NASA 'e-Deep Blue' aerosol update: MODIS Collection 6 and VIIRS
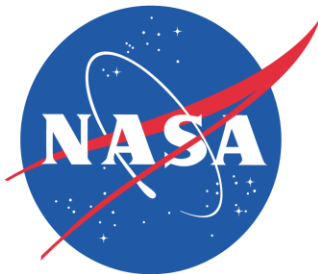
Andrew M. Sayer, N. Christina Hsu (PI), Corey Bettenhausen, Nick Carletta,
Jaehwa Lee, Colin Seftor, Jeremy Warner

*Past team members: Ritesh Gautam, Jingfeng Huang,
Myeong-Jae Jeong, Becky Limbacher, Clare Salustro*

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Overview

- Deep Blue basics
- 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/
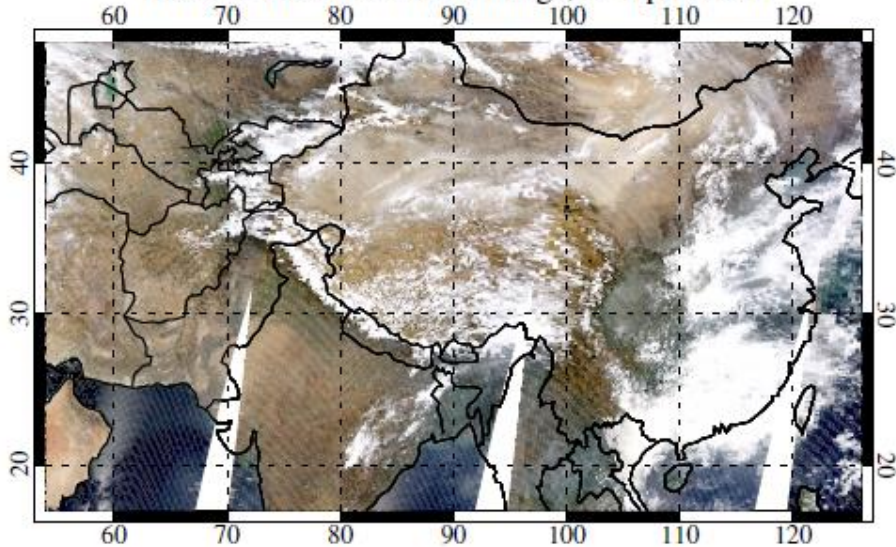
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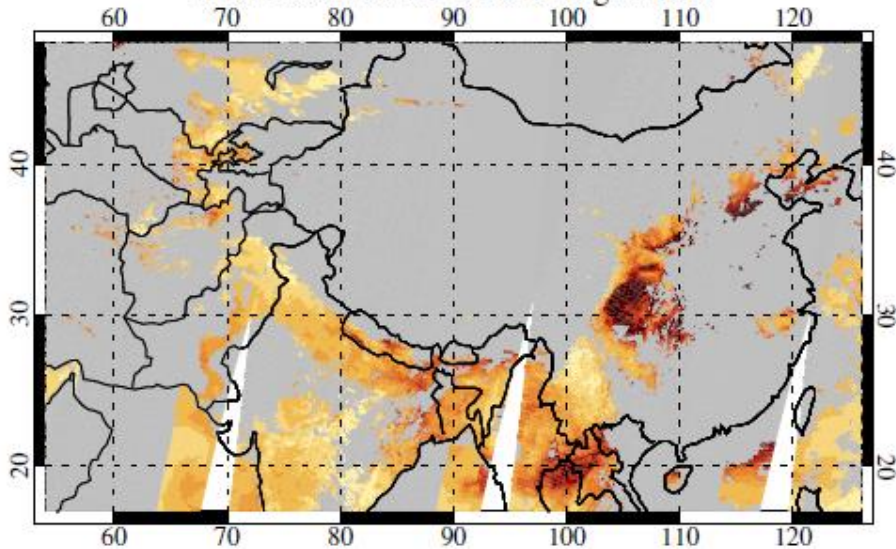
Deep Blue: original motivation

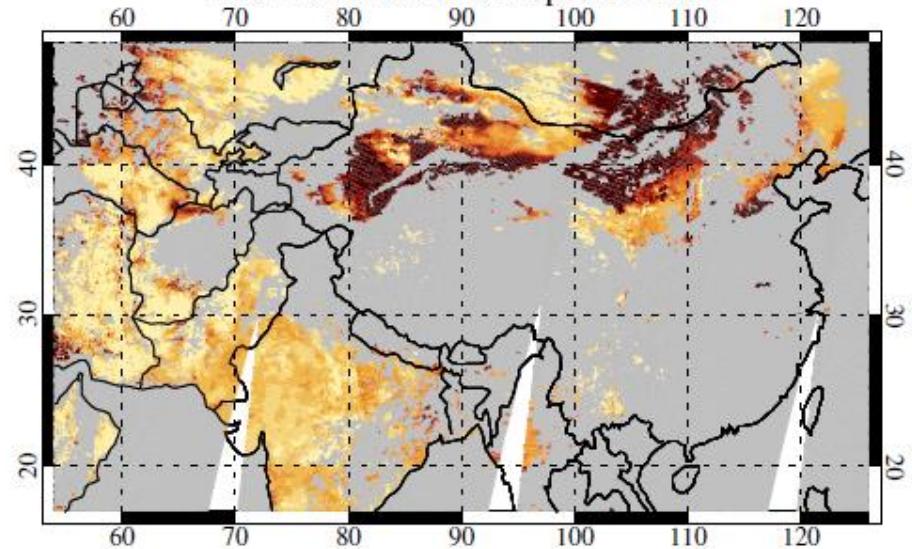MODIS Terra true-colour image, 6th April 2001

- 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**

MODIS Collection 5 Dark Target AOD
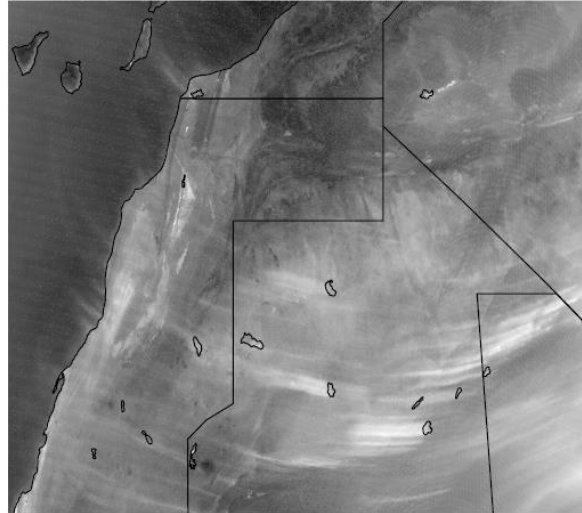
MODIS Collection 5 Deep Blue AOD

Deep Blue: key concepts

- Often, better surface/aerosol contrast in the violet/blue (~400-490 nm) than longer wavelengths
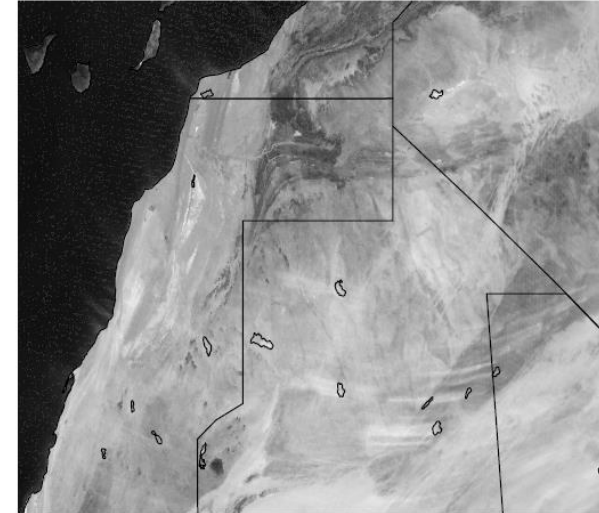

