Stitching a MODIS-VIIRS time series of aerosol properties using the Dark Target algorithm: Status in 2016

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Dark target group:
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* New people in 2016.

And many, many, many others

MODIS/VIIRS Science Team Meeting: June 2016

Aerosol from space as a climate record

➤ Aerosol optical depth (AOD or τ)
➤ "Essential Climate Variable" (ECV)
   ➤ Requires accuracy <±0.02
   ➤ Measured over multi-decades
➤ Yet, mostly a "regional" problem.
➤ Required uncertainty (per pixel) = <15%.

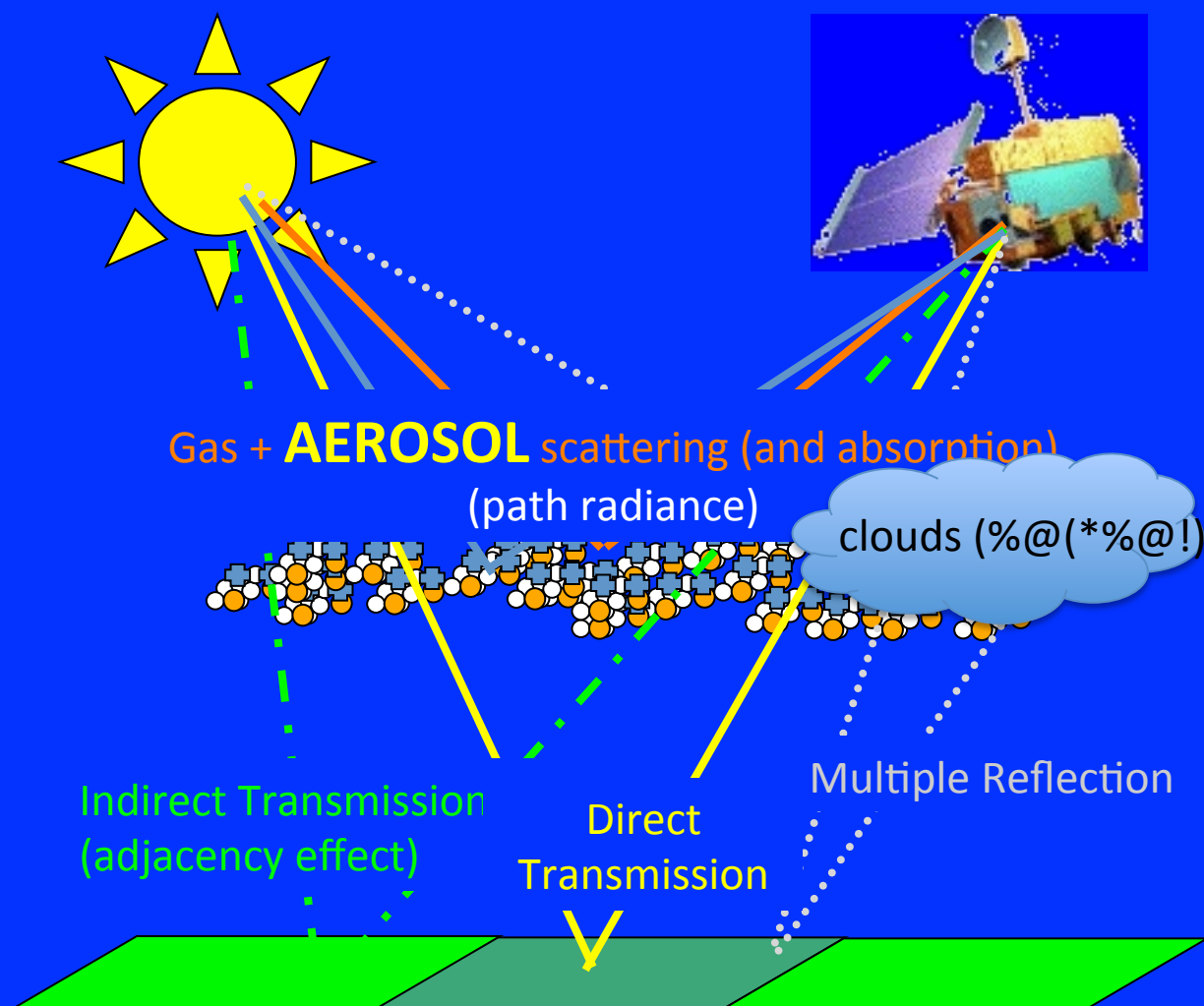➤ Also don't forget that aerosol is an air quality problem as well.
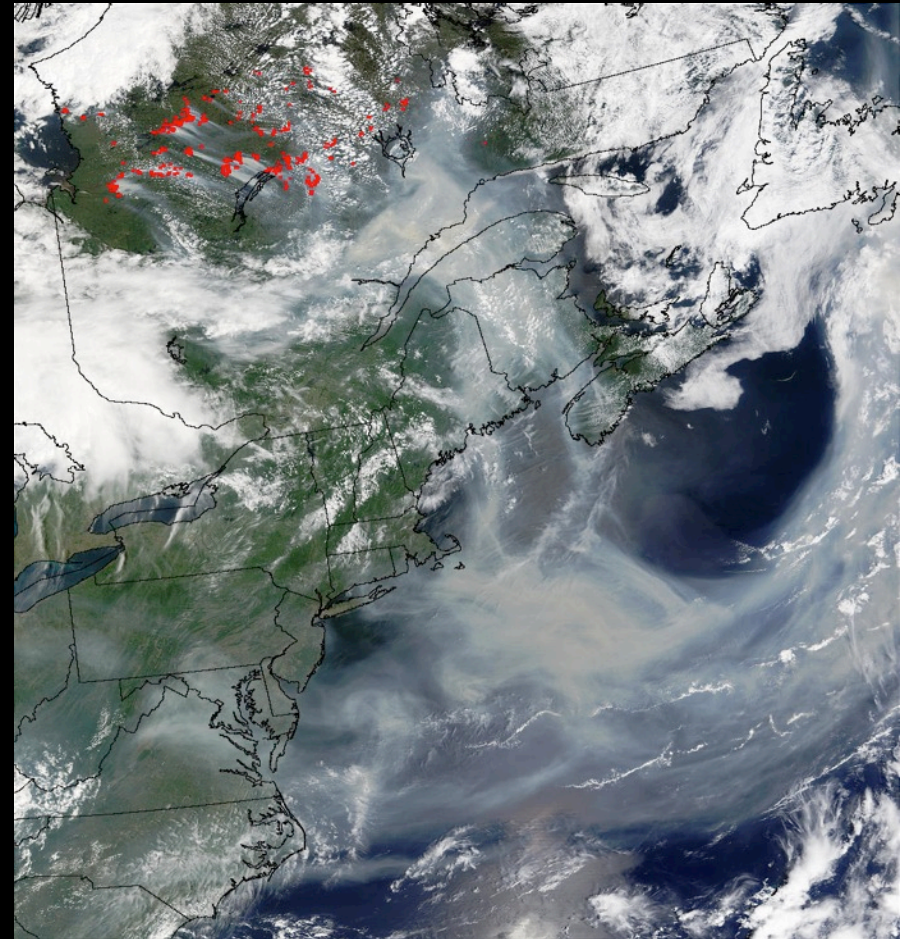
Smoke transported over Eastern Canada/USA (8 July 2002)
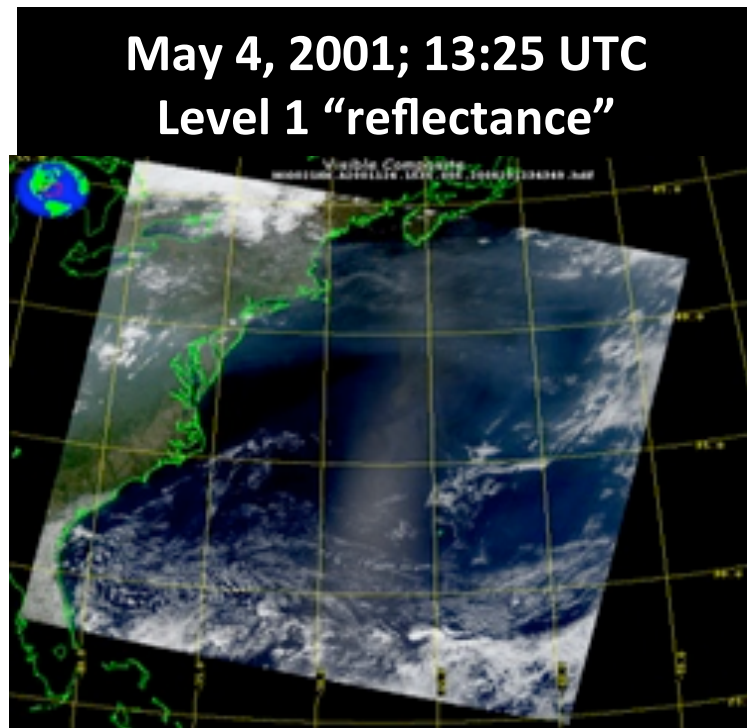
http://earthobservatory.nasa.gov/

Outline

1. "Dark-target" (DT) remote sensing on MODIS
2. Terra vs Aqua (and calibration and trends)
3. DT applied to VIIRS (using Wisconsin IFF)
4. Challenges of MODIS→VIIRS continuity
5. Advancing the DT algorithm
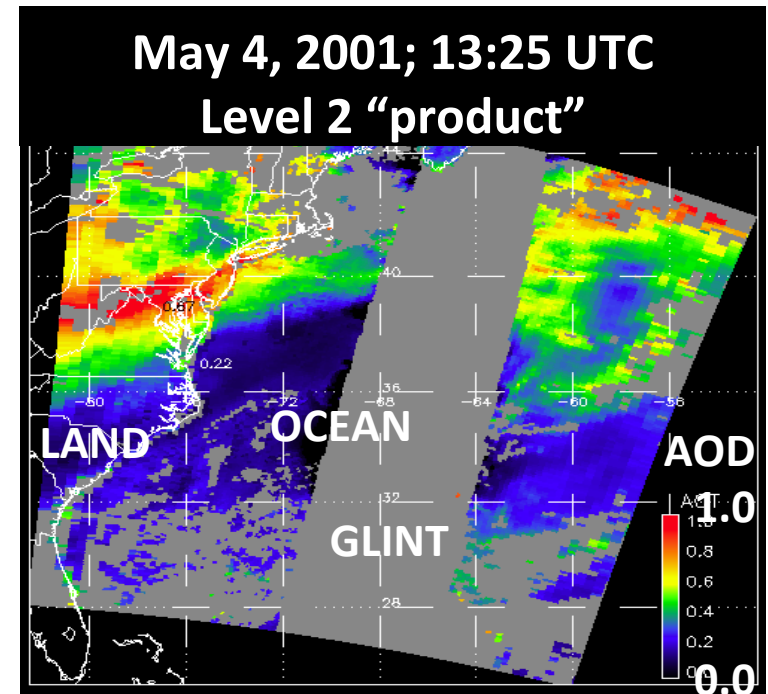6. Summary

Complicated TOA Signal: We want the AEROSOL

Gas + **AEROSOL** scattering (and absorption)

(path radiance)

clouds (%@(*%@!)

