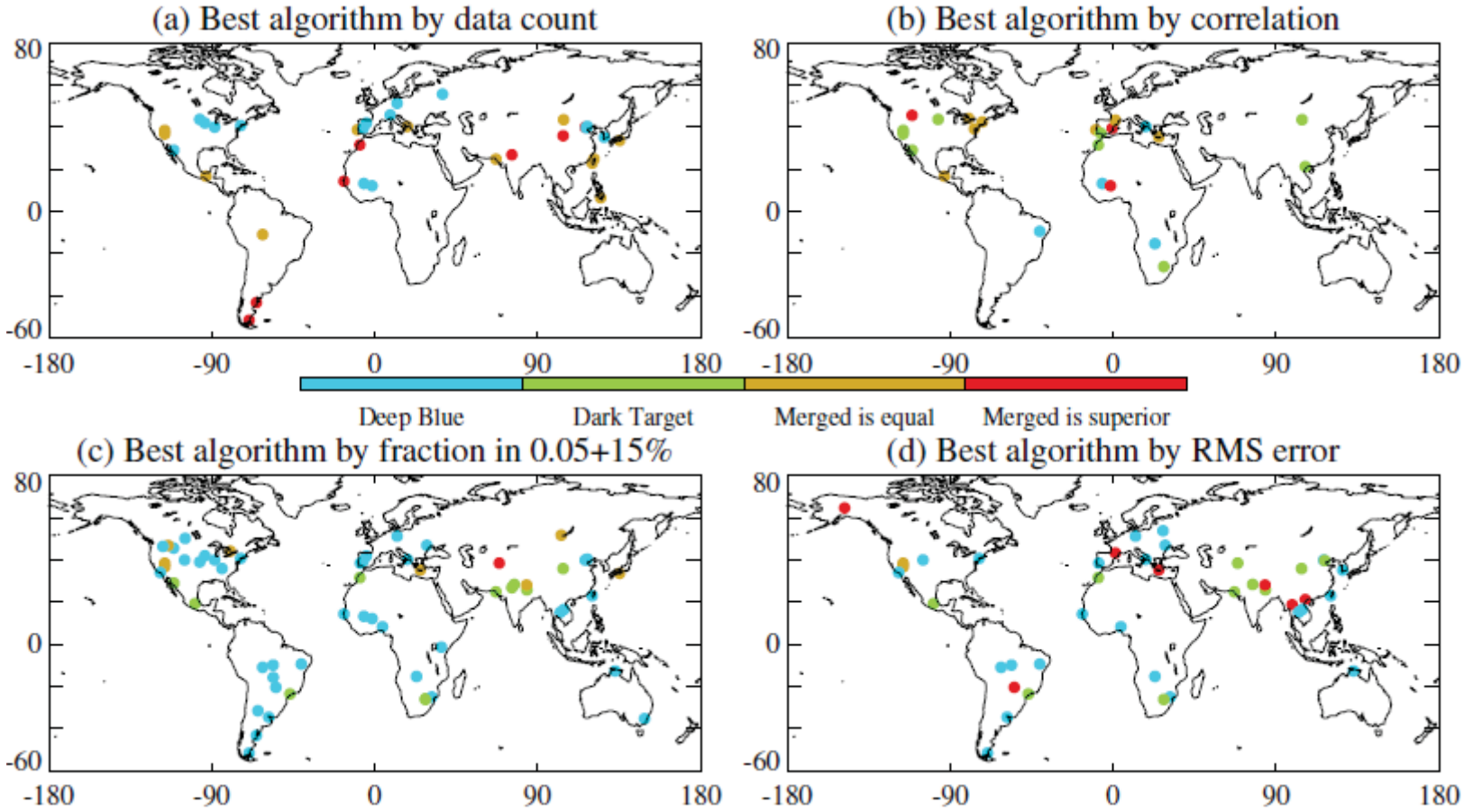

- Shown ‘Best algorithm’ vs. AERONET by different metrics, where differences are large
- Usage recommendations depend on your application and