

The Collection 6 MODIS Aerosol products

“Dark target team”:

Robert Levy, Shana Mattoo, Leigh Munchak, Richard Kleidman (SSAI and NASA/GSFC),
Lorraine Remer (now UMBC)

“Deep blue team”

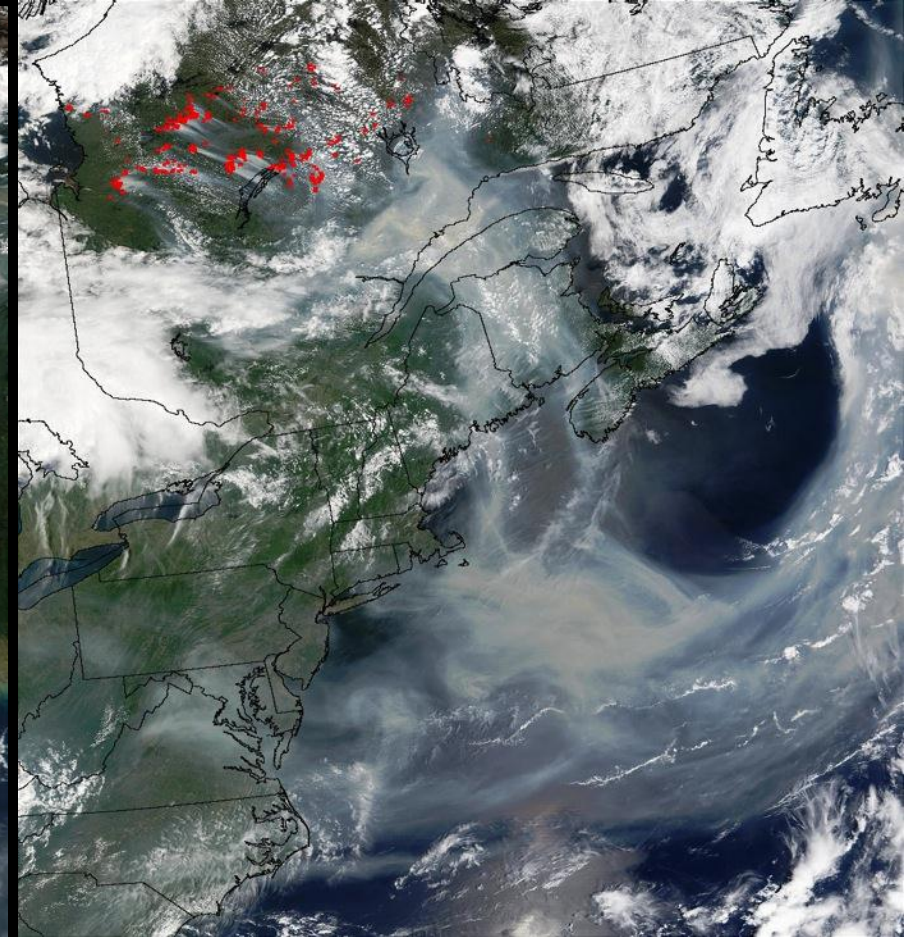
Christina Hsu (NASA), Andy Sayer (USRA and NASA), Corey Bettenhausen (SSAI/NASA)



Aerosols (why do we care?)

- They affect visibility
- They affect human health and morbidity
- They enable clouds and precipitation
- They have roles in Earth's chemical cycles
- They directly impact the radiative budget
- They are both natural and manmade
- They are inhomogeneous in space and time
- Their distributions are changing
- **We need aerosol climate data records.**

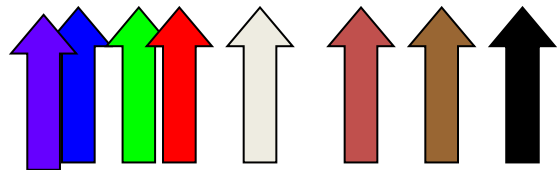
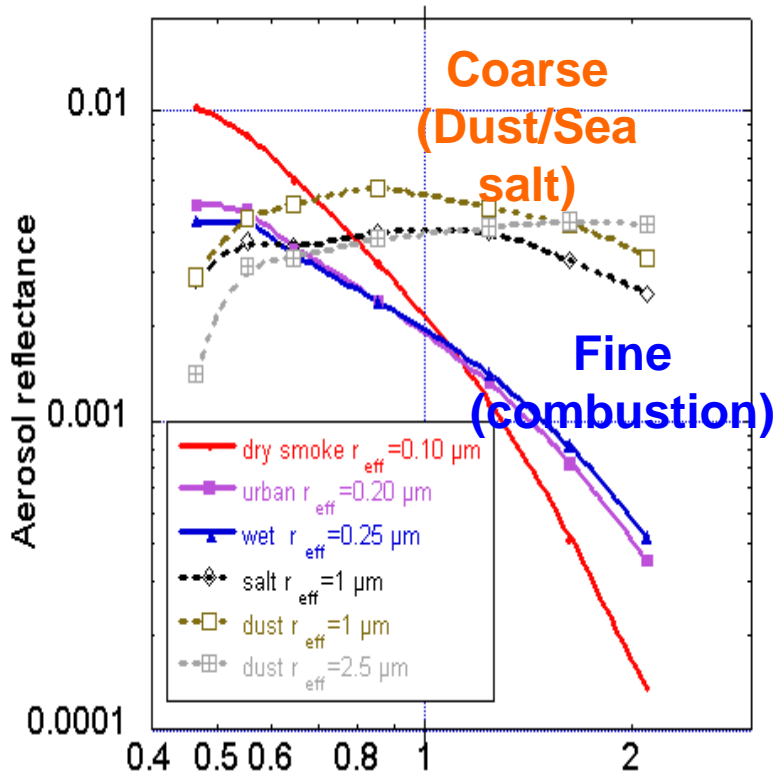
Haze and Smoke from space



Haze over the Ganges/Bay of Bengal (4 December 2001)

Smoke transported over Eastern Canada/USA (8 July 2002)

Spectral optical properties of aerosol



MODIS "Channels"



"Big" particles (e.g. Dust) reflect in IR
 "Small" particles (smoke/pollution) do not.

MODIS

Moderate resolution Imaging Spectroradiometer

Orbit: 705 km, sun-synchronous, over same point every 16 days

Equator crossing: 10:30 (Terra, since 2000), 13:30 (Aqua, since 2002)

Swath: 2330 km (55° cross track)

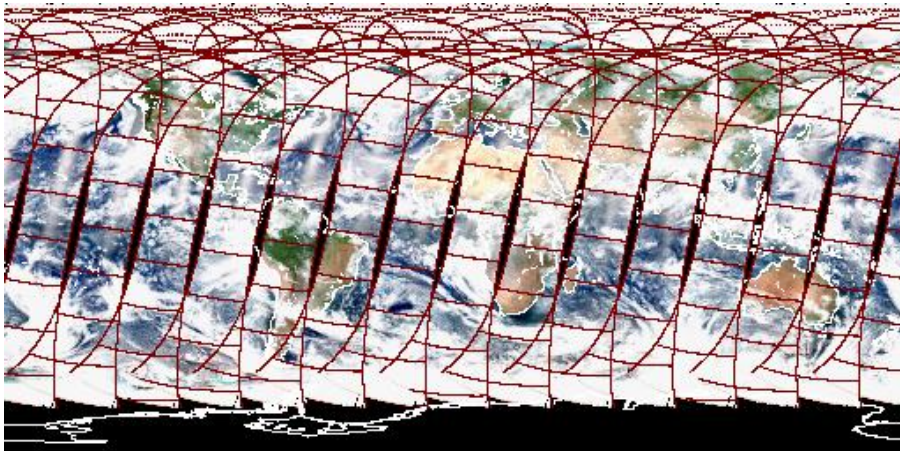
Spectral Range: 0.4-14.4 μ m (36 bands)

Spatial Resolution: 250m (2 bands) 500m (5 bands) 1000m (29 bands)

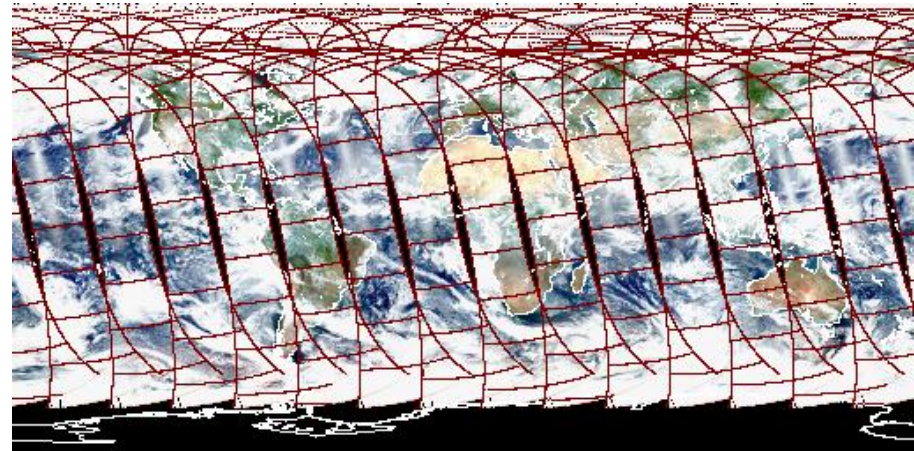
Calibration: On-board and continuously updated

Can observe: Clouds, Aerosols, Ocean Color, Temperature, Vegetation, Fires, etc.

Terra (10:30 Local Time, Descending)



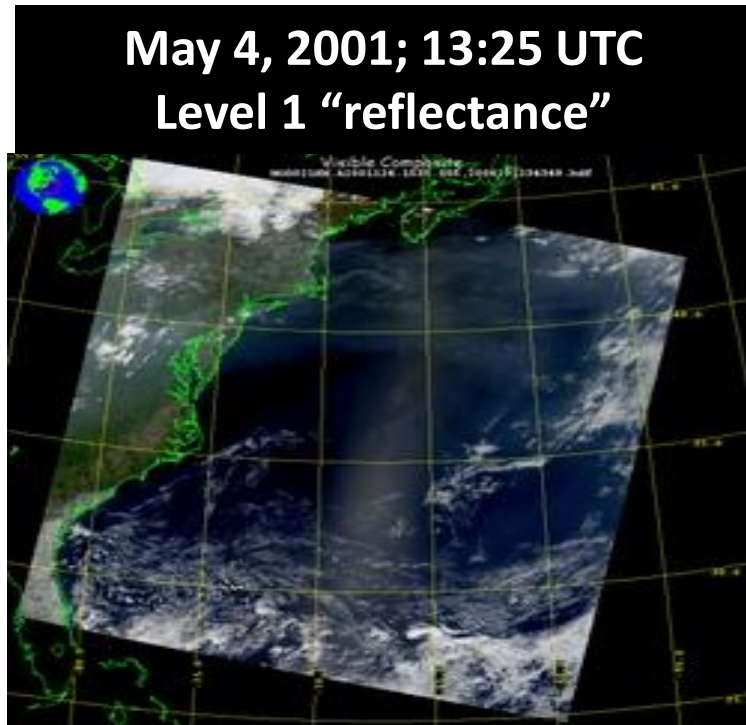
Aqua (13:30 Local Time, Ascending)



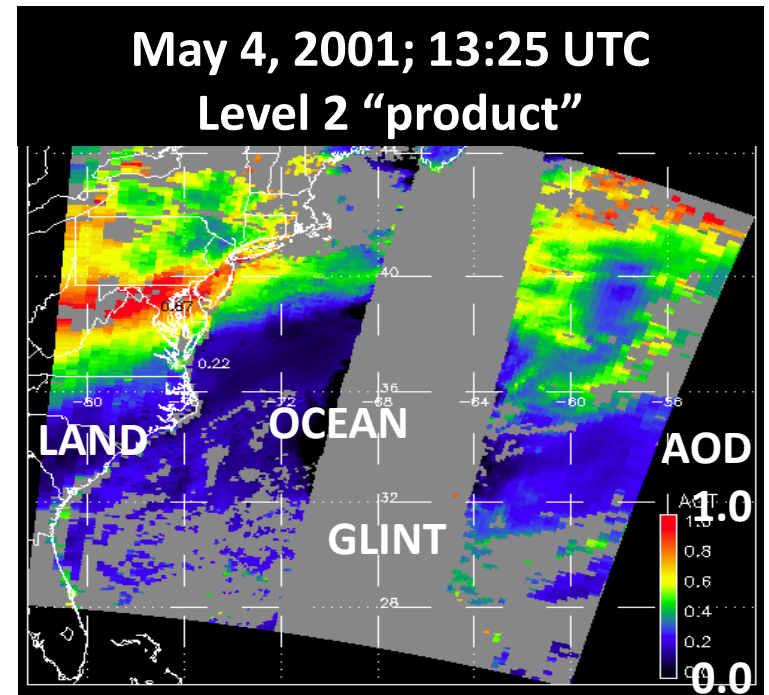
Twin MODIS instruments – Two views per day!

Aerosol retrieval from MODIS

What MODIS observes



Attributed to aerosol (AOD)



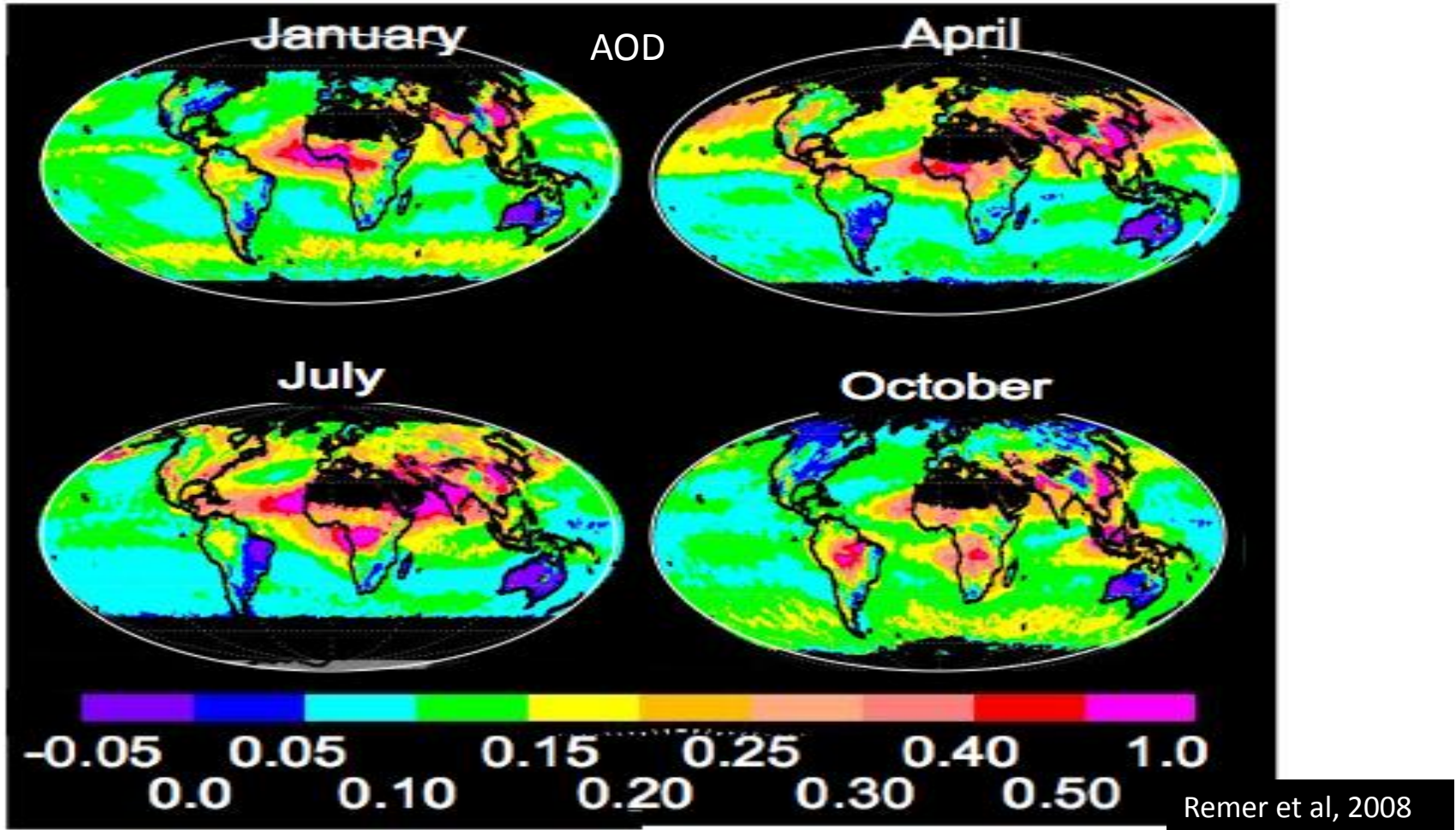
There are many different “algorithms” to retrieve aerosol from MODIS

1. **Dark Target (“DT” ocean and land; Levy, Mattoo, Munchak, Remer, Tanré, Kaufman)**
2. Deep Blue (“DB” desert and beyond; Hsu, Bettenhausen, Sayer,..)
3. MAIAC (coupled with land surface everywhere; Lyapustin, Wang, Korokin,...)
4. Ocean color/atmospheric correction (McClain, Ahmad, ...)
5. Etc (neural net, model assimilation, statistical, ...)
6. Your own algorithm (many groups around the world)

MODIS view of global aerosol system (over dark targets)

As envisioned by Y. Kaufman and D. Tanré

And produced by the MODIS-aerosol team at NASA GSFC



We have two sophisticated sensors (aboard Terra and Aqua), with stable orbits, excellent calibration teams and validated aerosol retrievals.