MODIS Terra, 10 Feb 2001, 11:50 UTC

412 nm (Deep Blue) reflectance
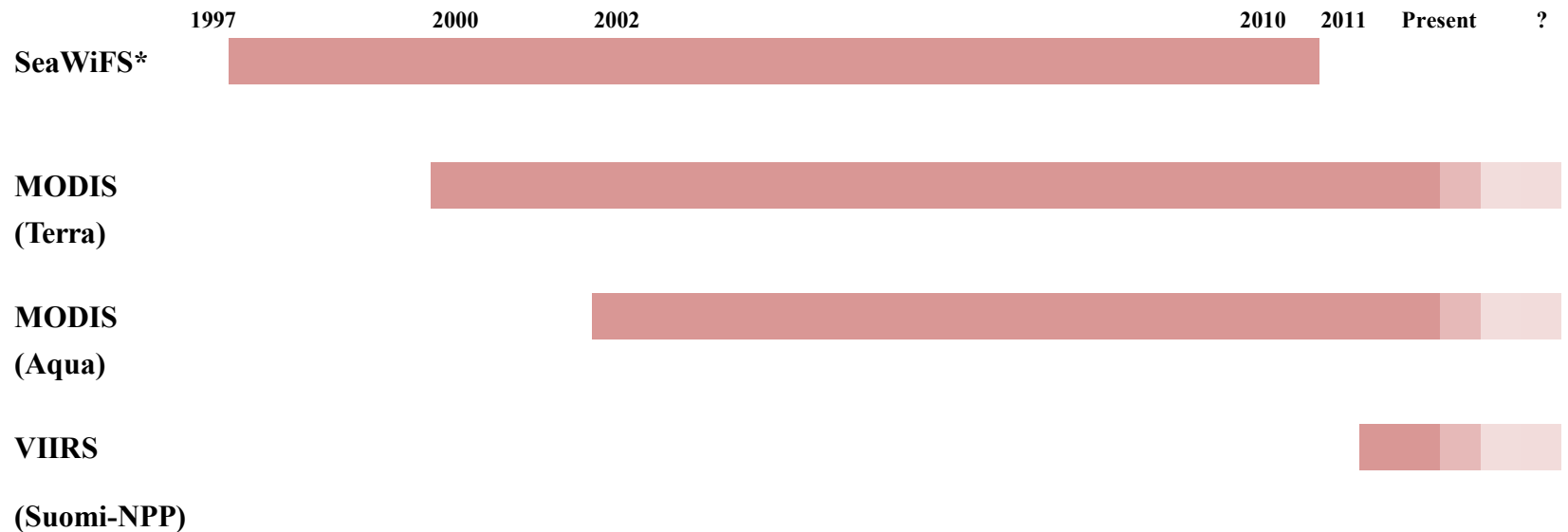
660 nm (red) reflectance

- **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

Sensors Deep Blue has been applied to

	1997	2000	2002		2010	2011	Present	?
SeaWiFS*								
MODIS (Terra)								
MODIS (Aqua)								
VIIRS (Suomi-NPP)								

*SeaWiFS ceased operations in December 2010 so is not further discussed here, although we have processed and archive the whole record with Deep Blue and ocean AOD retrieval algorithms
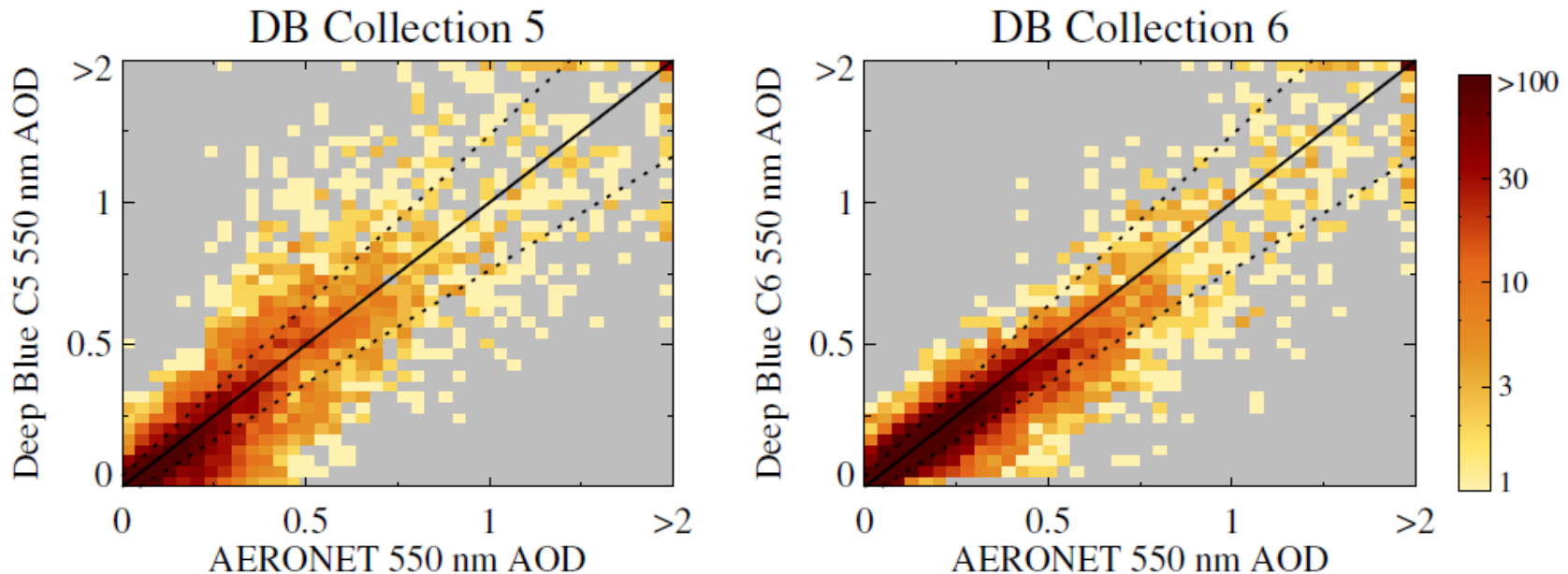
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Images from NASA Earth Observatory, http://earthobservatory.nasa.gov/Features/Aerosols/