comfort level with the data
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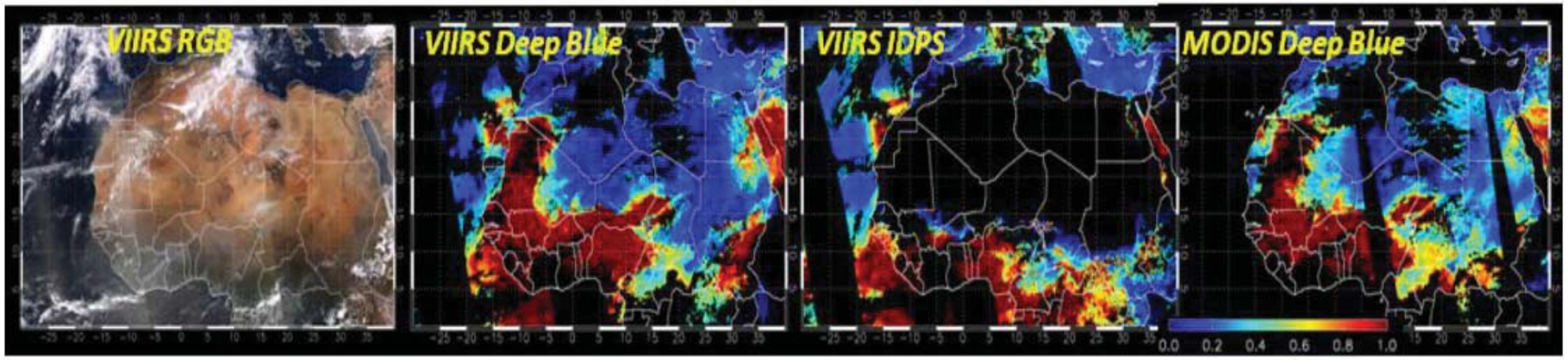
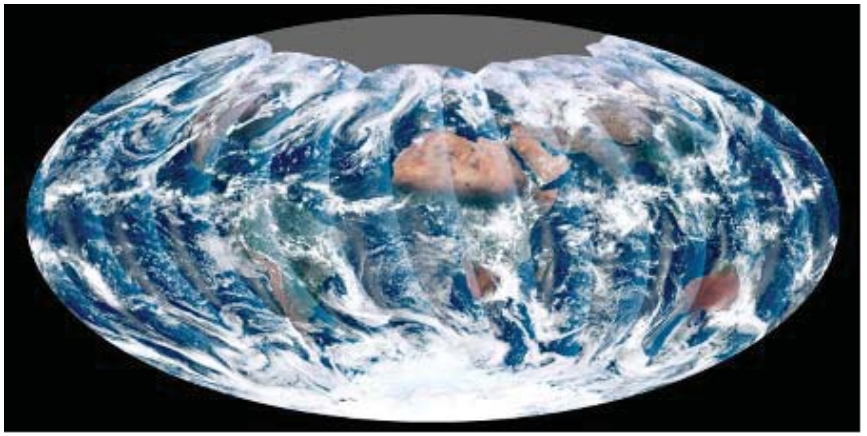
VIIRS – coming soon