Outline

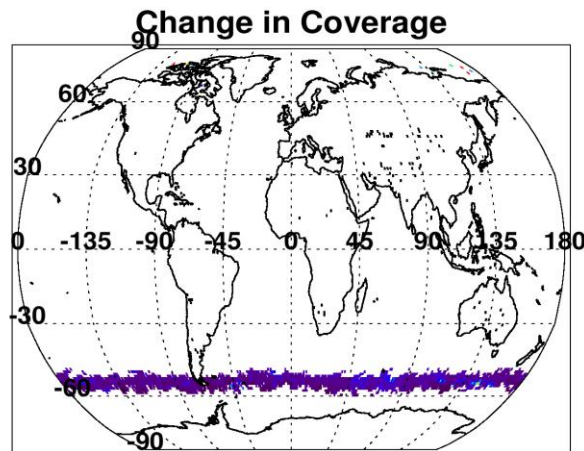
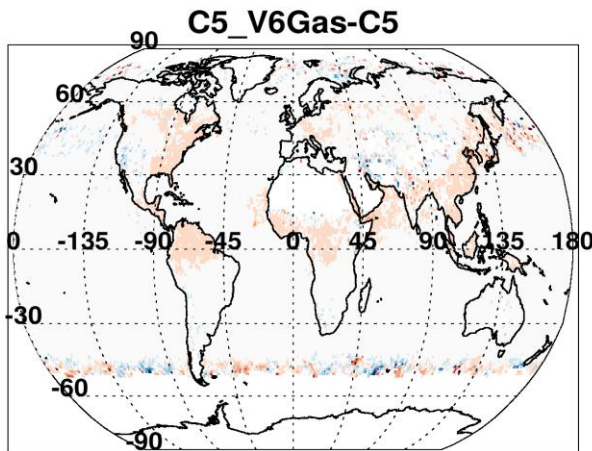
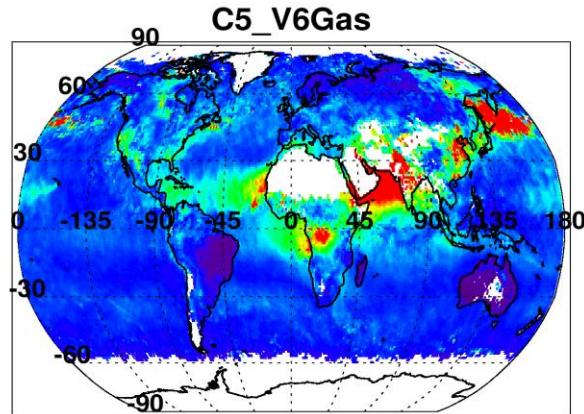
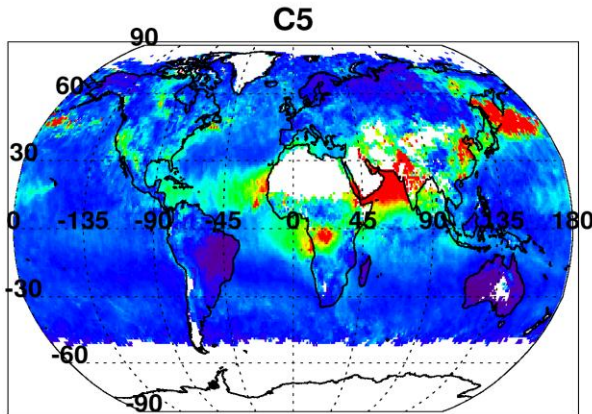
- Dark-target updates for C006
- MODIS aerosol trends and calibration?
- Dark target/Deep blue merge
 - The collection 6 aerosol product
- 3 KM resolution products for air quality applications**
- Future with Suomi-NPP VIIRS**

** If time and interest...

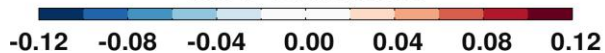
Dark target algorithm updates

LUT consistency (ocean VS land)

Jul 2008: Aqua



AOD Difference



AOD at 550 nm



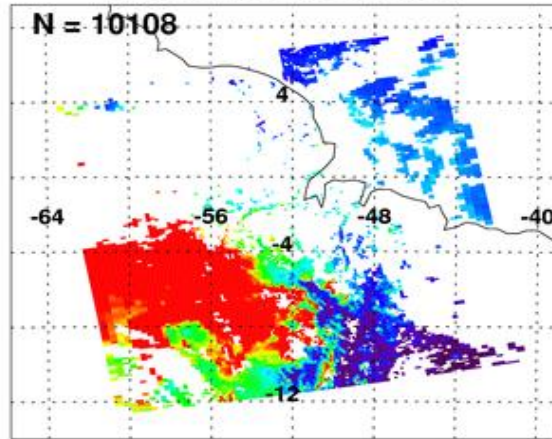
- Recalculate “center wavelengths” from MODIS filter functions
- Recalculate gas absorption coefficients and optical depths for H₂O, O₃, CO₂, NH₃, O₂, etc
- Extend valid solar zenith angle from 72° to 84°.

Update cloud masking (ocean & land)

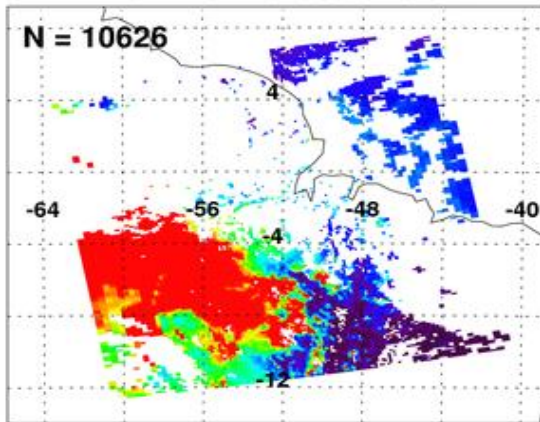
MYD04_L2.A2010227.1705.hdf



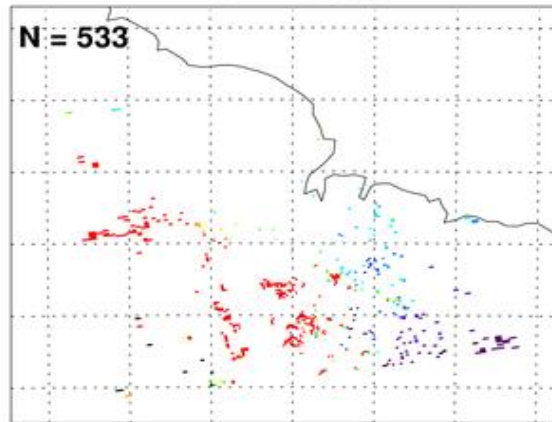
Without cloudmask



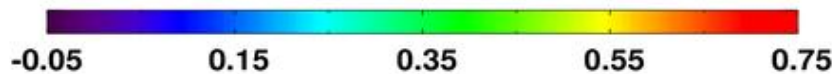
With new cloudmask



New Pixels



AOD at 550 nm



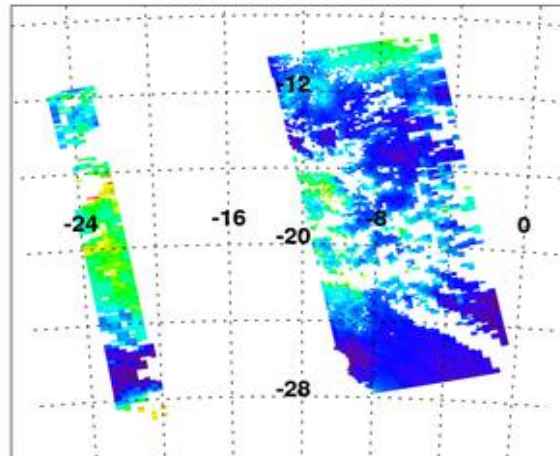
- Retrieve more “heavy smoke” cases
- Retrieve fewer “thin cirrus” cases
- Correct assignment of QAC due to clouds

Introduce wind speed dependence (ocean)

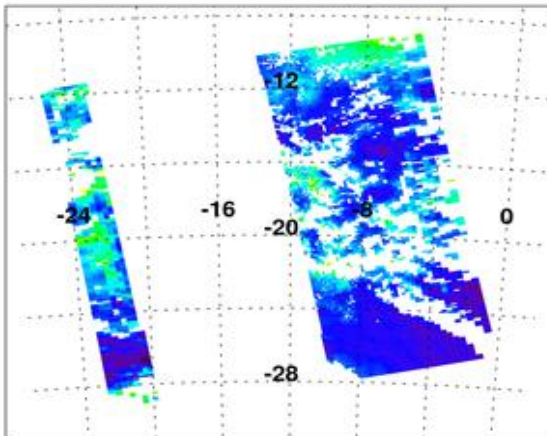
MYD04_L2.A2010018.1440.hdf



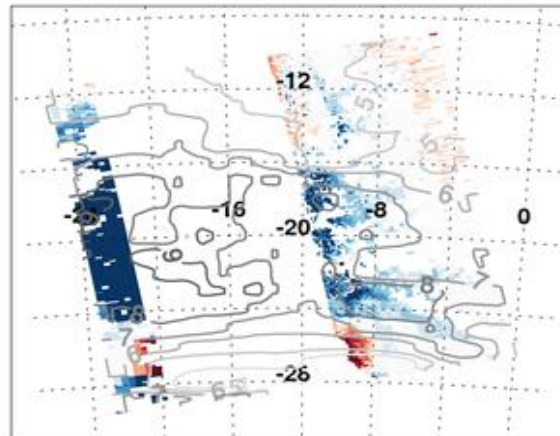
6 m/s winds



NCEP winds



NCEP winds - 6 m/s winds



AOD at 550 nm

AOD Difference

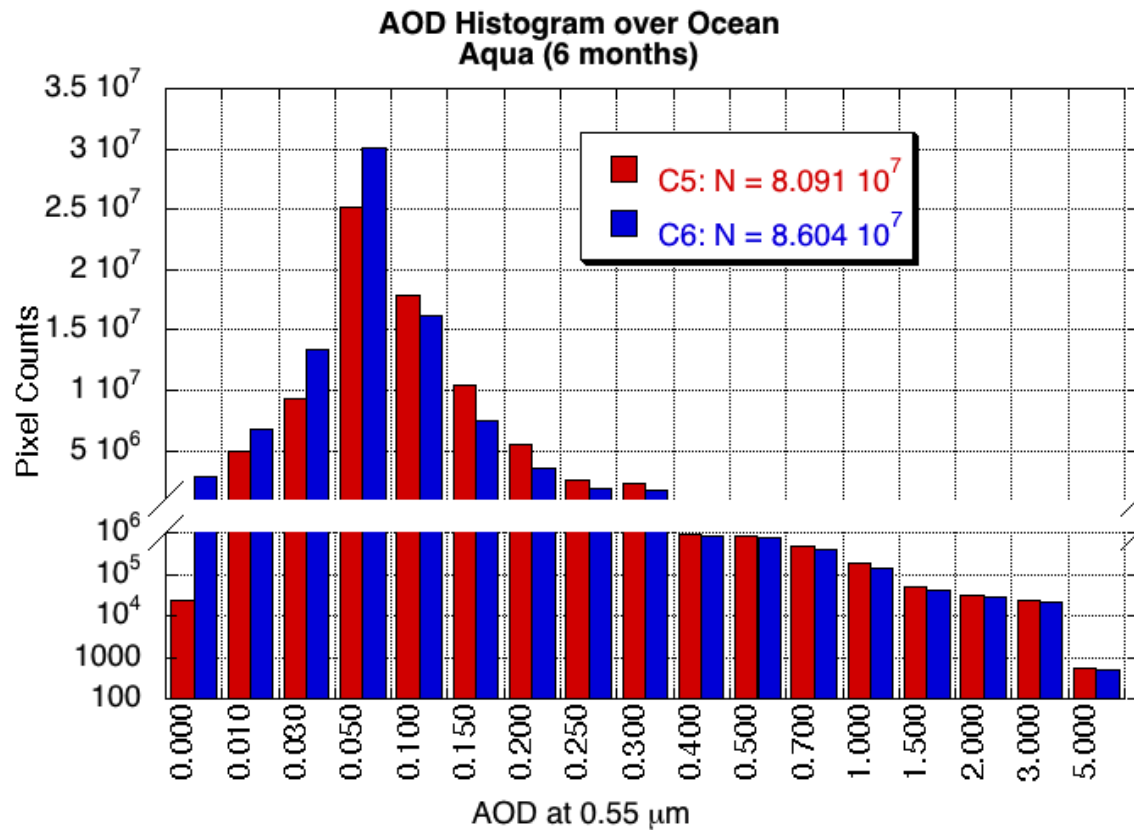
0.00 0.10 0.20 0.30

-0.03 -0.02 -0.01 0.00 0.01 0.02 0.03

- Higher wind speeds
→ more ocean foam
and diffused glitter
pattern
- Aerosol LUT now
calculated for 4 wind
speeds
($v=2, 6^*, 10, 14$ m/s)
- Retrieved AOD
reduced when $v \geq 6$
- Reduced AOD near
 40° glint mask edges
and in “Roaring 40s”
of southern Oceans.

Example of “minor” update

Quality assurance over ocean



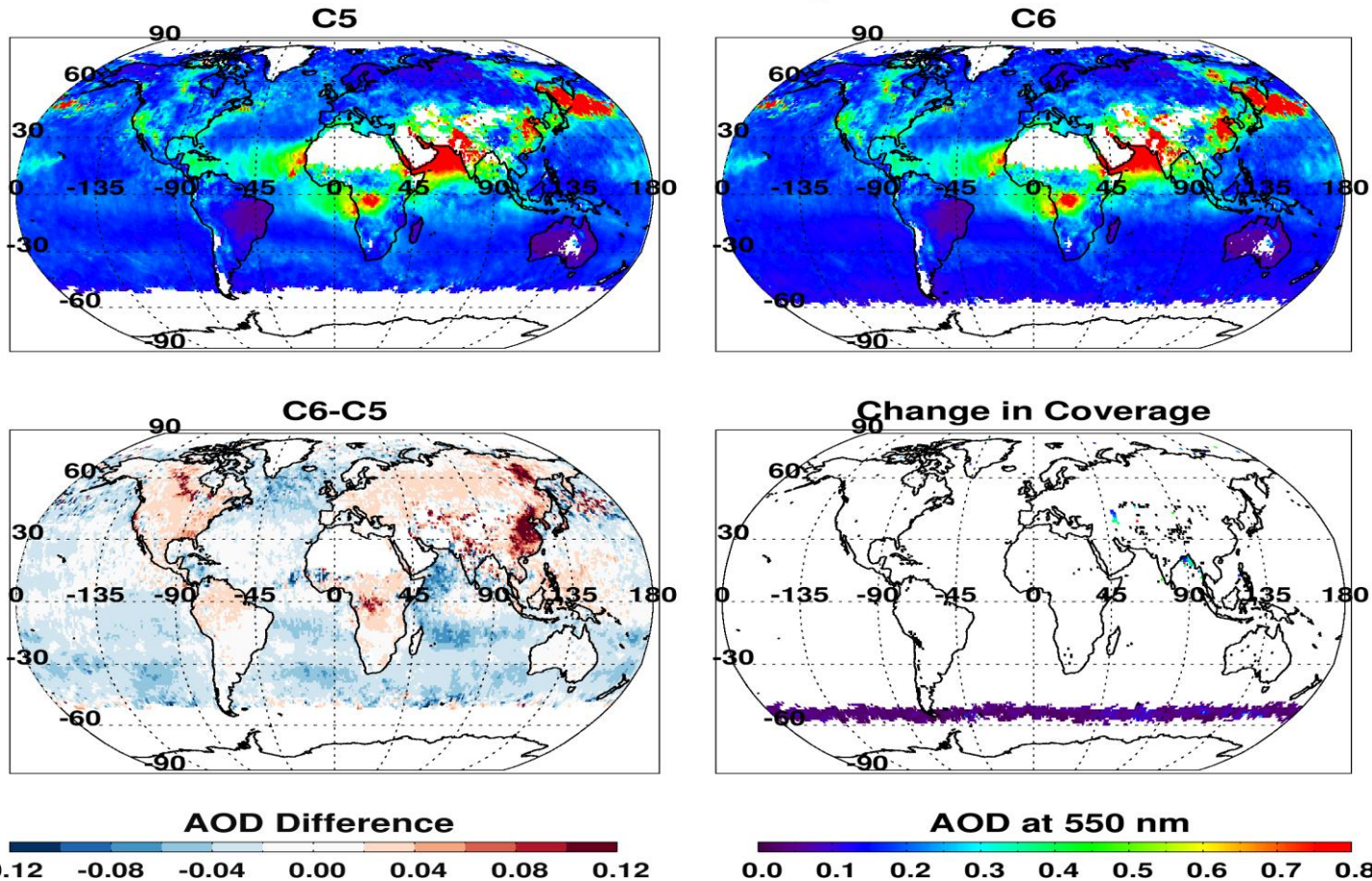
- Old (C5): Quality assurance depends on success of a retrieval solution. If aerosol signal is too small, then do not include in daily/monthly statistics.