Indirect Transmission
(adjacency effect)

Direct
Transmission

Multiple Reflection

Dark Target (DT) aerosol retrieval

What a sensor observes

**May 4, 2001; 13:25 UTC
Level 1 "reflectance"**

Attributed to aerosol (AOD)

**May 4, 2001; 13:25 UTC
Level 2 "product"**

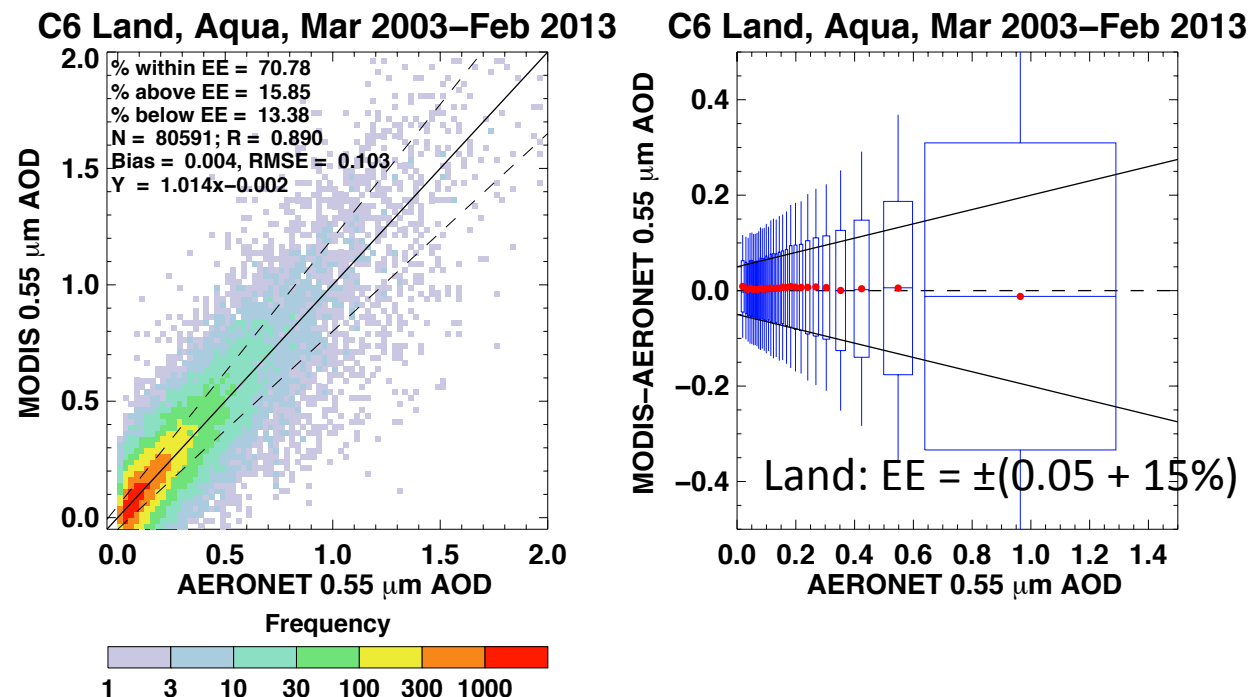LAND   OCEAN

GLINT

AOD
1.0

0.0

There are many different "algorithms" to retrieve aerosol from MODIS
Ours is **Dark Target (DT)**; "Established 1997" by Kaufman, Tanré, Remer, etc)

**Separate algorithms: Ocean and Land
Both are multi-channel inversions
Products = AOD at 0.55 μm, spectral AOD, diagnostics**

5

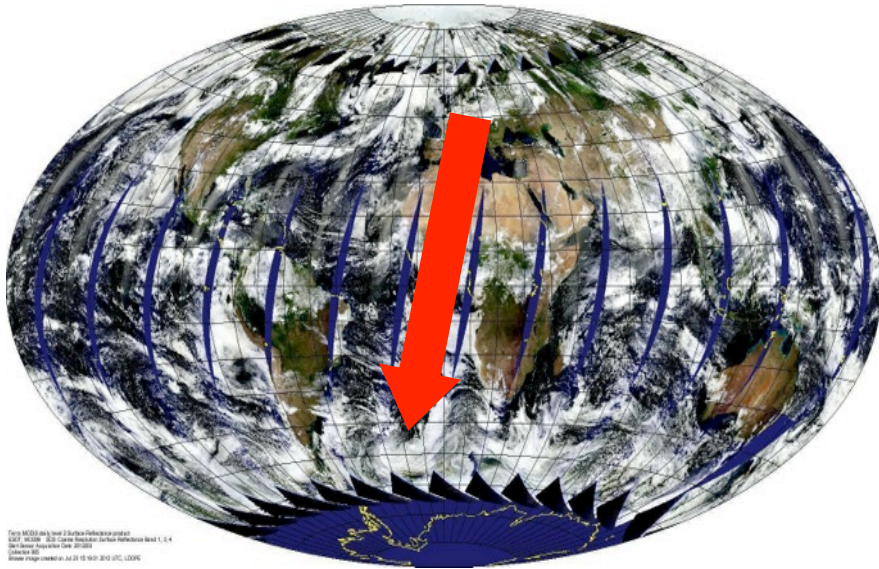# MODIS Collection 6 (10 km product): "Validated since 2014"

All assumptions related to assumed aerosol properties, surface reflectance, lookup tables, and cloud masks were updated for C6

Collection 6 "Webinars": http://aerocenter.gsfc.nasa.gov/ext/registration/
"dark-target" website: http://darktarget.gsfc.nasa.gov
MODIS product website: http://modis-atmos.gsfc.nasa.gov

C6 Land, Aqua, Mar 2003–Feb 2013

% within EE = 70.78
% above EE = 15.85
% below EE = 13.38
N = 80591; R = 0.890
Bias = 0.004, RMSE = 0.103
Y = 1.014x−0.002

MODIS 0.55 μm AOD

AERONET 0.55 μm AOD

C6 Land, Aqua, Mar 2003–Feb 2013

MODIS−AERONET 0.55 μm AOD

AERONET 0.55 μm AOD

Land: EE = ±(0.05 + 15%)

Frequency

1 3 10 30 100 300 1000

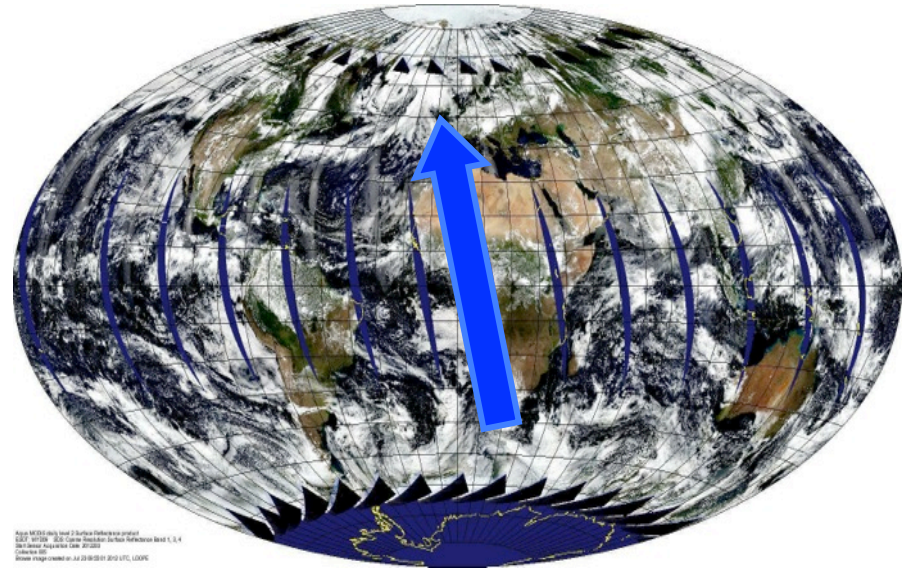# MODIS on Terra and Aqua
Validated AOD retrievals for both data sets

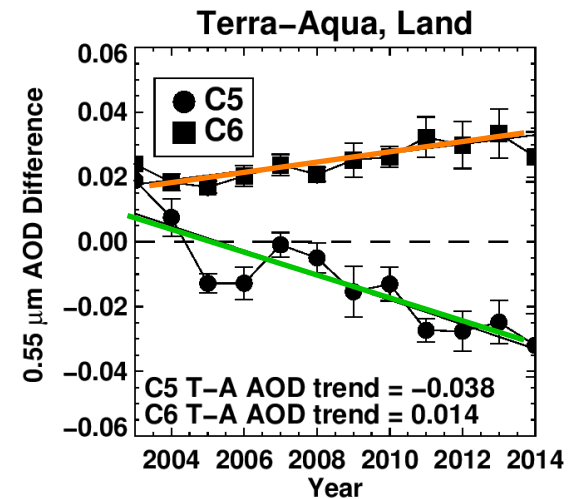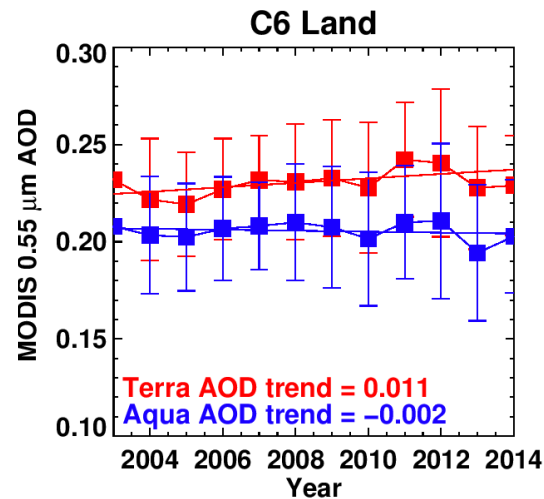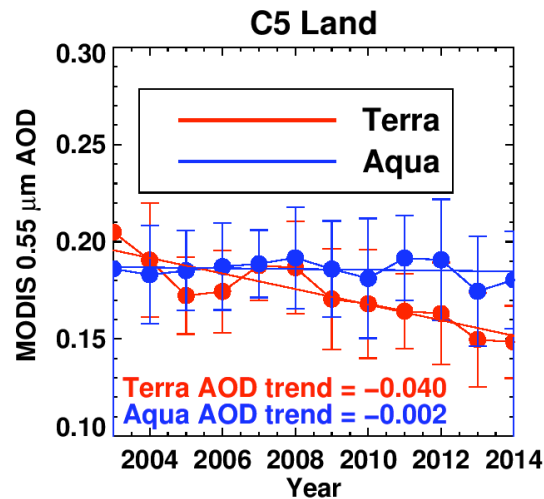Terra (10:30, Descending)   Aqua (13:30, Ascending)

