

The Collection 6 MODIS Aerosol products

“Dark target team”:

Robert Levy (NASA-GSFC)

Shana Mattoo, Leigh Munchak and Richard Kleidman (SSAI @ GSFC)

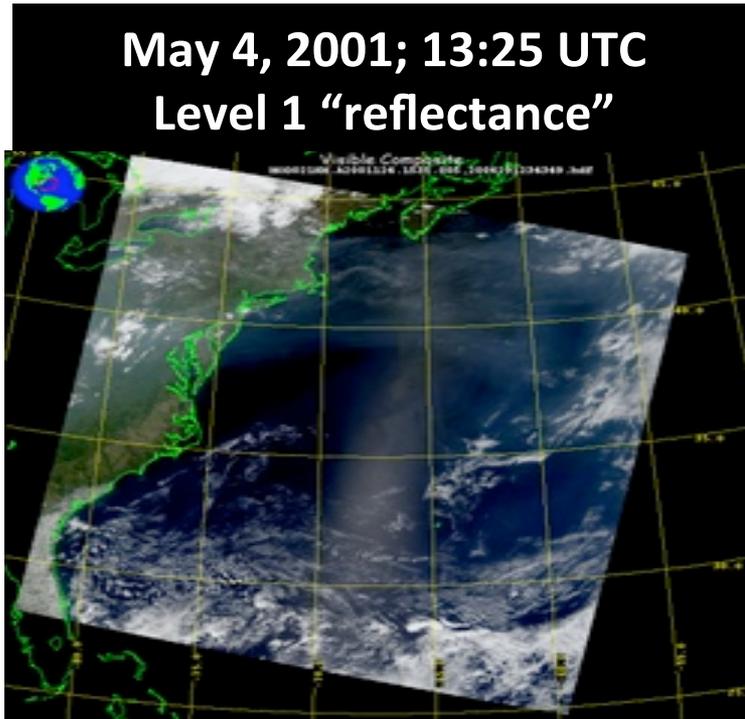
Falguni Patadia and Pawan Gupta (USRA @ GSFC),

and Lorraine Remer (UMBC)

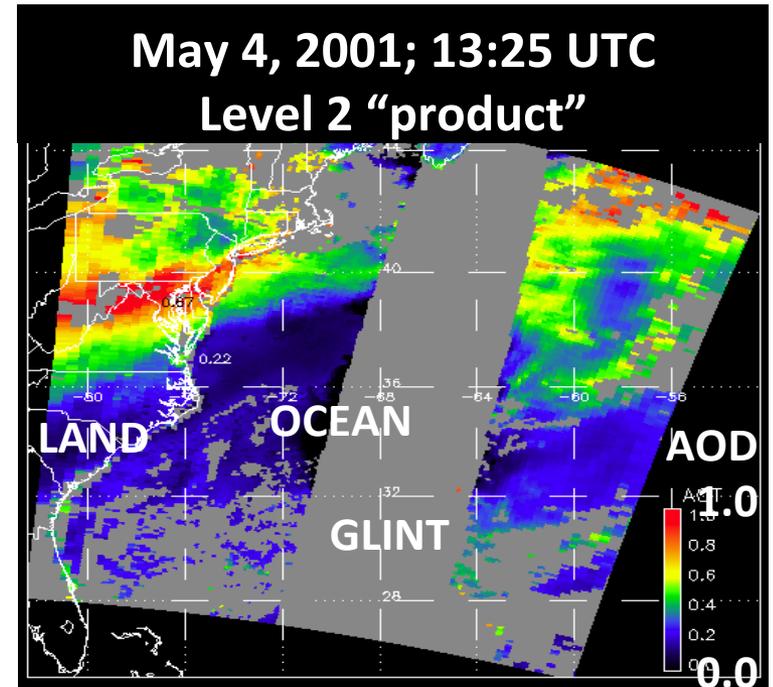


Aerosol retrieval from MODIS

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, Korkin,...)
4. Ocean color/atmospheric correction (McClain, Ahmad, ...)
5. Etc (neural net, model assimilation, statistical, ...)
6. Your own algorithm (many groups around the world)

Outline

- DT updates for “standard” 10 km product
- aerosol trends and calibration?
- Deep Blue/Dark target (DBDT) merge
- 3 KM resolution products for air quality applications
- Future with Suomi-NPP VIIRS
- Some uncertainties

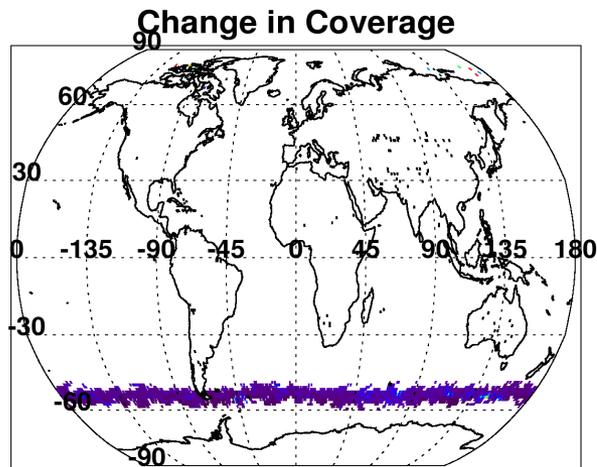
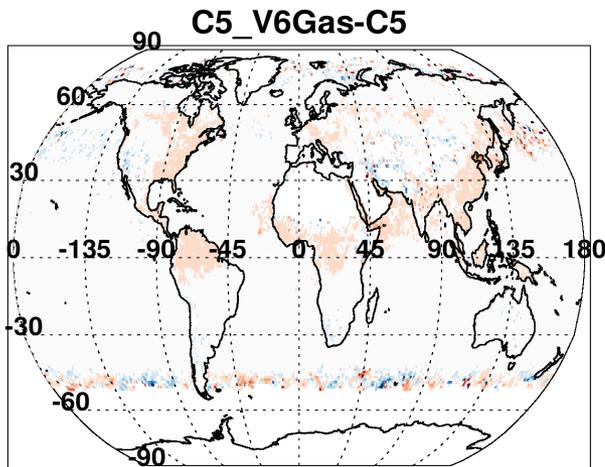
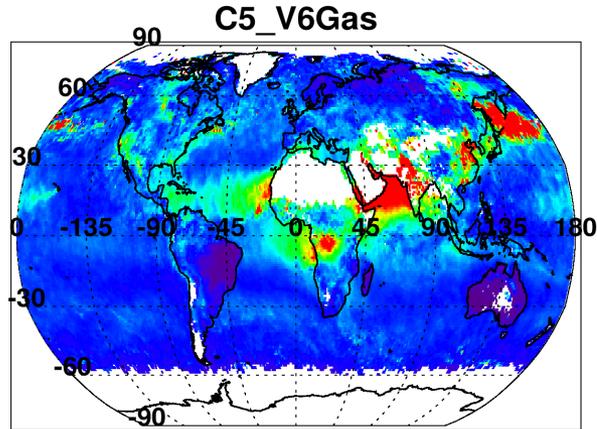
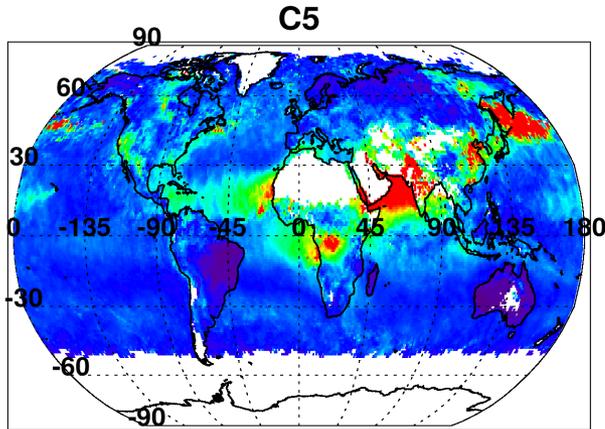
Dark target algorithm updates

In AMT-Discussions (in revision for AMT)

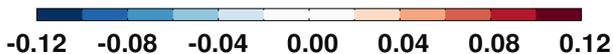
- [Levy, R., S. Mattoo, L.A. Munchak, L.A. Remer, A.M. Sayer, and N. Hsu](#) (2013). The Collection 6 MODIS Aerosol Products over Land and Ocean *Atmos. Meas. Tech. Disc.* (6), 159-259

Radiative Transfer updates

Jul 2008: Aqua



AOD Difference



AOD at 550 nm



Recalculate “center wavelengths” from MODIS filter functions

Recalculate gas absorption coefficients and optical depths for H_2O , O_3 , CO_2 , CH_4 , O_2 , etc

Extend valid solar zenith angle from 72° to 84° .

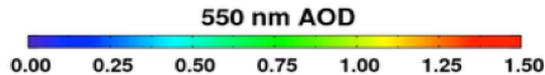
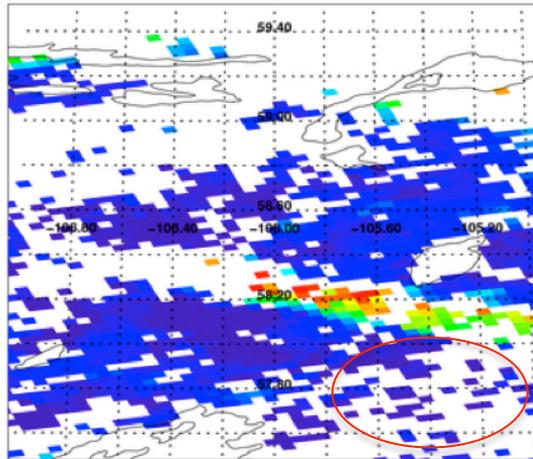
“Definitions” of land/coastal/water:

C5: Used MOD35; C6: Use MOD03 (It’s a long story)

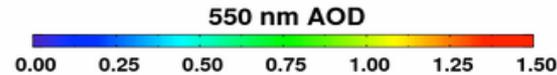
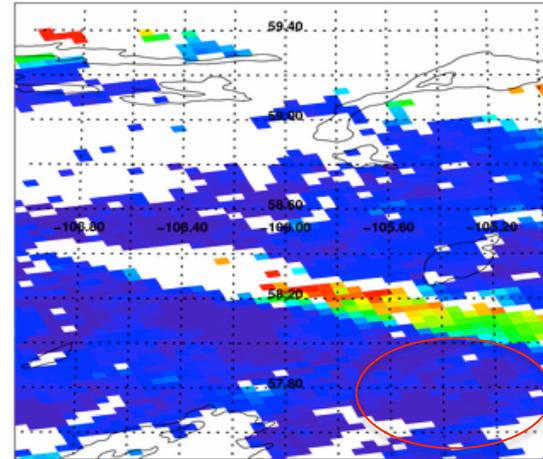
This is ARCTAS region in northern Canada.

Land ‘o lakes

MODIS AOD, with no coastline pixels

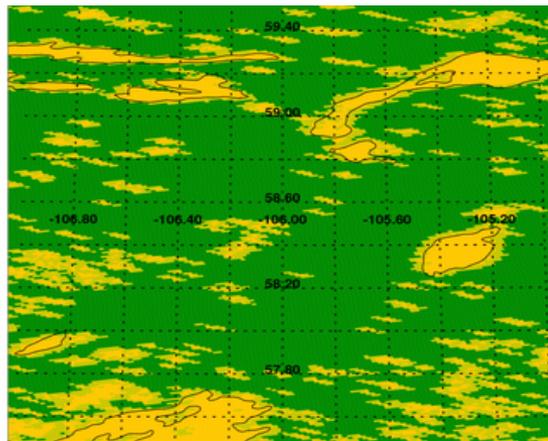


MODIS AOD, with coastline pixels



improved coverage near water

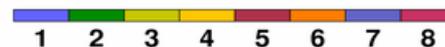
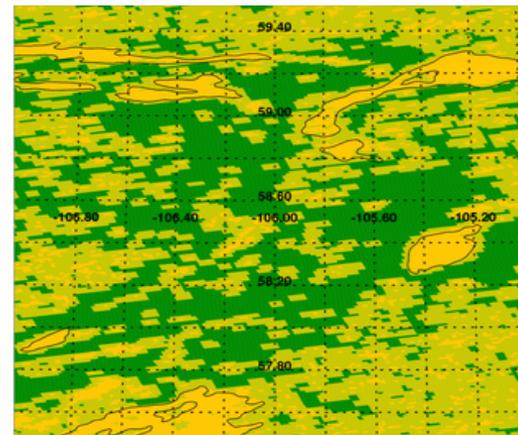
C5 MOD03 Land/Sea Mask



Note very little “coastal” in C5.

