

MODIS Atmospheres webinar series #3: Collection 6 'e-Deep Blue' aerosol products

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

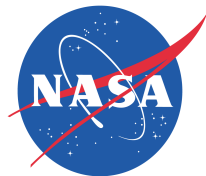
With thanks to many others: MODIS Characterization Support Team, MODIS Atmospheres Science Team, AERONET group

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



Webinar schedule

Topic	Presenter(s)	Date
Overview of Collect 6 update L1 Calibration Overview	Steve Platnick Jack Xiong	25-Jun-14
MODIS Dark Target Global 10 Km Product	Rob Levy	2-Jul-14
MODIS Aerosols Deep Blue	Andy Sayer	9-Jul-14
MODIS Aerosols Merged Dark Target: Deep Blue Product	Rob Levy / Andy Sayer	16-Jul-14
MODIS Dark Target 3 Km Product	Leigh Munchak	23-Jul-14
MOD035 Cloud Mask and Clear Sky Products atmosphere profile and clear sky radiance maps	Steve Ackerman	13-Aug-14
MOD06 Cloud Top Properties Product	Paul Menzel	20-Aug-14
MOD06 Cloud Optical Properties Product	Steve Platnick	27-Aug-14
MOD08 Level 3 Product	Steve Platnick / Bill Ridgway	3-Sep-14
Archives/Data Acquisition: LAADSWEB, MIRADOR, ECHO-Reverb	To Be Determined.	10-Sep-14
MODIS Atmosphere Educational Materials & Resources	Richard Kleidman	17-Sep-14
Giovanni - Aerosols Express	Jim Acker	24-Sep-14
MAIAC 1 Km Aerosol Product	Alexei Lyapustin	01-Oct-14



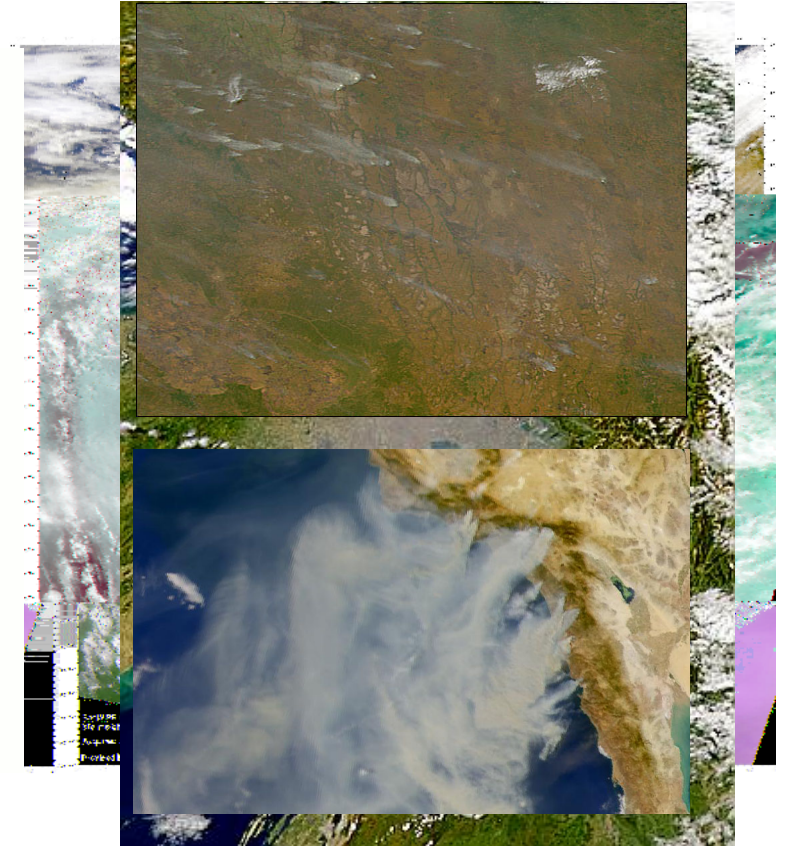
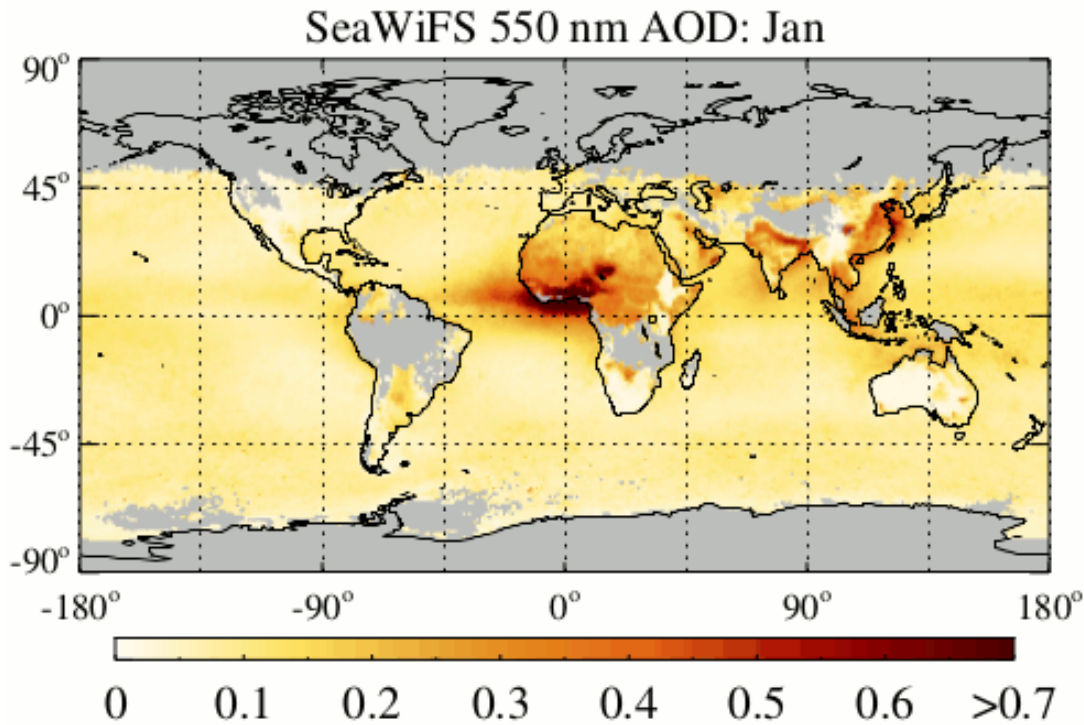
Overview

- Aerosol terminology
- MODIS terminology
- e-Deep Blue
 - Principles
 - Examples of level 2 data
 - New for Collection 6
 - Validation
- Summary

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Aerosols and properties of interest: AOD



- Aerosol Optical Depth (AOD): total column optical extinction of aerosol at a given wavelength
 - Most commonly, 550 nm (τ_{550})
 - Related to how much aerosol is in the atmosphere
 - Also termed aerosol optical thickness (AOT)

Aerosols can travel a long way

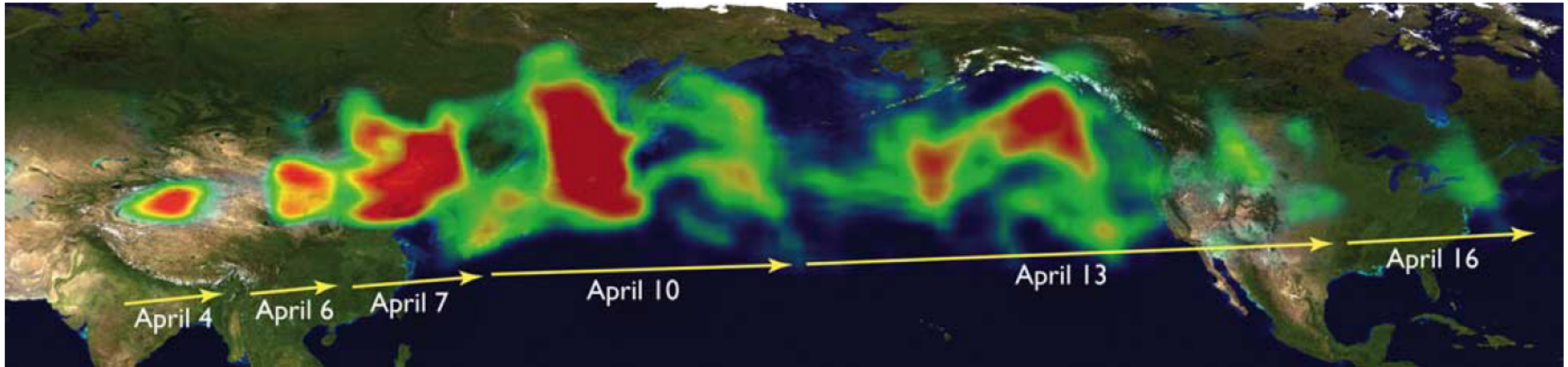
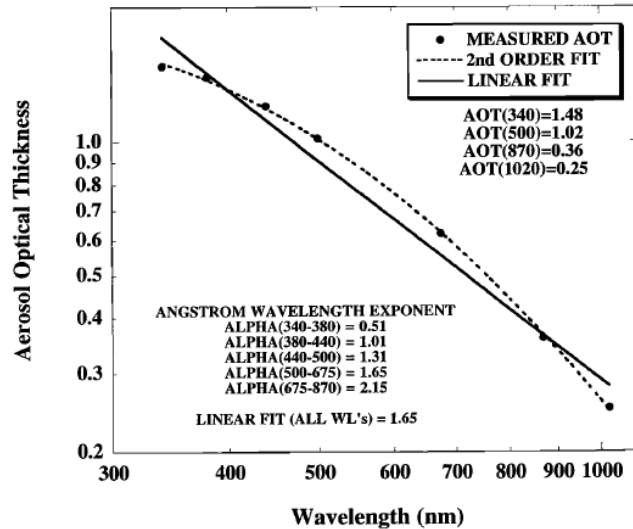


Fig. 1. Time series of TOMS AI composite in April 2001 showing the long-range transport of Asian dust across the Pacific reaching as far as the east coast of the U.S.