- Same instrument hardware (optical design)
- Same spatial and temporal sampling resolution
- Same calibration/processing teams
- Same aerosol retrieval algorithms
- The two MODIS instruments are Identical twins!
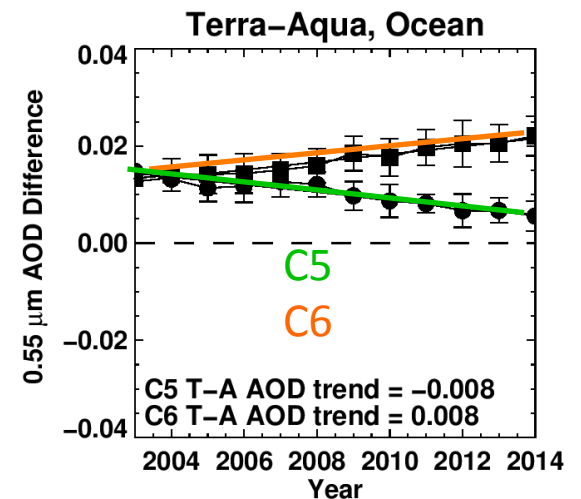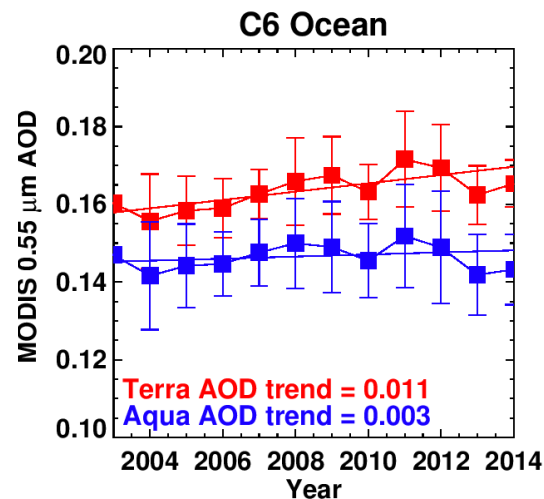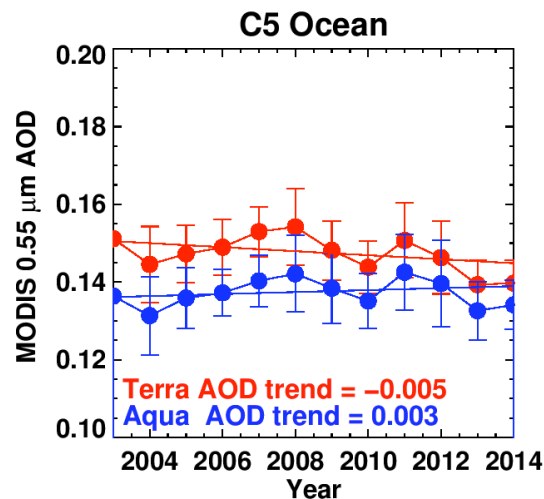   Do they observe the world in the same way?

Time series of MODIS-derived AOD

$\Delta\tau$ = Terra - Aqua

Good news: Strong $\Delta\tau$ negative "trending" is reduced in C6
Bad news: 1) $\Delta\tau$ offset increases, and 2) there is now a positive trend

MODIS C6 (and calibration adjustments?)

- Trending issues reduced with C6 product, but:
  - Still significant offsets (13%) and
  - Still residual co-trending (<0.01 / decade)
- Why? Sampling? diurnal cycles? Cloud masking?

- Calibration?
  - Test different options
  - "C6+" of Alexei Lypustin et al.,
  - Ocean vicarious corrections
  - Many others
  - Me, playing on my own.
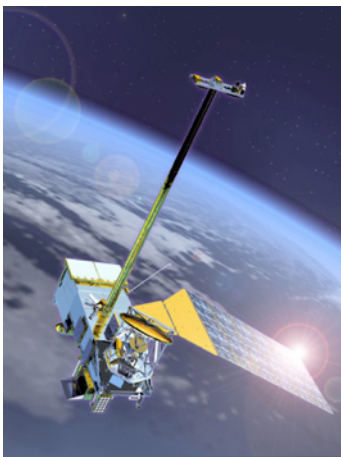 - Etc.

- Still working on problem

June 2013, land grid cells
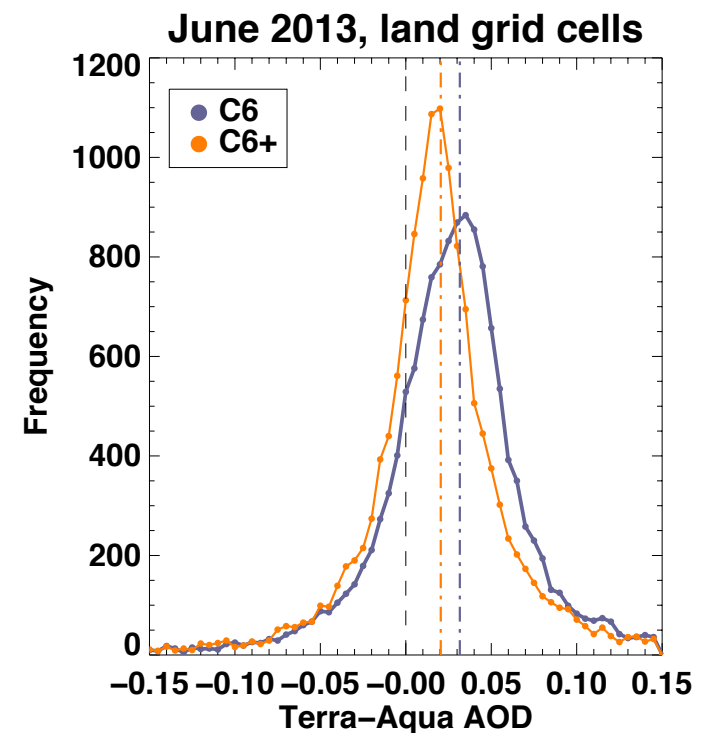
Beyond **MODIS**
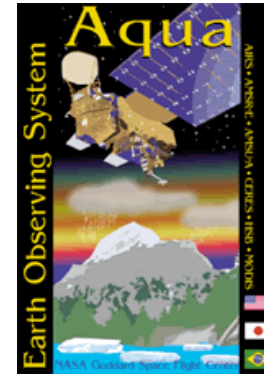
- Terra (16 years old) is driving in Maryland
- Aqua (14) "seems" well behaved, but is a teenager
- Both have well-exceeded their planned mission lifetimes
- Calibration continues to get trickier, and there are end-of-lifetime plans

How do we make AOD climate data record? (20+ years of global AOD)?

VIIRS?

Visible-Infrared Imager Radiometer Suite
aboard Suomi-NPP
(and future JPSS)

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 (vs on Aqua since 2002)
Swath: 3050 km (vs 2030 km)
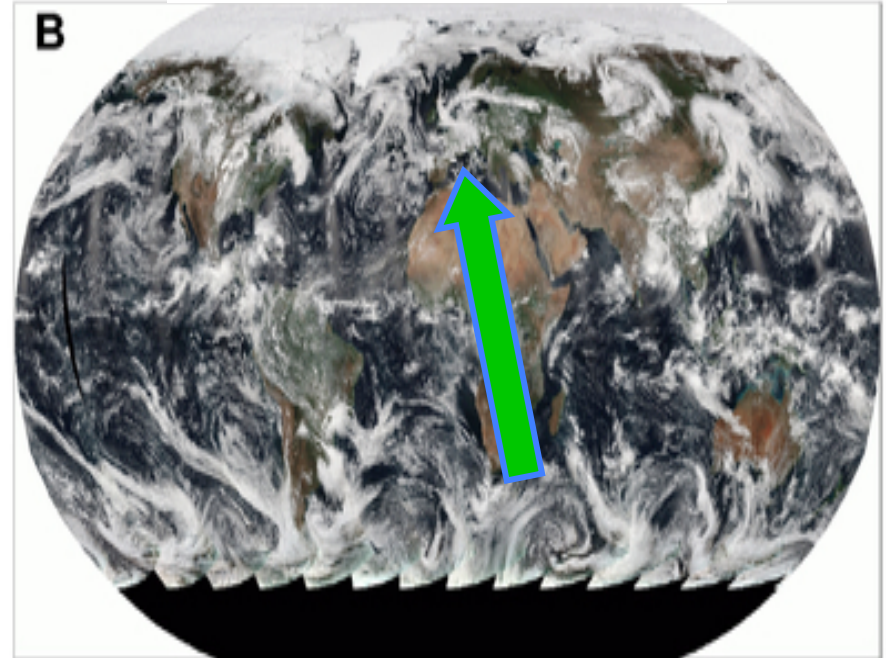**Spectral Range**: 0.412-12.2μm (22 bands versus 36 bands)
Spatial Resolution: 375m (5 bands) 750m (17 bands): versus 250m/500m/1km