New (C6) : Sometimes signal is small, but we are confident that it is small. Include in daily/monthly statistics.

- But “major” influence on estimating regional and global mean AOD

Results from algorithm changes

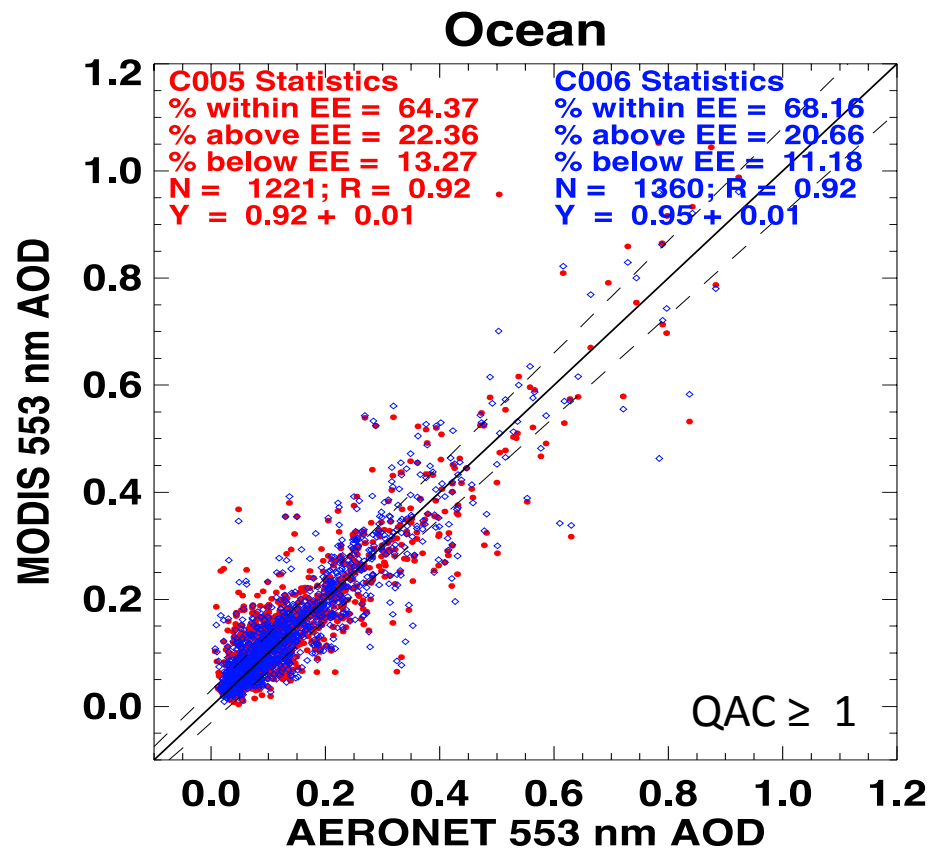
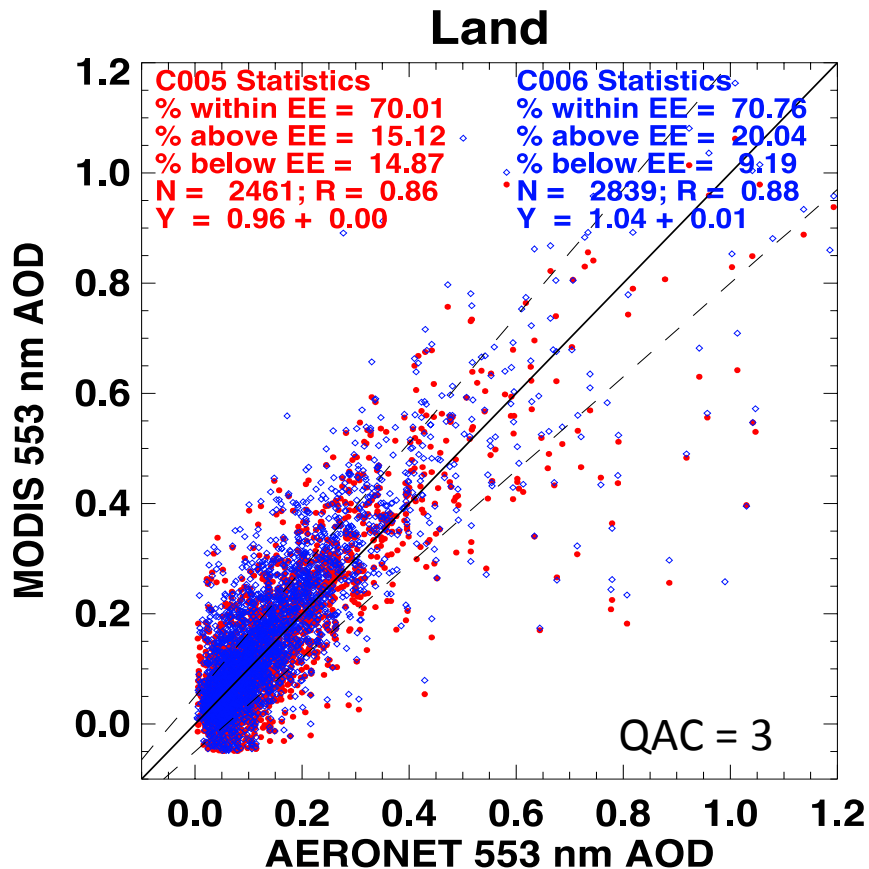
Jul 2008: Aqua



- Retrieval technique remains same as C005
- Differences due to updates in quality flagging, cloud masking, pixel selection, gas correction, use of wind speed over ocean, ...
- Products available beginning fall 2012.

Scatterplots

6 months testing (on Aqua)



- No major changes, but 10-20% more valid collocations with AERONET
- C6 algorithm has slightly better (68% vs 64%) retrieved over ocean

MODIS: Climate Data Records (CDRs)?

“A time series of measurements of sufficient length, consistency, and continuity to determine climate variability and change.”



From: Climate Data Records from Environmental Satellites: Interim Report (2004)

Some requirements

- Measurements sustained over decades
- Measurement of measurement performance (e.g. calibration, stability)
- Acquired from multiple sensors / datasets

Have we sufficiently characterized the MODIS aerosol product?

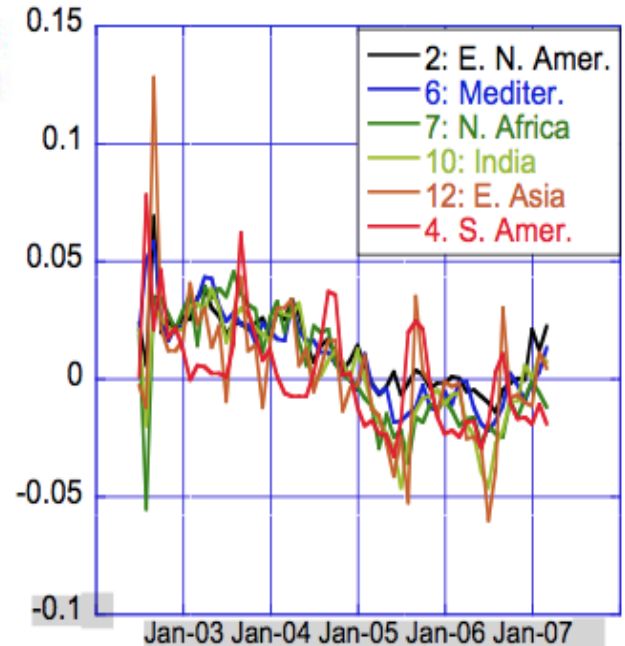
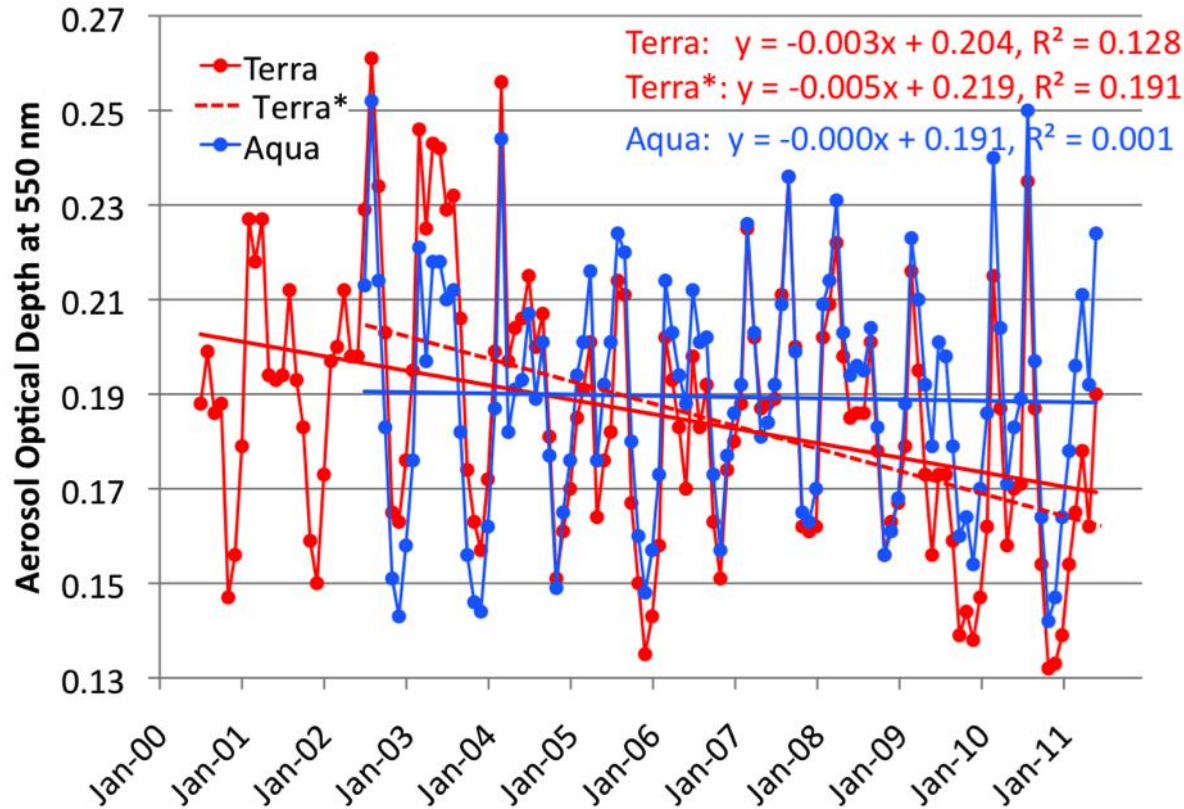
From C5 data,
we have “validated” DT aerosol products, and we have >10 years of data

so...

Is global aerosol increasing or
decreasing?

Answer: ??????

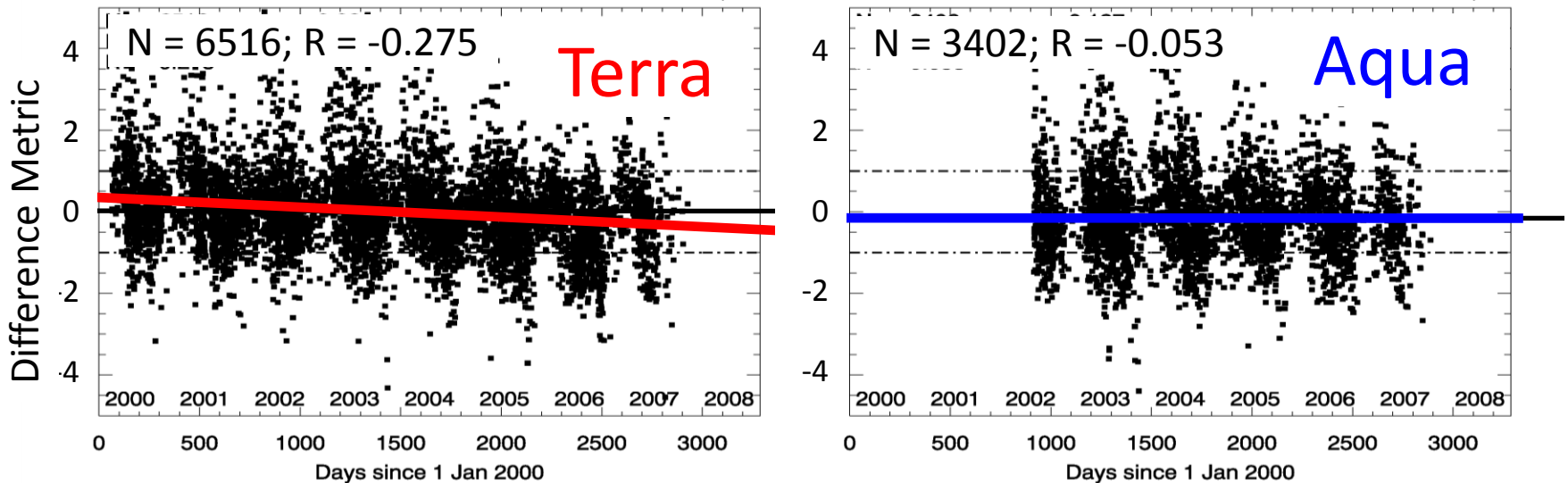
MODIS AOD Monthly Mean - Land Only



- Over land, **Terra** decreases (-0.04/decade), **Aqua** constant
- **Terra** / **Aqua** divergence is the same everywhere on the globe!
- So, probably not due diurnal cycle of aerosol
- Why?