Clean divide between Green (land) and Yellow (Lakes)

C6 MOD03 Land/Sea Mask

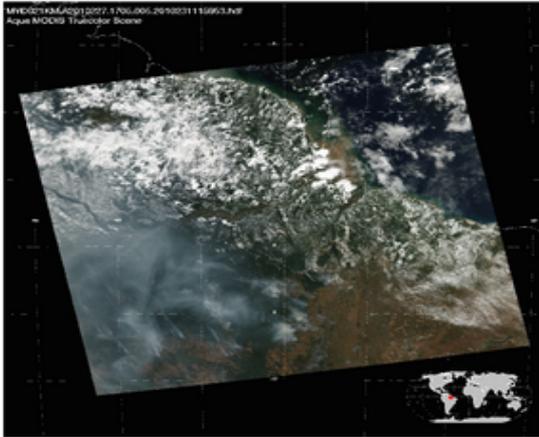


Note much more “coastal” in C6.

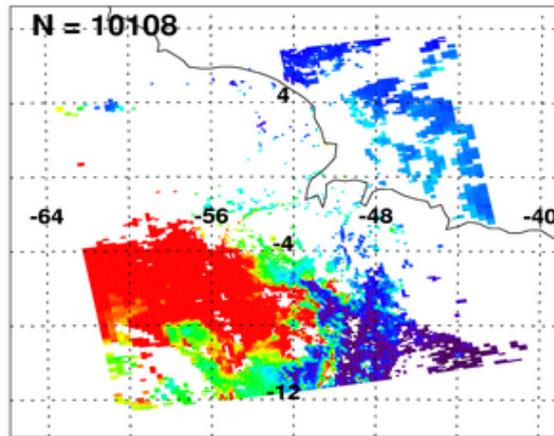
Lots of shorelines (lime colored) pixels that would be thrown out.

Update cloud masking (ocean & land)

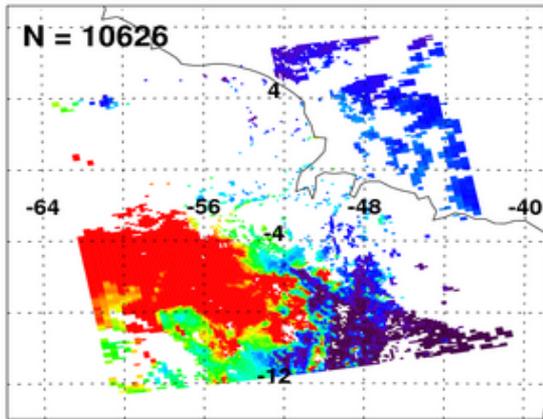
MYD04_L2.A2010227.1705.hdf



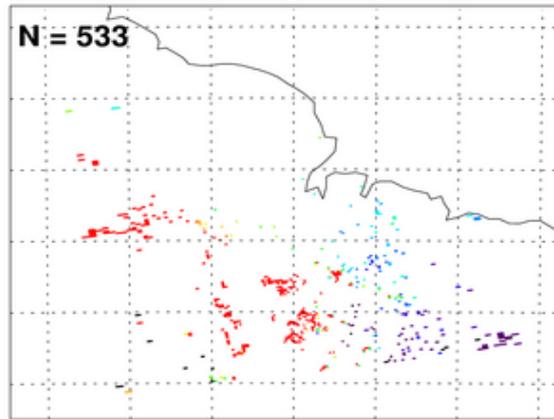
Without cloudmask



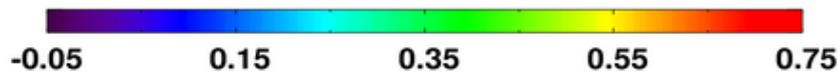
With new cloudmask



New Pixels



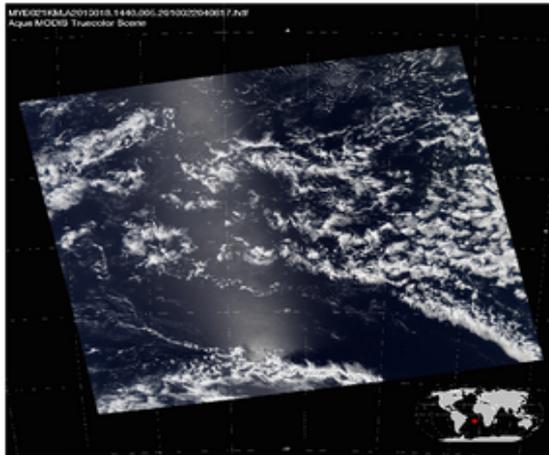
AOD at 550 nm



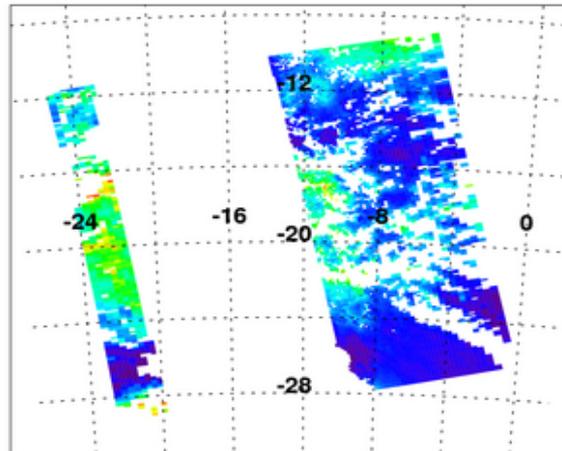
- Retrieve more “heavy smoke” cases
- Retrieve fewer “thin cirrus” cases
- Correct assignment of QAC due to clouds

Introduce wind speed dependence (ocean)

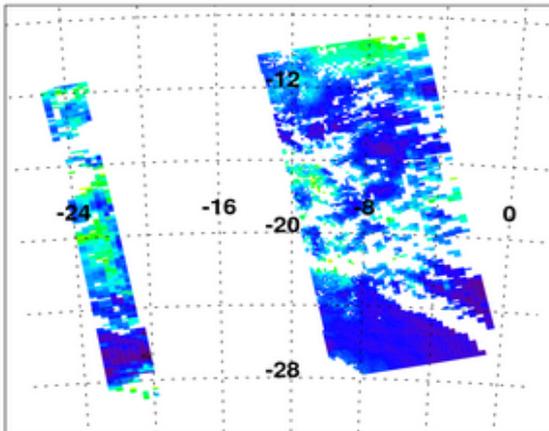
MYD04_L2.A2010018.1440.hdf



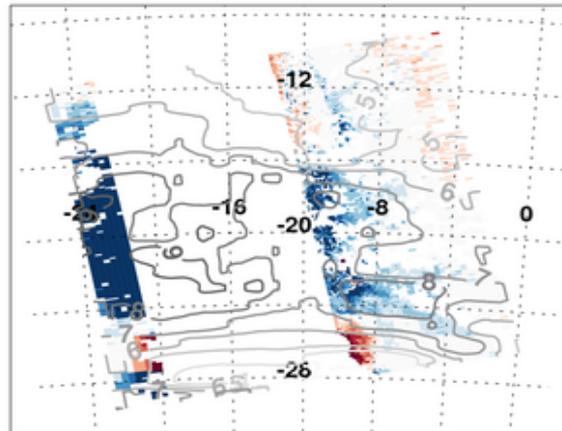
6 m/s winds



NCEP winds



NCEP winds - 6 m/s winds



AOD at 550 nm

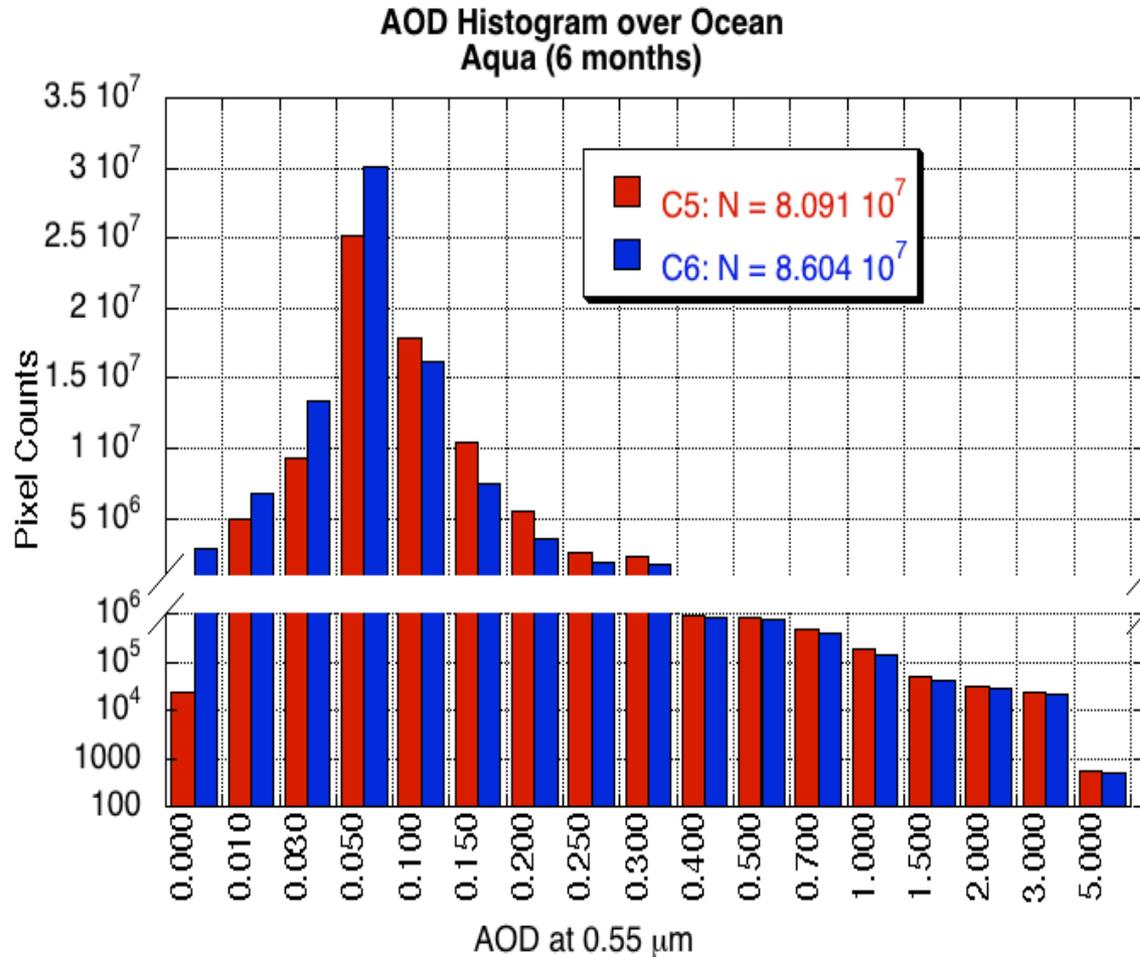
AOD Difference

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 $v \geq 6$
- Reduces AOD near 40° glint mask edges and in “Roaring 40s” of southern Oceans.