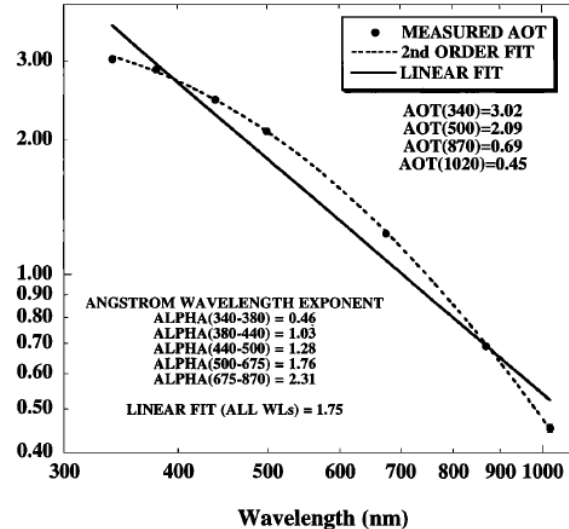
- Mineral dust from Taklimakan desert transported to North America
 - Hsu *et al.*, *IEEE TGARS* (2006)
 - Renewed attention in Yu *et al.*, *Science/Atmos. Res.*, (2012)
- We also see Asian pollution transported to North America, Saharan dust transported to the Amazon and Europe, African smoke transported to South America, Asian dust to Europe, high-latitude smoke circling the world in both hemispheres, etc...

Aerosols and properties of interest: AE

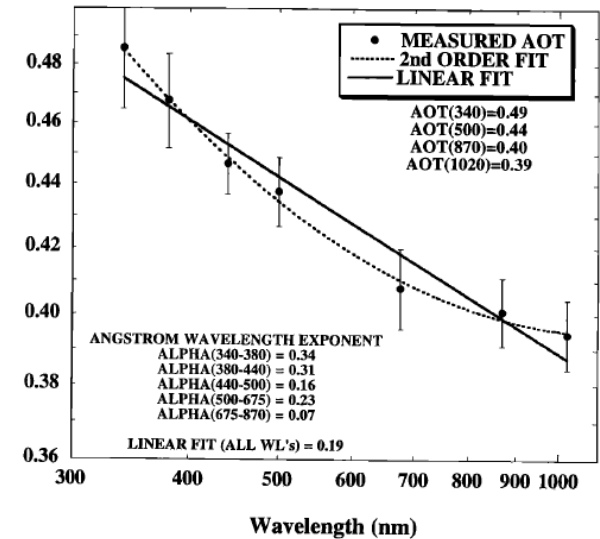
**Urban aerosols
(NASA GSFC, USA)**



**Smoke aerosols
(Bolivia)**



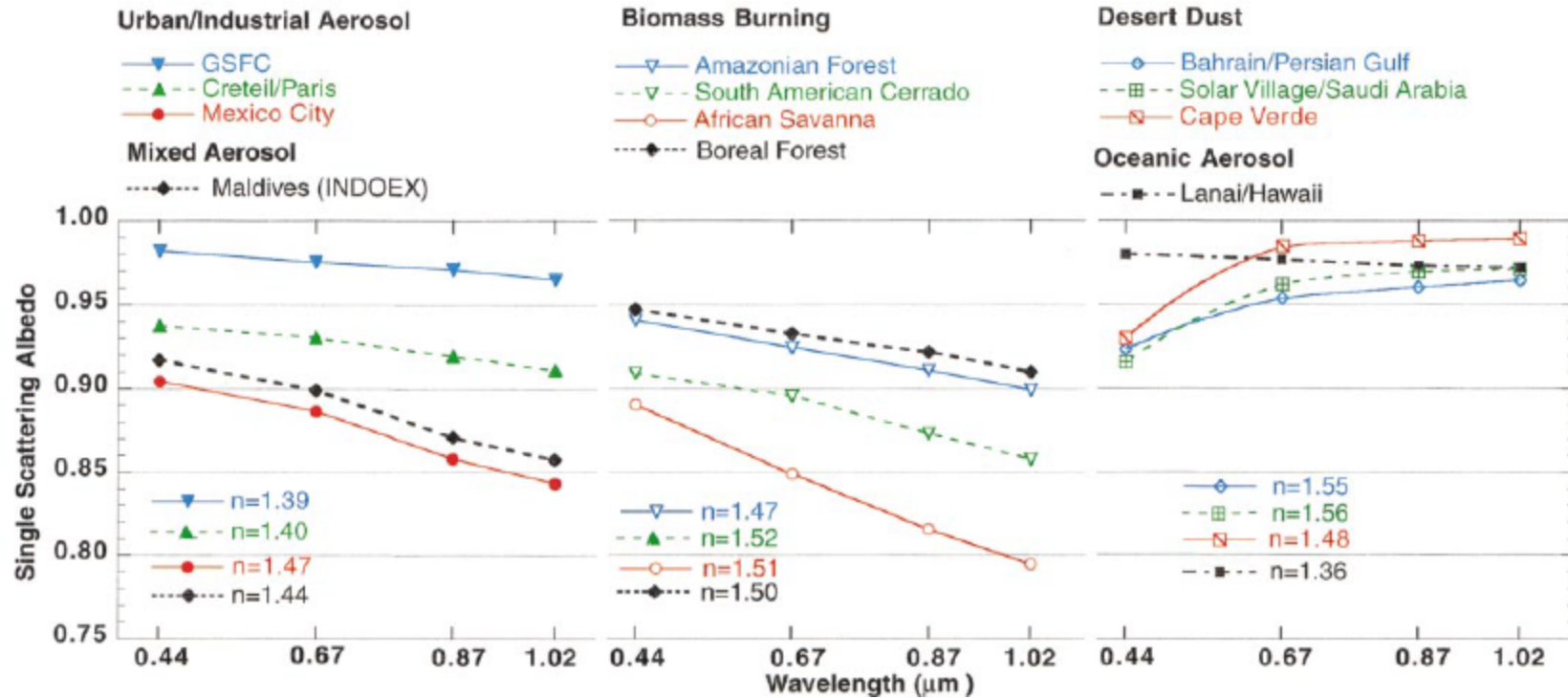
**Mineral dust aerosols
(Dalanzadgad, Mongolia)**



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 Scatter 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

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MODIS data product terminology

MODIS: Moderate Resolution Imaging Spectroradiometer

- Data product ‘Level’ designations relevant to the MODIS Deep Blue aerosol products
 - Level 1b (L1b): calibrated/geolocated instrument data
 - Level 2 (L2): derived geophysical retrieval data (‘pixel’ level)
 - Level 3 (L3): gridded data (spatiotemporal aggregation of Level 2)
- MODIS data “Collection”
 - A (re)processing production run with consistent baseline algorithms
 - Collection 5 (C5) reprocessing (2006) was the first to include Deep Blue
 - Current version is Collection 6 (C6)
 - Aqua level 2 processing complete
 - Aqua level 3 imminent
 - Terra level 2/3 to follow after
- This webinar is about MODIS C6 (mostly Aqua Level 2) data

MODIS data product terminology

Terra MODIS: **MOD06_L2.AYYYYDDD.HHMM.CCC.YYYYDDDDHHMMSS.hdf**

Aqua MODIS: **MYD06_L2.AYYYYDDD.HHMM.CCC.YYYYDDDDHHMMSS.hdf**

Definition of highlighted text:

MOD06 = Earth Science Data Type name

L2 = Denotes a Level-2 product (or L3 for Level-3, etc.)