MODIS trends with respect to AERONET

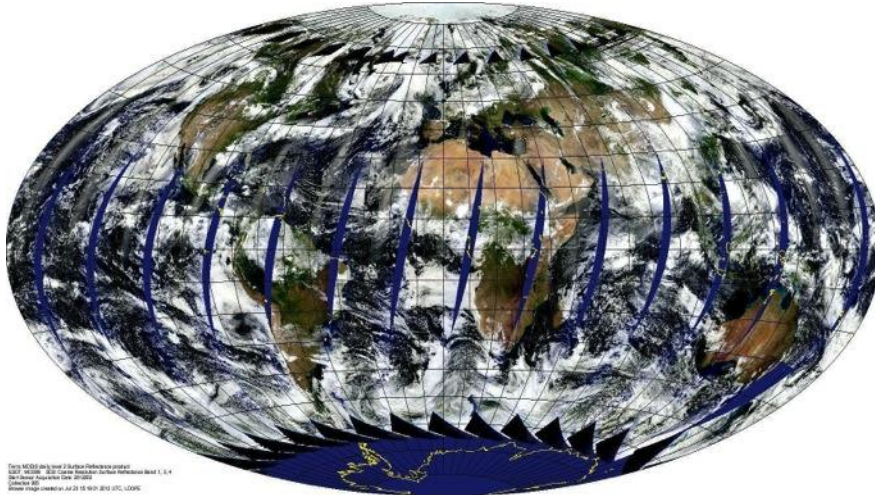
Trends of MODIS-AERONET “agreement” over time (land)



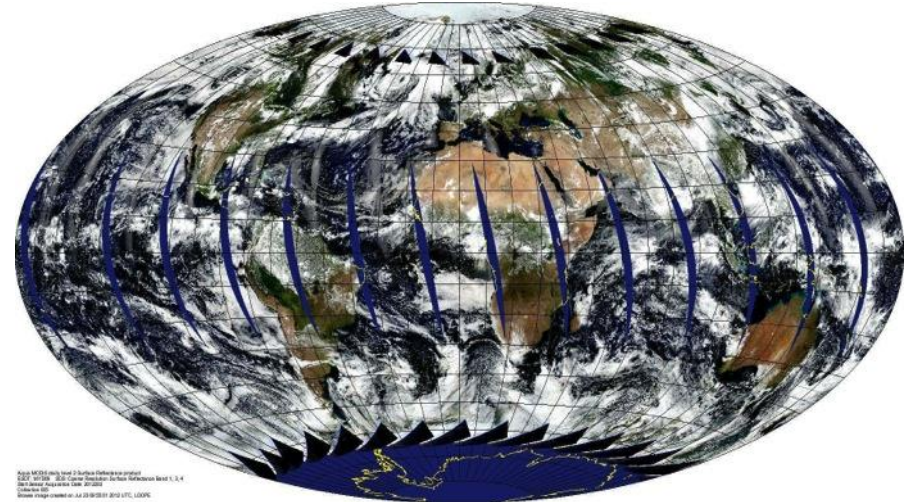
- Over land: 14 AERONET sites with >7 years of data
- Difference Metric *decreases* for **Terra**:
 - Pre-2004, MODIS overestimates AOD
 - Post-2004 MODIS underestimates AOD.
- divergence of **Terra** – AERONET consistent with **Terra** – **Aqua**!
- Why?

MODIS instruments = “identical twins”

Terra (10:30 Local Time, Descending)



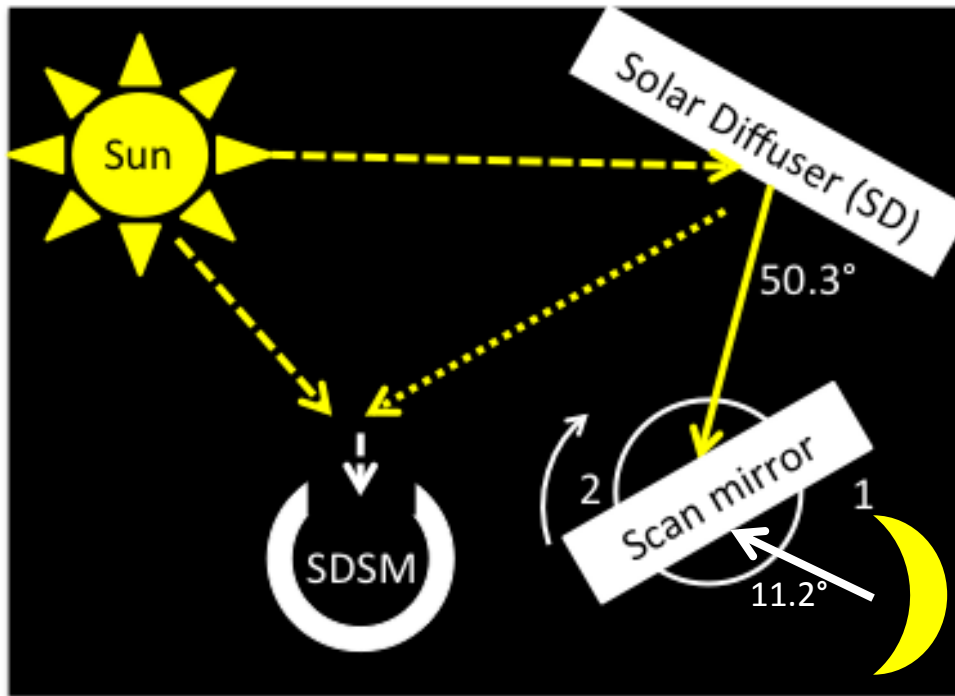
Aqua (13:30 Local Time, Ascending)



Like human twins:

- Each instrument has had a different life experience (pre-launch, during-launch, during orbit)
- They see the same world, but from different perspective
- Different *aging* patterns (for optics, sensor characteristics, electronics)
- **Have different personalities!!!**

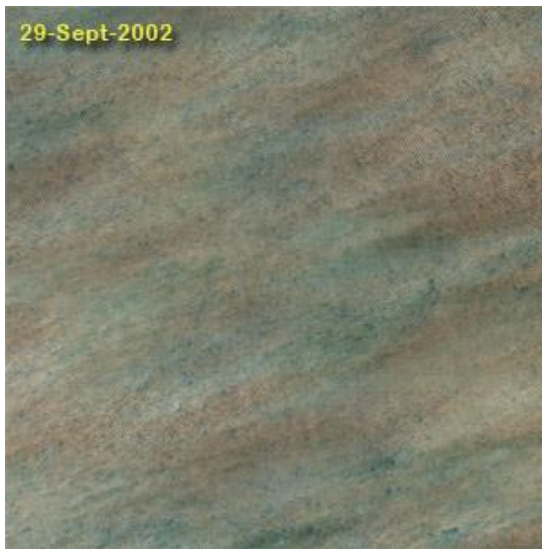
Instrument calibration tied to pre-launch assumptions



- The Solar Diffuser Stability Monitor (SDSM) views the Solar Diffuser (SD) at a fixed angle.
- The BRFs of the SD and mirrors were characterized pre-launch.
- What if the BRF of Terra's SD/mirrors has changed? (Accumulation of "junk").
- The SDSM and one angle wouldn't be sufficient to monitor changing BRF.



MODIS reflectance trends over desert sites



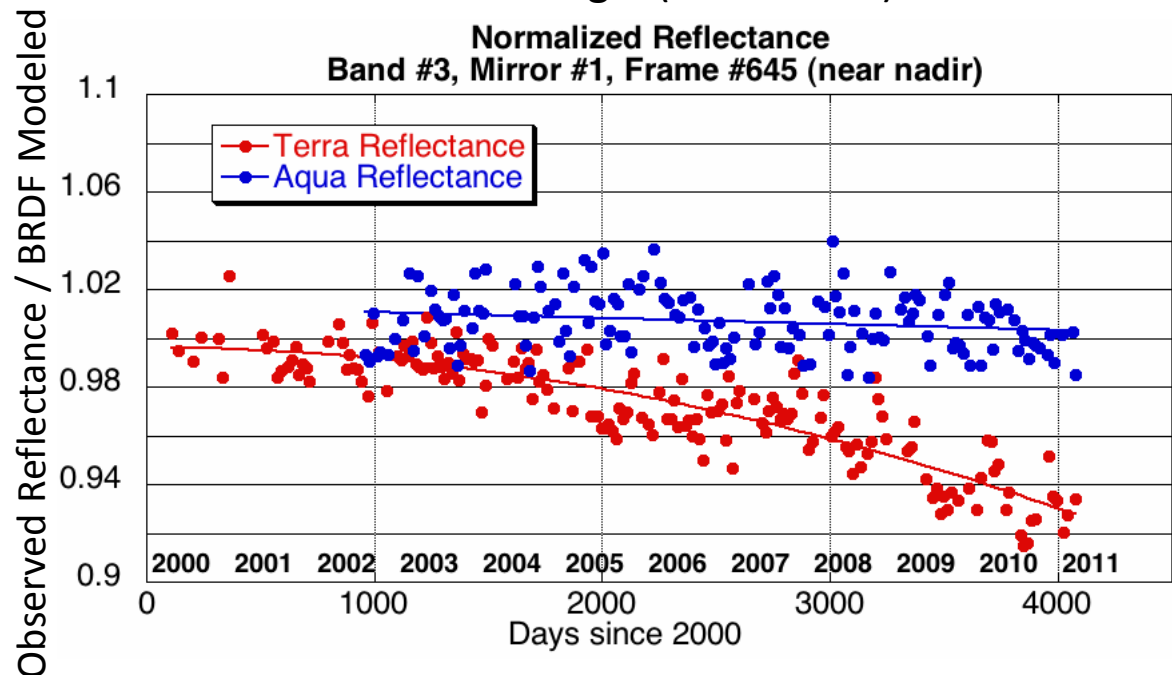
desert test sites



MCST (Sun, Xiong et al)

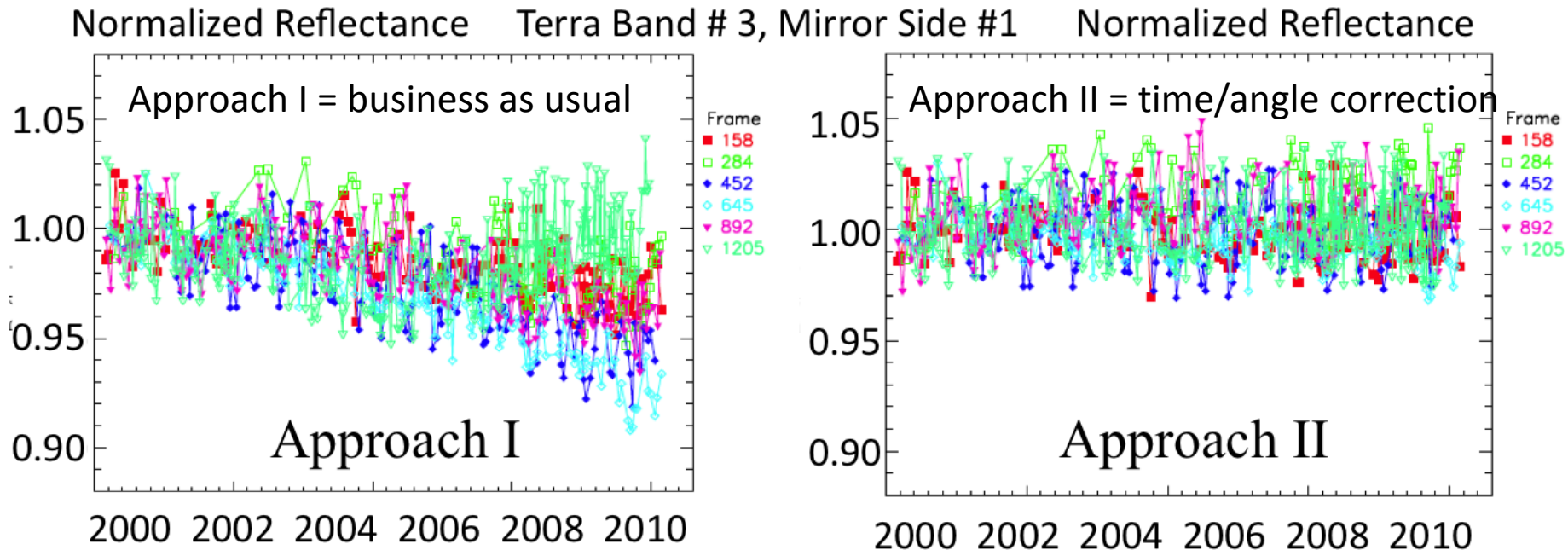
- (1) Collect clear-sky MODIS data over desert sites
- (2) Develop site-specific BRDF from first 3 years of mission
- (3) Over time, compare “observed” reflectance with BRDF modeled reflectance, for different view angles

- Trends in Terra Band #3 ($0.47 \mu\text{m}$). No trend for Aqua
- Trend varies with Scan Angle (or Frame #)



- (4) Apply de-trending algorithm to MODIS observations

Approach II applied to C6: Removes the temporal/angular reflectance trends



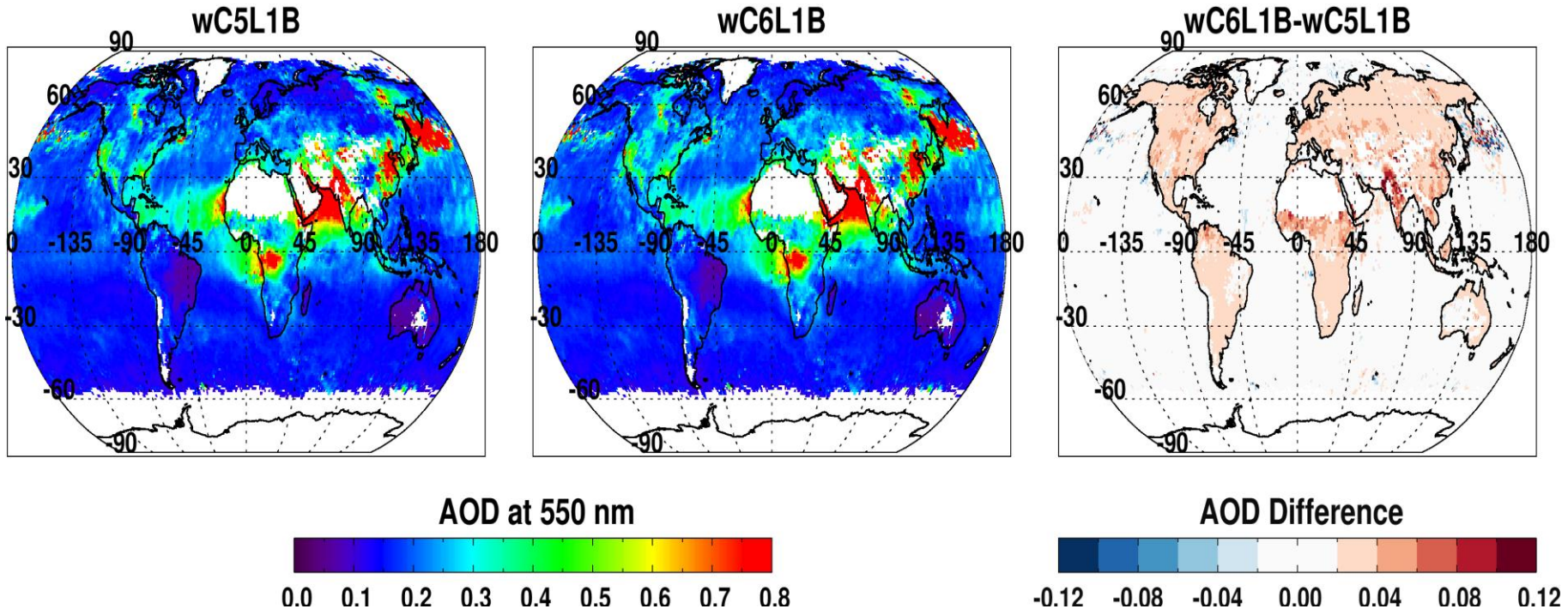
MCST: Junqiang Sun

- B3 (466 nm)
 - 7% decrease near nadir
 - 0% change on right (near Moon)
 - 3% increase on left