Wavelength bands (nm) / DT aerosol retrieval: 482 (466), 551 (553) 671 (645), 861 (855), 2257 (2113) → differences in Rayleigh optical depth, surface optics, gas absorption.
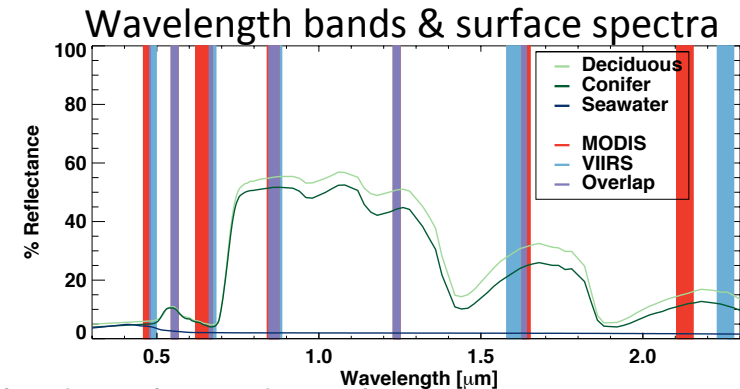
MODIS-Aqua – 29 May 2013
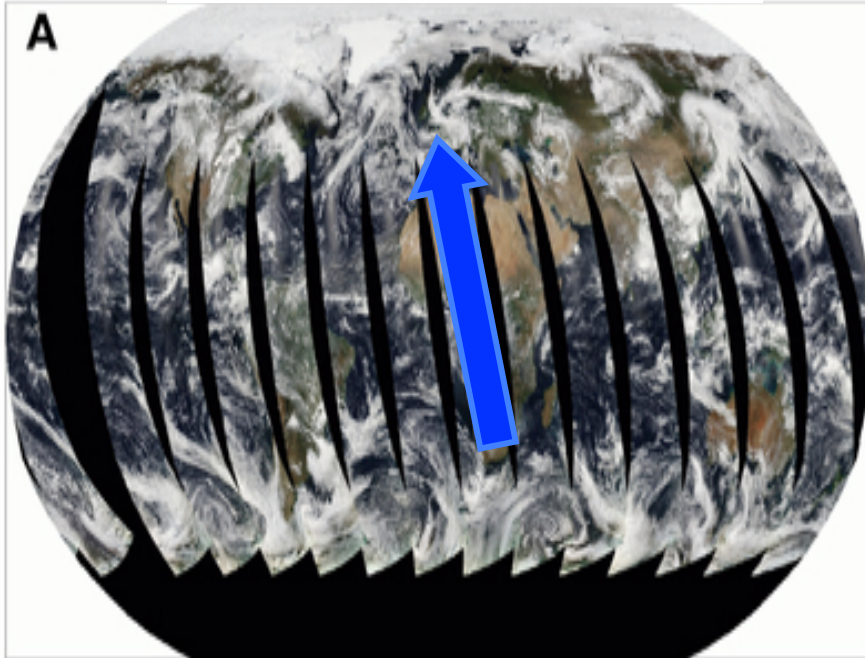
VIIRS-SNPP – 29 May 2013

To develop "continuity"
Port the DT algorithm!
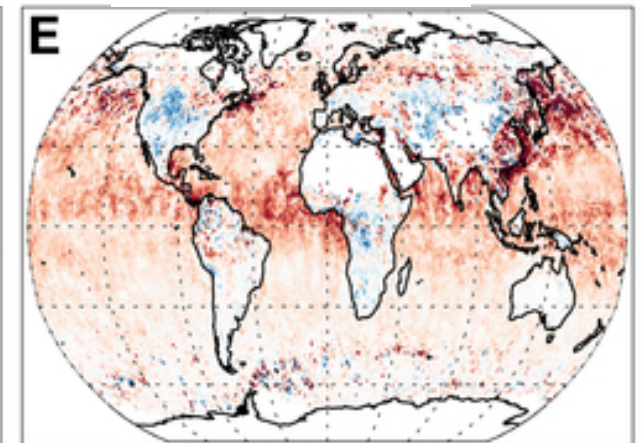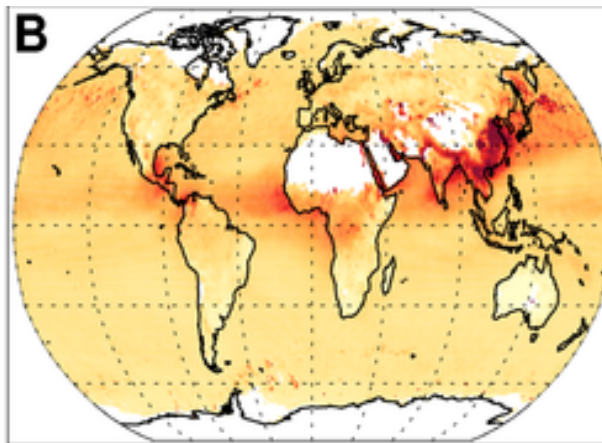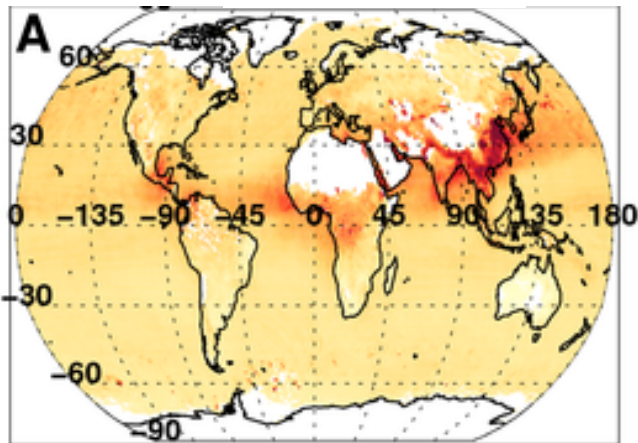

Wavelength bands & surface spectra

- We use Intermediate File Formats (IFF) and tools developed at the "Atmosphere-SIPS", at the University of Wisconsin
- Deal with differences in wavelengths (gas corrections/Rayleigh, etc)
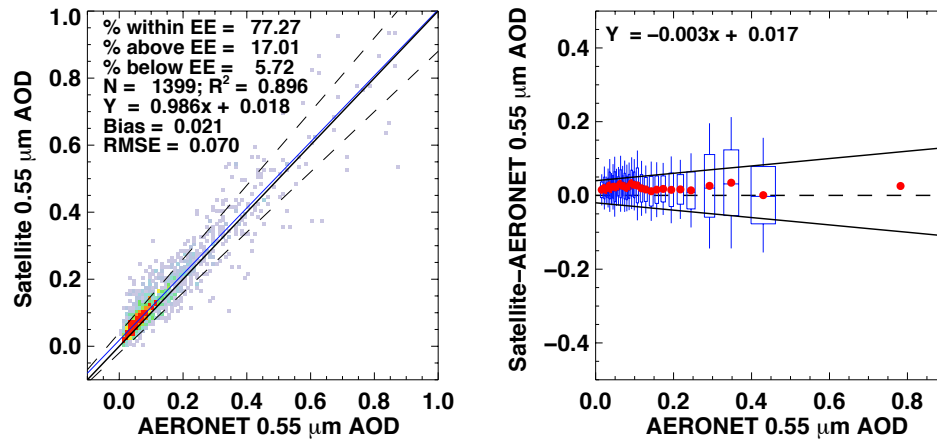- DT on VIIRS (compared with DT on MODIS):

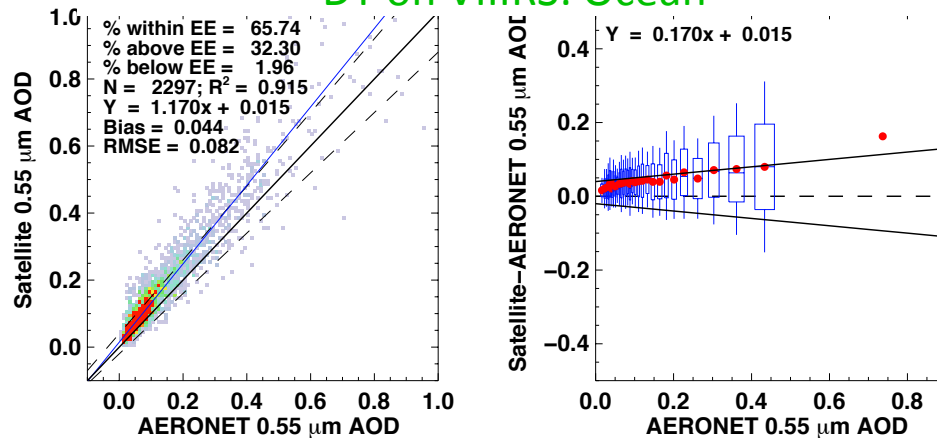DT on MODIS   DT on VIIRS   Difference M - V

- There is a systematic bias over ocean (VIIRS high by 20%).
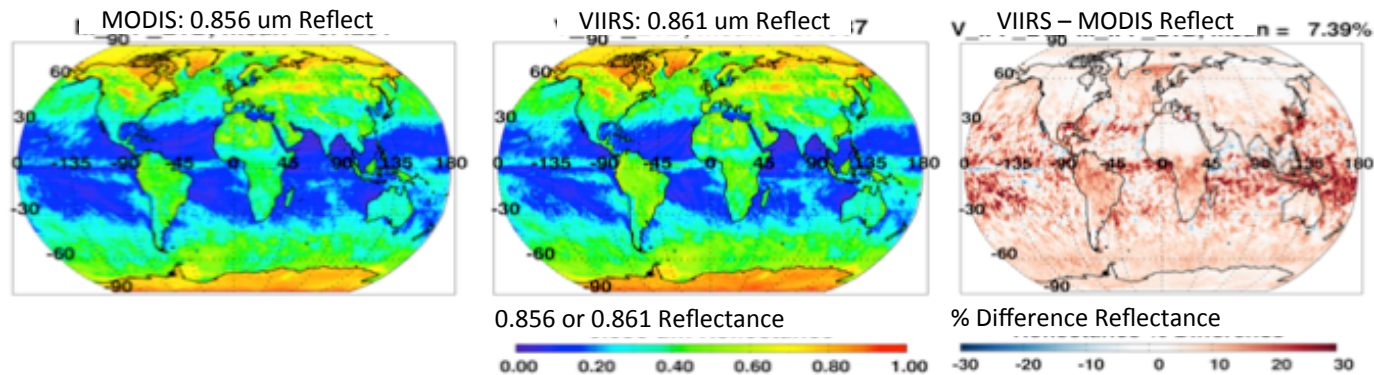- Déjà vu? Terra versus Aqua? (Terra high by 13%)

Levy et al., 2015

Comparing to AERONET and calibration

DT on MODIS: Ocean

% within EE = 77.27
% above EE = 17.01
% below EE = 5.72
N = 1399; R² = 0.896
Y = 0.986x + 0.018
Bias = 0.021
RMSE = 0.070

Y = −0.003x + 0.017

DT on VIIIRS: Ocean

% within EE = 65.74
% above EE = 32.30
% below EE = 1.96
N = 2297; R² = 0.915
Y = 1.170x + 0.015
Bias = 0.044
RMSE = 0.082

Y = 0.170x + 0.015

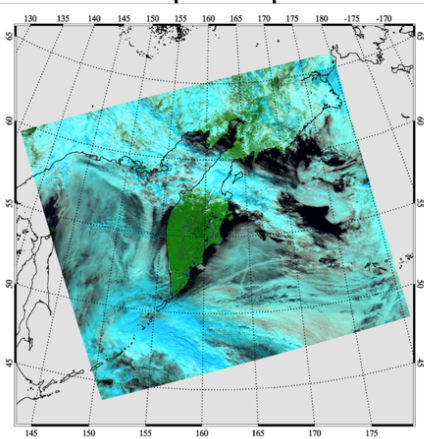- DT on VIIRS has same great correlation as on MODIS, but 1.17 slope!

- Could VIIRS biased by 2% in some bands?