A = indicates following date/time information is for the acquisition (observation)

YYYYDDD = acquisition year and day-of-year

HHMM = acquisition hour and minute start time

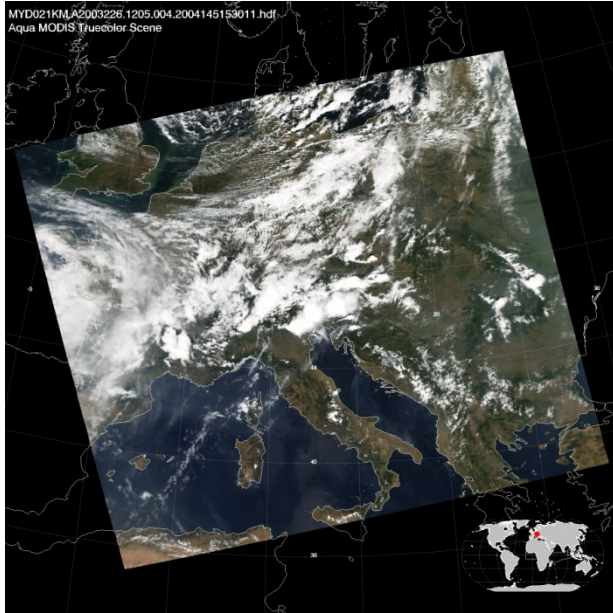
CCC = collection (e.g., '006' for Collection 6)

YYYYDDDDHHMMSS = production data and time

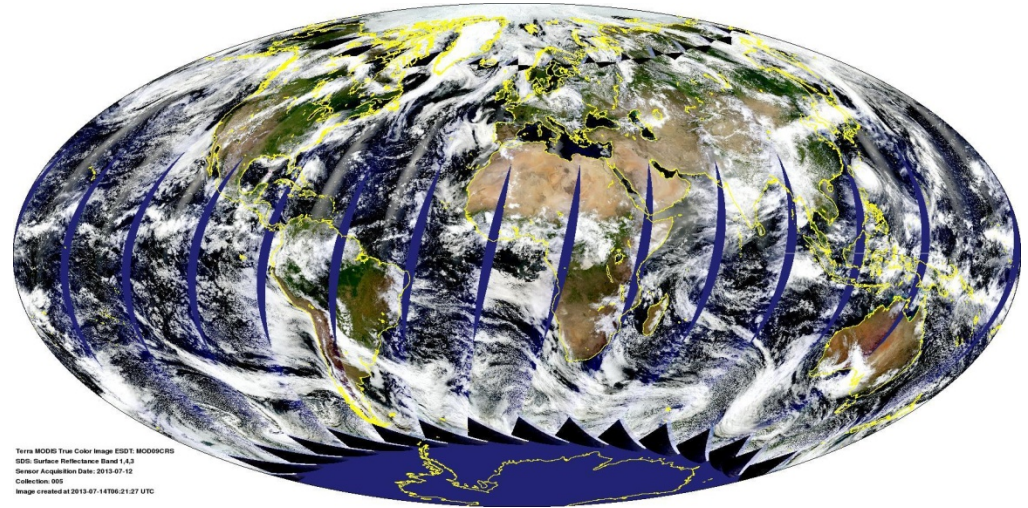
hdf = denotes HDF file format

- Data products relevant to this presentation:
 - **MOD04, MYD04** (Level 2 aerosols)
 - **MODATML2, MYDATML2** (Level 2 joint atmospheres)
 - **MOD08, MYD08** (Level 3 joint atmospheres)

The MODIS sensor



MODIS Aqua granule RGB composite for August 14th, 2003, 12:05 UTC



MODIS Terra daytime RGB composite for July 12th, 2013

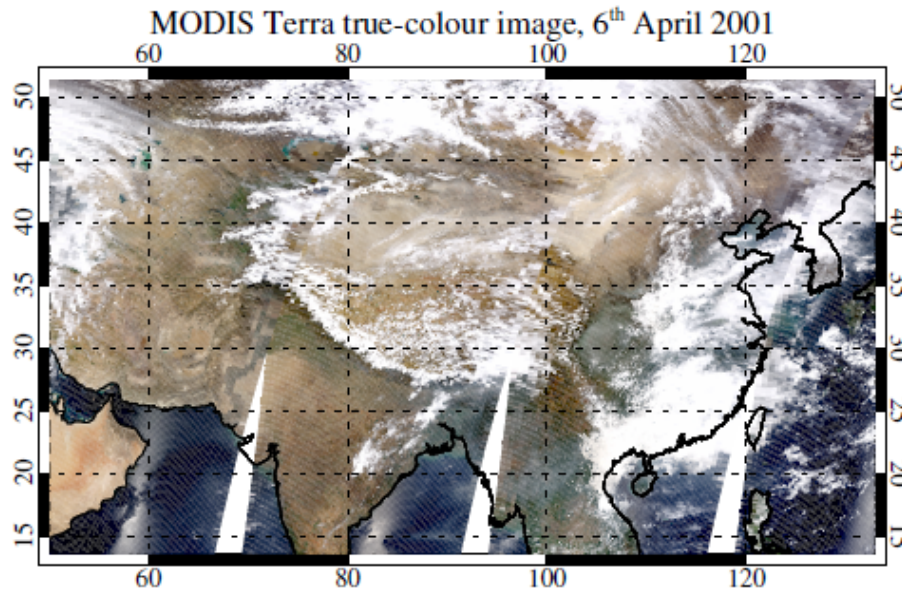
Images available online at <http://modis-atmos.gsfc.nasa.gov>

- 36 spectral bands from visible to thermal IR
- Spatial resolutions (level 1b) 250 m to 1 km at nadir
 - ‘Bowtie effect’ leads to pixel enlargement and distortion near swath edges
 - Note standard MODIS aerosol products are at nominal 10 km resolution
- Swath width 2,300 km, giving near-global daily coverage
- Flying on polar-orbiting platforms
 - Near-constant local solar time of observation ~10:30 am (Terra, descending), ~1:30 pm (Aqua, ascending)
 - 14-15 orbits per day, 16-day orbital repeat cycle
 - Data organised into 5-minute ‘granules’

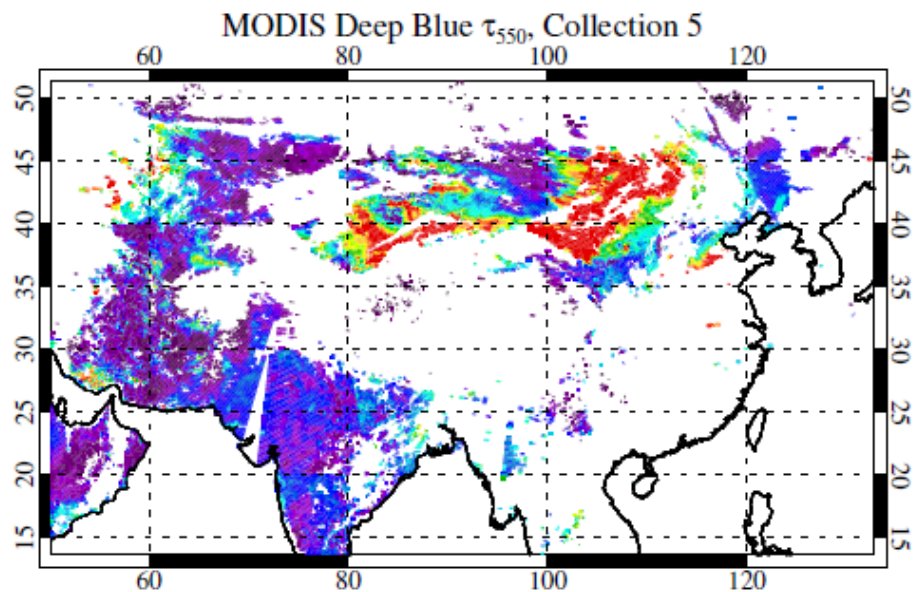
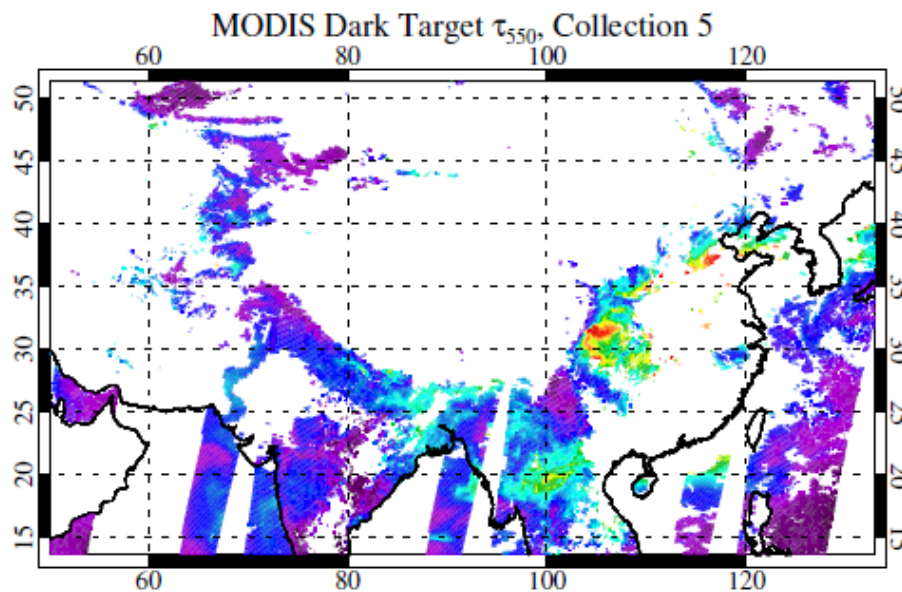
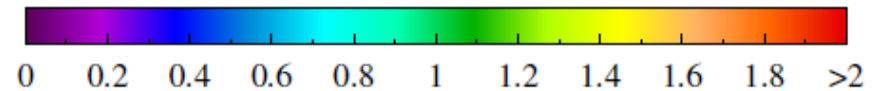
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Deep Blue: original motivation