(5) Apply de-trended observations to aerosol retrieval algorithm

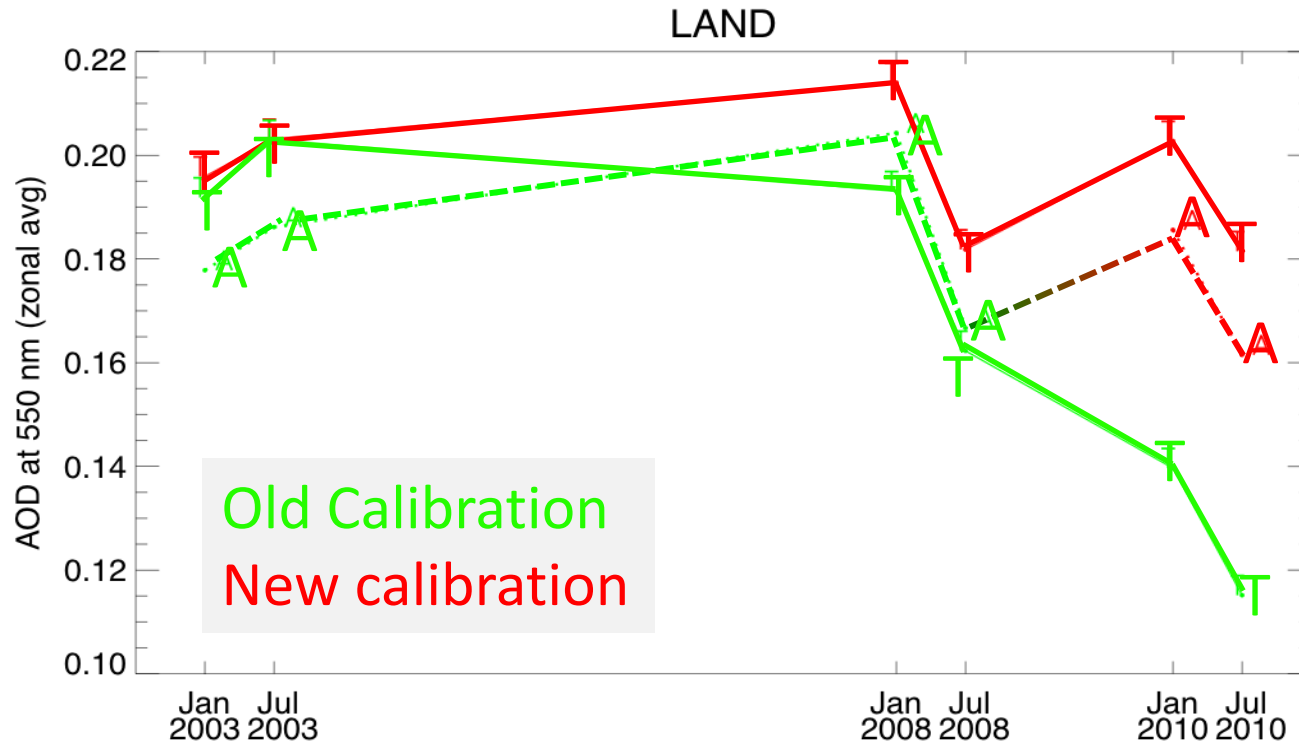
Impact of New Terra calibration

Jul 2008: Terra



- Main impacts over land
 - Global increase by 0.02 (for this particular month)
- Impact over ocean is small
 - Global increase by 0.004 (for this particular month)

Impact of new calibration on trend

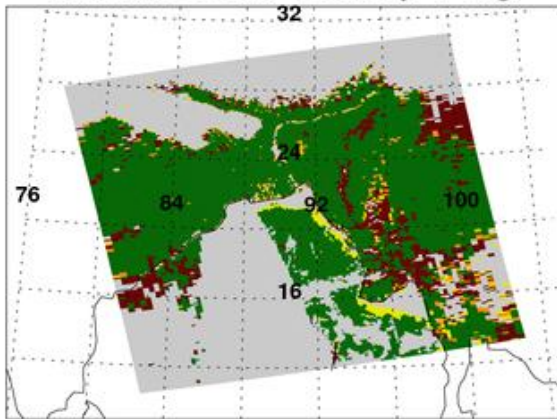


- 6 months processed with same dark-target aerosol algorithms
- Terra (T) Approach II now “in sync” with Aqua (A) time series
- (Terra-Aqua) offset remains 0.01 (ocean) and 0.015 (land)
- **New calibration → Terra/Aqua divergence removed for C006!**

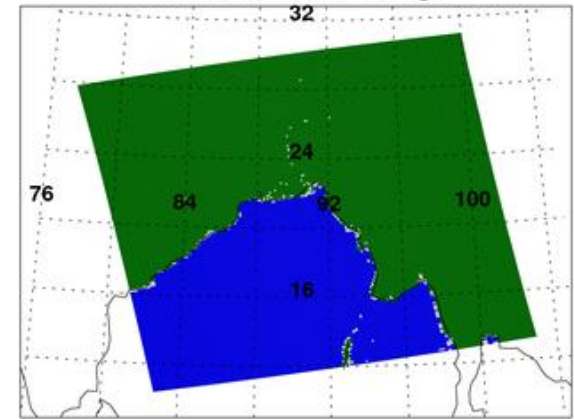
What else for C6 Level 2?

Users have complained, we listened: Diagnostic SDSs

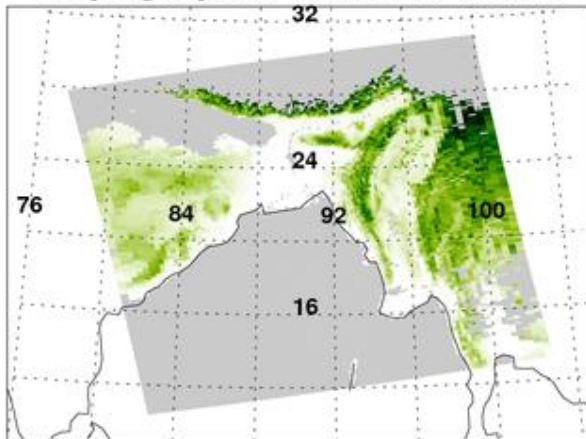
Land_Ocean_Quality_Flag



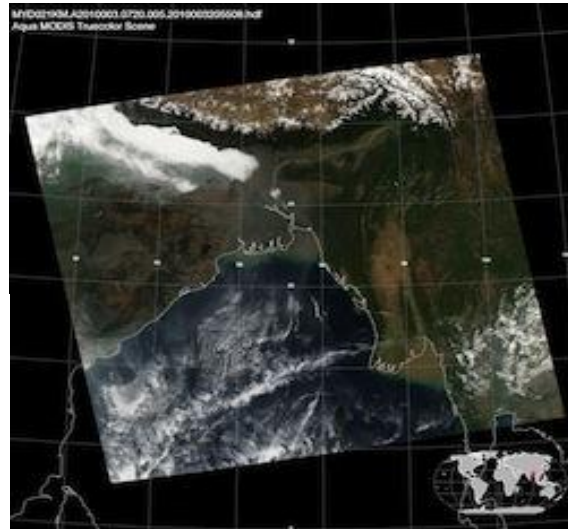
Land_Sea_Flag



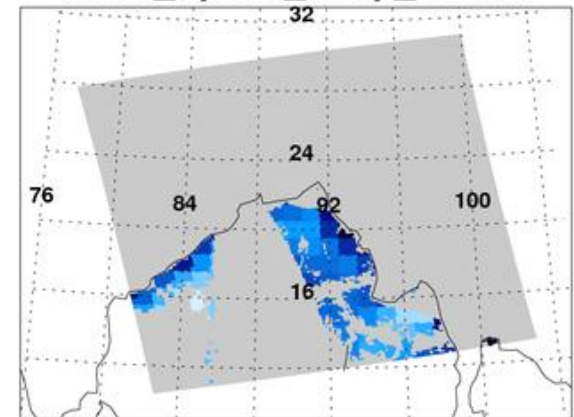
Topographic_Altitude_Land



Surface Height [km]



Wind_Speed_Ncep_Ocean

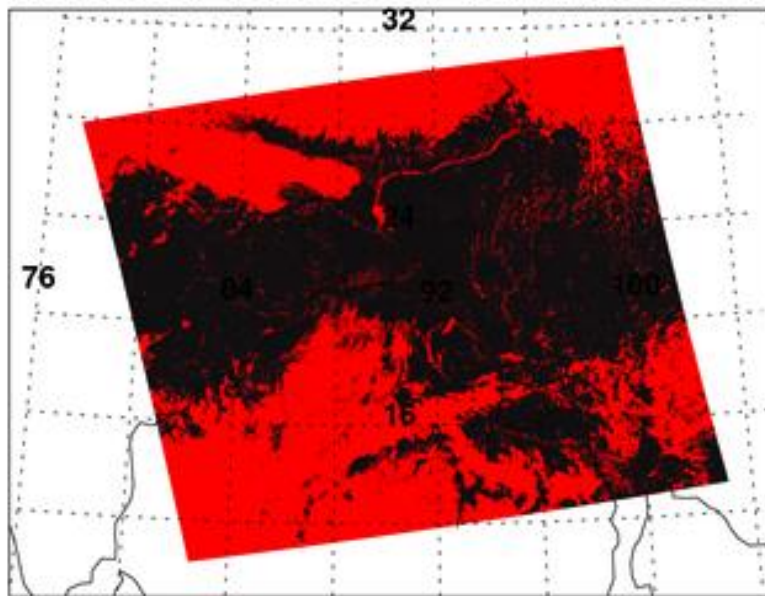


Wind Speed [m/s]



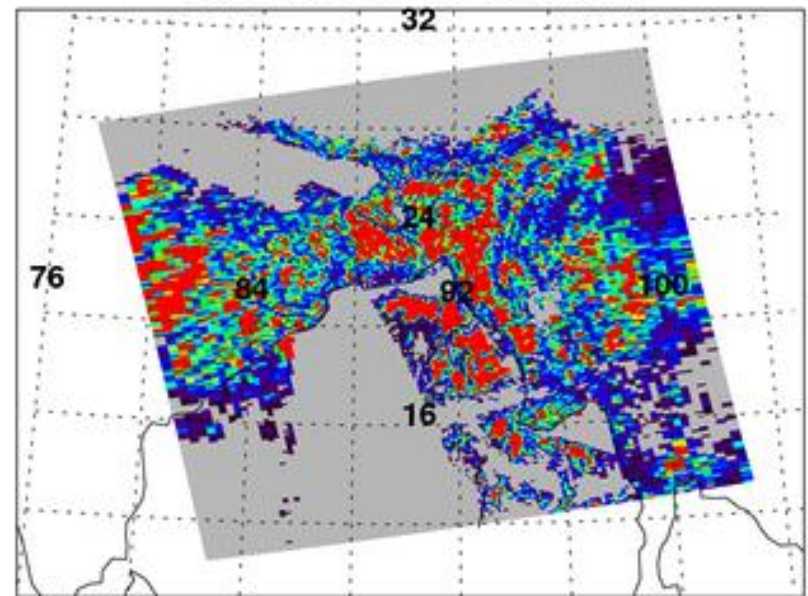
Cloud and Aerosol SDSs

Aerosol_Cldmask_Land_Ocean



500 meter resolution cloud mask used in aerosol retrieval. Can be (at times, significantly) different than MOD35

Distance to Cloud



Number of pixels between an aerosol retrieval and the closest cloud. Not thoroughly validated yet.

The Dark/Deep merge

what everyone has been looking forward to:

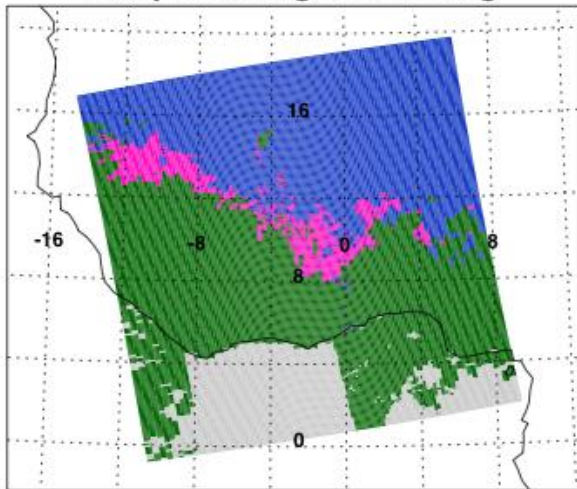
C. Hsu, A. Sayer, C. Bettenhausen, S. Mattoo, L. Munchak, R. Kleidman, et al.,

Jan 21 2010 at 13:40 UTC



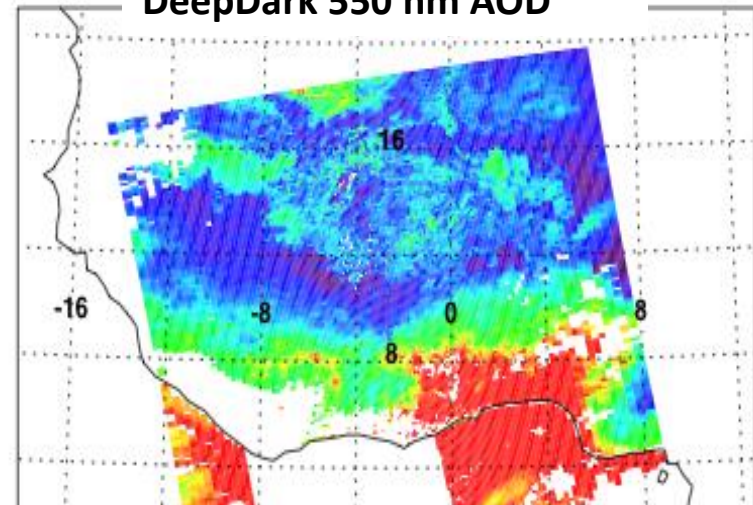
- **Dark**, **bright**, and **transitional** regions are identified by monthly mean NDVI
- In **Dark** regions, value from dark-target retrieval is used
- In **bright** regions, value from deep-blue is used
- In **transition** regions, AOD is merged, dependent on QA of retrievals

DeepDark Algorithm Flag



0: Dark Target 1: Deep Blue 2: Mixed

DeepDark 550 nm AOD

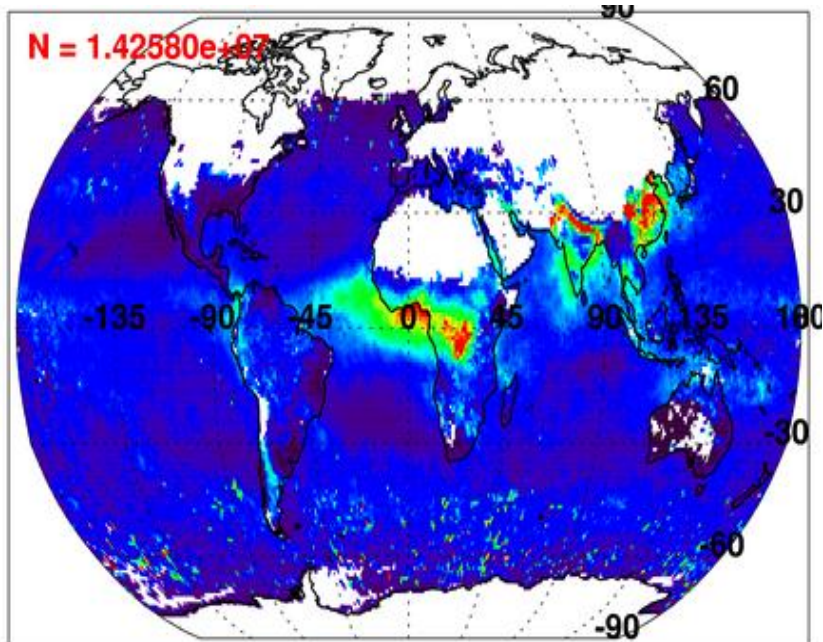


AOD at 550 nm

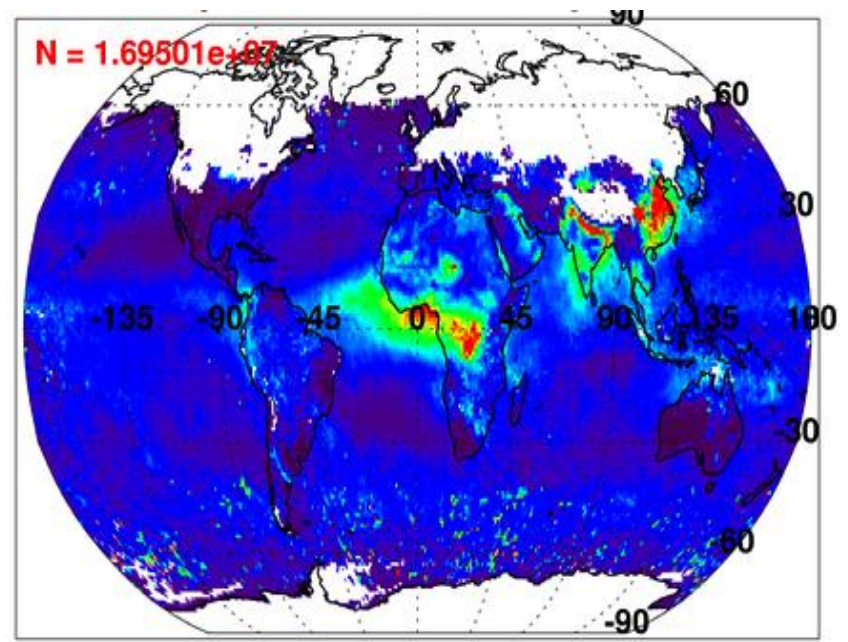
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