Quality Confidence “definitions”

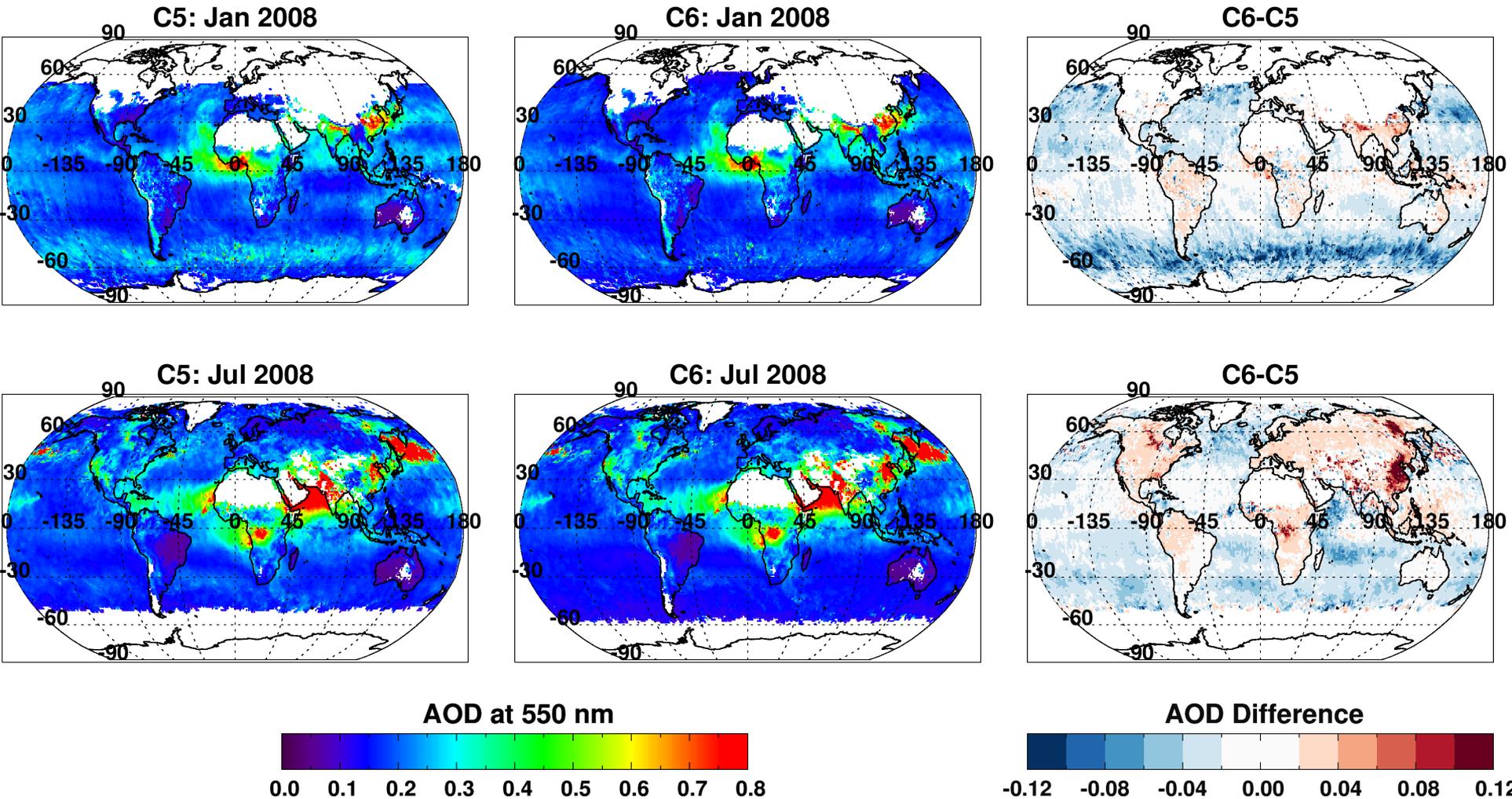


Old (C5): Quality assurance depends on success of a retrieval solution. If aerosol signal is too small, then do not include in daily/monthly statistics.

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

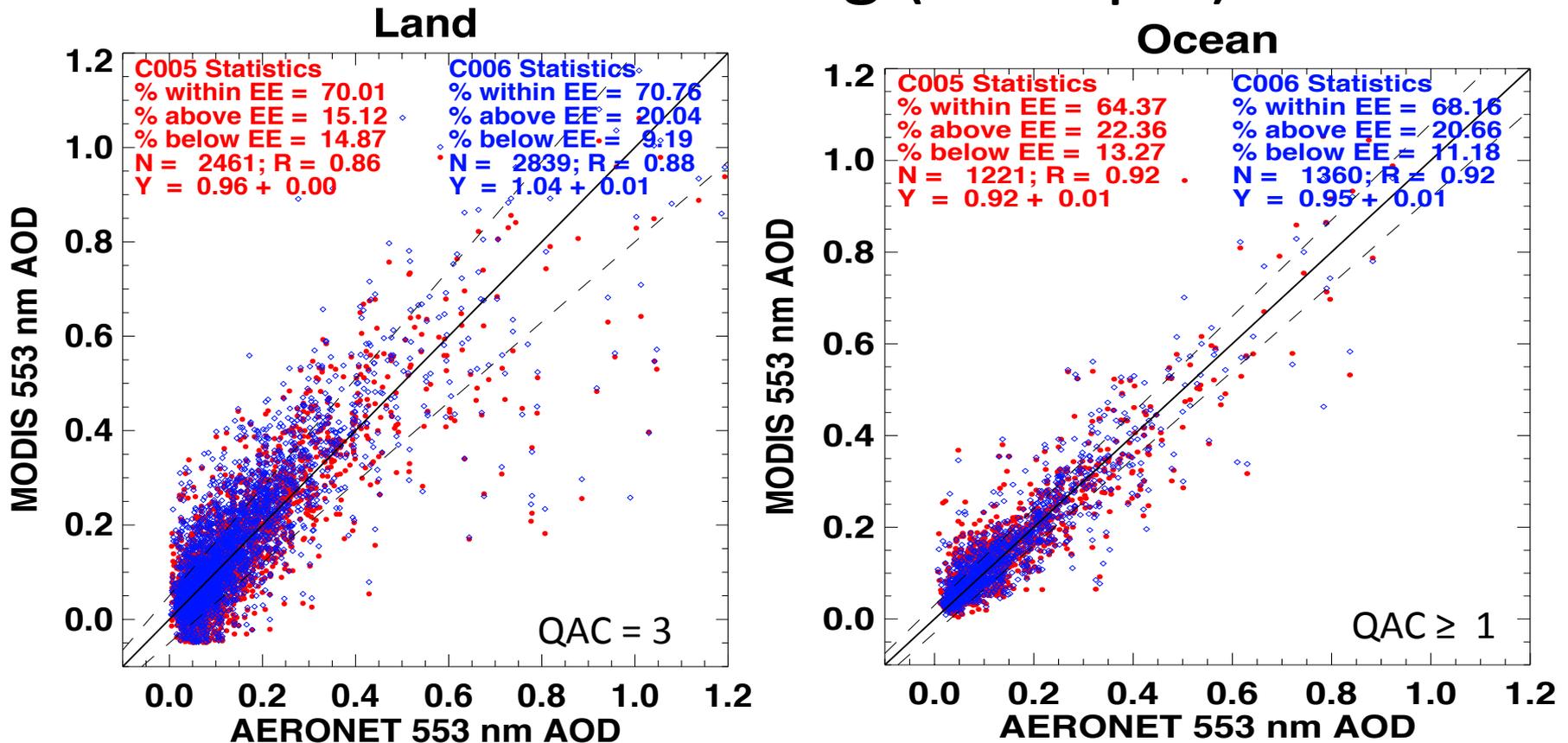
- But “major” influence on estimating regional and global mean AOD

DT-Combined: Aqua 2008



- Retrieval technique is unchanged, but everything else is:
 - lower AOD over ocean, but significantly lower over southern oceans
 - Higher AOD over all land, but significant differences over hotspots.

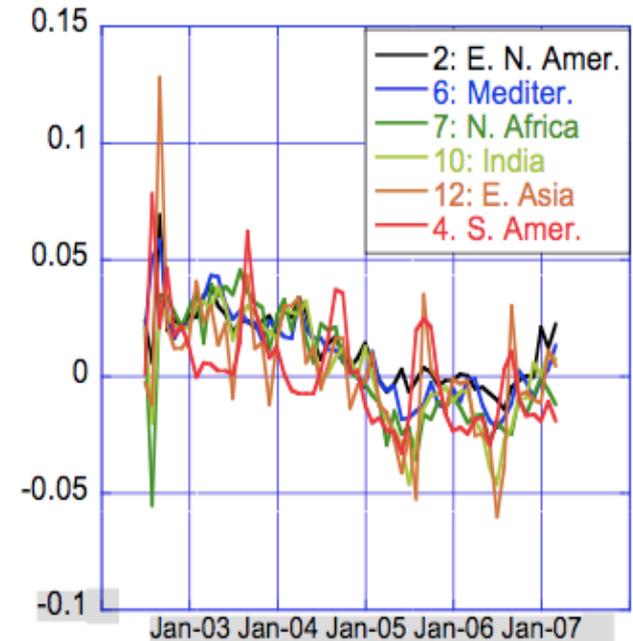
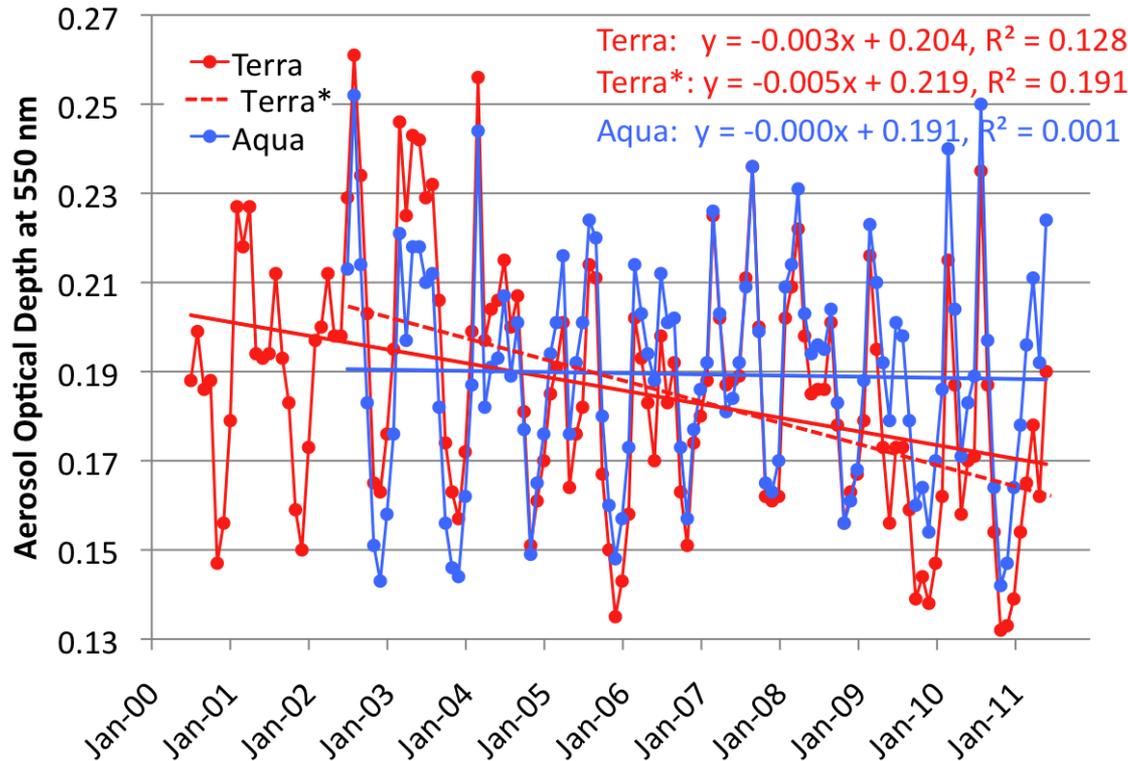
Preliminary “validation” of C6 6 months testing (on Aqua)