MODIS C6: main developments

DB Collection 5 — Deep Blue C5 550 nm AOD vs AERONET 550 nm AOD

DB Collection 6 — Deep Blue C6 550 nm AOD vs AERONET 550 nm AOD

- Scatter density plots for 10 AERONET sites where both C5 and C6 Deep Blue provide retrievals
  - 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, and QA-filtered AOD SDS included
6. Radiometric calibration improvements
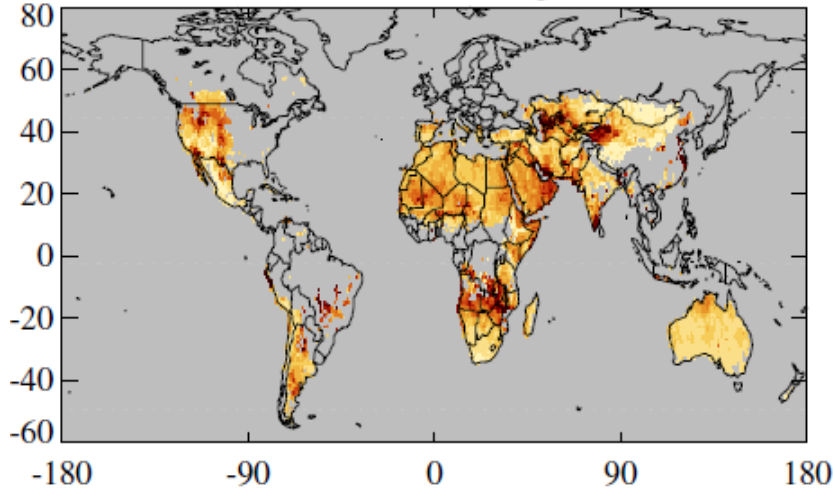7. AOD uncertainty estimates for every retrieval
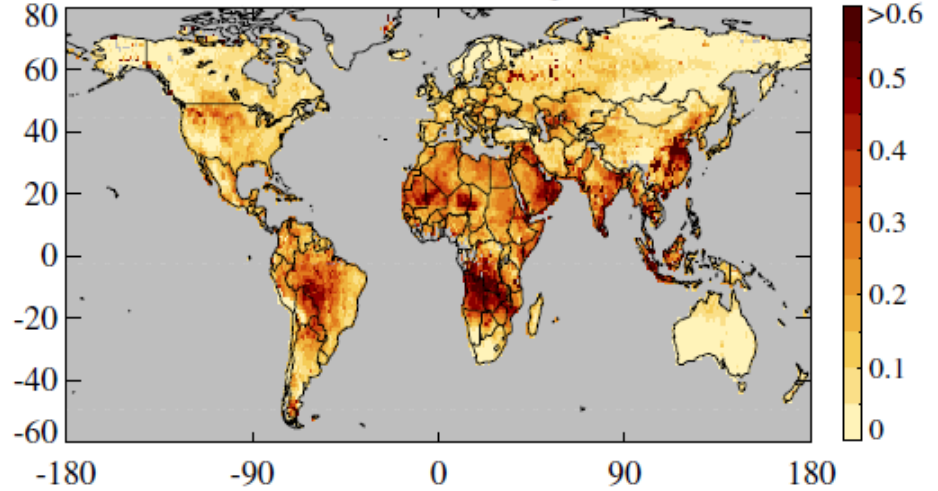
MODIS C6: Sample granule
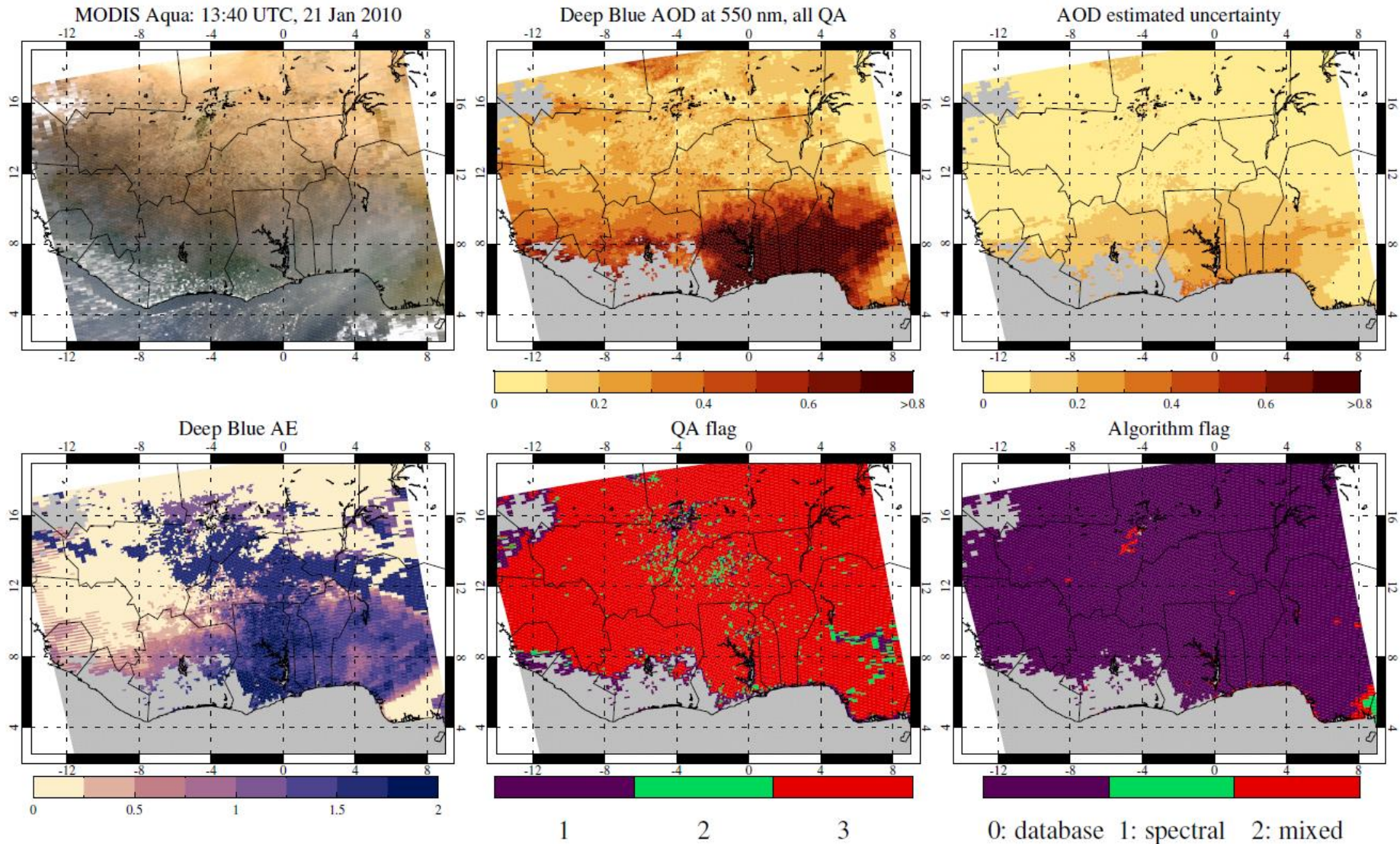
- Nominal 10 km horizontal resolution
- Each 550 nm AOD retrieval has associated uncertainty estimate and quality flag
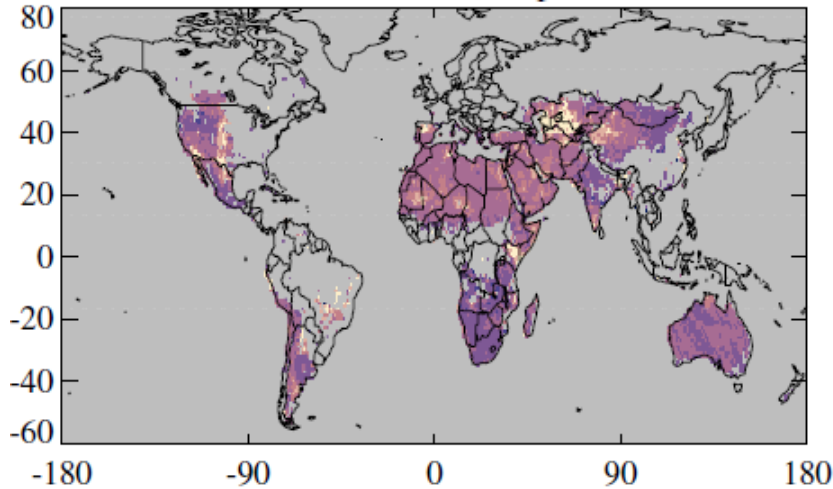
MODIS C6: extended spatial coverage
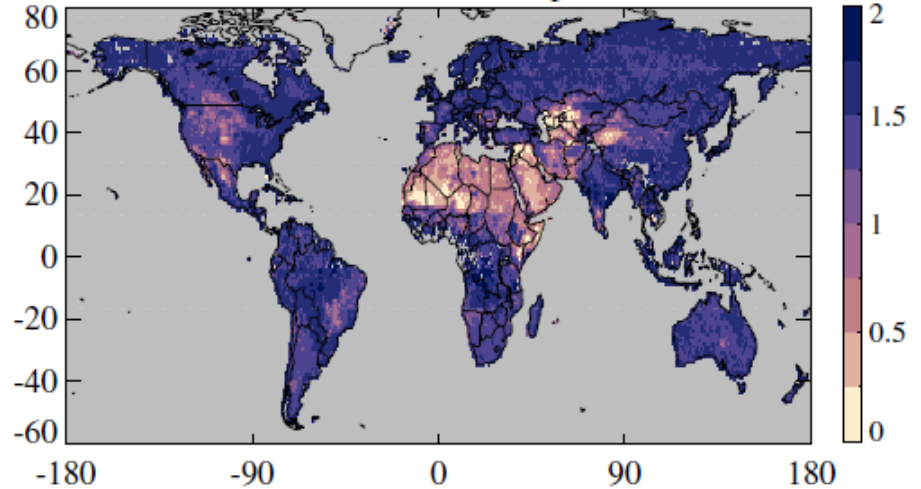