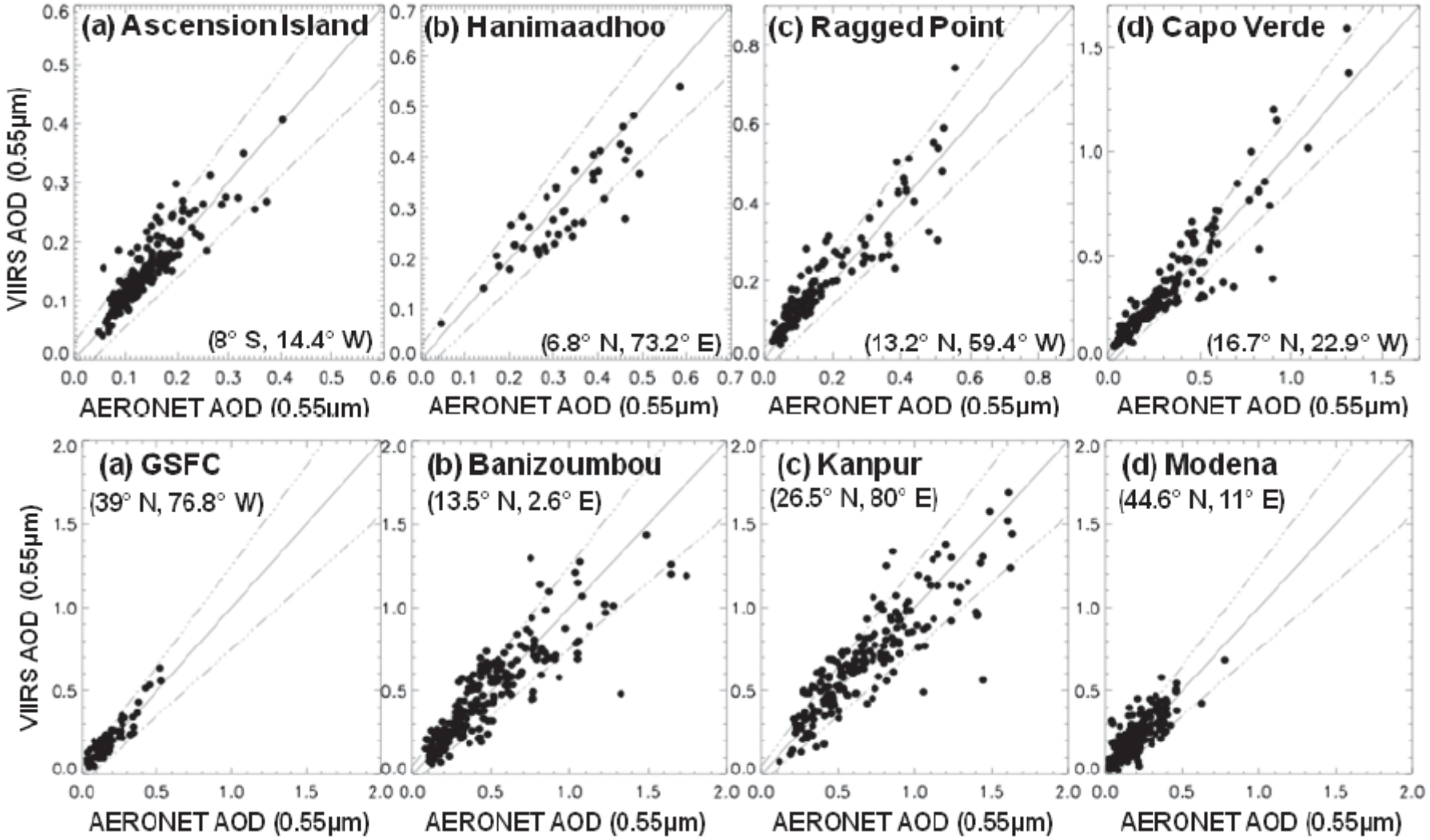


- Visible Infrared Imaging Radiometer Suite (VIIRS), launched on Suomi-NPP at end of 2011
  - Similar to MODIS (for our purposes)
- e-Deep Blue over land, improved SeaWiFS algorithm over water
  - Both algorithms enhanced over previous applications
- Match NOAA product spatial resolution of ~6x6 km



VIIRS daily coverage – note overlap between orbits (no gaps)

Preliminary VIIRS validation



- Looked at a selection of land and ocean AERONET sites
  - Performance already approaching that of MODIS/SeaWiFS
  - Further refinements before release

Summary

- Deep Blue datasets:
  - SeaWiFS version 4 – available
    - http://disc.gsfc.nasa.gov
  - MODIS Collection 6
    - Aqua: level 2, 3 available now
    - Terra: level 2, 3 probably by around end of year
    - http://modis-atmos.gsfc.nasa.gov/
    - Expanded spatial coverage, AOD uncertainty estimates, includes dataset already filtered for QA
  - VIIRS – funded, in development
- Please use the data, ask questions, tell us when you find something exciting (or troubling)
  - We are happy to help you read the data, and use it appropriately
  - It's nice to hear from users ☺