- No dramatic changes, but 10-20% more valid collocations with AERONET
- C6 algorithm has slightly better (68% vs 64%) retrieved over ocean
- C6 will have more of a high bias over land, but slightly better correlation. 11

C5: Trends Terra ≠ Aqua

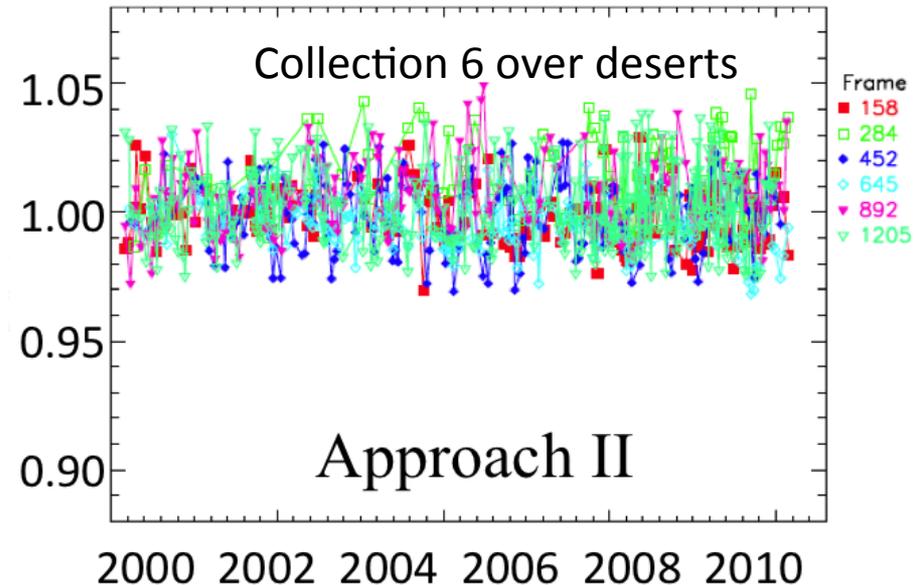
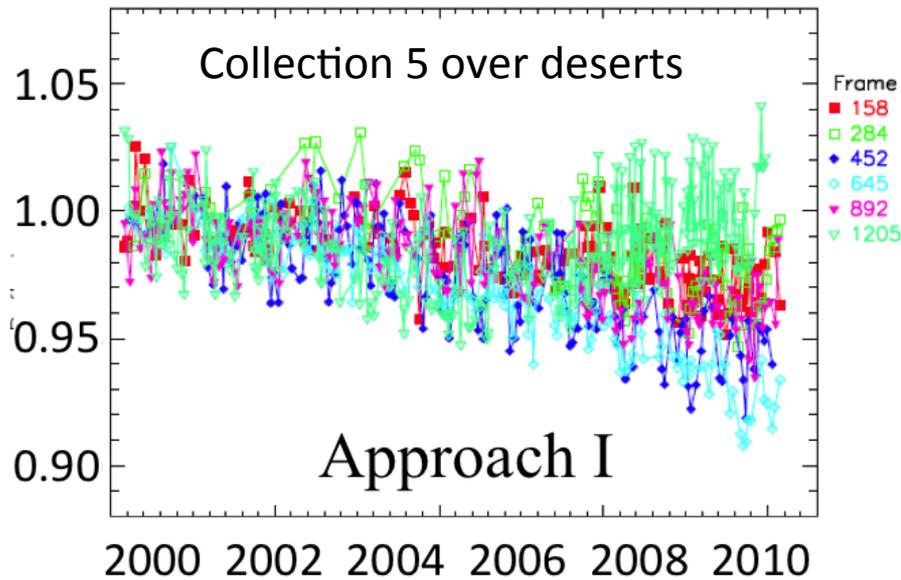
MODIS AOD Monthly Mean - Land Only



- 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?

In C5: Terra's "observations" were trending

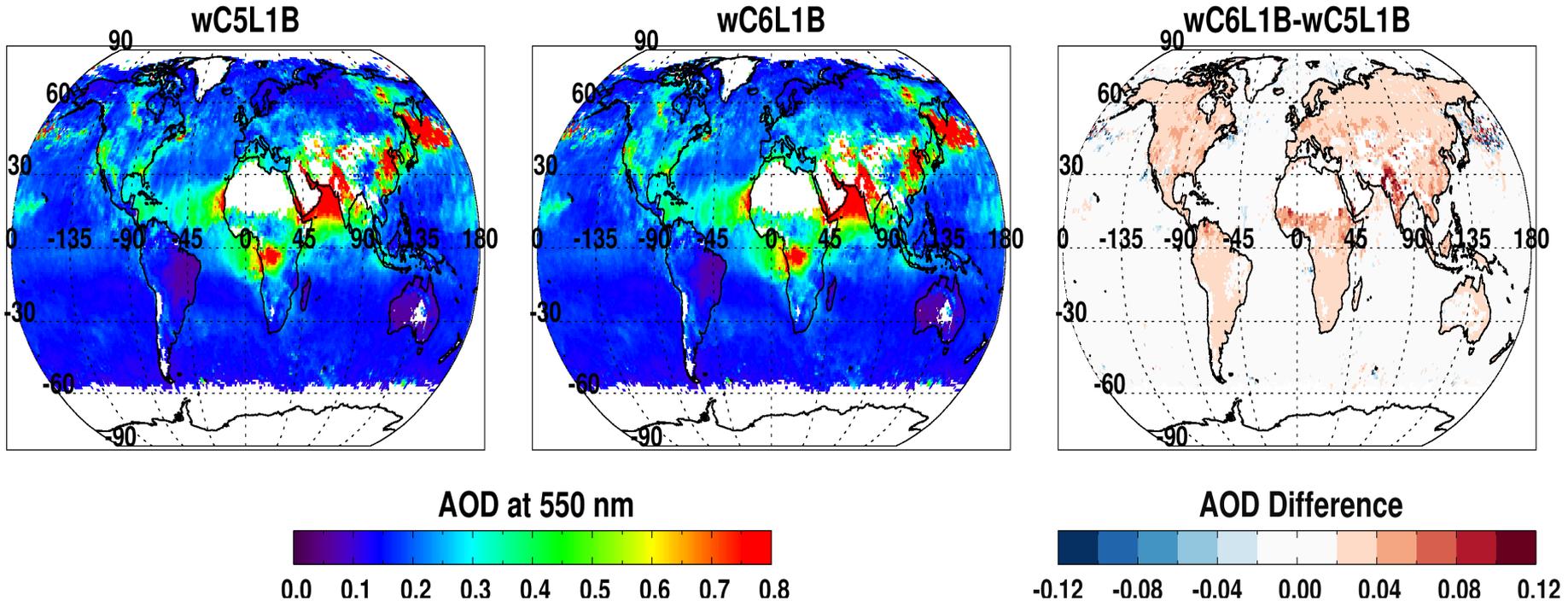
Normalized Reflectance Terra Band # 3, Mirror Side #1 Normalized Reflectance



For C6: Improve calibration to remove trend

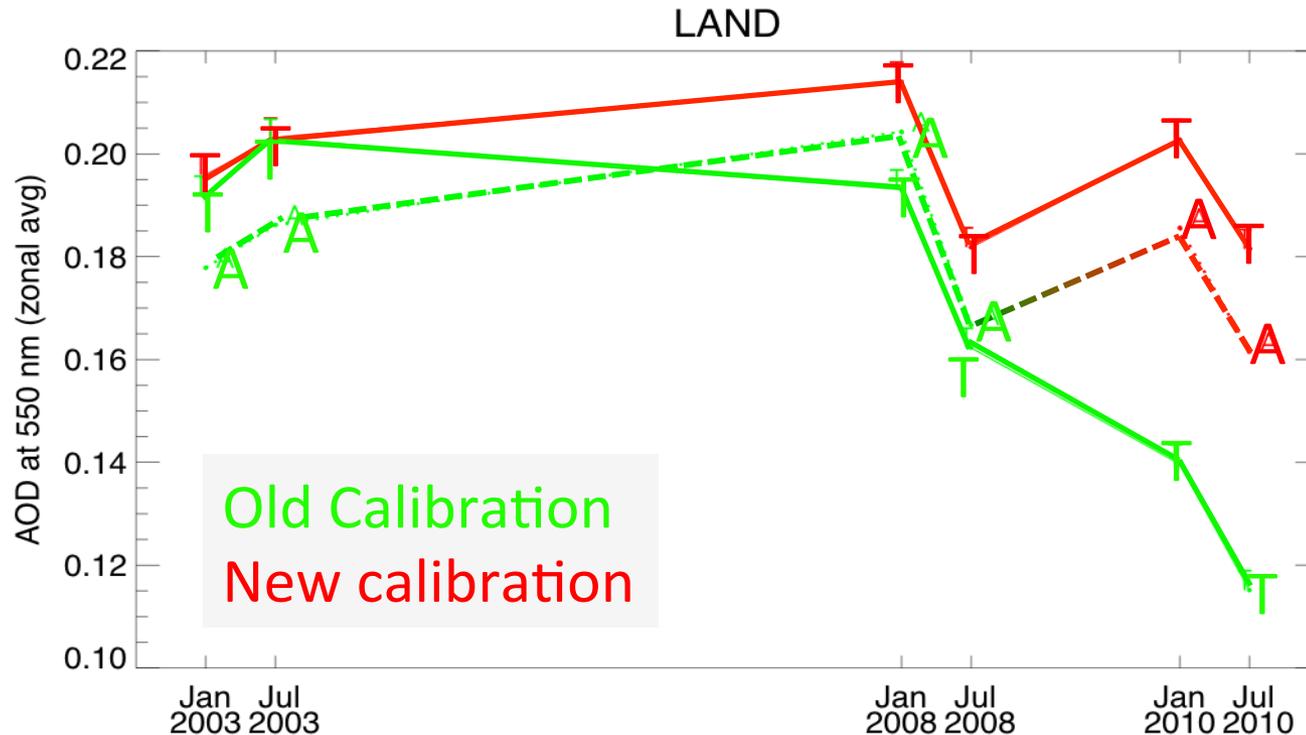
C6: Impact of New Terra calibration

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)

C6: Impact of new calibration on trend?

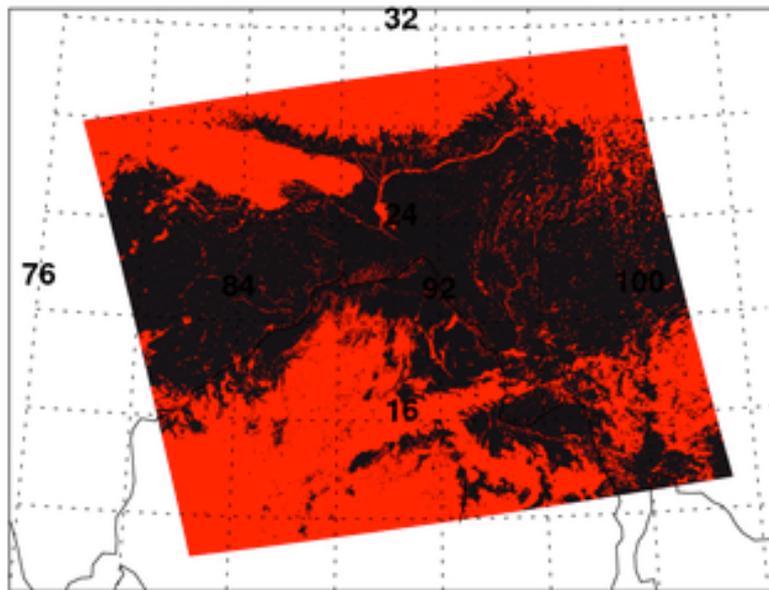


- 6 months processed with same dark-target aerosol algorithms
- Terra (T) Approach II now “in sync” with Aqua (A) time series
- (Terra-Aqua) offset remains 0.01 (ocean) and 0.015 (land)
- **New calibration → Terra/Aqua divergence removed for C006!**

What else for C6 Level 2?