DB Collection 5 AOD, September 2012

eDB Collection 6 AOD, September 2012

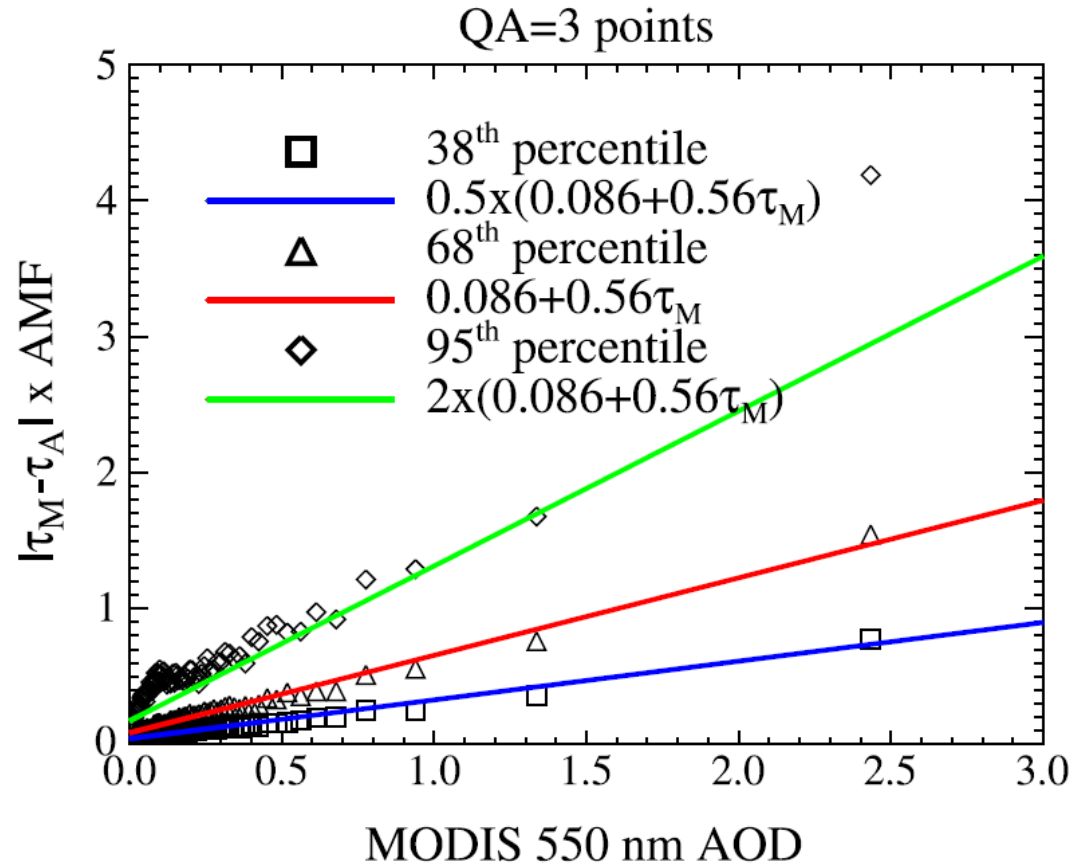DB Collection 5 ANG, September 2012
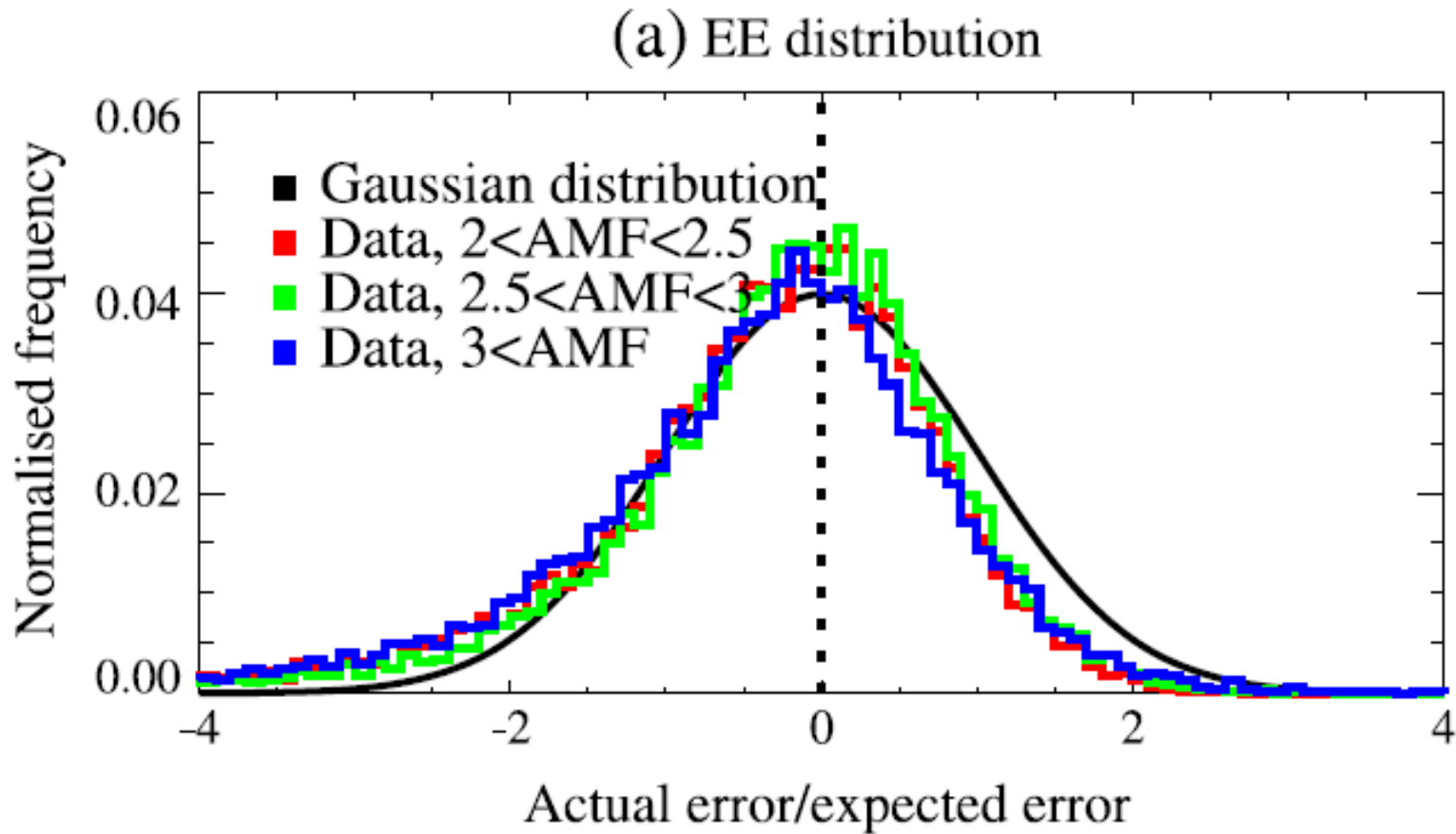
eDB Collection 6 ANG, September 2012

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)

QA=3 points

$\square$ 38th percentile
— 0.5x(0.086+0.56τ_M)
$\triangle$ 68th percentile
— 0.086+0.56τ_M
$\diamond$ 95th percentile
— 2x(0.086+0.56τ_M)

y-axis: $|\tau_M - \tau_A| \times$ AMF
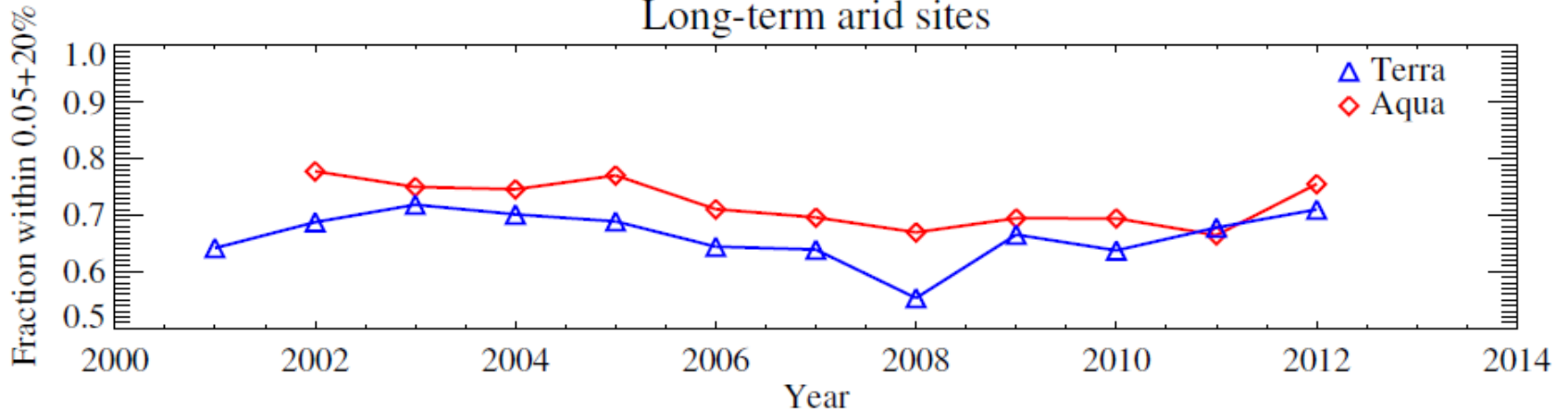
x-axis: MODIS 550 nm AOD