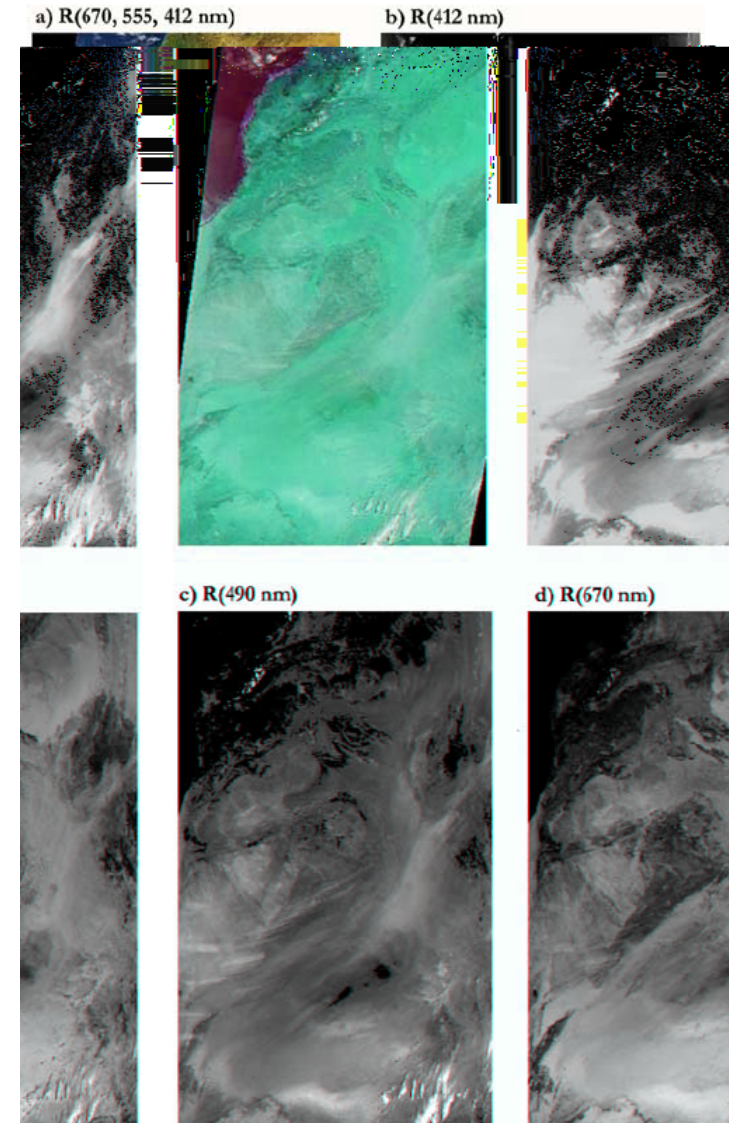


- ‘Dark Target’ AOD algorithm does not retrieve over bright surfaces
 - Violates algorithmic assumptions
- These are important aerosol sources, especially mineral dust
- Deep Blue filled in some gaps
 - (Now, it does more than that)



Deep Blue: key concepts

- Often, darker surface and stronger aerosol signal in the violet/blue ($\sim 400\text{-}490\text{ nm}$) than at longer wavelengths
 - Prescribe surface reflectance
 - Retrieve AOD independently at several wavelengths
- **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
- **Disadvantages:**
 - Drastic departures from expected surface cover type can lead to localised artefacts
 - Can't directly calculate aerosol effective radius, volume etc

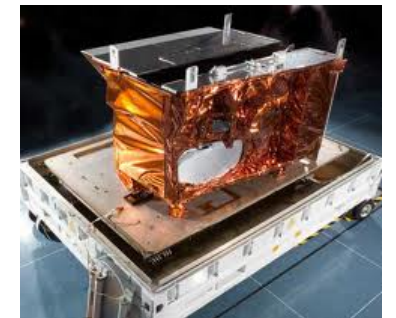
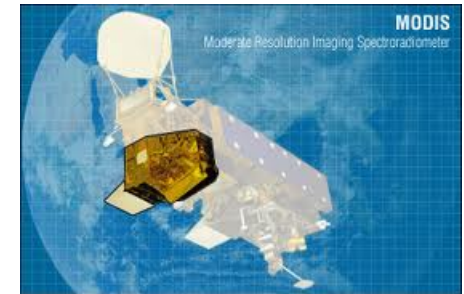
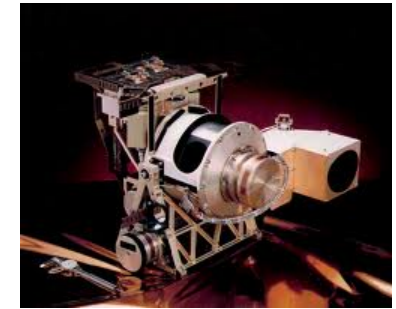
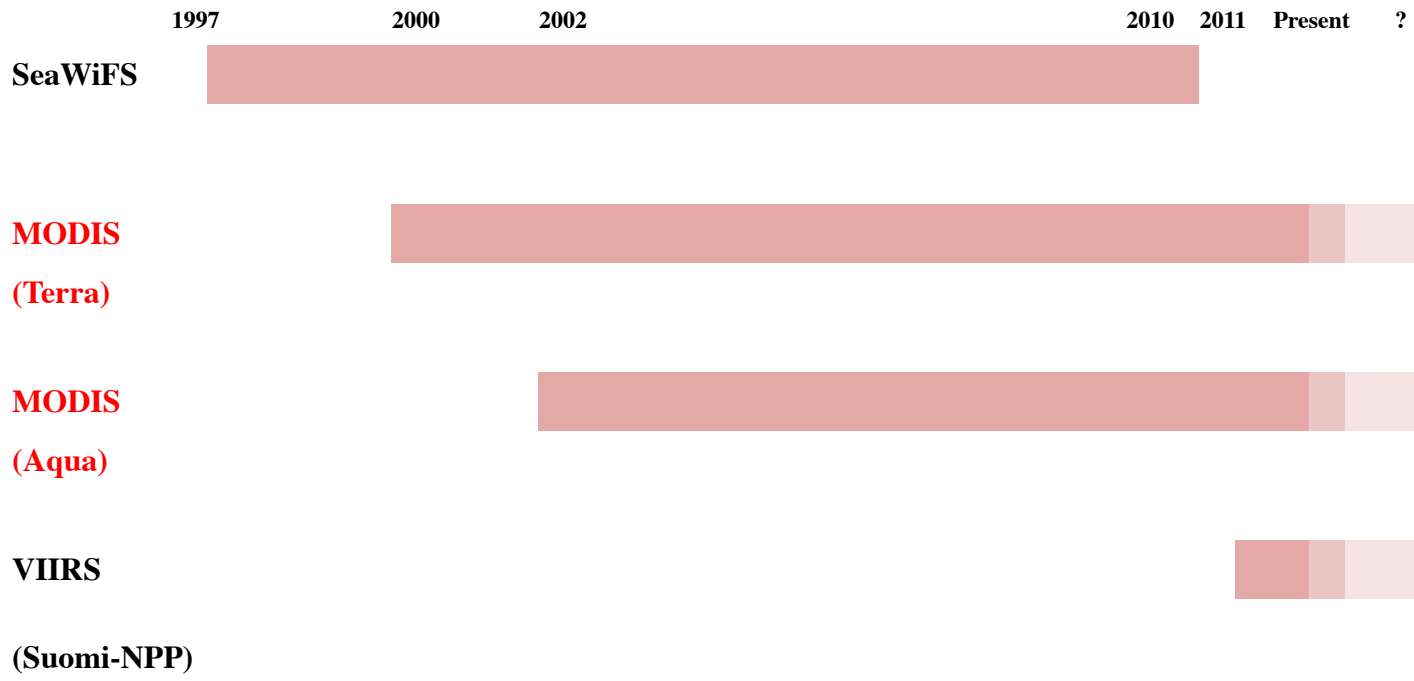


0, 2001. The
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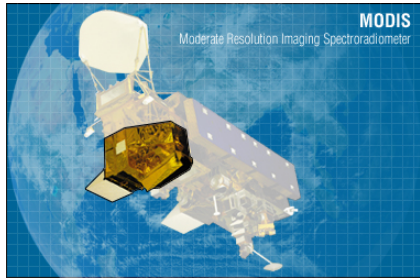
Fig. 2. SeaWiFS images over northeast Africa on February 1
dynamical ranges of the grayscale used in (b)–(d) are individual
to optimize the appearance of atmospheric features against the
surfaces.