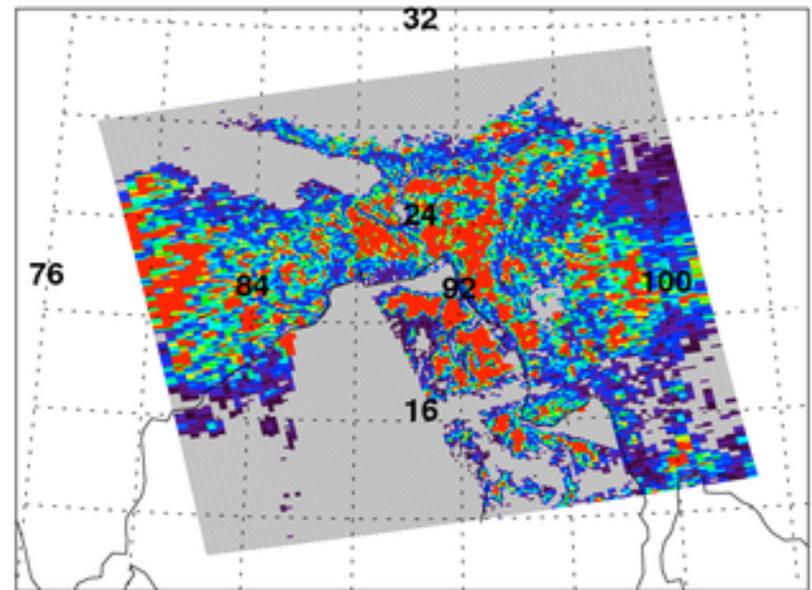
Cloud and Aerosol SDSs

Aerosol_Cldmask_Land_Ocean



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

Distance to Cloud



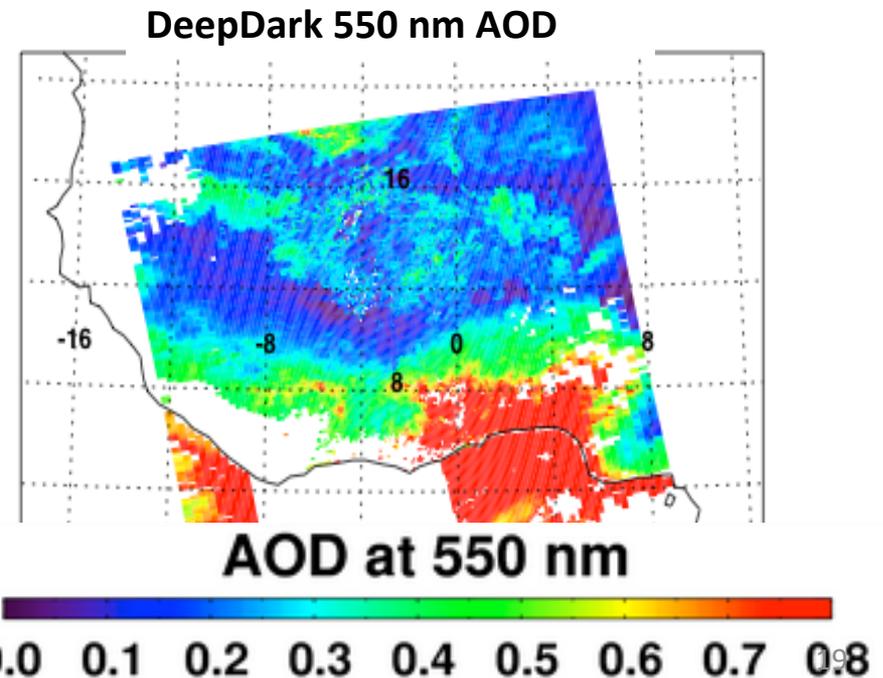
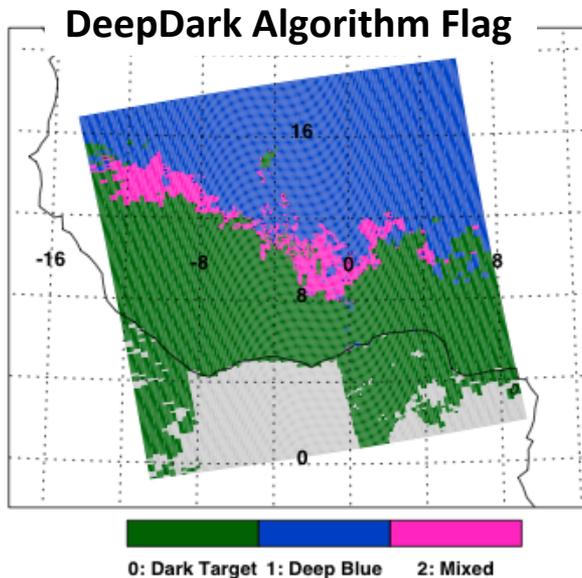
Number of pixels between an aerosol retrieval and the closest cloud. Not thoroughly validated yet.

Jan 21 2010 at 13:40 UTC



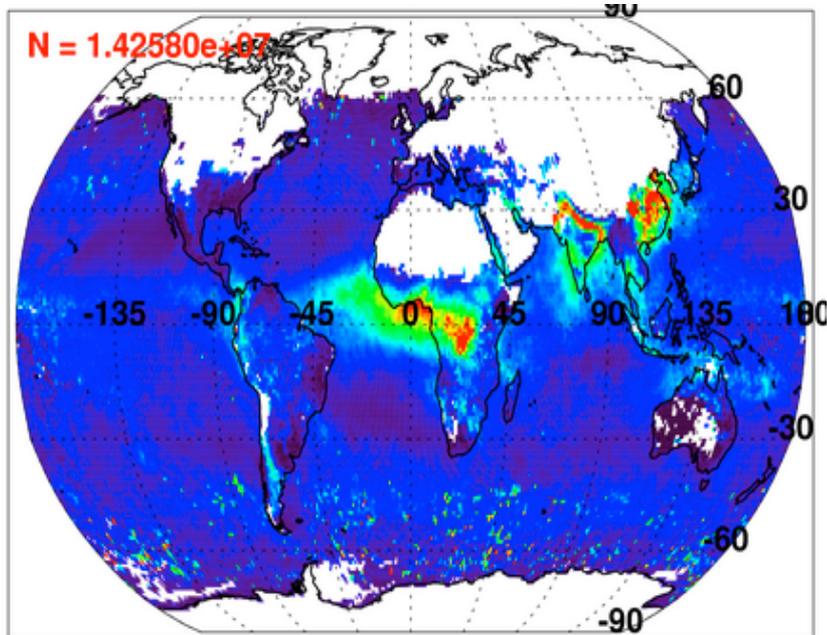
The Deep/Dark merge

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



Monthly mean AOD for Aqua, January 2010

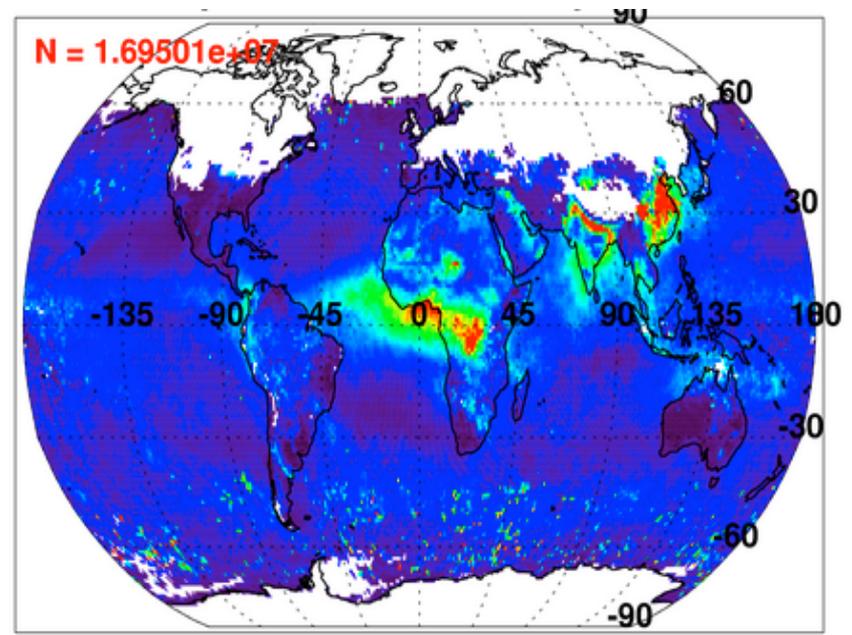
Dark Target AOD



AOD at 550 nm



DeepDark AOD



AOD at 550 nm



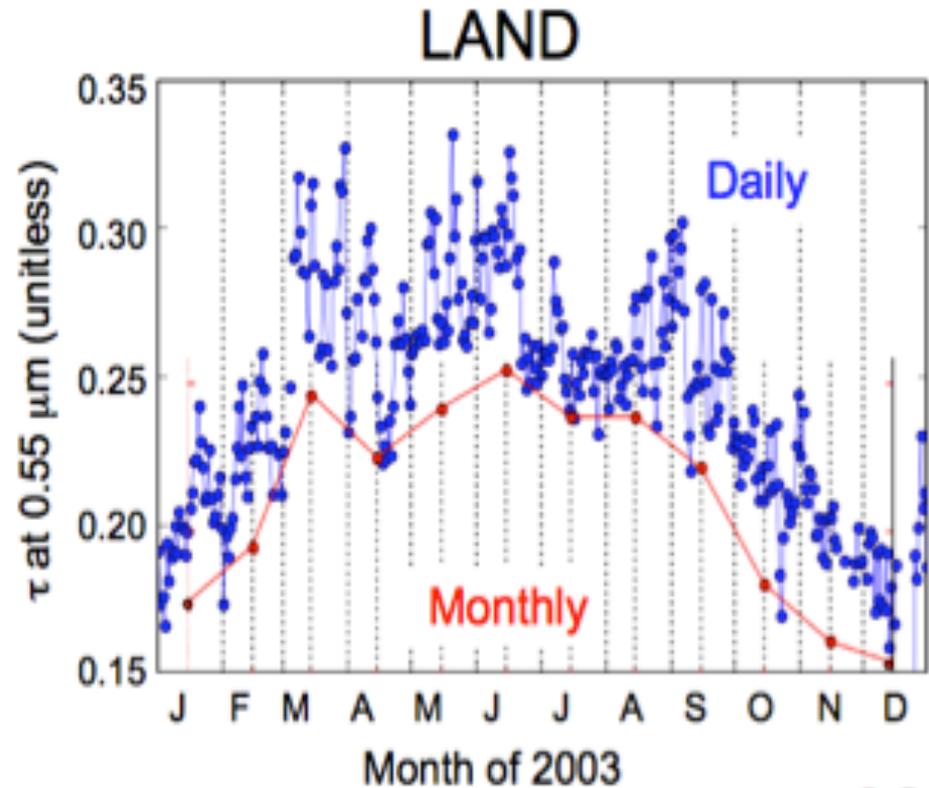
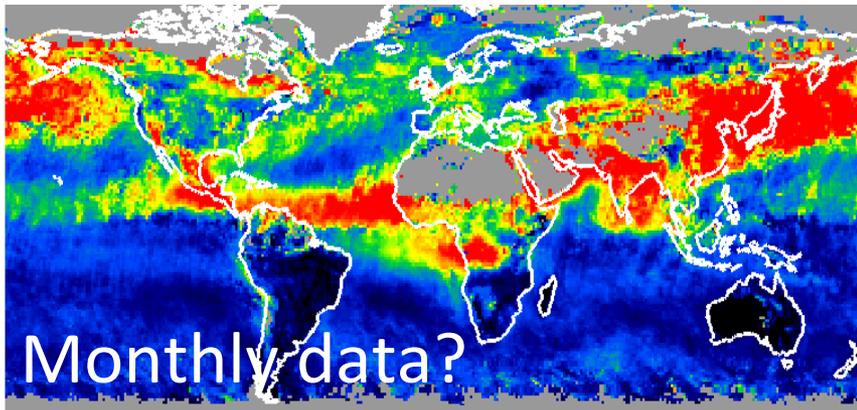
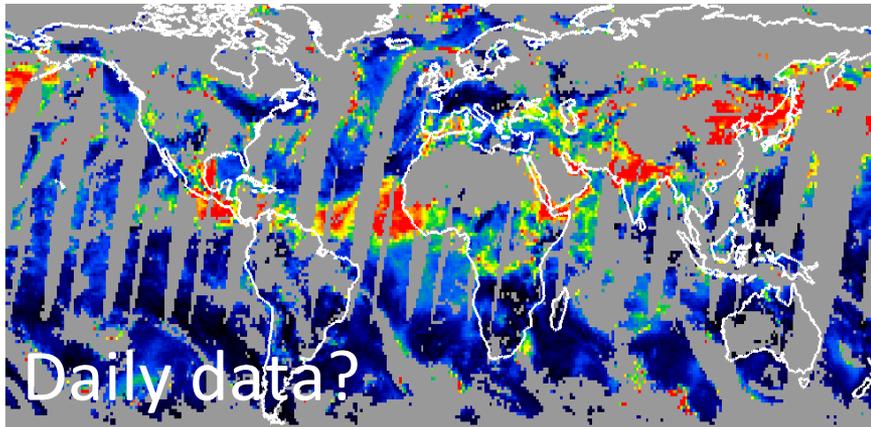
Merging deep blue & dark target produces best global coverage

- 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?