Error histograms are nearly* zero-centered Gaussian
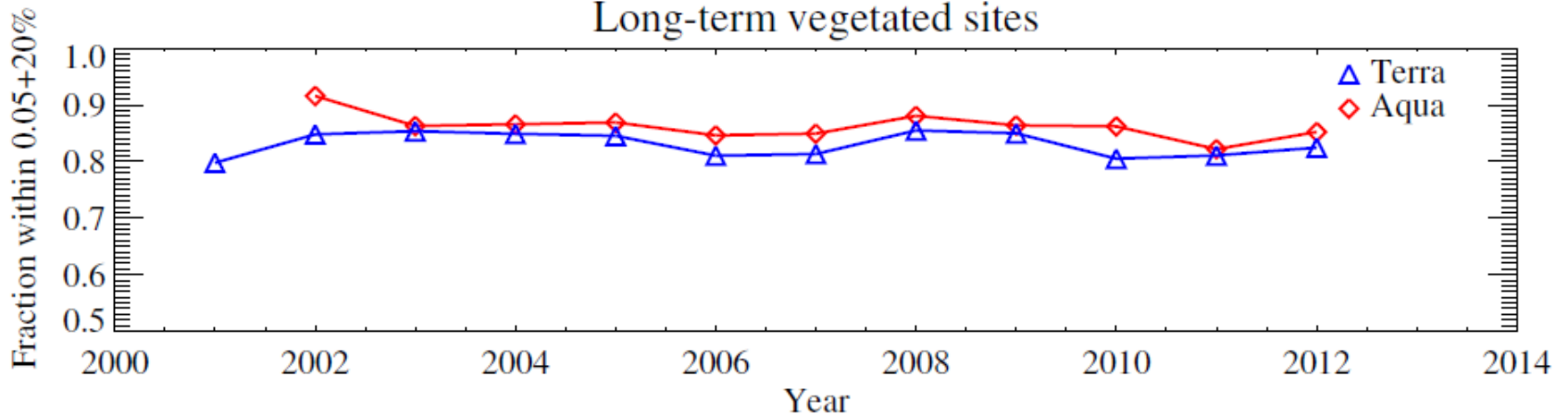

(a) EE distribution

*not perfectly – scope for future refinement

What about Terra?

Long-term arid sites

Long-term vegetated sites

- 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, improved from C5
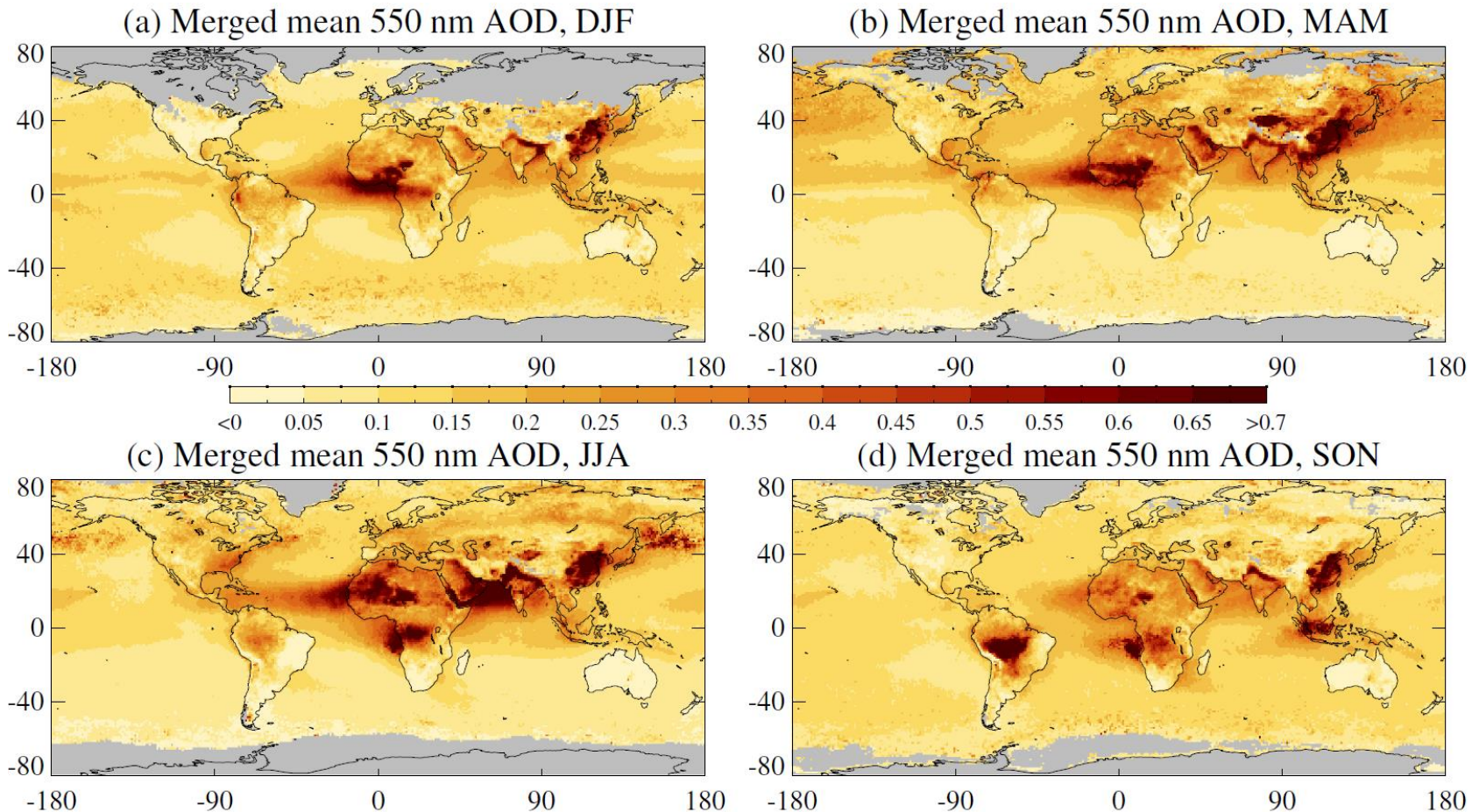
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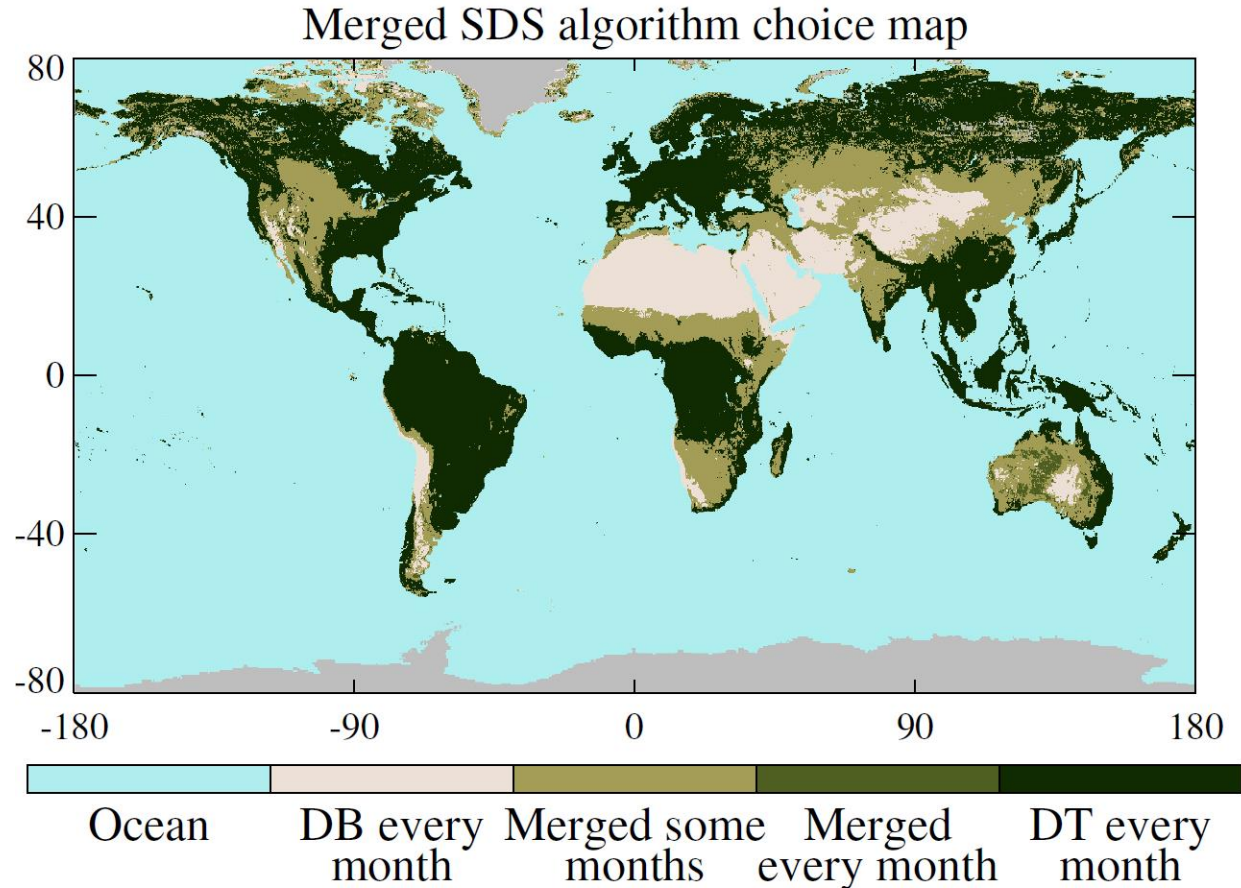