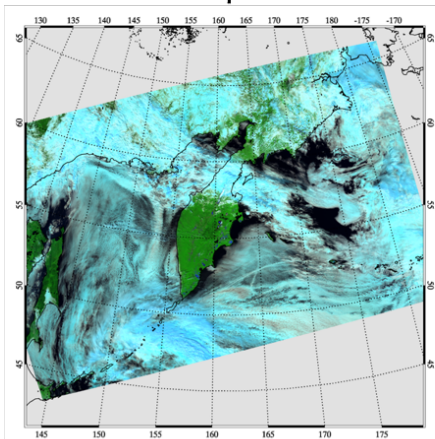- 2% high bias in 0.86 μm band is sufficient to give a 1.17 slope over ocean without the adding bias over land

MODIS: 0.856 um Reflect

VIIRS: 0.861 um Reflect

VIIRS − MODIS Reflect   n = 7.39%

0.856 or 0.861 Reflectance

% Difference Reflectance

Calibration: Match files

- Can we "prove" calibration differences? It's hard!
  - Differences in orbit → no true matches inside ±70° latitude
  - Common geometry is very limited
  - University of Wisconsin is creating "match" files for us to look at
  - MODIS = master; VIIRS data if "close" in time and geometry

Close overpass (space and time) between Aqua and SNPP near the Kamchatka Peninsula and surrounding waters.
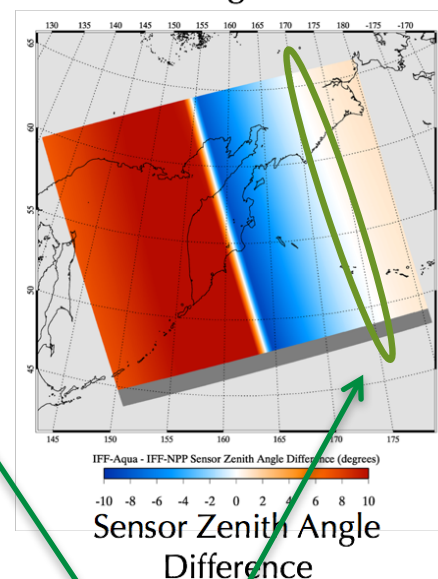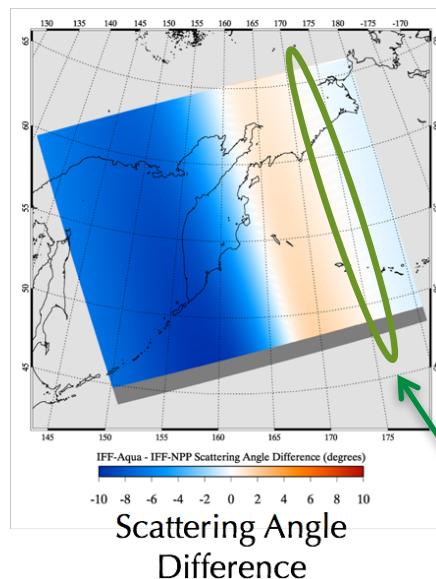
MODIS False Color
(Bands 7, 2, 1)

VIIRS False Color
(M11, M7, M5)

From Steve Platnick

IFF-Aqua - IFF-NPP Scattering Angle Difference (degrees)
-10 -8 -6 -4 -2 0 2 4 6 8 10
Scattering Angle Difference

IFF-Aqua - IFF-NPP Sensor Zenith Angle Difference (degrees)
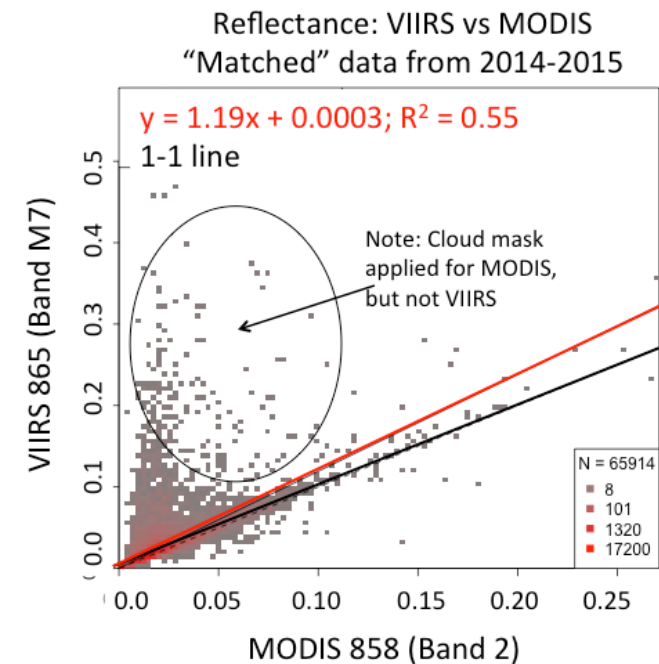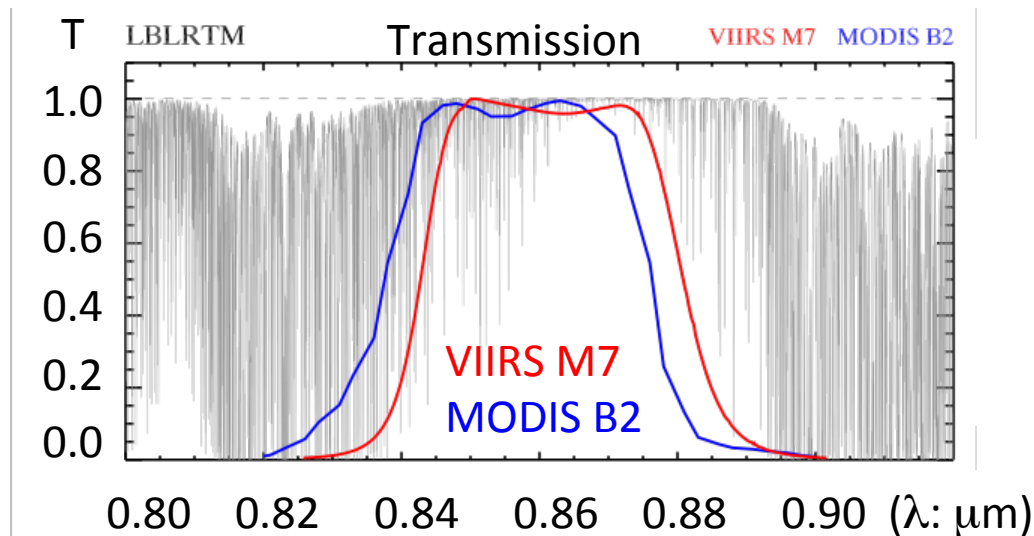-10 -8 -6 -4 -2 0 2 4 6 8 10
Sensor Zenith Angle Difference

6 July 2014

"common" geometry/angles
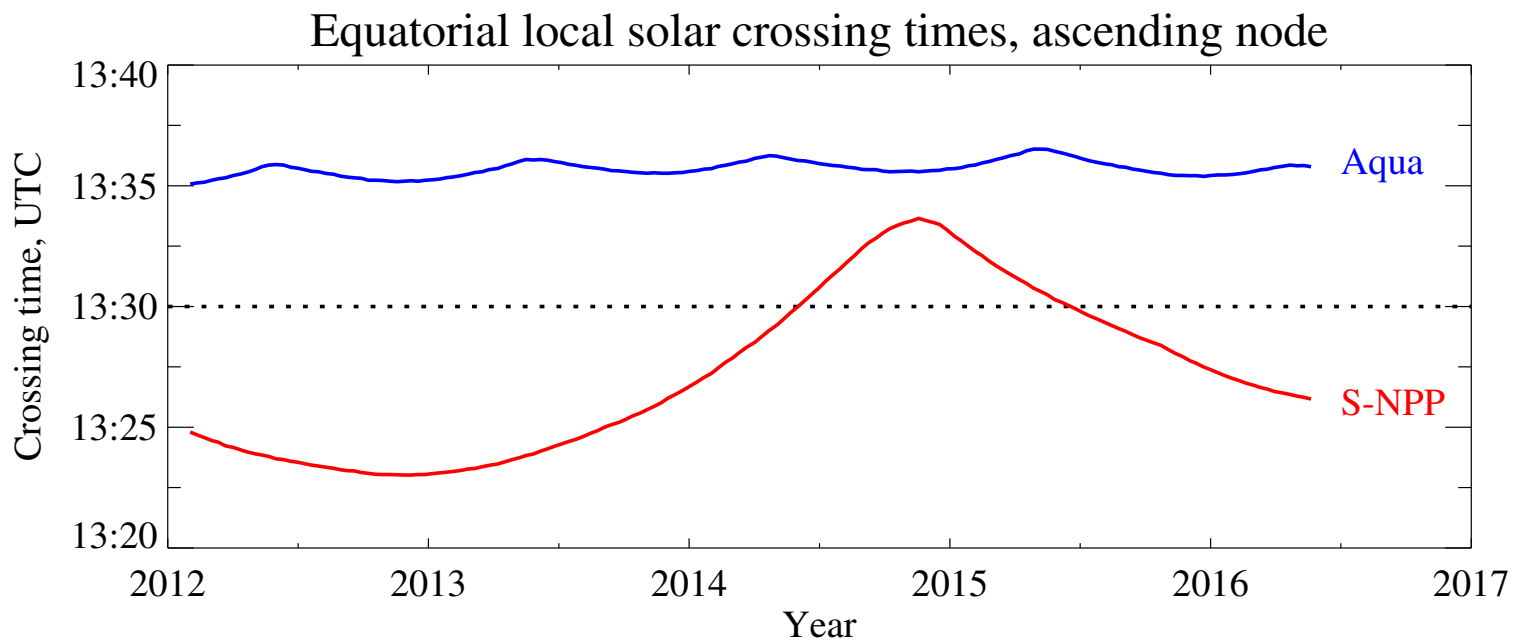
Calibration: Match files (2)

- Slight differences in wavelength
- Slight differences in Rayleigh optical depths,
- Sometimes major differences in gas absorptions
- Clouds everywhere; hard to find mutual cloud free.
- And so far, both datasets are not cloud-masked equally.

Example: 0.86 μm channel over "clear" sky

T   LBLRTM   Transmission   VIIRS M7   MODIS B2

VIIRS M7
MODIS B2

0.80 0.82 0.84 0.86 0.88 0.90 (λ: μm)

Reflectance: VIIRS vs MODIS
"Matched" data from 2014-2015

$y = 1.19x + 0.0003; R^2 = 0.55$
1-1 line

Note: Cloud mask
applied for MODIS,
but not VIIRS

VIIRS 865 (Band M7)

MODIS 858 (Band 2)

N = 65914
8
101
1320
17200

Match files (3)

- Drifting orbits: confound it!