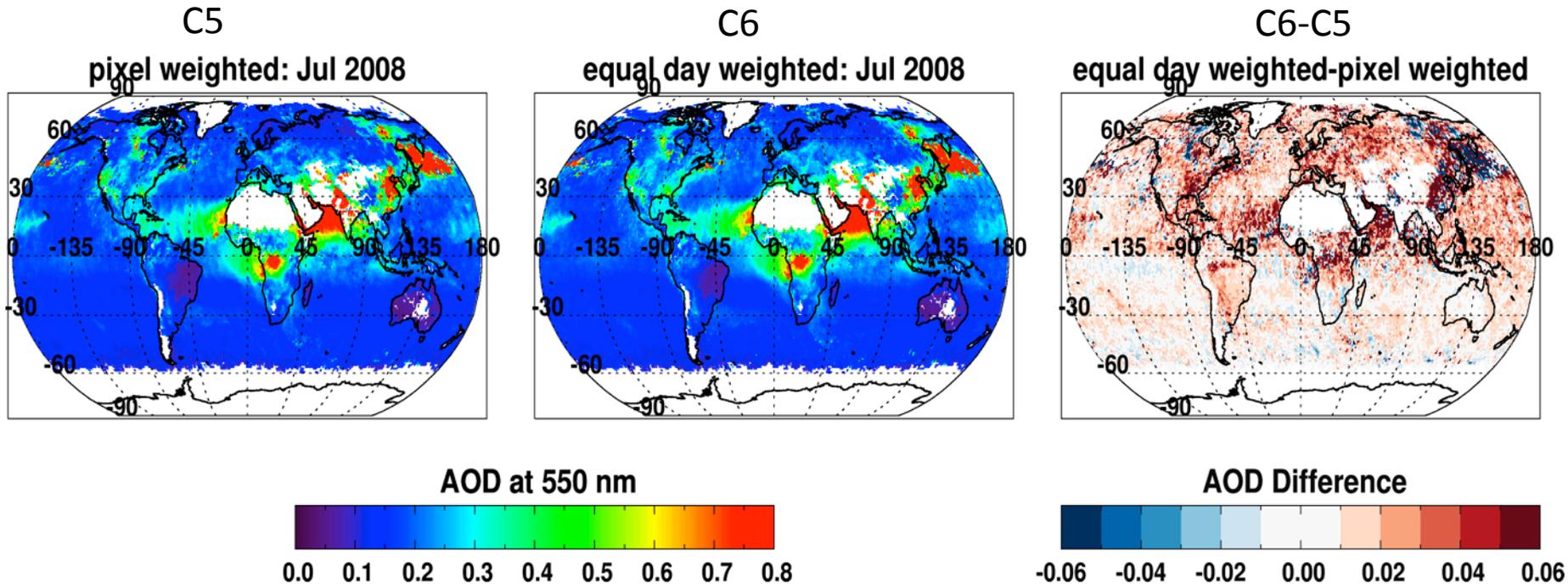
Calculating mean AOD



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

Changes to Level 3: monthly



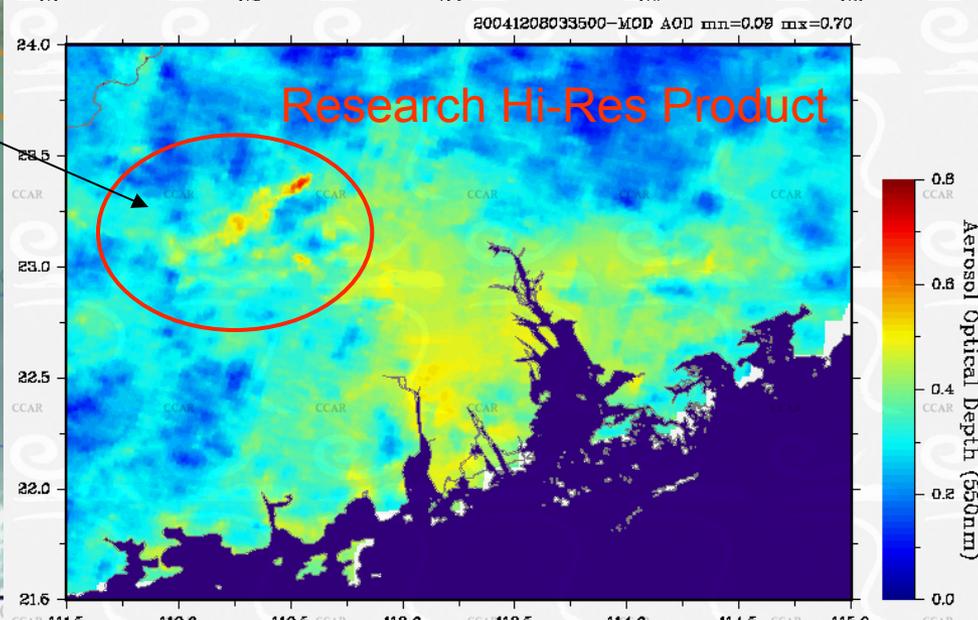
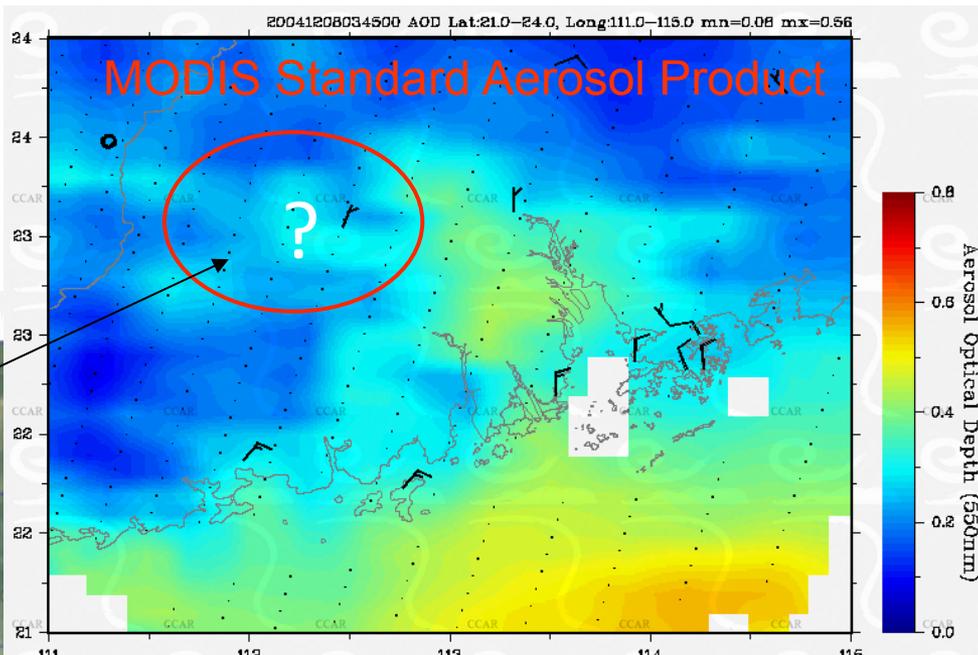
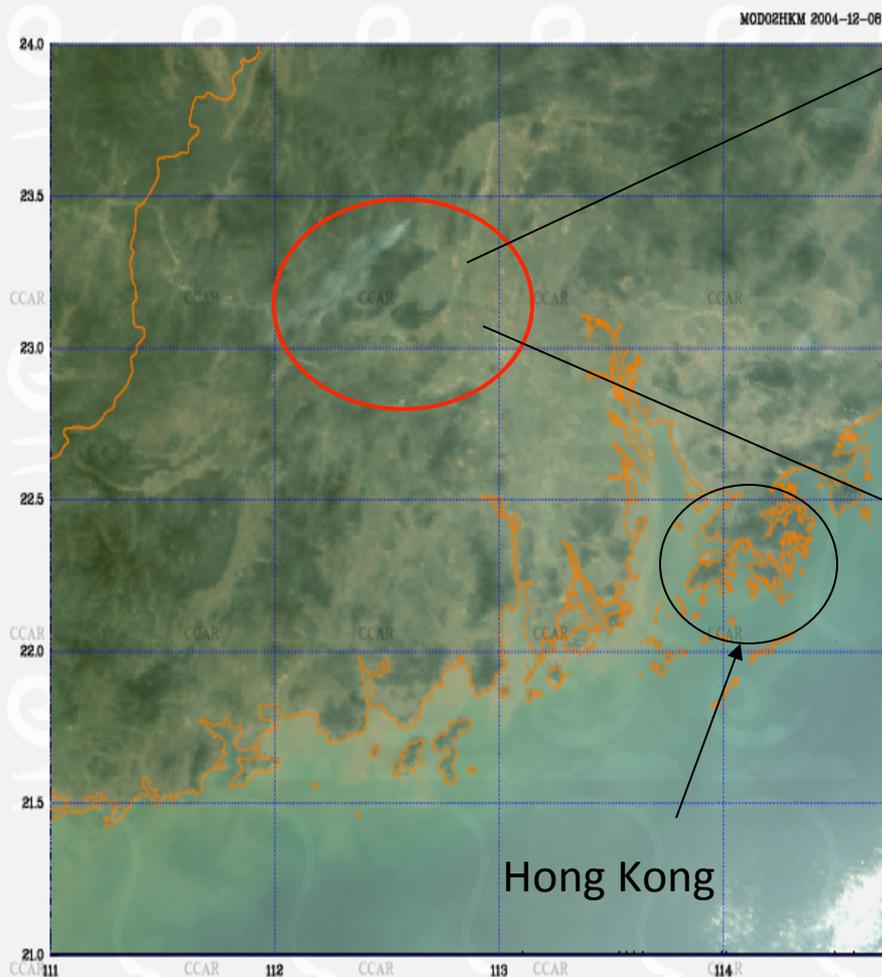
- Pixel weighting for monthly data is removed
- Replaced by “equal day” weighting (assuming at least 5 observations per day).
- → Increase monthly mean AOD over land, and ocean

Global → 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.

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

(where people live!!)