Images from NASA Earth Observatory, http://earthobservatory.nasa.gov/Features/Aerosols/

What is the 'merged' MODIS dataset?

(a) Merged mean 550 nm AOD, DJF
(b) Merged mean 550 nm AOD, MAM
(c) Merged mean 550 nm AOD, JJA
(d) Merged mean 550 nm AOD, SON

<0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65 >0.7

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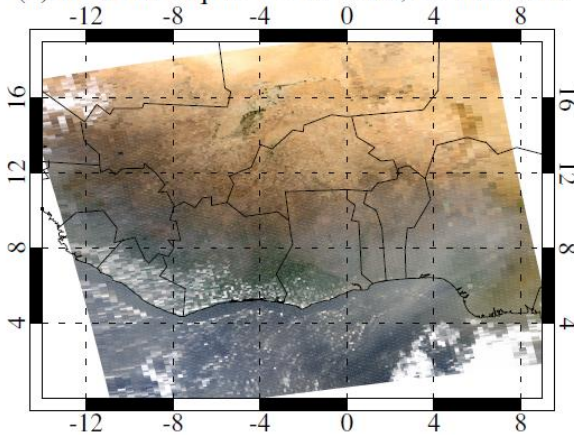- Seasonal mean of daily mean AOD from the 'merged' SDS, 2006-2008

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

Merged SDS algorithm choice map

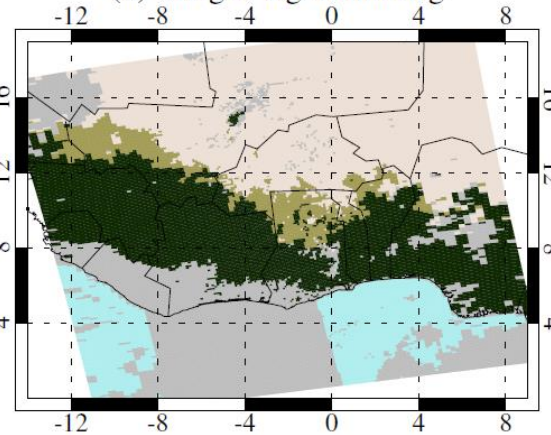| Ocean | DB every month | Merged some months | Merged every month | DT every month |

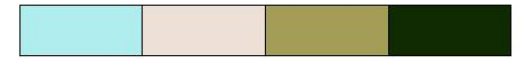# What does merging look like?

(a) MODIS Aqua: 13:40 UTC, 21 Jan 2010
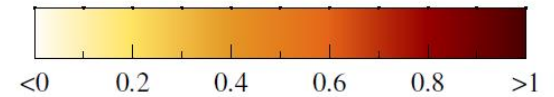
(b) Merged algorithm flag

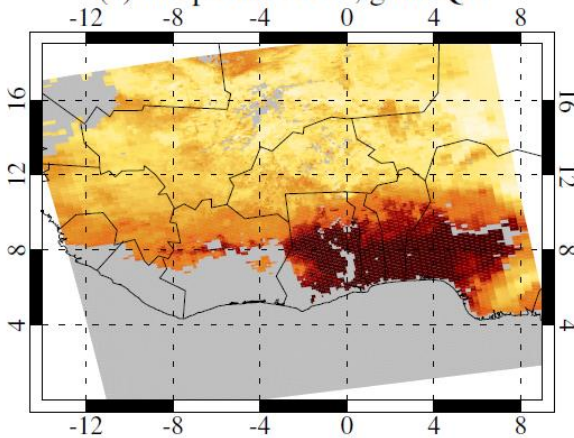Merged algorithm flag

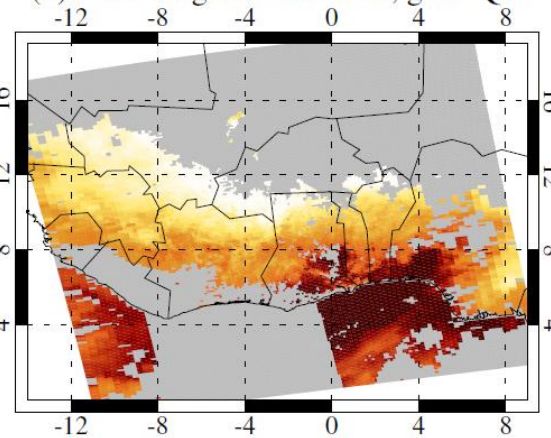Ocean   DB   Merged   DT

550 nm AOD

<0   0.2   0.4   0.6   0.8   >1

(c) Deep Blue AOD, good QA

(d) Dark Target/ocean AOD, good QA

(e) Merged AOD, good QA

So… what should I use?