Equatorial local solar crossing times, ascending node
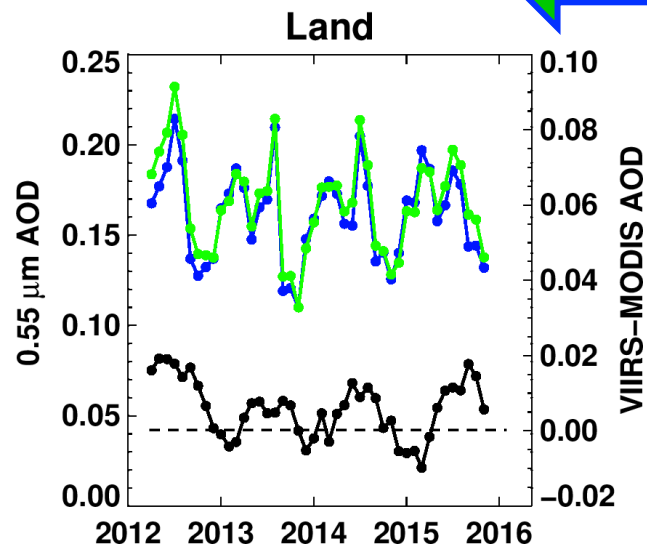

Plot drawn by Andy Sayer (GSFC), source data from Greg Quinn at SSEC Wisconsin.

Current status: DT-VIIRS vs DT-MODIS
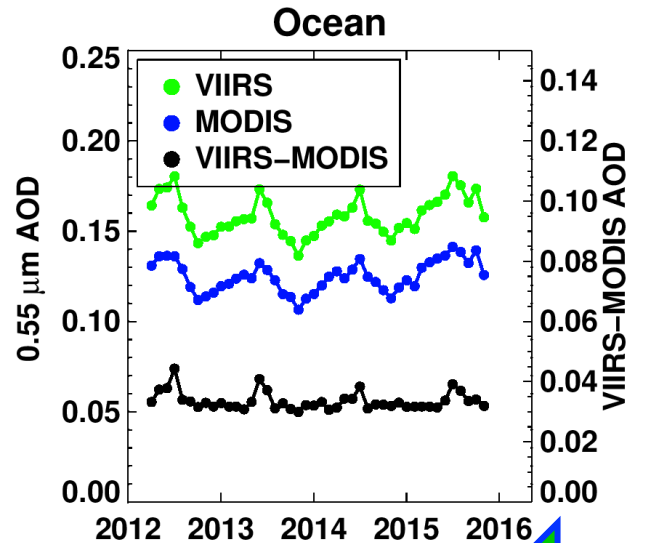
- 2012-2015.

- Ocean: Consistent offset = 0.03 (20%) with spikes in summer

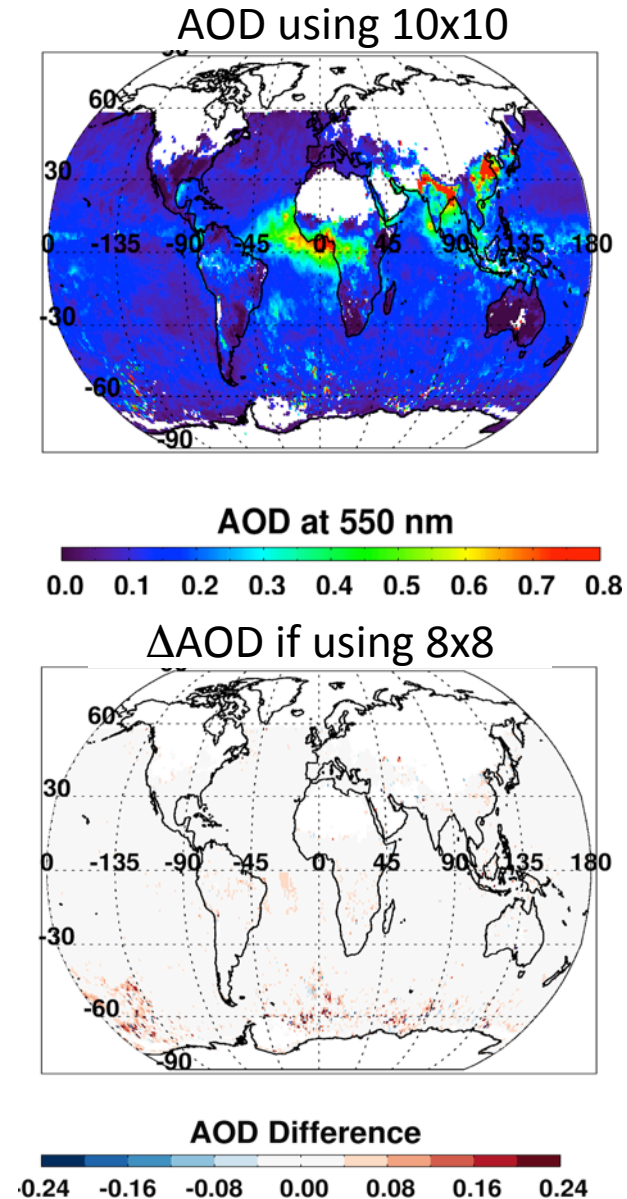- Land: Average offset is near zero, but seasonal dependence

What is good enough for what?

- Convergence: of gridded (Level 3 –like) data
  - For a day? A month? A season?
  - What % of grid boxes must be different by less than X?
    - in AOD?   In Angstrom Exponent?   Size parameters?

- Validation: Comparison with AERONET, etc?

- "Retrievability": Do algorithms make same choices under same conditions?

- Other metrics?

MODIS (Aqua): MAM 2013

Fraction of pixels with retrieval

0.00   0.25   0.50   0.75
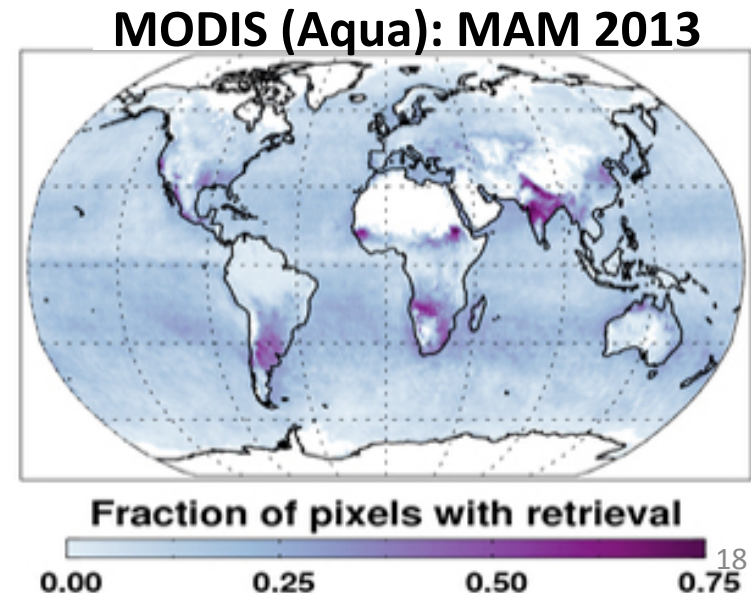
Loose ends

- I-Bands:
  - High resolution data (375 m) could help with cloud-masking/pixel selection
- Decision on NxN pixel size:
  - MODIS scans are units of 10 detectors (e.g. 10, 20, 40)
  - VIIRS scans are units of 8 detectors (e.g. 8 or 16)
  - Current MODIS-like is 10x10, but that mixes can lines for VIIRS
  - Doesn't make too much of a difference →
- Land surface reflectance ratios (that exactly follow MODIS logic).
- Cloud mask (thermal-infrared tests)

- Formats, etc:
  - We are reporting products in MODIS-like formats.
  - Still awaiting science-team decision on archival formats, meta-data, etc.
  - Hopefully worked out this week at M-V Science Team meeting!

AOD using 10x10

AOD at 550 nm

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8

ΔAOD if using 8x8

AOD Difference

-0.24 -0.16 -0.08 0.00 0.08 0.16 0.24

Summary (MODIS →VIIRS)

- MODIS-DT Collection 6
  - Aqua/Terra level 2, 3; entire record processed
  - "Trending" issues reduced
  - Still a 15% or 0.02 Terra vs Aqua offset.
  - Terra/Aqua convergence improved with C6+, but bias remains.
  - Other calibration efforts yield mixed results

- VIIRS-DT in development
  - VIIRS is similar, yet different then MODIS
  - With 50% wider swath, VIIRS has daily coverage
  - Ensures *algorithm* consistency with MODIS.
  - Currently: 20% NPP vs Aqua offset over ocean.
  - Only small bias (%) over land (2012-2016)
  - Can VIIRS/MODIS create aerosol CDR?

- Calibration for MODIS – VIIRS continues to fundamentally important.
- It is not just Terra, or just Aqua, or just NPP-VIIRS (or future VIIRS, or...), it should be synergistic.

Terra–Aqua, Ocean

C6

C5 T–A AOD trend = −0.008
C6 T–A AOD trend = 0.008

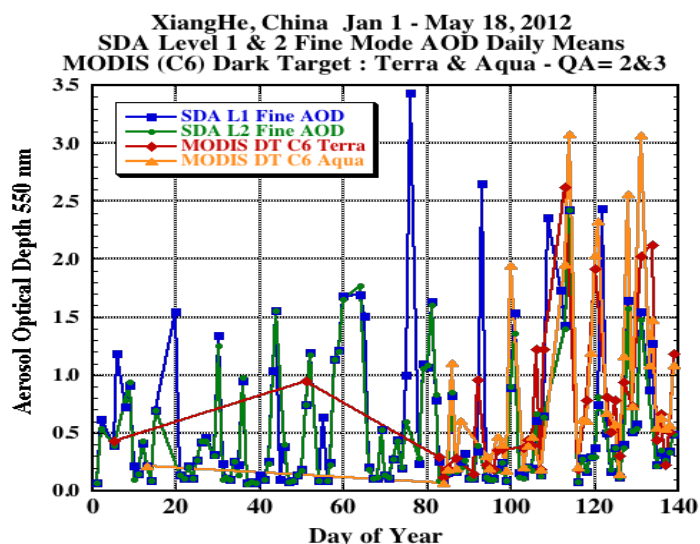VIIRS – MODIS (Aqua): Ocean
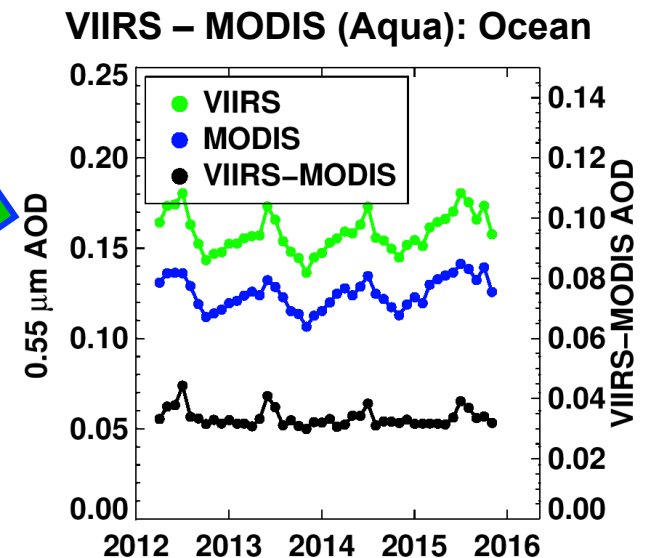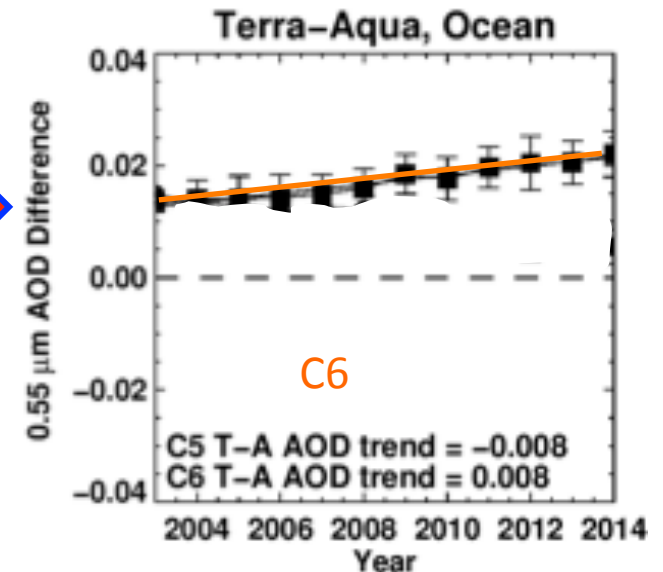
DT retrieval: Improvements