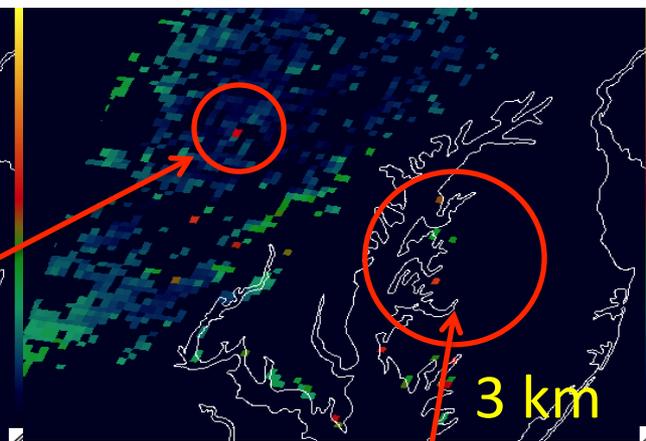
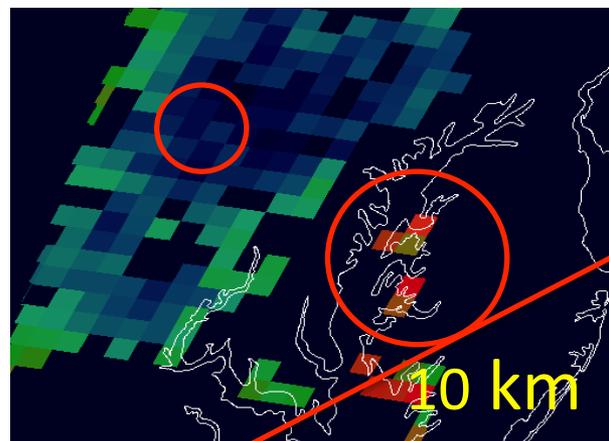
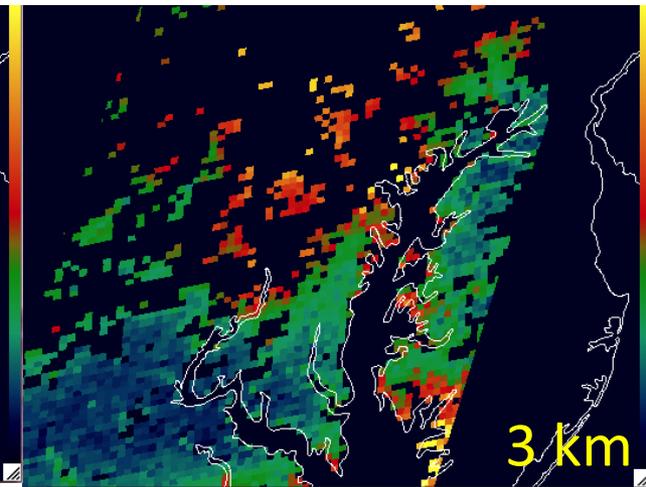
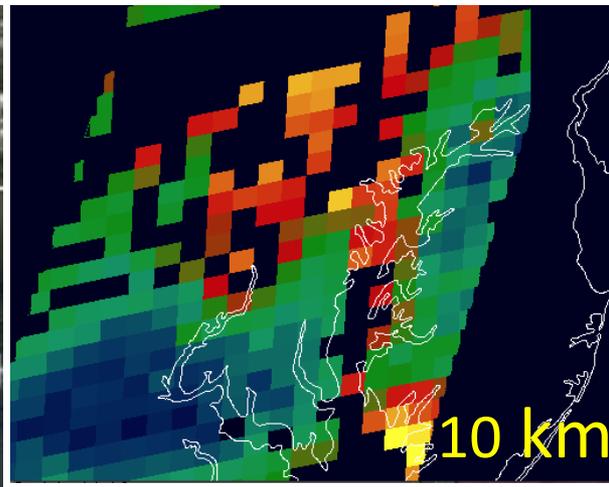
Hong Kong

3 km algorithm

In two AMT-Discussion Papers (in revision for AMT)

- [Munchak, L., R.C. Levy, S. Mattoo, L.A. Remer, B.N. Holben, J.S. Schafer, C.A. Hostetler, and R.A. Ferrare \(2013\). MODIS 3km Aerosol Product: applications over land in an urban/suburban region, Atmos. Chem. Phys. Dis, 6, 1683-1716
doi:10.5194/amtd-6-1683-2013](#)
- [Remer, L., S. Mattoo, R.C. Levy, and L. Munchak \(2013\). MODIS 3km Aerosol Product: Algorithm and Global Perspective, Atmos. Meas. Tech. Disc., \(6\), 69-112
doi:10.5194/amtd-6-69-2013](#)
- [J. M. Livingston, J. Redemann, Y. Shinozuka, R. Johnson, P. B. Russell, Q. Zhang, S. Mattoo, L. Remer, R. Levy, L. Munchak, and S. Ramachandran, \(2013\). Comparison of MODIS 3-km and 10-km resolution aerosol optical depth retrievals over land with airborne Sunphotometer measurements during ARCTAS summer 2008, Atmos. Chem. Phys. Dis, \(submitted last week\).](#)

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

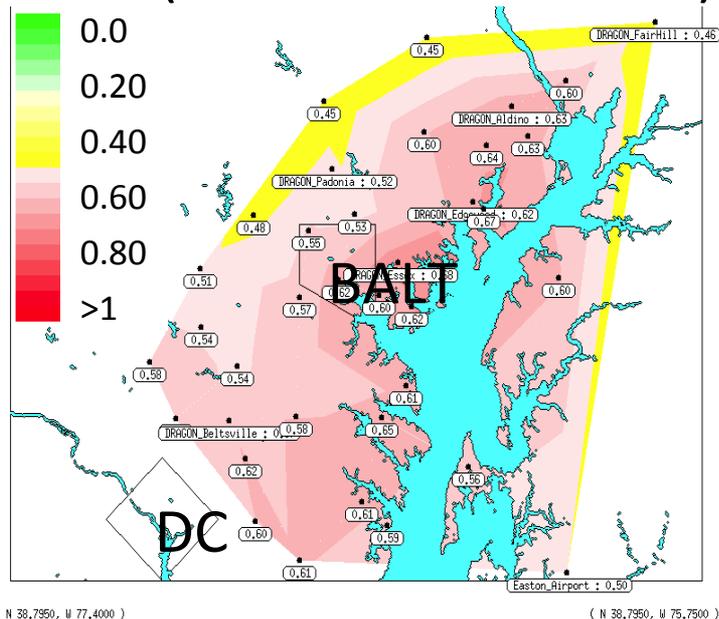


- 3 km mirrors 10 km product (pattern and magnitude)
- 3 km introduces **noise**, but also can reduce spatial impact of **outliers**

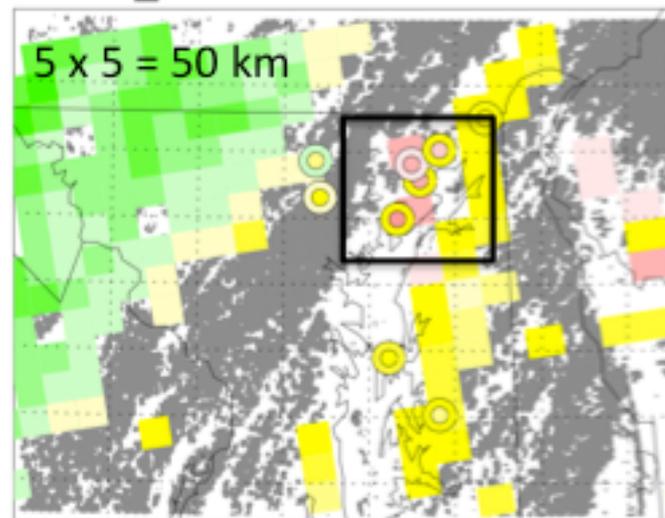
MODIS vs DRAGON

July 21, 2011

AOD (AERONET: DRAGON)

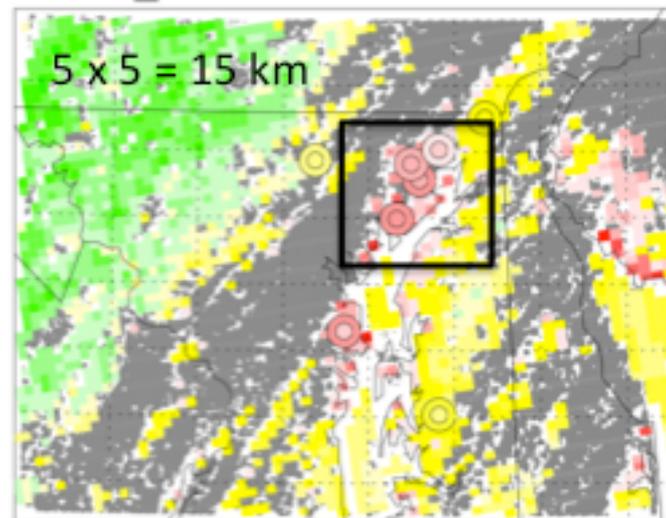


MYD04_10km 550 um 2011202 18:30



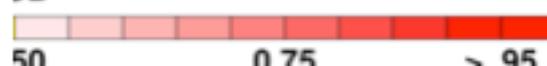
0.0 0.25 0.8

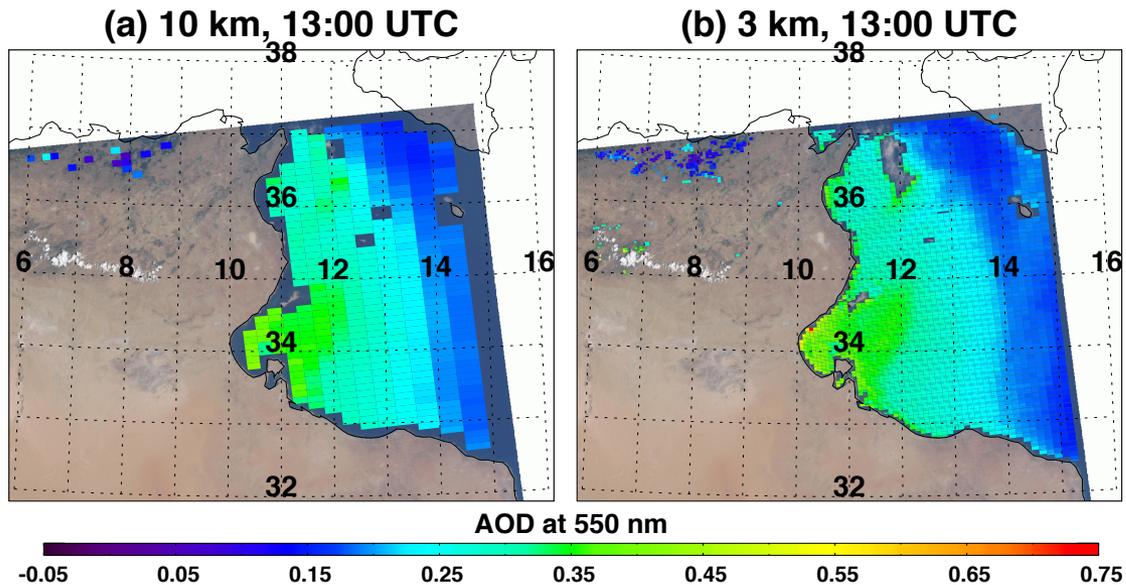
MYD04_03km 550 um 2011202 18:30



- 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

0.0





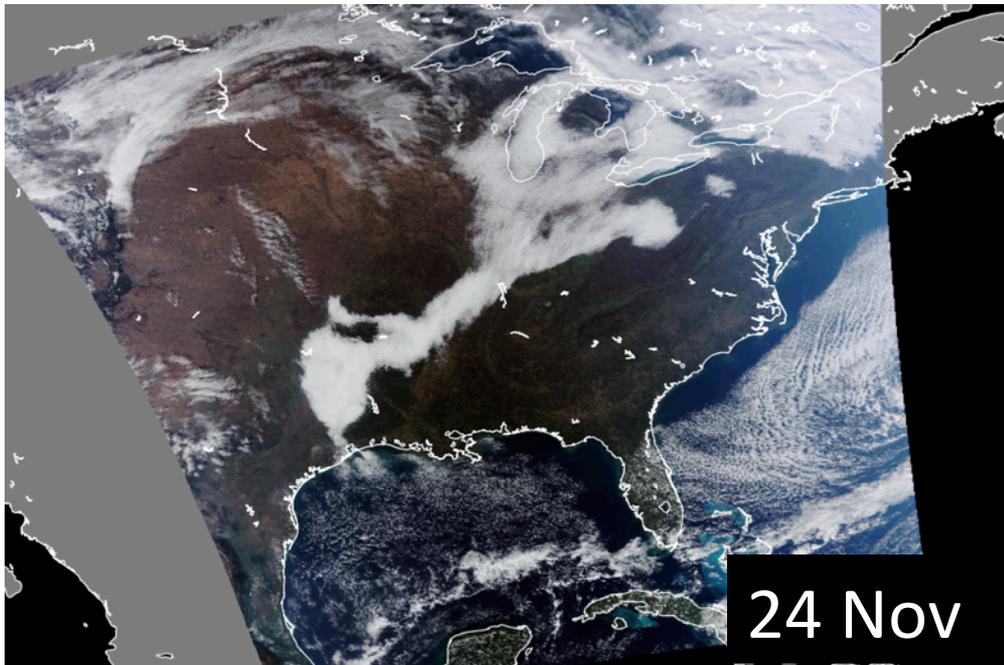
MODIS 3 km product (operational for C006)

- Algorithm structurally identical to standard “10 km” retrieval
- Results will be in new files, ***‘MOD04_3K’***
- Over land and ocean, (but no Deep Blue yet).
- Both MOD04_L2 and MOD04_3K will be available

And to the next big thing...