(a) Best algorithm by data count

(b) Best algorithm by correlation

Deep Blue | Dark Target | Merged is equal | Merged is superior

(c) Best algorithm by fraction in 0.05+15%

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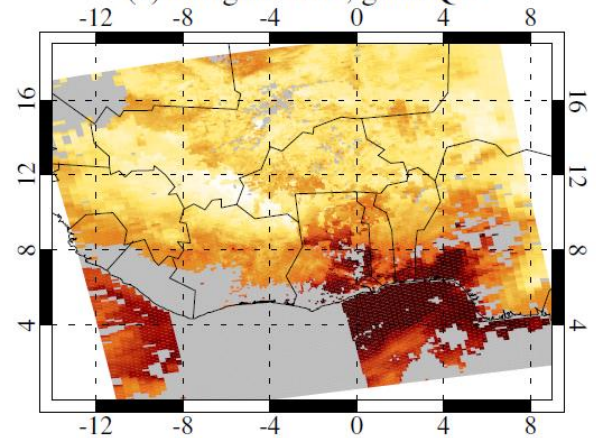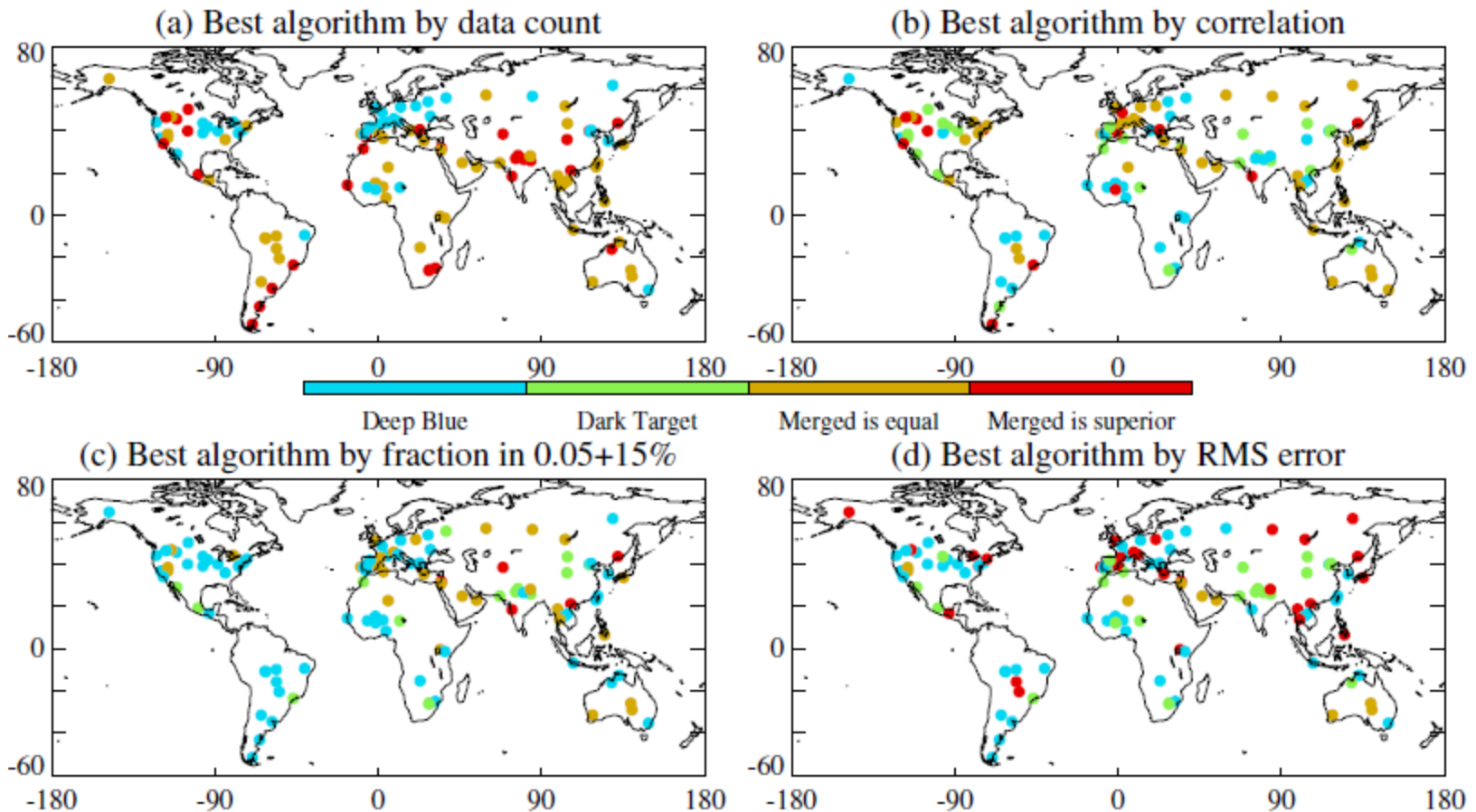
- Shown 'Best algorithm' vs. AERONET by different metrics
- Usage recommendations depend on your application and comfort level with the data
- No single algorithm is better than the others by all metrics, or for all regions/seasons
- Paper in review at JGR on this topic (and more general Deep Blue/Dark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

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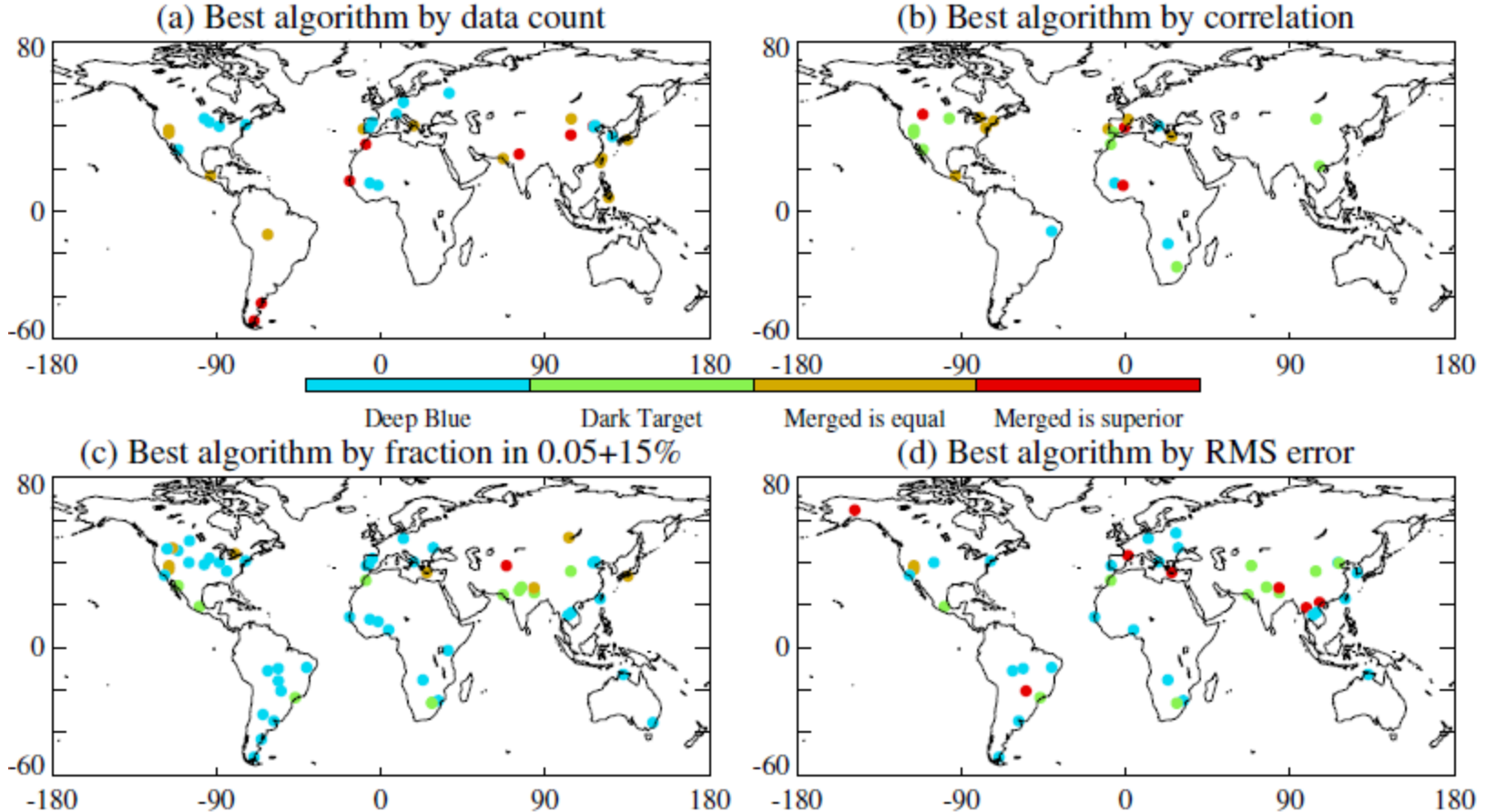(c) Best algorithm by fraction in 0.05+15%
(d) Best algorithm by RMS error