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

Sensors Deep Blue has been applied to



Images courtesy of SeaWiFS/MODIS projects and Raytheon



MODIS vs. SeaWiFS

Deep Blue

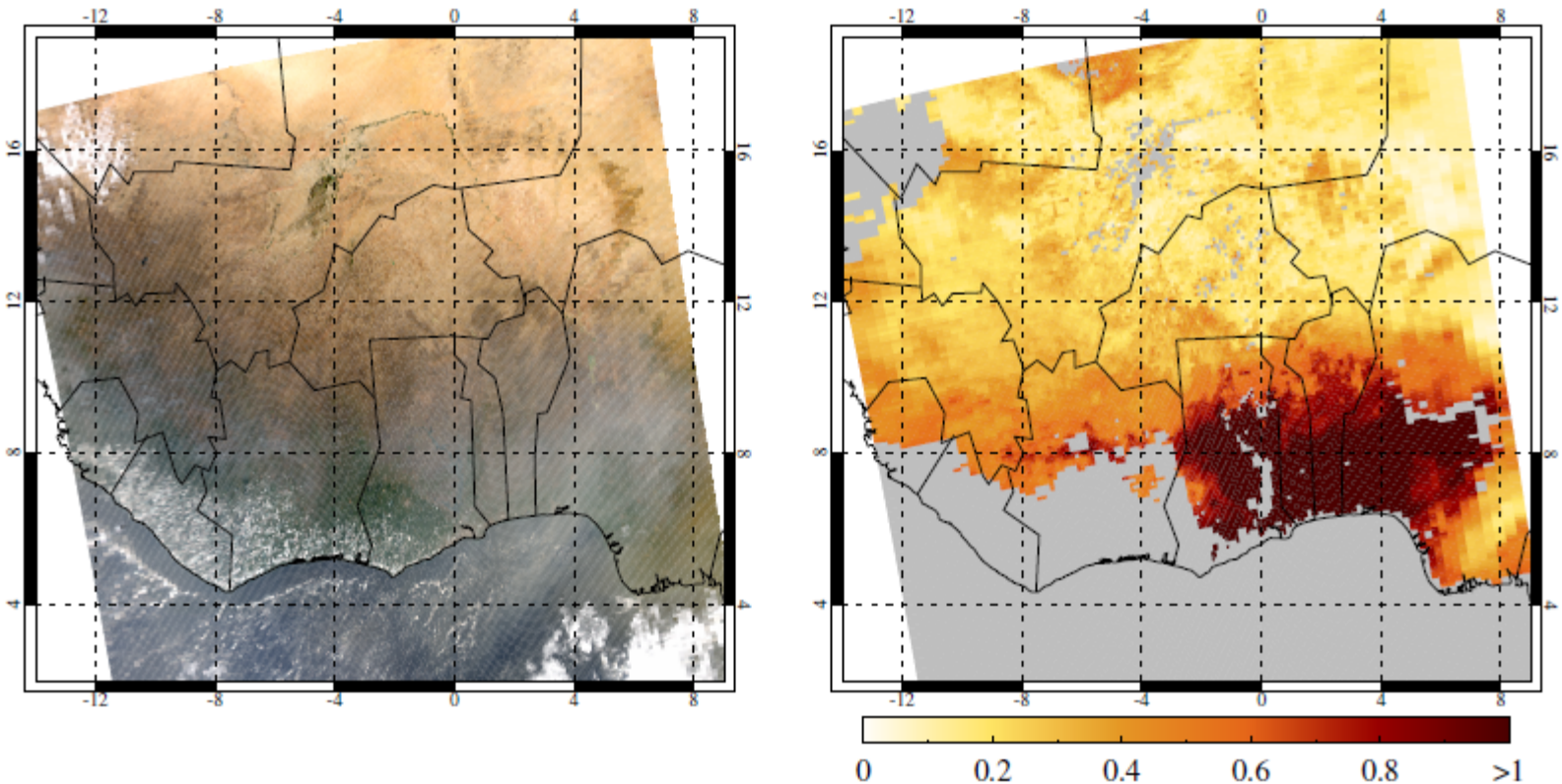


Dataset	MODIS (Collection 6, C6)	SeaWiFS (Version 4, V4)
Time series	MODIS Terra (2000 onwards) MODIS Aqua (2002 onwards)	SeaStar satellite (1997-2010, a few gaps)
Coverage	Daytime cloud-free snow-free land only	Daytime cloud-free snow-free land Daytime cloud-free ice-free non-turbid water
Data products	Main product is AOD at 550 nm Also provides AOD at 412/470/670 nm, Ångström exponent, and SSA (for heavy dust)	Main product is AOD at 550 nm Land: also provides AOD at 412/490/670 nm, Ångström exponent, and SSA (for heavy dust) Water: also provides 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

- Hsu *et al.*, *IEEE TGARS* 2004, 2006; *JGR* 2013; Sayer *et al.*, *JGR* 2012a,b; *AMT* 2013 17

Example Level 2 data

MODIS Aqua: 13:40 UTC, 21 Jan 2010 Deep Blue AOD at 550 nm, passing QA



- 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

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

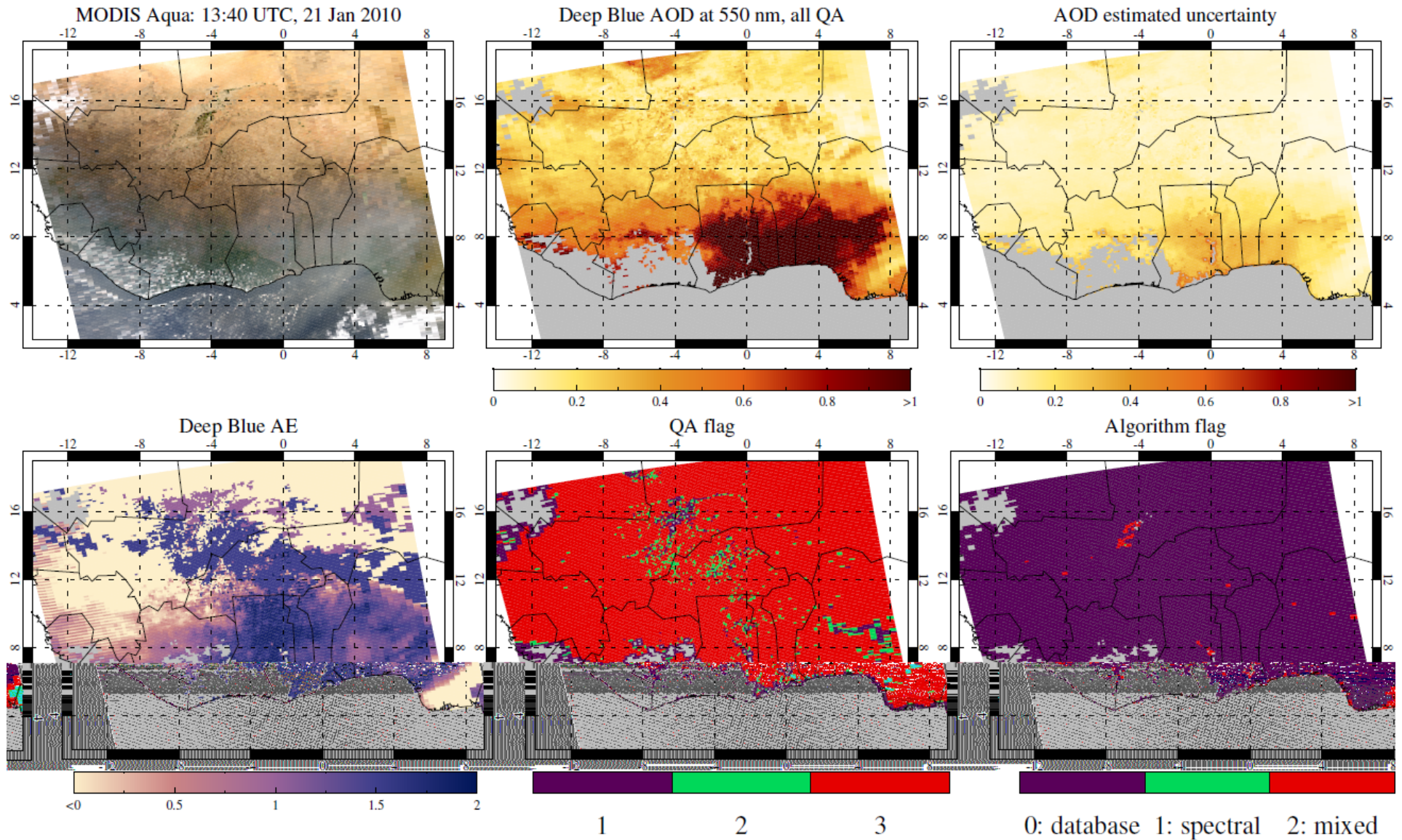
Name	Dimensions ^a	Description
Deep_Blue_Angstrom_Exponent_Land	[Cell_Along_Swath, Cell_Across_Swath]	Angstrom Exponent Over Land.
Deep_Blue_Aerosol_Optical_Depth_550_Land	[Cell_Along_Swath, Cell_Across_Swath]	Aerosol Optical Depth at 550 nm Over Land.
Deep_Blue_Aerosol_Optical_Depth_550_Land_Best_Estimate	[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.