Monthly mean AOD for Aqua, January 2010

Dark Target AOD



DeepDark AOD



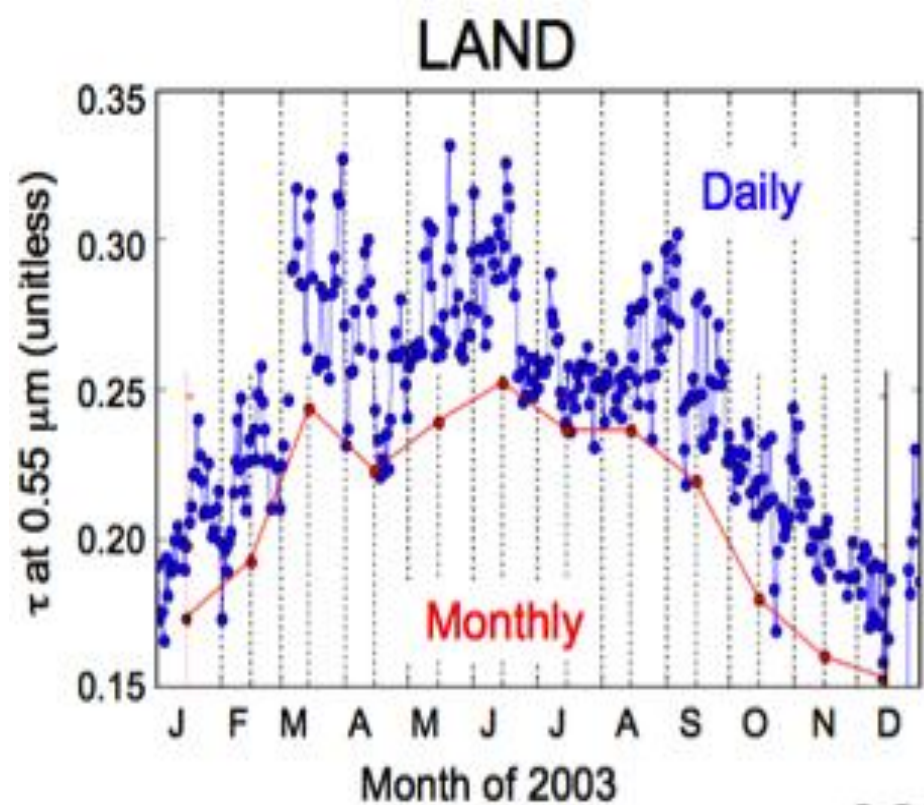
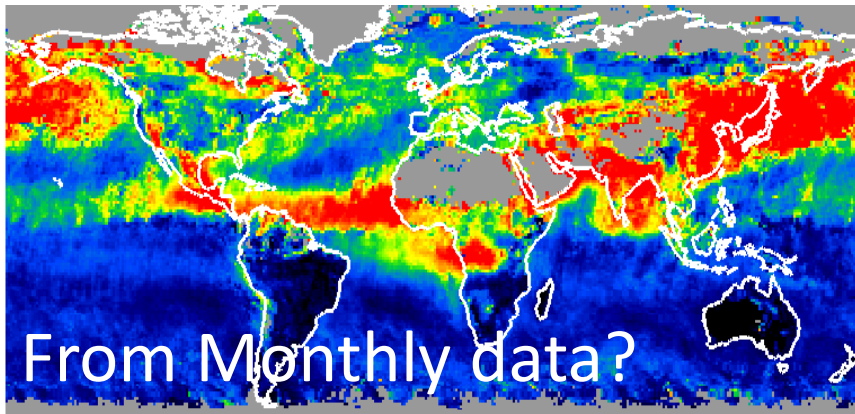
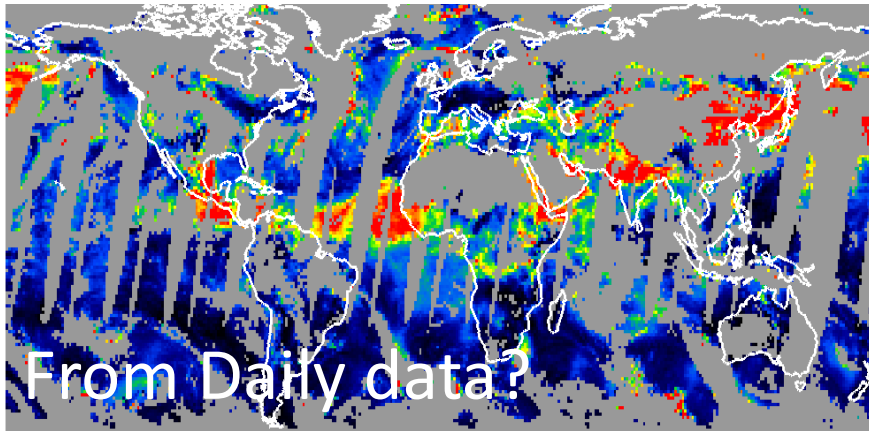
Merging deep blue & dark target produces best global coverage

- Deep blue is land-only; need dark target for oceans
- Deep blue introduces coverage over Australian outback, Sahara desert and Arabian peninsula
- Still no coverage over snow (see: most of Northern Hemisphere).

LOOKS REASONABLE, BUT NOT VALIDATED YET!!!!

What about C6 Level 3?

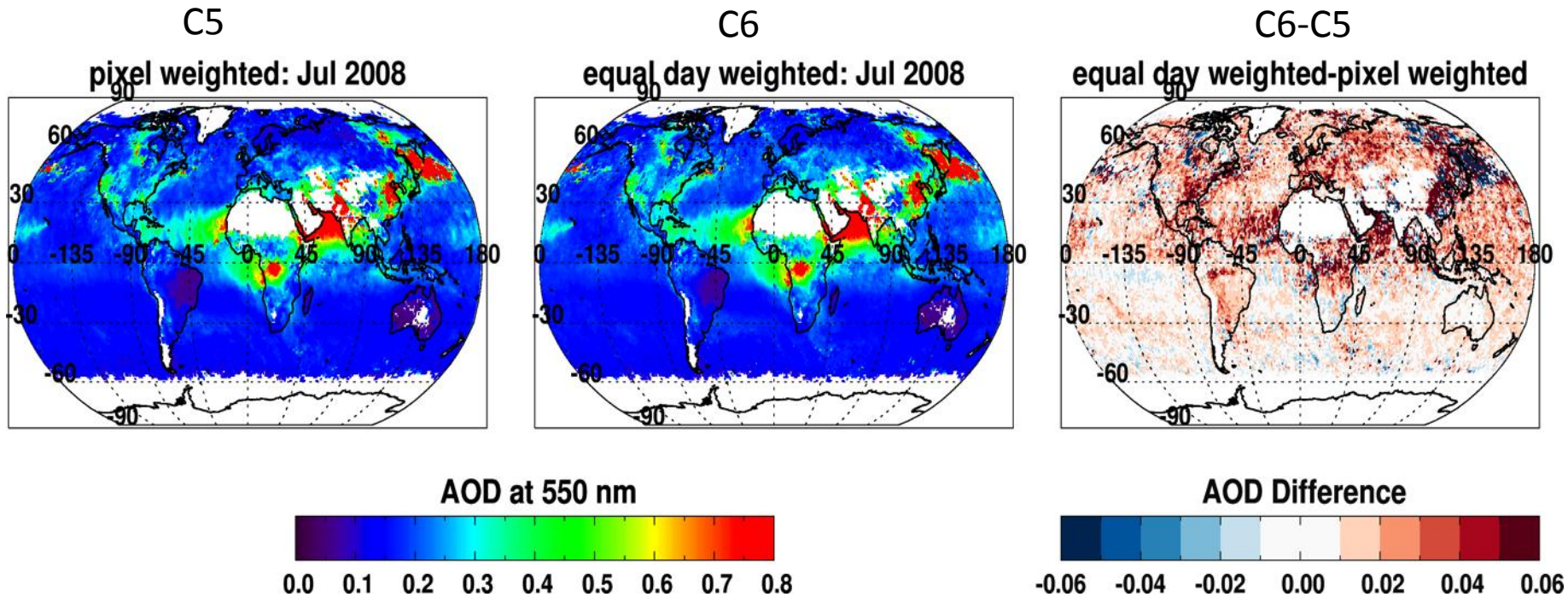
Calculating mean AOD



Levy et al., TRGS, 2009

- It depends on the post-processing path
- Many choices for aggregation and weighting
- Accentuate different limitations of original (L2) sampling
- There is no one “number”, but we can still ask other questions.

Changes to Level 3



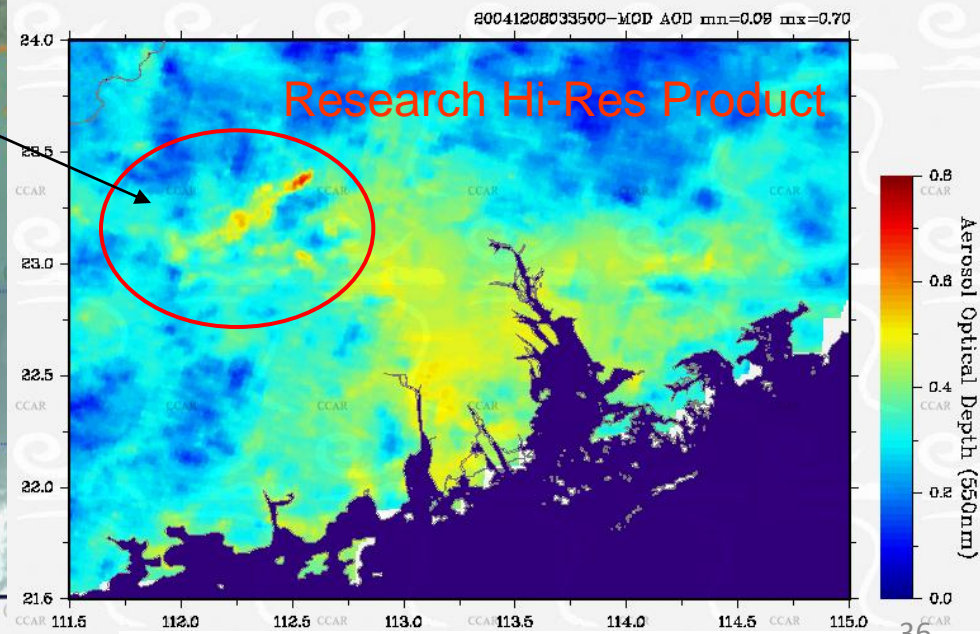
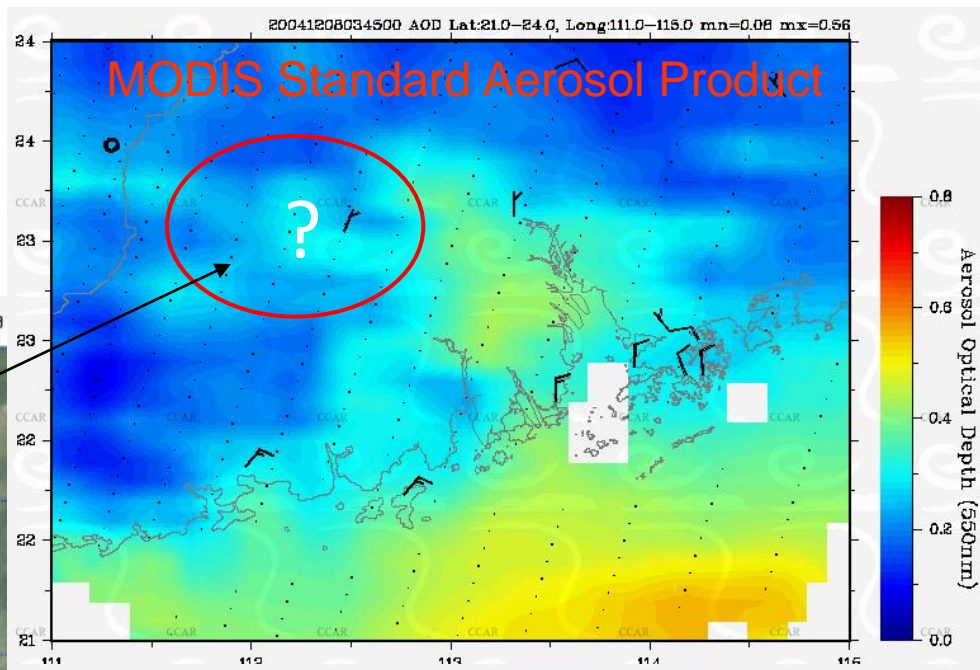
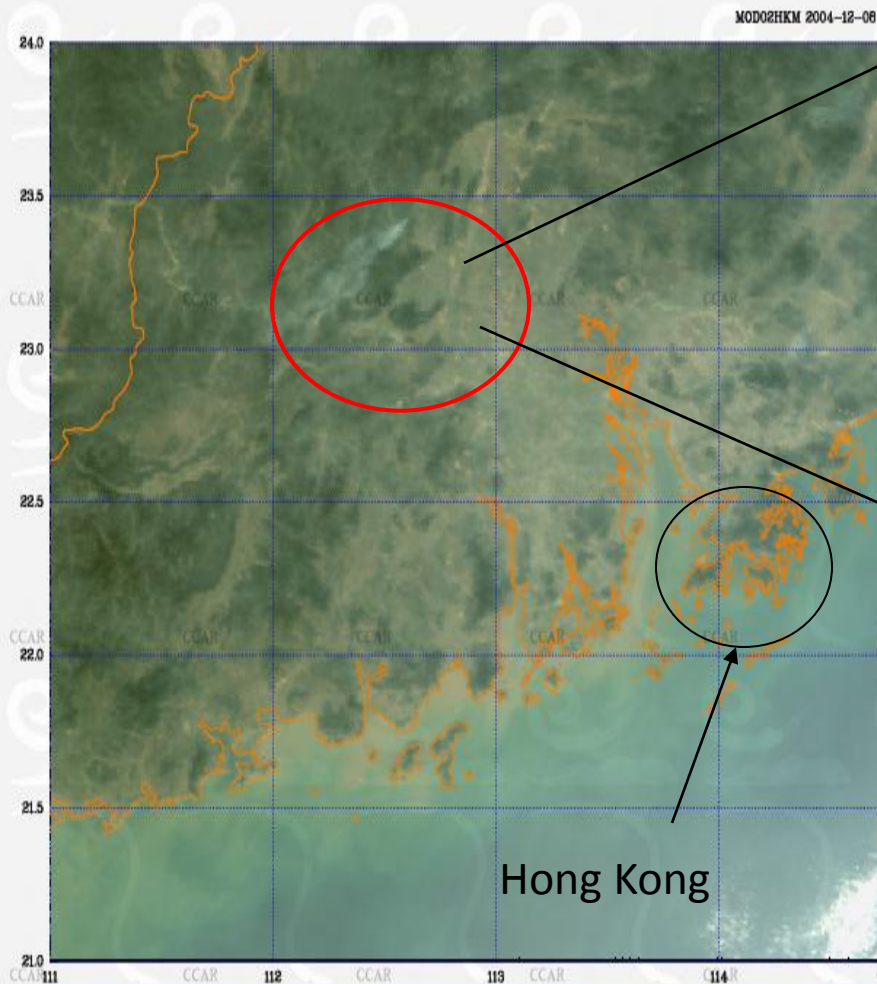
- Pixel weighting for monthly data is removed
- Replaced by “equal day” weighting (assuming at least 5 observations per day).
- → Increase monthly mean AOD over land, and ocean

Aerosols (why do we care?)