Deep Blue — Dark Target — Merged is equal — Merged is superior

- Shown 'Best algorithm' vs. AERONET by different metrics, where differences are large
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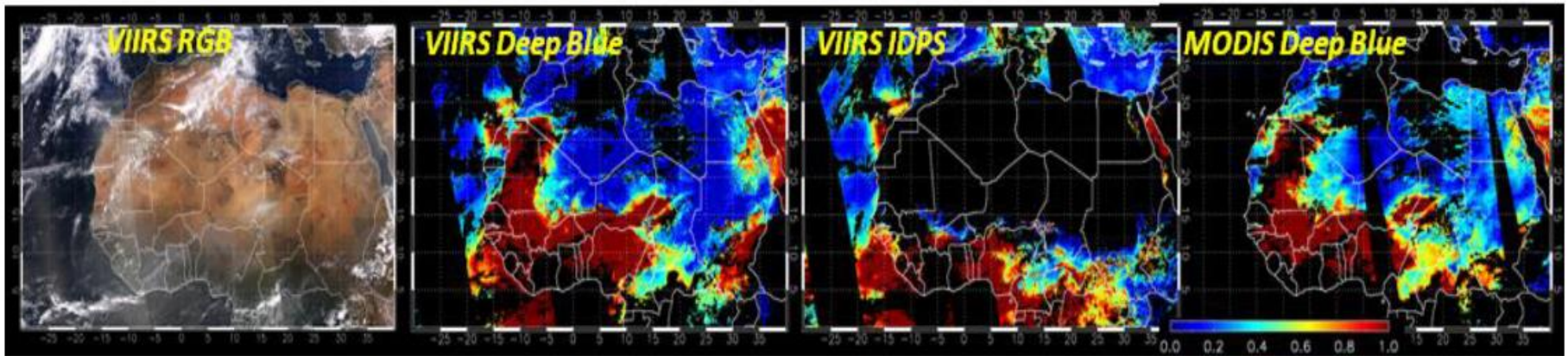
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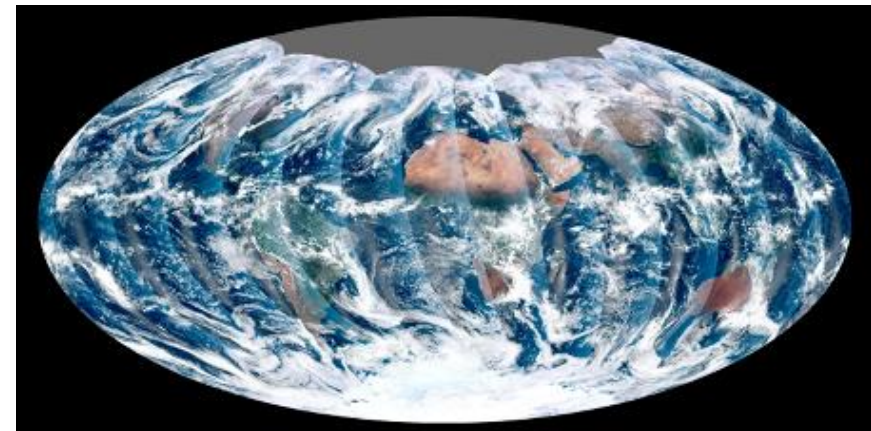
Visible Infrared Imaging Radiometer Suite (VIIRS)

- Launched on Suomi-NPP at end of 2011
- Similar to MODIS (for our purposes)
- e-Deep Blue over land, improved SeaWiFS algorithm over water
- Match NOAA product spatial resolution of ~6x6 km
- Will also provide level 3 products

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

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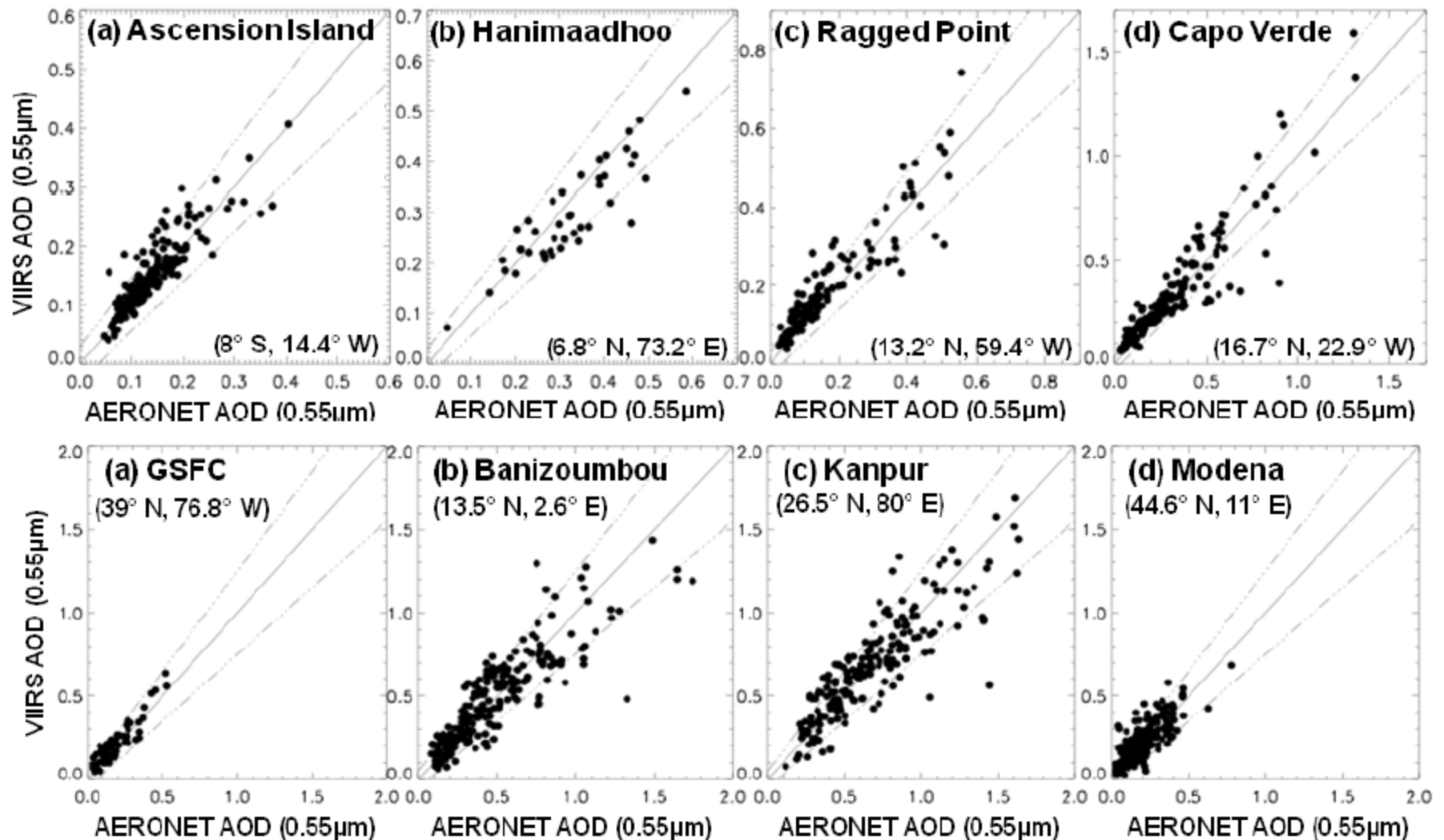
- Looked at a selection of land and ocean AERONET sites
  - Performance already approaching that of MODIS/SeaWiFS
  - Further refinements before release

Summary

- Deep Blue datasets:
  - SeaWiFS version 4 – available at http://disc.gsfc.nasa.gov
  - MODIS Collection 6 – http://modis-atmos.gsfc.nasa.gov/
    - Aqua level 2, 3 available now; Terra level 2, 3 probably around end of year
    - Expanded spatial coverage, AOD uncertainty estimates, includes dataset already filtered for QA
  - VIIRS – funded, in development, hopeful beta release early 2015
- Please 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!

• Hsu *et al.* (2004), Aerosol properties over bright-reflecting source regions, *IEEE Trans. Geosci. Remote Sens.*, 42 (3), 557-569, doi:10.1109/TGRS.2004.824067

• Hsu *et al.* (2006), Deep Blue retrievals of Asian aerosol properties during ACE-Asia, *IEEE Trans. Geosci. Remote Sens.*, 44, 3180–3195, doi:10.1109/TGRS.2006.879540

• Hsu *et al.* (2013), Enhanced Deep Blue aerosol retrieval algorithm: The second generation, *J. Geophys. Res.*, 118, 9296–9315, doi:10.1002/jgrd.50712

• Levy *et al.* (2013), The Collection 6 MODIS aerosol products over land and ocean, *Atmos. Meas. Tech.*, 6, 2989-3034, doi:10.5194/amt-6-2989-2013

• Sayer *et al.* (2013), Validation and uncertainty estimates for MODIS Collection 6 "Deep Blue" aerosol data, *J. Geophys. Res.*, 118, 7864–7872, doi:10.1002/jgrd.50600

• Sayer *et al.*, MODIS Collection 6 aerosol products: comparison between Aqua's e-Deep Blue, Dark Target, and `merged' datasets, and usage recommendations, *J. Geophys. Res.* (submitted; in revision)