^aCell_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)

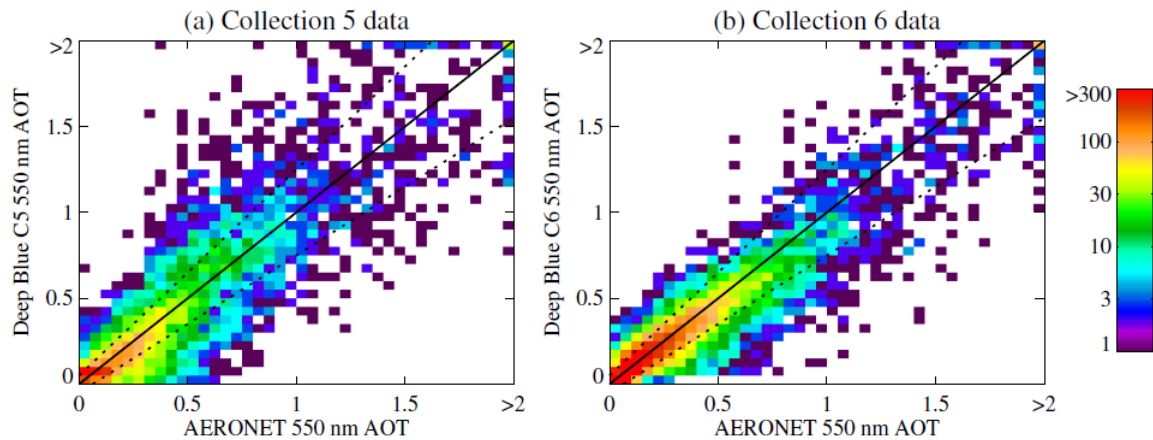
- Other stuff included in files but not listed above:
 - Diagnostic information (e.g. geometry, land/sea mask)
 - Dark Target and ocean aerosol data (*cf.* Rob Levy's webinar last week)
 - Deep Blue/Dark Target 'merged' SDS (*cf.* next week's webinar)

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

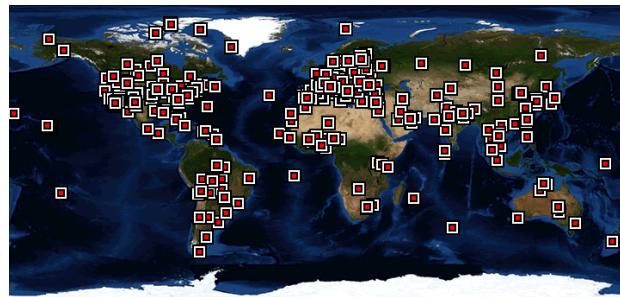
Improved surface reflectance models

Improved aerosol optical models

Improved cloud screening

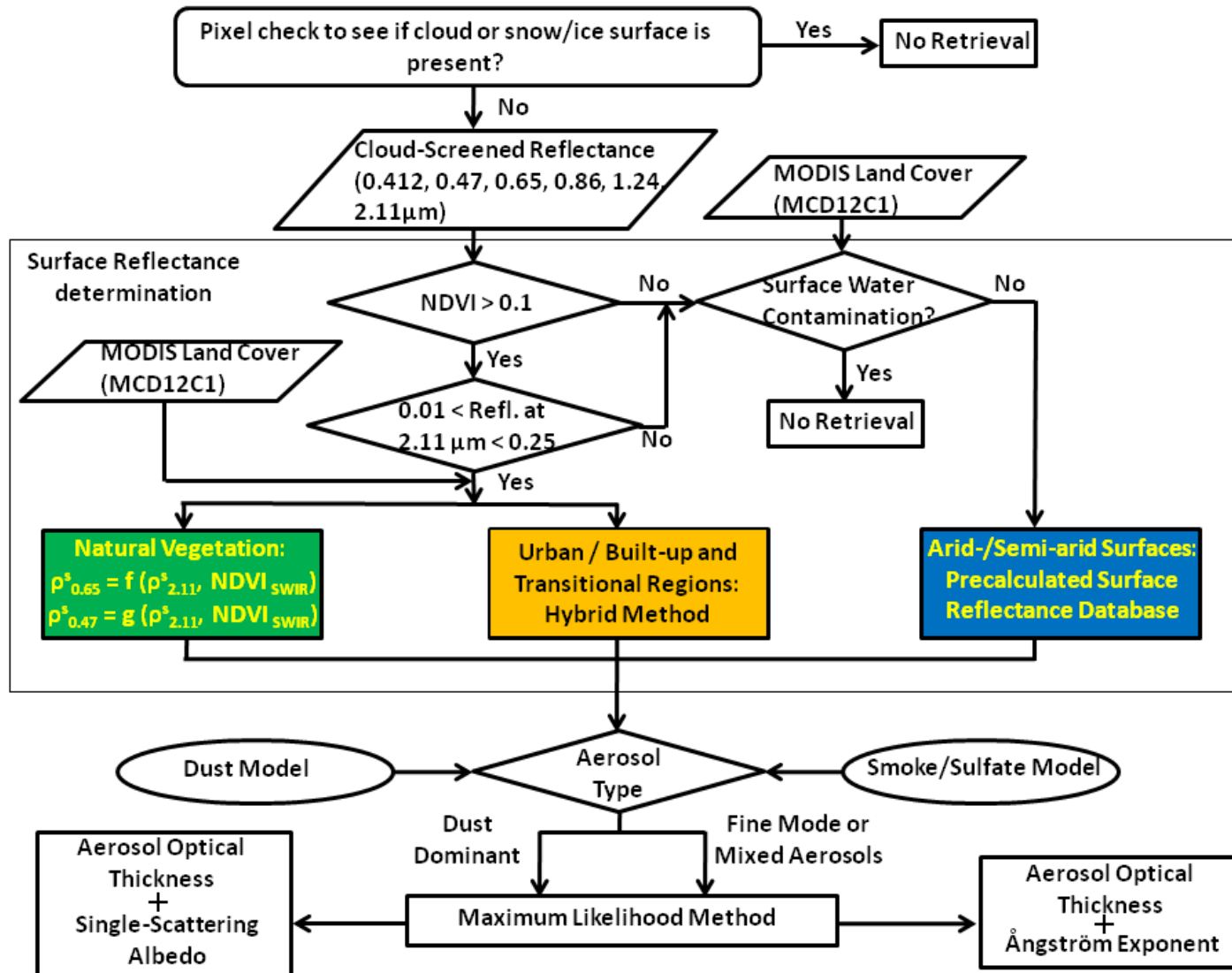
Simplified quality assurance (QA) flag reading