- Improving coverage (two slides, one poster)
- Removing bias over urban areas (one slide, one poster)
- A better dust retrieval over ocean (one slide, one poster)
- A new coastal retrieval (one slide)
- Uncertainty "products" (too many slides to show)

- Which updates will be in "forward" stream (e.g. a Collection 6.1), and which can go into reprocessing? (Wait for Collection 7?)
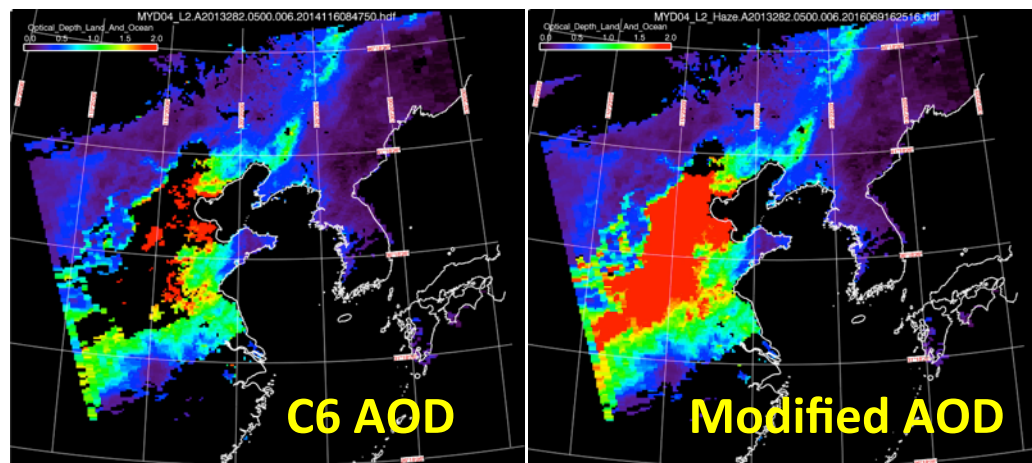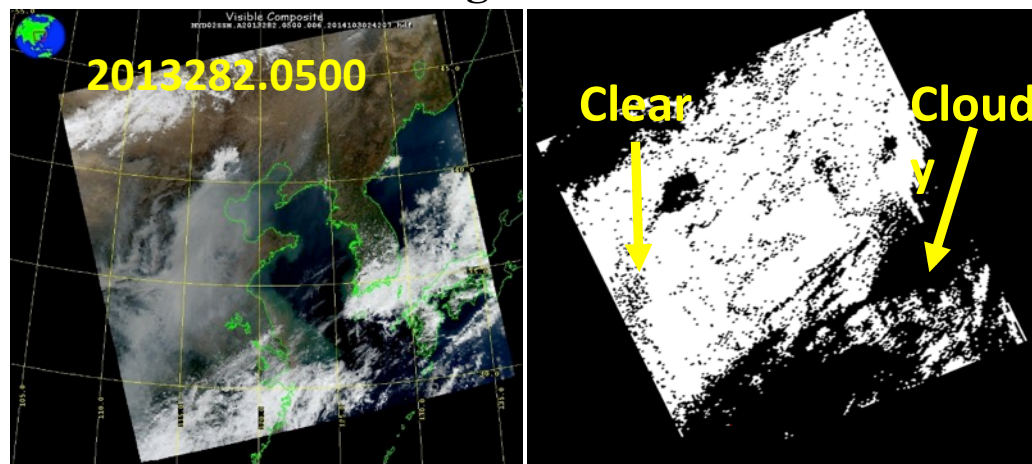
Improving coverage (1)

MODIS (C6) misses many AOD events during winter months (AERONET confirms not cloud)

XiangHe, China Jan 1 - May 18, 2012
SDA Level 1 & 2 Fine Mode AOD Daily Means
MODIS (C6) Dark Target : Terra & Aqua - QA= 2&3

Instead it is the "In-land water mask" that is preventing retrieval over Beijing.

Case study over Beijing area shows that our cloud mask is working

Q: **Can we relax masks, but not degrade global retrieval?**
A: **Maybe: Testing during current KORUS experiment (Korea)**

Leiku Yang and Yingxi Shi

Improving coverage (2)

- For MODIS, the Deep Blue (DB) algorithm is used for routine, single-look (pixel by pixel) retrieval over arid regions.
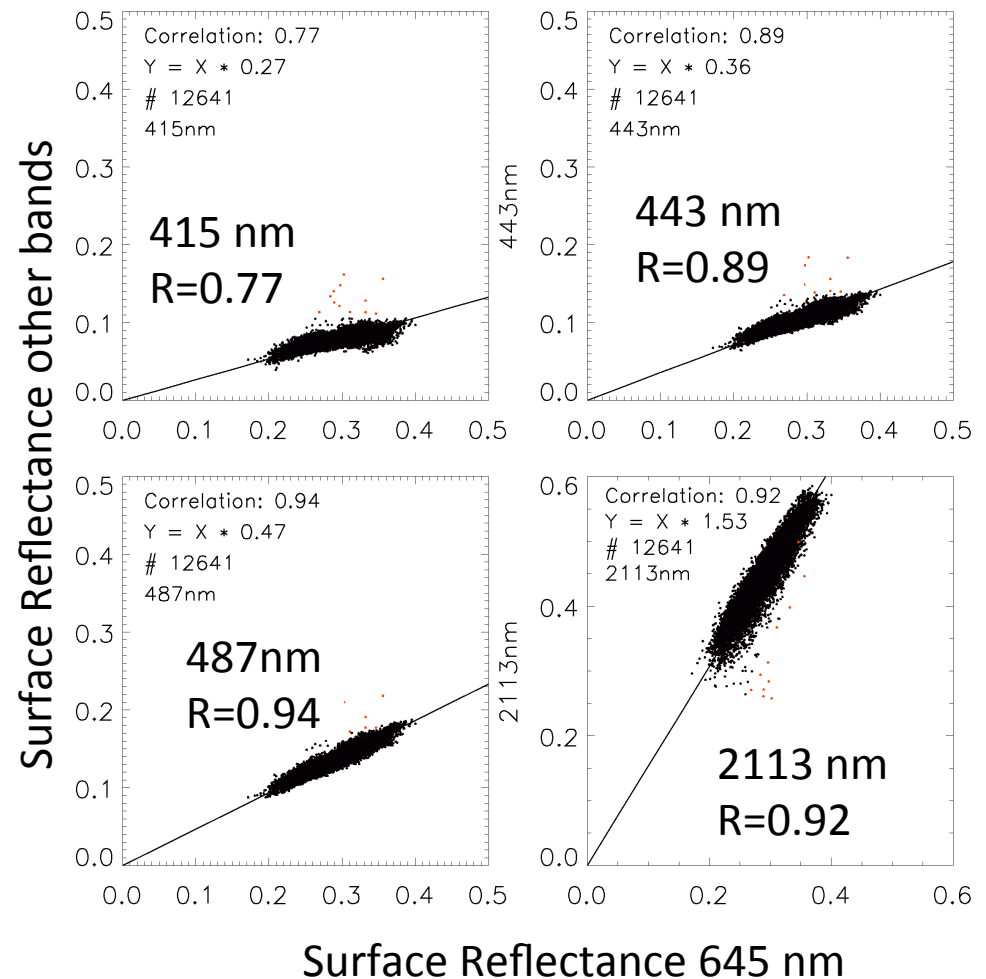
- C6 includes a combined DT/DB product with non-optimized weightings for merging.

- Using DT-like logic, we test use of SWIR (2113 nm) and red (645 nm) channels to estimate blue channel surface reflectance. We also look at DB channels (e.g., 412 and 443).

- On right plots Atmospheric correction (AC). We also test MODIS reflectance (e.g. MOD09) and see similar slopes.