- They affect visibility
- They affect human health and morbidity
- They enable clouds and precipitation
- They have roles in Earth's chemical cycles
- They directly impact the radiative budget
- They are both natural and manmade
- They are inhomogeneous in space and time
- Their distributions are changing
- **We need to monitor aerosol with high resolution because that is where people are**

The need of High Resolution AOD data to Resolve Fine-Scale Emission Sources

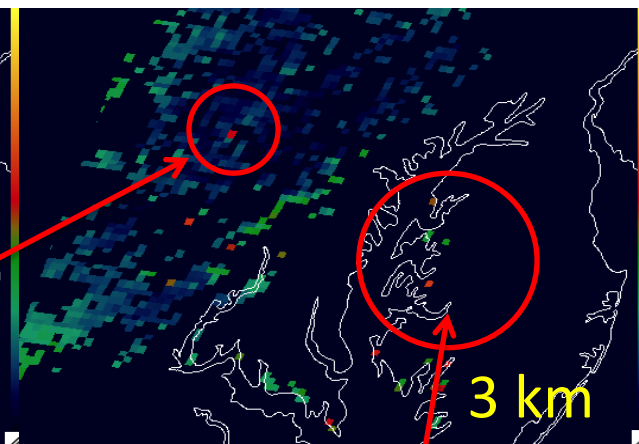
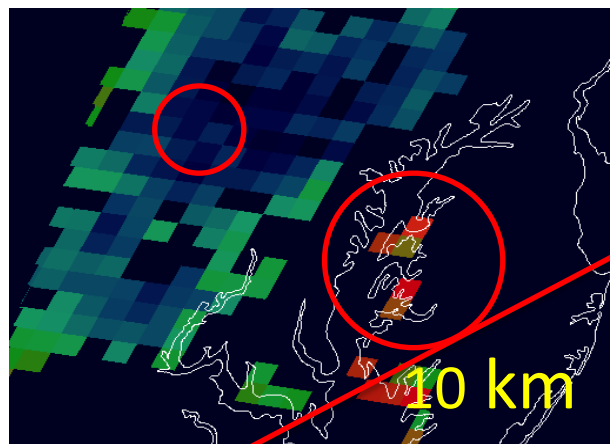
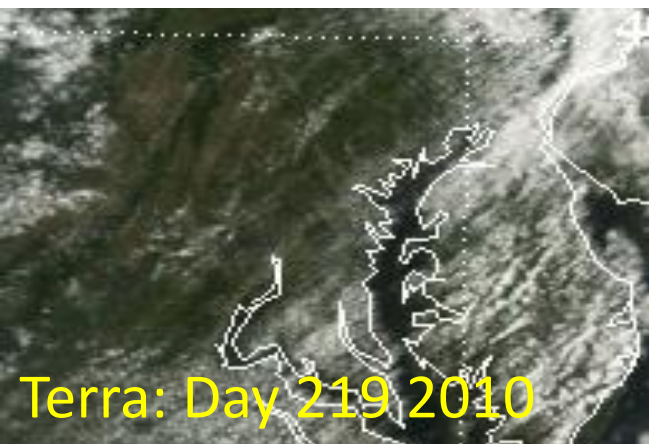
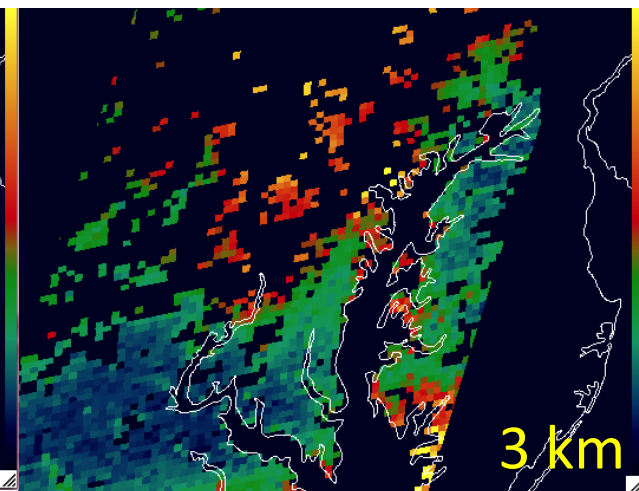
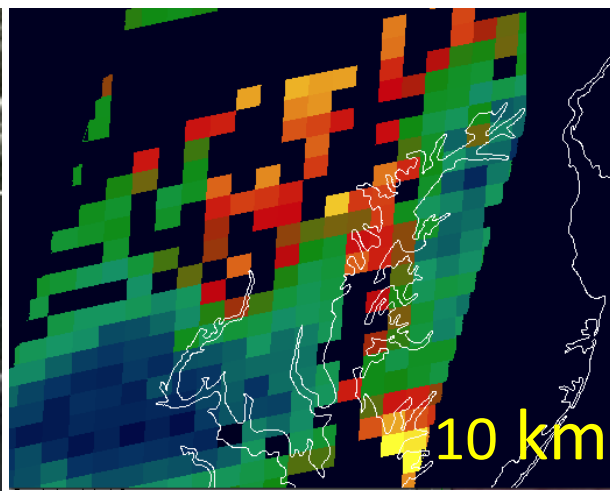
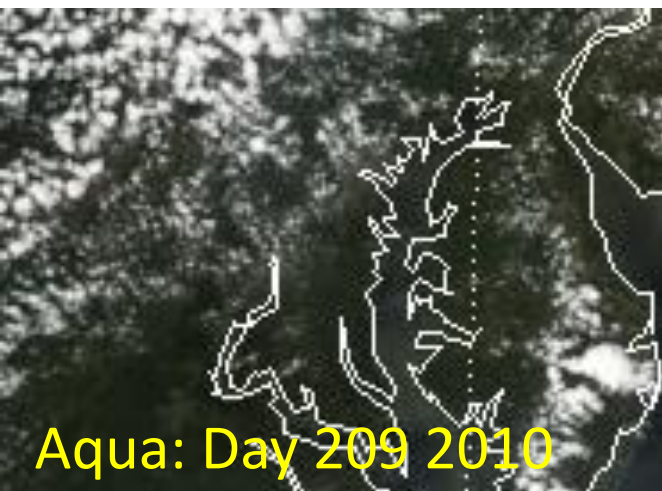
(where people live!!)



Regional → Local

- Nominal resolution (e.g. 10 km) cannot resolve higher scale (e.g. urban, neighborhood) variability
- Air Quality community has been asking (no, *pleading!*) for higher resolution data
- We have been afraid to lose the advantage (pixel statistics) of the 10 km.
- But we decided to try... 3km was the compromise

MODIS 3 km product over suburban (MD) landscape (summer 2010)

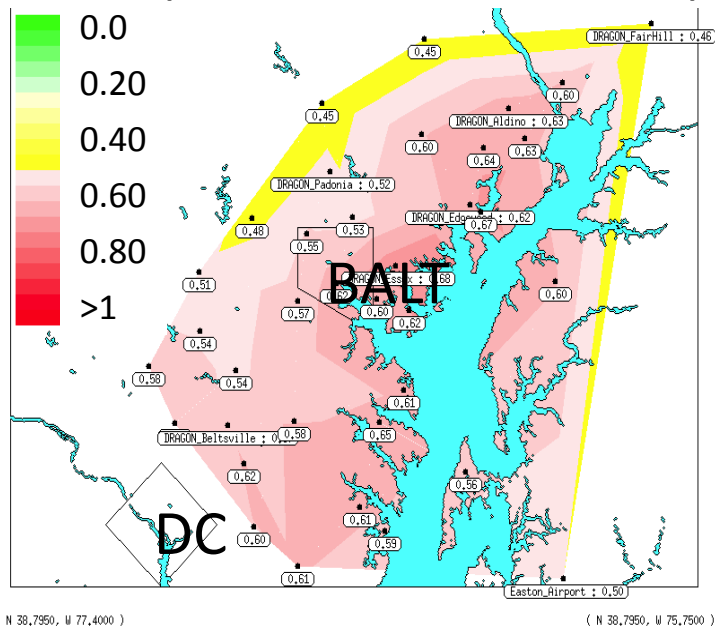


- 3 km mirrors 10 km product (pattern and magnitude)
- 3 km introduces **noise**, but also can reduce spatial impact of **outliers**

MODIS vs DRAGON

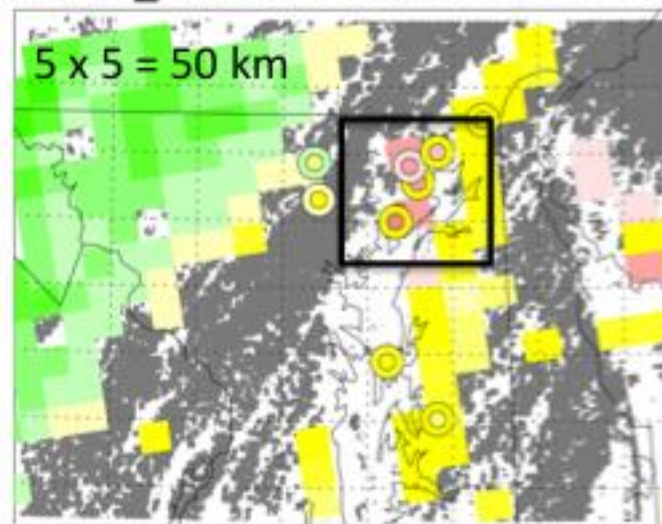
July 21, 2011

AOD (AERONET: DRAGON)



- DRAGON = Many AERONET over Maryland during DISCOVER-AQ experiment, July 2011
- For MODIS plots, QA=3 only
 - Circle Center = AERONET ± 2 hours
 - Circle Outer = MODIS 5 x 5 box
- 3km (bottom) resolves Baltimore maxima
- Gray is MODIS-Aerosol cloud mask
- 3km also resolves aerosol over Ches. Bay

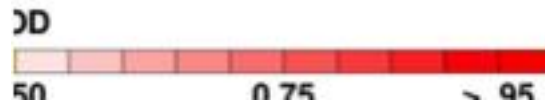
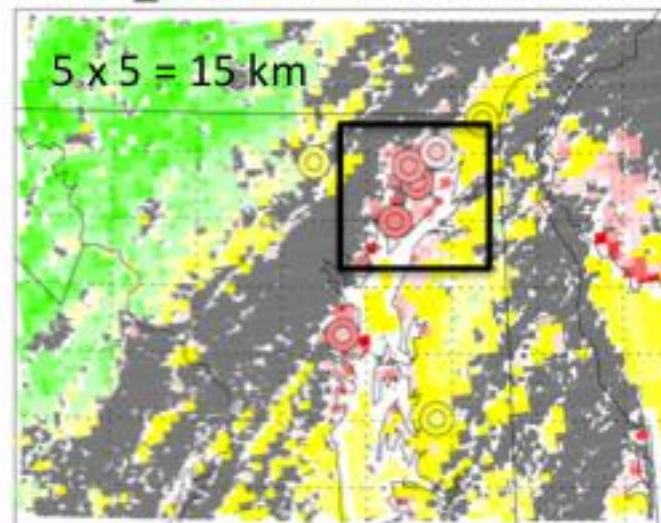
MYD04_10km 550 um 2011202 18:30



Legend for MYD04_03km 550 um 2011202 18:30:

- 0.0 (Green)
- 0.25 (Yellow)
- 0.8 (Red)

MYD04_03km 550 um 2011202 18:30



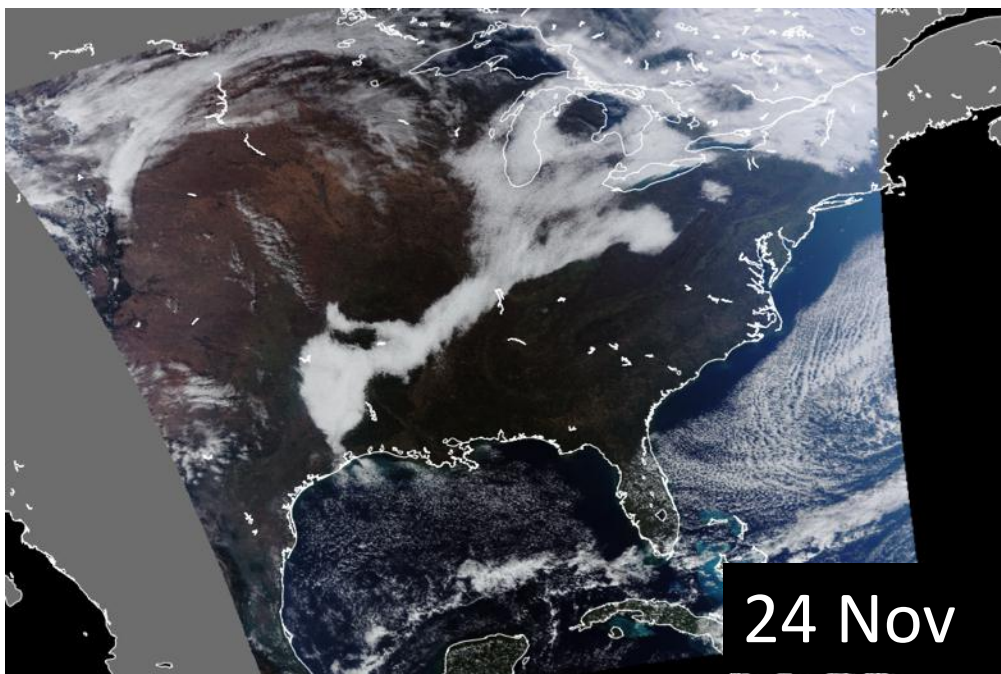
MODIS 3 km product (operational for C006)

- Algorithm structurally identical to standard “10 km” retrieval
- Results will be in new files, ***‘MOD04_3K’***
- Both MOD04_L2 and MOD04_3K will be available

And to the next big thing...

Suomi-NPP VIIRS

Visible Infrared Imager Radiometer Suite



Multiple VIIRS granules stitched. Image by Geoff Cureton, CIMSS

- Launched Oct 28; “first light” Nov 22
- Different instrument, resolution, sampling, cloud masking, algorithms, etc.
- Will VIIRS “continue” the MODIS aerosol data record?

VIIRS versus MODIS

Orbit: 825 km (vs 705 km), sun-synchronous, over same point every 16 days

Equator crossing: 13:30 on Suomi-NPP, since 2012 (versus on Aqua since 2002)

Swath: 3050 km (vs 2030 km)

Spectral Range: 0.412-12.2 μm (22 bands versus 36 bands)

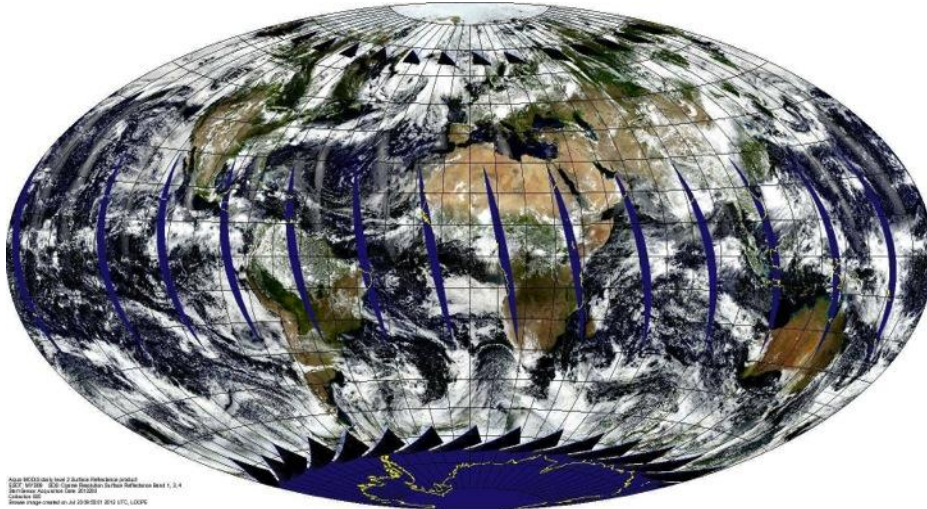
Spatial Resolution: 375m (5 bands) 750m (17 bands): versus 250m/500m/1km

Wavelength bands (nm) used for DT aerosol retrieval: 482 (466), 551 (553) 637 (645), 861 (855), 2257 (2113) \rightarrow differences in Rayleigh optical depth, surface optics, gas absorption.

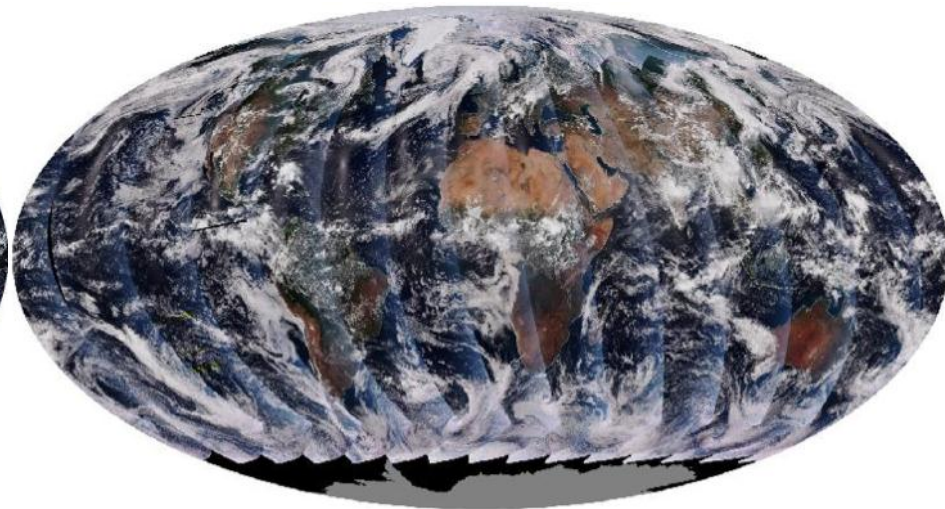
Aerosol Retrieval: Created and maintained by scientists partnered with NOAA (NASA), with a strategy of maximizing environmental data record - EDR (climate data record – CDR)

ALSO: Different cloud masks, different aggregation techniques, different pixel selections.