Radiometric calibration improvements



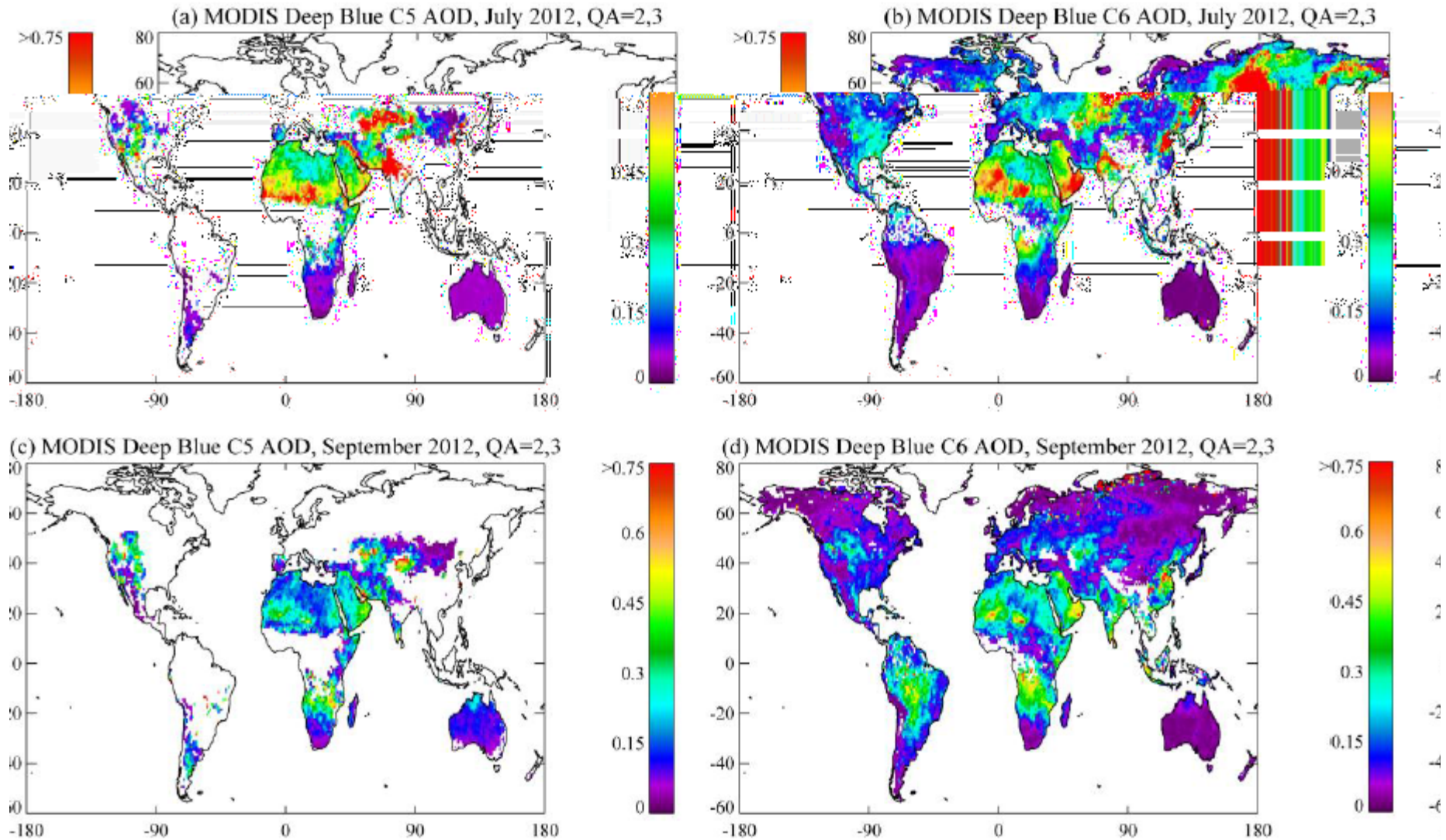
Images from NASA AERONET page, <http://aeronet.gsfc.nasa.gov/>

e-Deep Blue: C6 flow chart



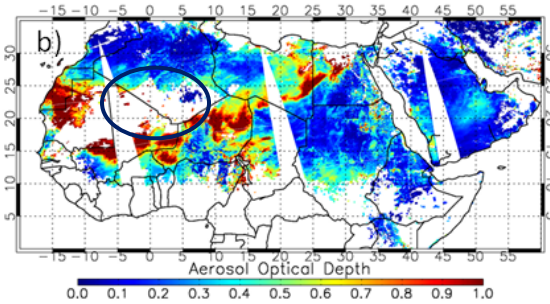
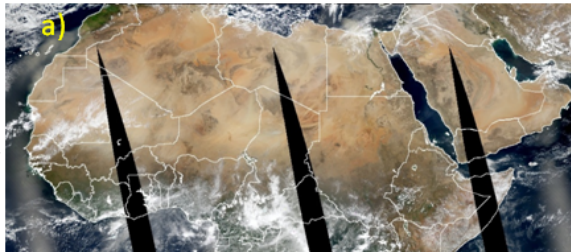
- Described by Hsu *et al.*, *JGR* (2013)

MODIS C6: extended spatial coverage



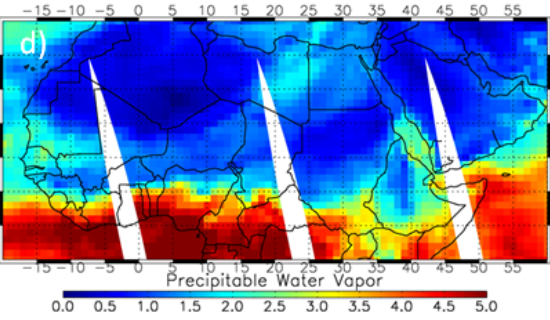
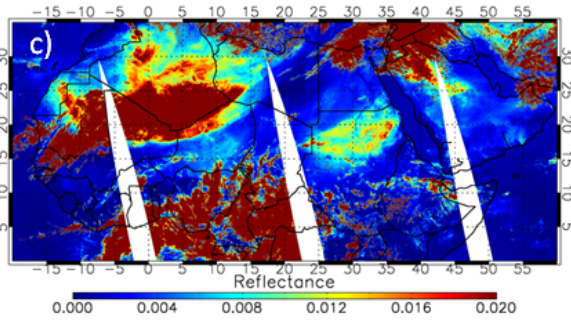
MODIS C6: improved cloud screening

MODIS RGB image over northern Africa on March 7, 2006



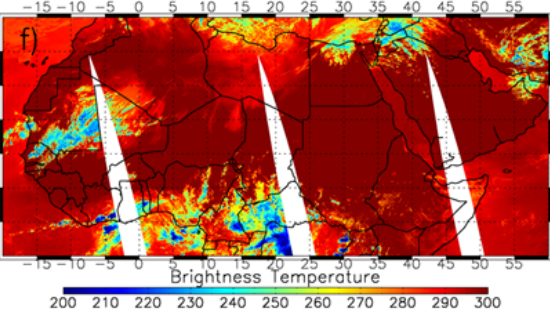
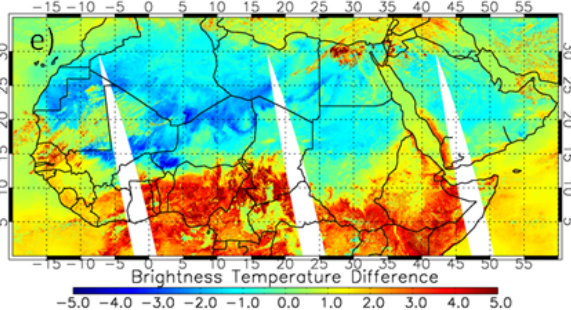
MODIS C5
Deep Blue
AOD