Suomi-NPP VIIRS

Visible Infrared Imager Radiometer Suite

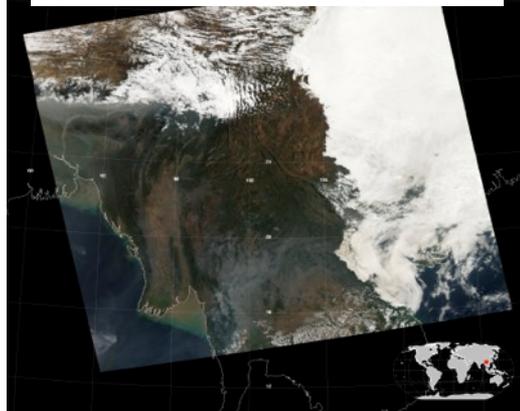


Multiple VIIRS granules stitched. Image by Geoff Cureton, CIMSS

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

MODIS-like algorithm on VIIRS data for climate continuity (on hold until C6 has started)

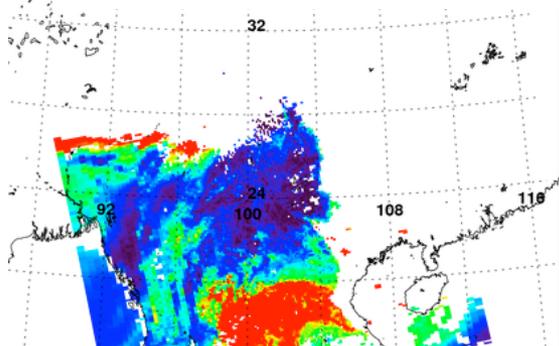
RGB image for MODIS



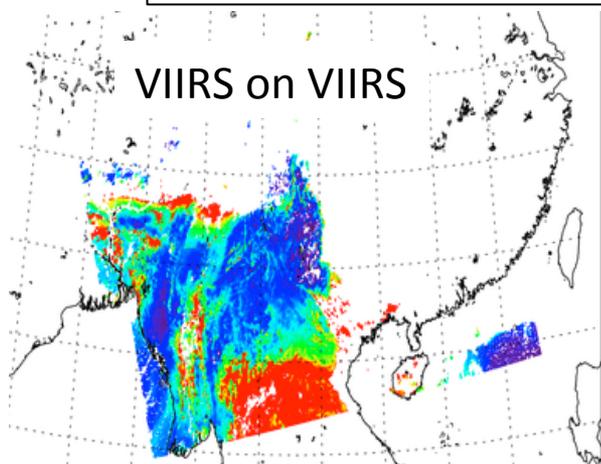
Both satellites overpass within minutes

- 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!)

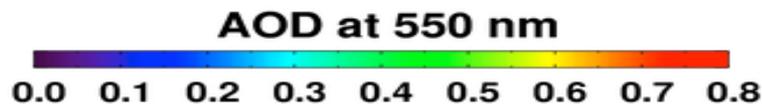
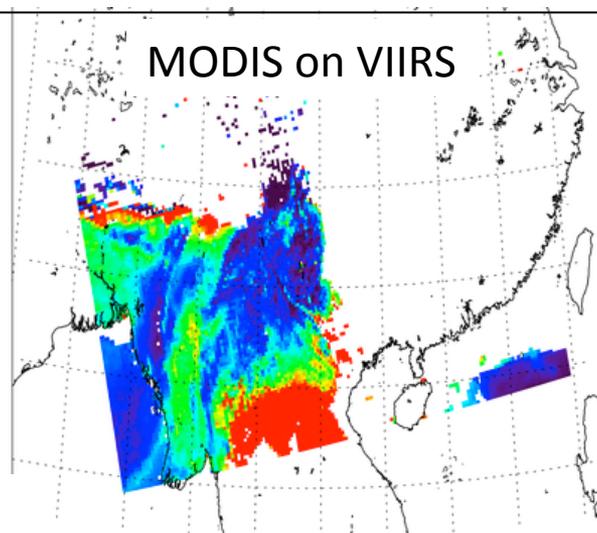
MODIS on MODIS-Aqua



VIIRS on VIIRS



MODIS on VIIRS



MODIS-like algorithm on ANY sensor!

For climate continuity

- MODIS
- VIIRS
- MAS/E-MAS/AMS (Airborne spectrometers and historical experiment data)
- International sensors
- Future sensors (e.g. PACE / ACE) as a baseline for testing new ideas

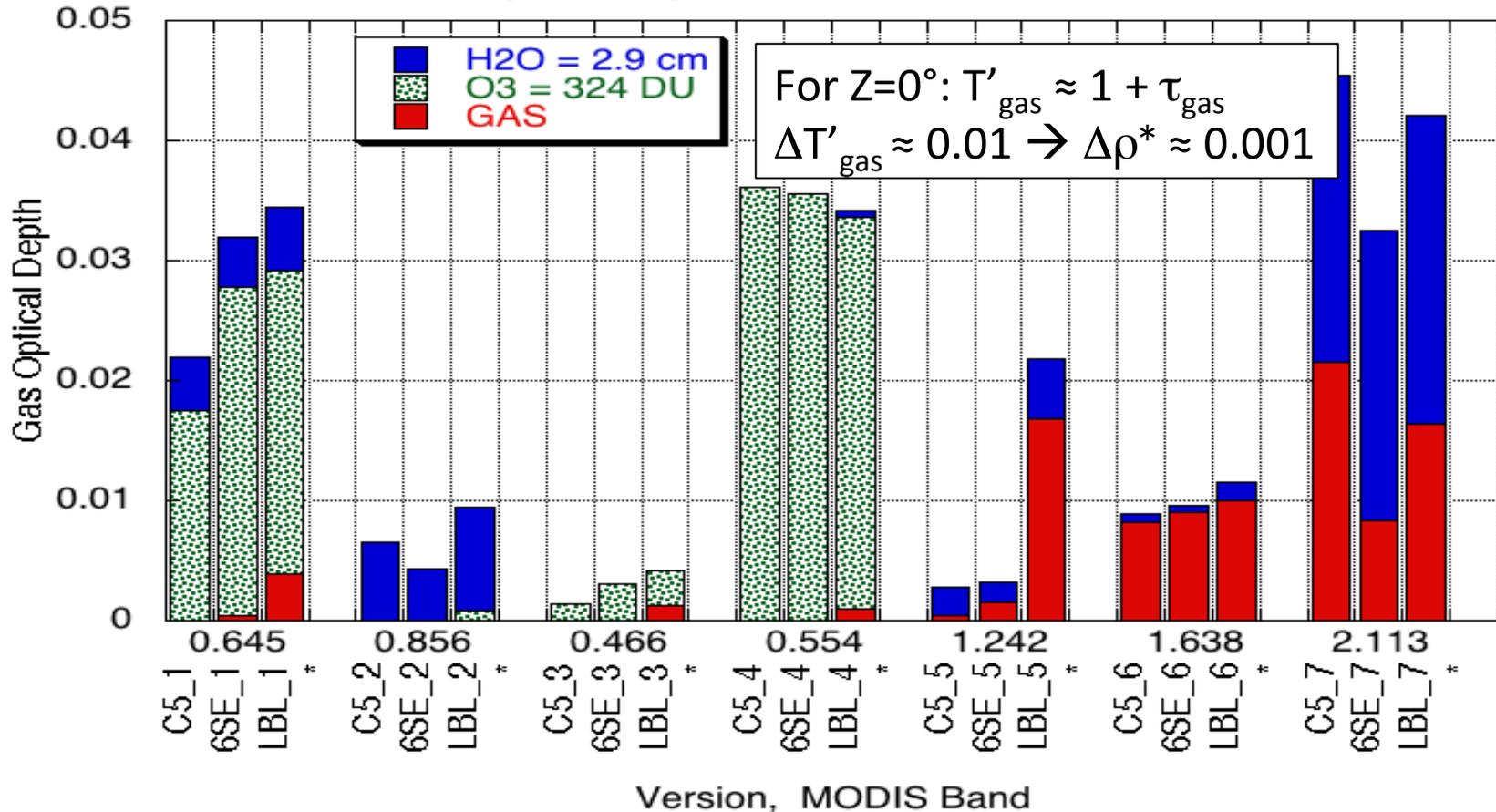
Opens up many cans of worms (and makes Shana very unhappy).

Example : Gas Corrections

- Gases (H₂O, O₃, CO₂, NO₂, etc...) absorb radiation.
- $T_{\text{gas}} < 1.0$, varies spectrally and function of gas optical depth:
$$T_{\text{gas}} = \text{EXP}(-\tau_{\text{gas}}M) \approx 1 - M\tau_{\text{gas}} \quad (\text{where } M \text{ is air mass})$$
- Our aerosol LUTs assume $T_{\text{gas}} = 1.0$.
- We compensate by multiplying observed reflectance ρ by the inverse, T'_{gas} $\rho^* = \rho T'_{\text{gas}}$ (and use ρ^*).
- How is T'_{gas} (or τ_{gas}) assumed / calculated? Depends on
 - A) radiative transfer code used,
 - B) spectral band filter function assumptions
 - C) spectral resolution of RT
 - D) equations to fit
 - E) Etc
- We did not know where our C5 assumptions came from. And we wanted to apply consistently to C6-MODIS, VIIRS, etc

Gas Corrections (cont.)

Gas Optical Depths for Mid Latitude Summer



- Consistent “bias” of $\Delta \rho^* \approx 0.001 \rightarrow$ “bias” of AOD of 0.01.
- Bias is **double** for $Z=60^\circ$. **Quadruple** for two-way transmission!
- Something really weird is happening at 1.24 μm channel. .
- **ACE: We want to know global AOD to ± 0.01 ? **Not when we don't know gas!!!****

Trying to get C6 into product is like...



Video found on You-Tube
Noting no harm to cat

Summary (1)

- Dark-target algorithm/products are updated for C6, but only “modest” changes (no major science updates).
- “Modest” is relative... Many difficult decisions about seemingly small things that actually were significant. (e.g. Gas Correction, Cloud Mask, Quality Assurance etc).
- Dark-target and Deep-blue products are merged, leading to more global coverage
- New C6 calibration, new C6 geo-location

Summary (2)

- 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 (3)

- MODIS is not the only thing
 - NPP-VIIRS is online
 - VIIRS is “similar”, yet different than MODIS
 - For “climate continuity” purposes, we will have a MODIS-like algorithm to run on VIIRS
 - ... any other sensor that is MODIS-like.
- On towards development of Collection 7
 - Proposal season!

THANK YOU FOR YOUR ATTENTION!!!!