Aqua (13:30 Local Time, Ascending)



Suomi-NPP (13:30 Local Time, Ascending);



VIIRS is like the “little brother” of the MODIS twins.

Two different science questions

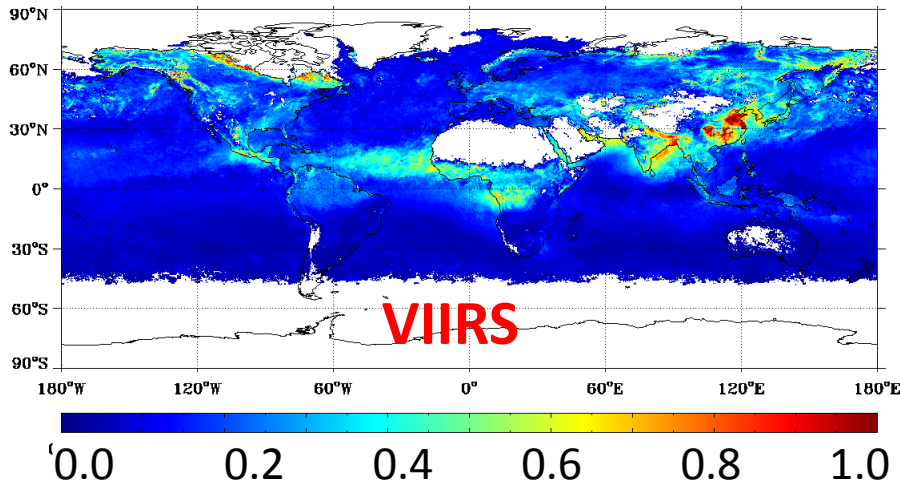
- What will VIIRS aerosol products look like?
 - What are the statistics of VIIRS products?
 - How well do they compare with ground truth (e.g. AERONET)?
 - Will VIIRS give a meaningful aerosol environmental data record?
- Will the VIIRS climate data record continue that started by MODIS?
 - What are the statistics of the VIIRS products as compared to MODIS
 - Why are there differences? Capability of Instrument? cloud mask? aggregation of pixels? Aerosol retrieval algorithm? Other?
 - Regardless of whether VIIRS “should” continue the MODIS data record, we want to know, “can” it?

There are subtle differences between the two questions, and they are inter-related.

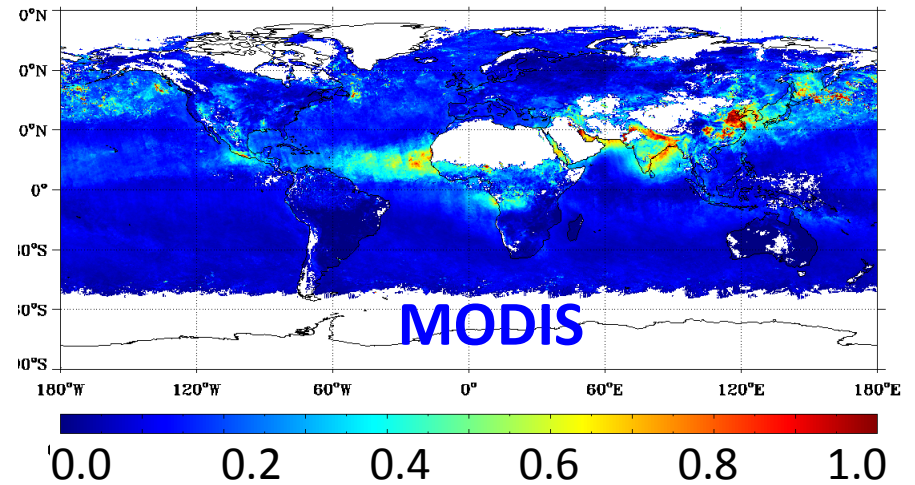
We are trying to answer the second question, although we also need to answer the first. .

Differences between VIIRS and MODIS (operational products: May 2012)

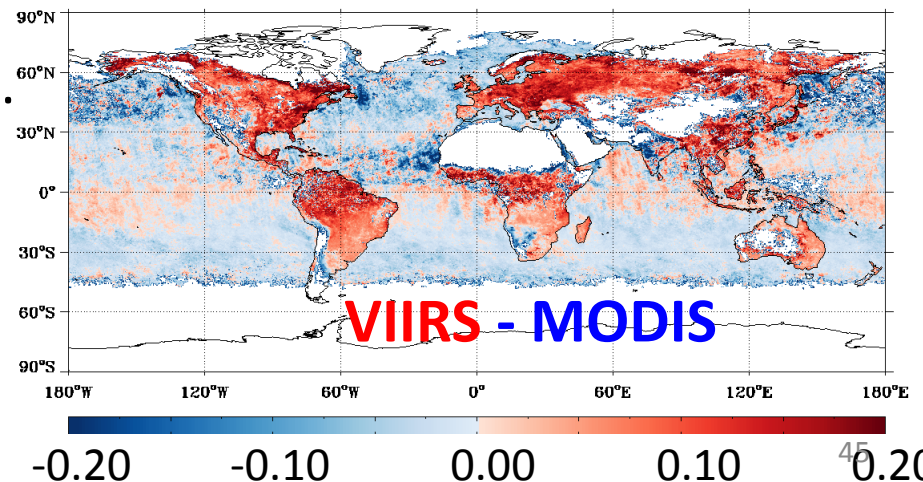
2012.05.02–2012.06.02 VIIRS EDR Aerosol Optical Depth at 550nm



2012.05.02–2012.06.02 Aqua MODIS Aerosol Optical Depth at 550nm

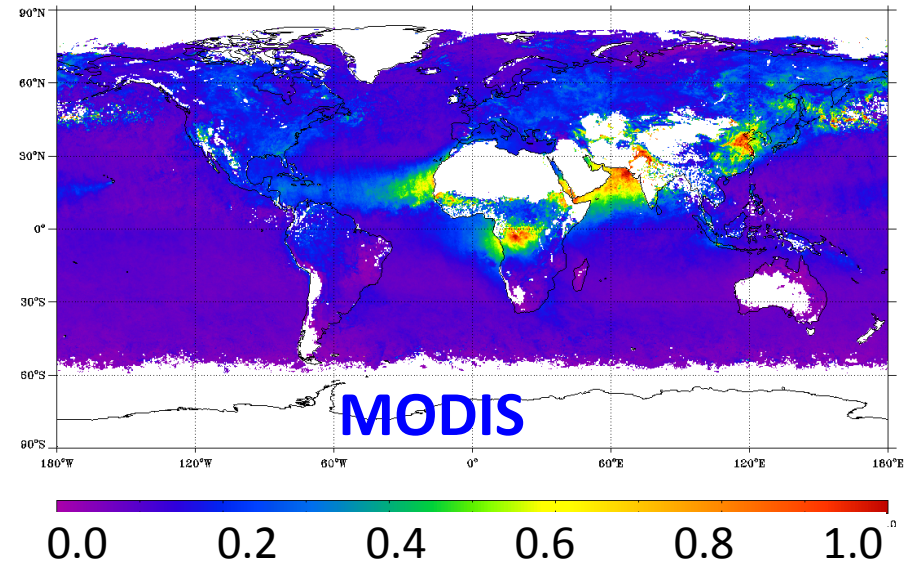
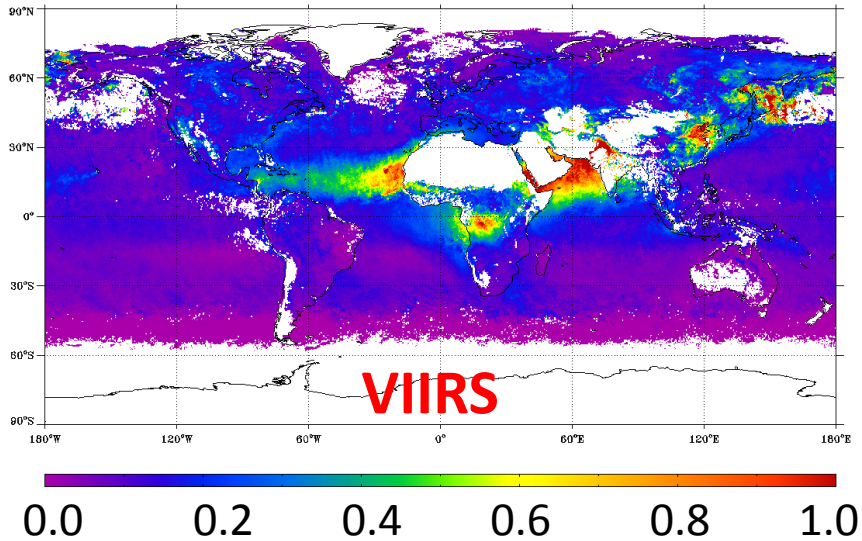


- Differences due to algorithm + instrument + cloud/snow screening.
- Except for 0.09 bias over land,
- They are essentially “agreeing” within each other’s specifications most places

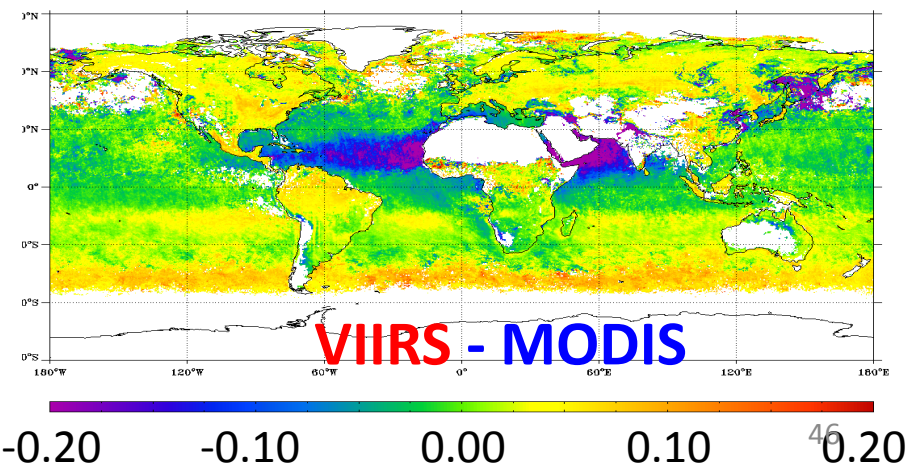


STAR-VIIRS (VIIRS-like algorithm on MODIS)

Using MODIS L2 reflectance data: July 2008



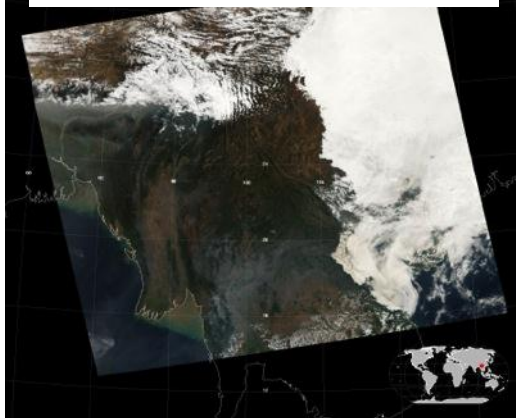
- MODIS pixel selection
 - Gas correction by MODIS
 - Cloud/snow screening by MODIS
- Differences only due to retrieval algorithm.



Going half-way

MODIS-like algorithm on VIIRS data

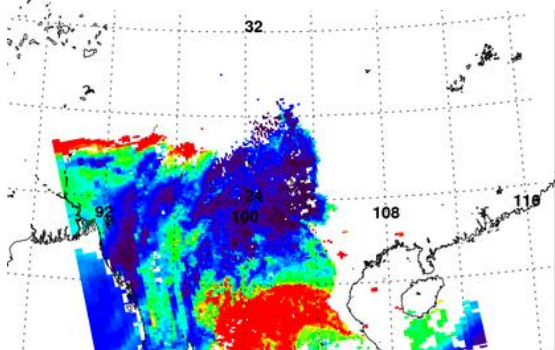
RGB image for MODIS



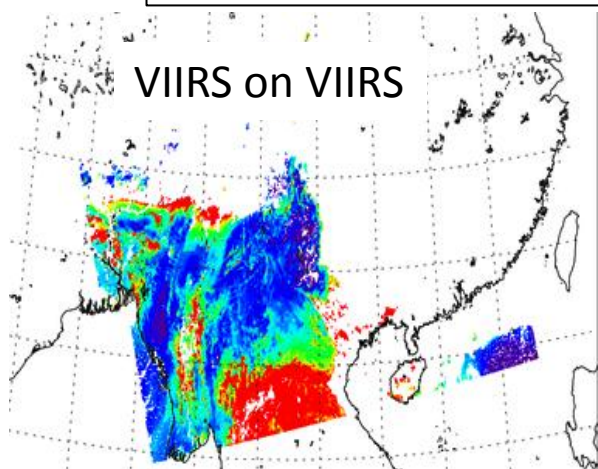
Both satellites overpass within minutes

- Preparation of “5 minute” VIIRS granule
 - Create MODIS-like cloud mask, gas corrections, pixel selection/averaging, quality assurance, etc
- Using MODIS algorithm on VIIRS looks much more like MODIS
- More processing, including entire months of data are forthcoming
- Necessary for continuation of other data (e.g. CERES records!)

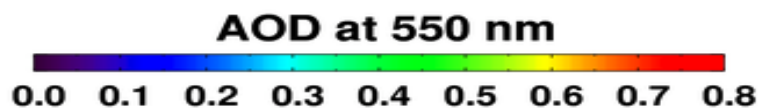
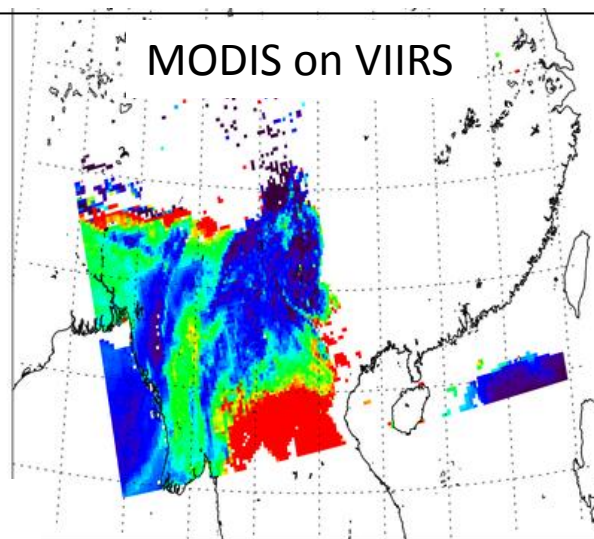
MODIS on MODIS-Aqua



VIIRS on VIIRS



MODIS on VIIRS



Summary (1)

- There are many ways to retrieve aerosol properties from MODIS, and there is more than one set of algorithms/products
- Dark-target algorithm/products are updated for C6, but only “modest” changes
- Dark-target and Deep-blue products are merged, leading to more global coverage
- Documentation is still under development. Please contact us for details!
- Official C6 products have not been released, but there are many months of test data. Please ask.

Summary (2)

- The MODIS aerosol products have matured over the last 13 years.
 - They are well characterized
 - We understand the strengths and limitations
 - Our products are “useful” and in a useful format.
 - The global community (both research and operational) depends on the MODIS aerosol products
 - Maintenance, while not necessarily “sexy”, is necessary (Note for program managers in audience)

Summary (3)

- MODIS aerosol retrieval was intended for global *climate* applications
 - MODIS aerosol products → climate data records?
 - Not yet
 - but artificial trends are being removed by reformulating instrument calibration.
 - More evaluation is needed.

Summary (4)

- MODIS aerosol retrieval was intended for *global* climate applications
 - Air quality events are sometimes on urban and local scales
 - Aerosol properties change near clouds
 - → The MODIS dark-target team is offering 3 km operational aerosol data.
 - More evaluation is needed.

Summary (5)

- MODIS is not the only thing
 - NPP-VIIRS is coming online
 - VIIRS is “similar”, yet different than MODIS
 - TBD: How different?
 - More evaluation is needed.
- On towards development of Collection 7