TOA
Reflectance
at 1.38 μm



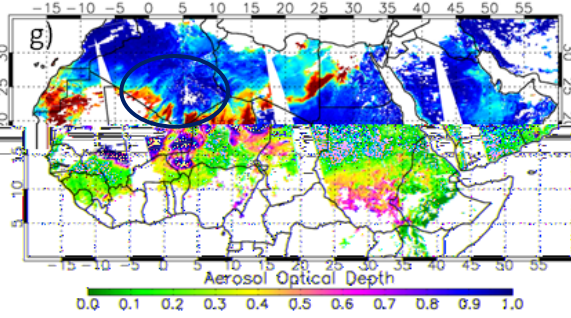
Precipitable water
vapor, cm

BTD,
11-12 μm , K



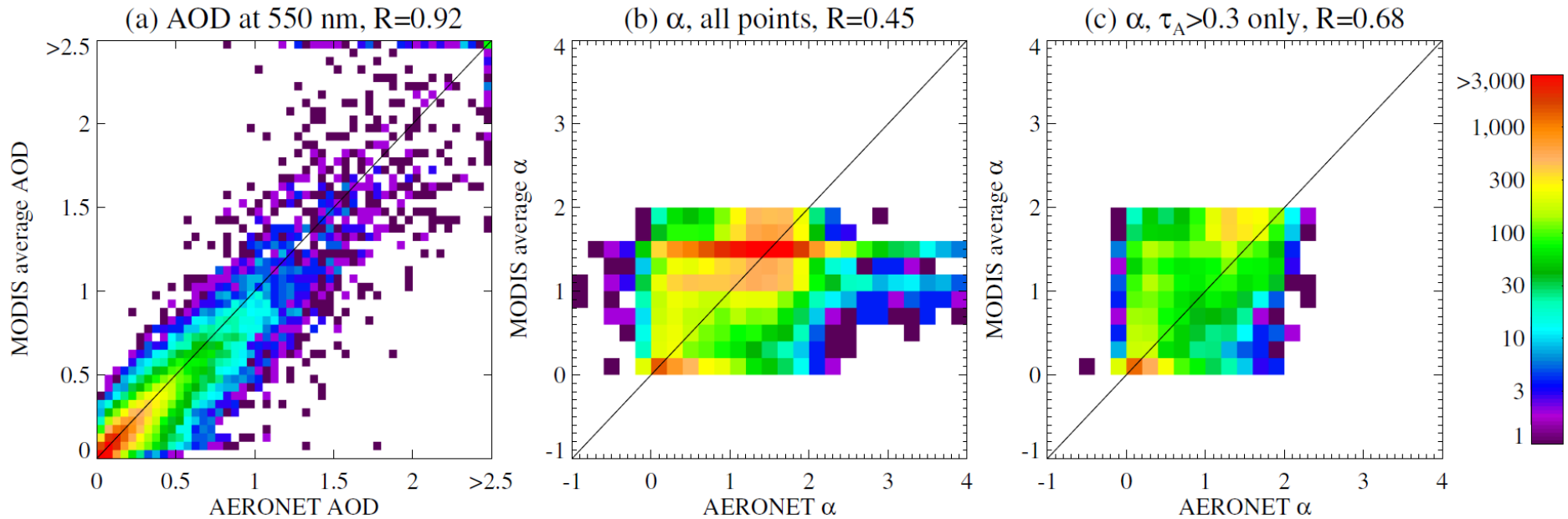
Brightness
temperature at
11 μm , K

MODIS
C6 Deep
Blue AOD



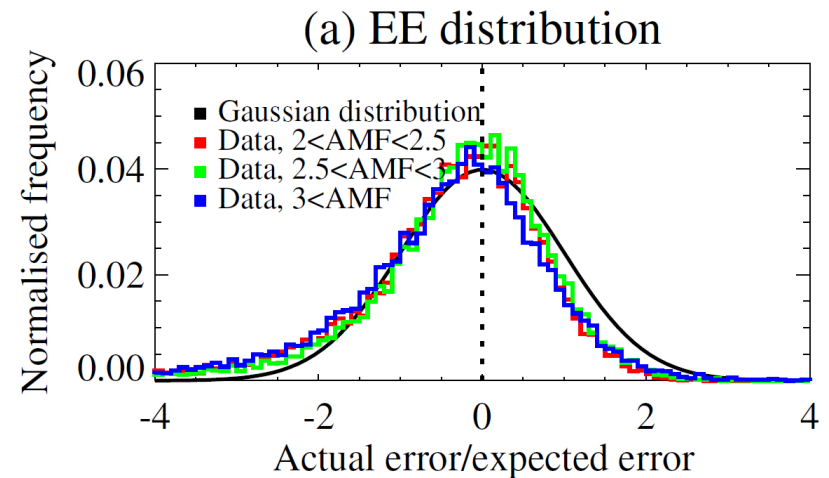
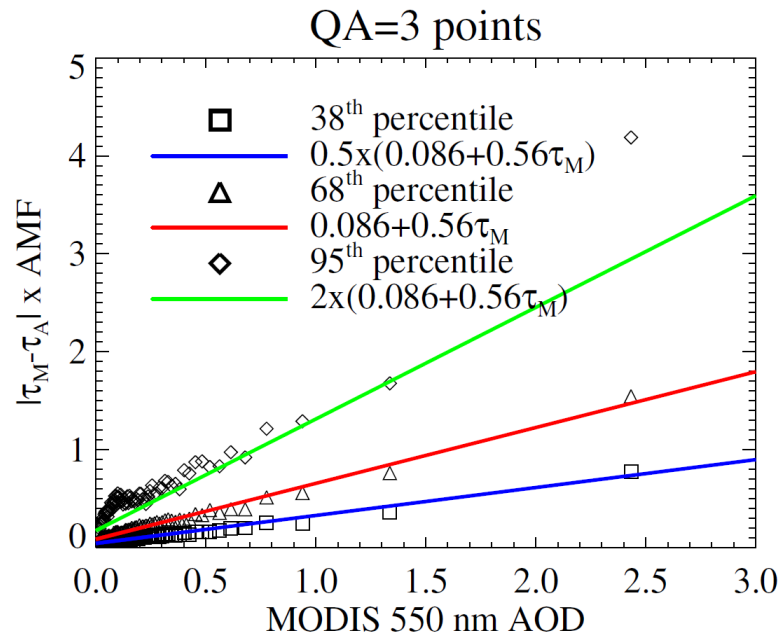
- Traditional cirrus detection techniques can fail over moisture-deprived regions

Validation



- See Sayer *et al.*, JGR (2013)
- AOD at 550 nm well-correlated with AERONET
 - AOD at other wavelengths shows similar behaviour
- AE (denoted α here) shows little skill in low-AOD cases, some skill for higher-AOD cases
 - Note AERONET AOD also has some uncertainty in low-AOD conditions

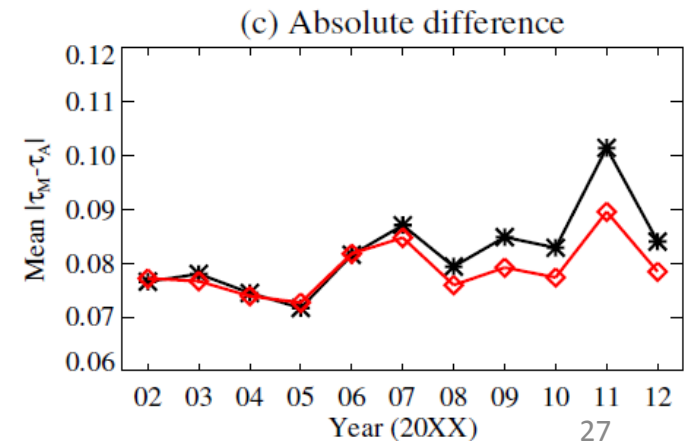
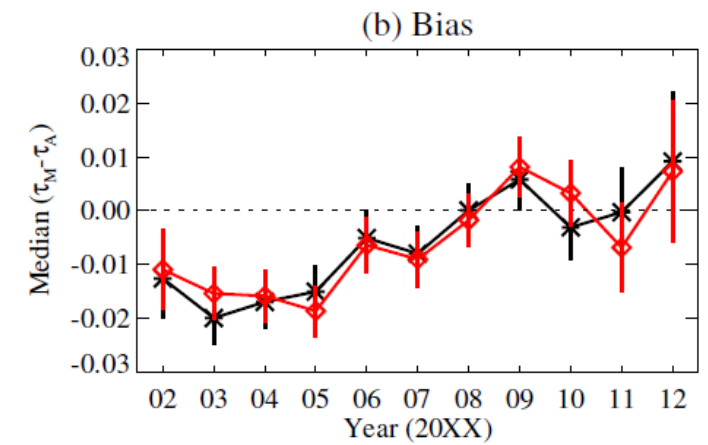
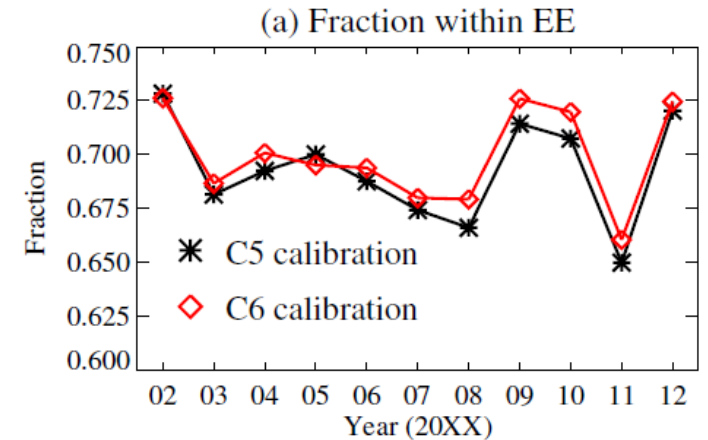
Retrieval-level uncertainty estimates



- See Sayer *et al.*, JGR (2013) for Aqua (Terra is similar)
- AOD at 550 nm uncertainty estimates as a function of AOD, QA level, and geometric air mass factor (AMF)
 - For typical AMF, uncertainty of order $0.03 + 20\%$
 - Provided within level 2 products for each individual retrieval
 - Prognostic, not diagnostic
 - Determined by validation against AERONET, in line with theoretical values
 - Estimates designed to represent a Gaussian one standard deviation confidence interval

Importance of Level 1 radiometric calibration

- Effort by MODIS Characterization Support Team to improve absolute and temporal stability of MODIS level 1 calibration
 - Important for minimising error in AOD/AE retrieval, especially long-term trends (Sayer *et al.*, JGR 2013)
 - Assess calibration via long-term stable surface targets, the moon, and intersensor calibration
 - Verify through validation at long-term AERONET sites
 - Aqua drift became more noticeable in more recent years (2008+)
 - MODIS Terra is older and has degraded more strongly, which is why C6 has taken longer for Terra
- Collection 6 data for both Terra and Aqua have a better Level 1 calibration, leading to more stable Level 2 data, with lower uncertainties



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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
 - Aqua L2 available now, Aqua L3 imminently, Terra L2/L3 shortly after
- Please use the data, ask questions, tell us when you find something unusual/exciting
 - We are happy to help, and it's nice to hear from users

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

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