- **This is a first step towards a consistent aerosol retrieval across more of the world's land surface.**
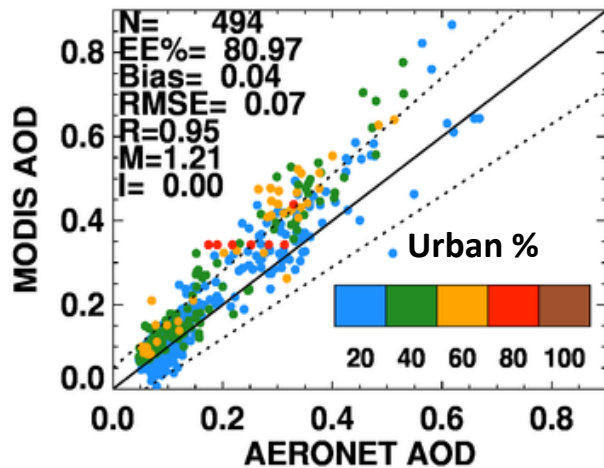
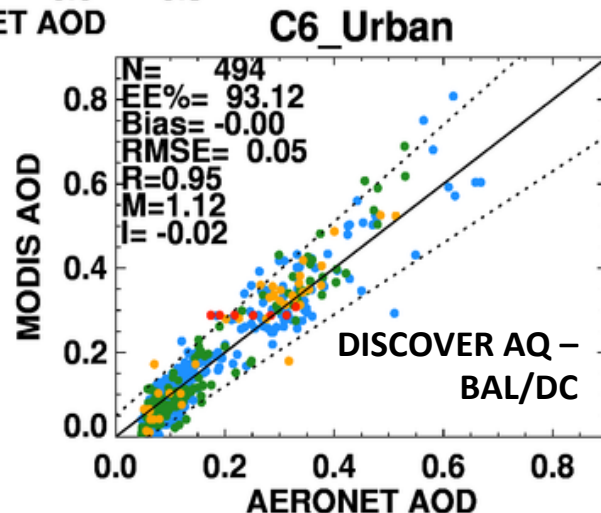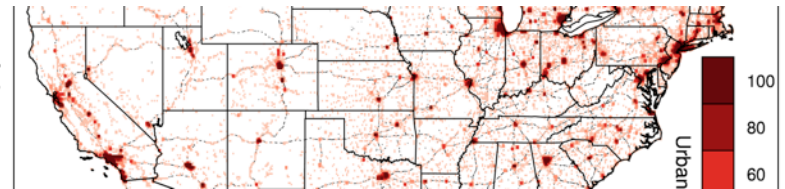Atmospheric Correction over Solar Village AERONET

Surface Reflectance other bands

Correlation: 0.77
Y = X * 0.27
# 12641
415nm

415 nm
R=0.77

Correlation: 0.89
Y = X * 0.36
# 12641
443nm

443 nm
R=0.89

Correlation: 0.94
Y = X * 0.47
# 12641
487nm

487nm
R=0.94

Correlation: 0.92
Y = X * 1.53
# 12641
2113nm

2113 nm
R=0.92

Surface Reflectance 645 nm

Characterizing / correcting urban surface bias

(MDT AODs over urban surface are biased high w.r.t. AERONET)

Urban % in the U.S. (Cities)

N= 494
EE%= 80.97
Bias= 0.04
RMSE= 0.07
R=0.95
M=1.21
I= 0.00

Urban %

20 40 60 80 100

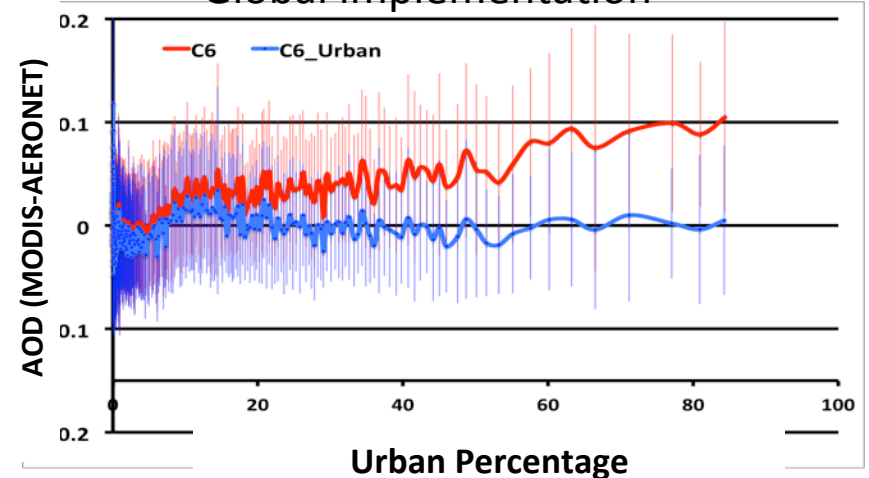**Surface scheme is revised over urban areas by integrating land cover type information in the retrieval algorithm.**

Global implementation

C6_Urban

N= 494
EE%= 93.12
Bias= -0.00
RMSE= 0.05
R=0.95
M=1.12
I= -0.02

DISCOVER AQ – BAL/DC

C6   C6_Urban

Revised urban algorithm works very well in the US
Global implementation is challenging, but forthcoming

Gupta et al., (AMT in revision)

Improving dust retrieval over ocean

- DT-Ocean algorithm uses VIS,NIR and SWIR bands for retrieval.

- DT-O assumes *spherical* aerosol models, which leads to bias in retrievals of AOD and AE.

- There are dust signatures in TIR and Deep Blue wavelengths and published dust-detection algorithms. Do they work for MODIS?

- Then, we could use dust-detection to inform DT to choose *non-spherical* dust models instead
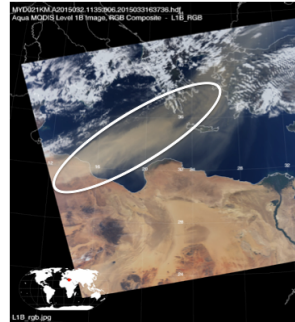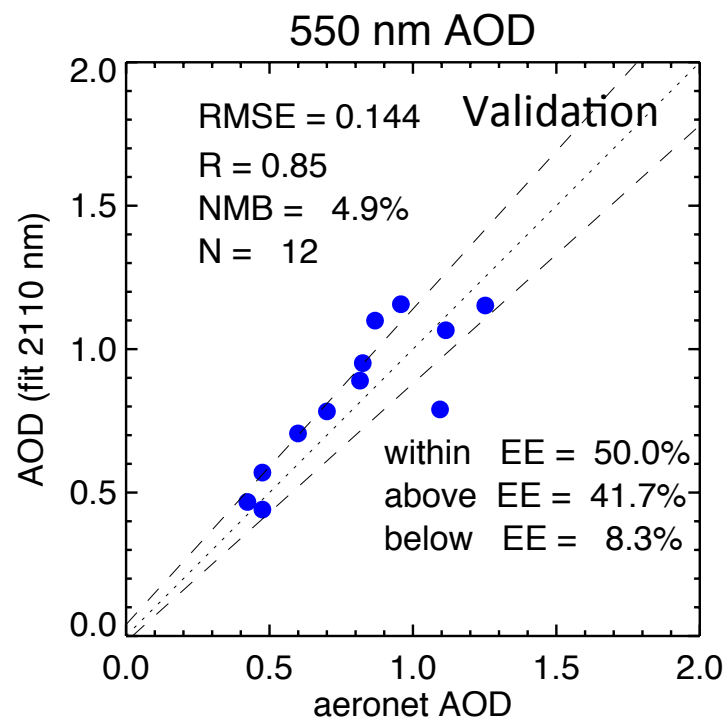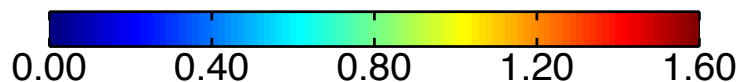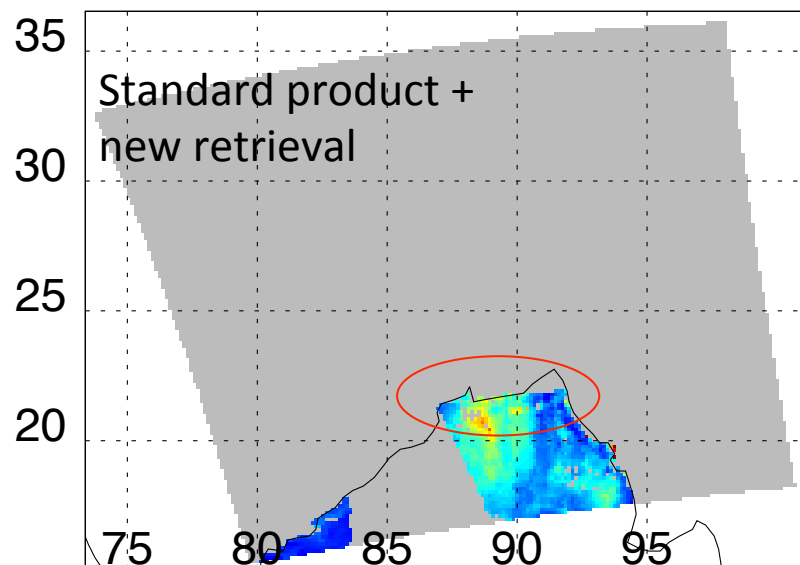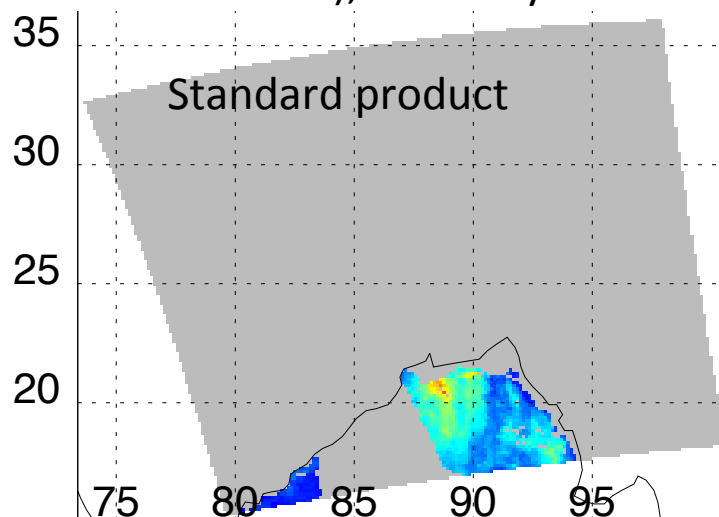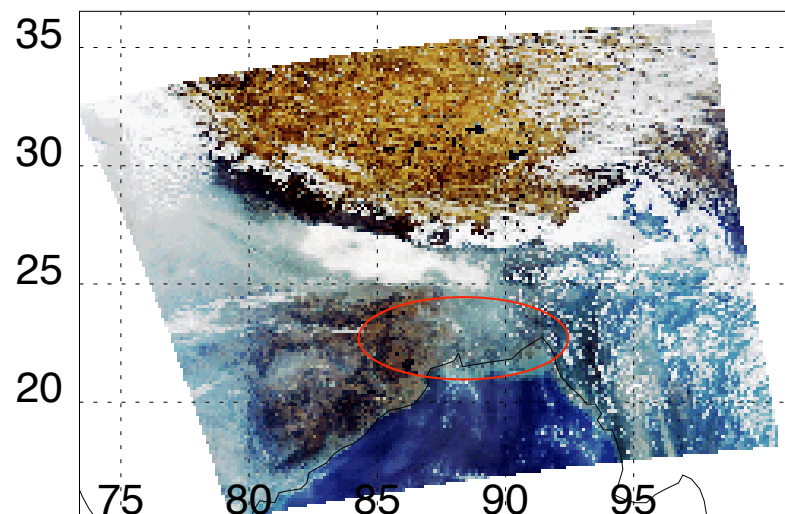
A dust image

Standard dust retrieval: high AOD, but moderate AE
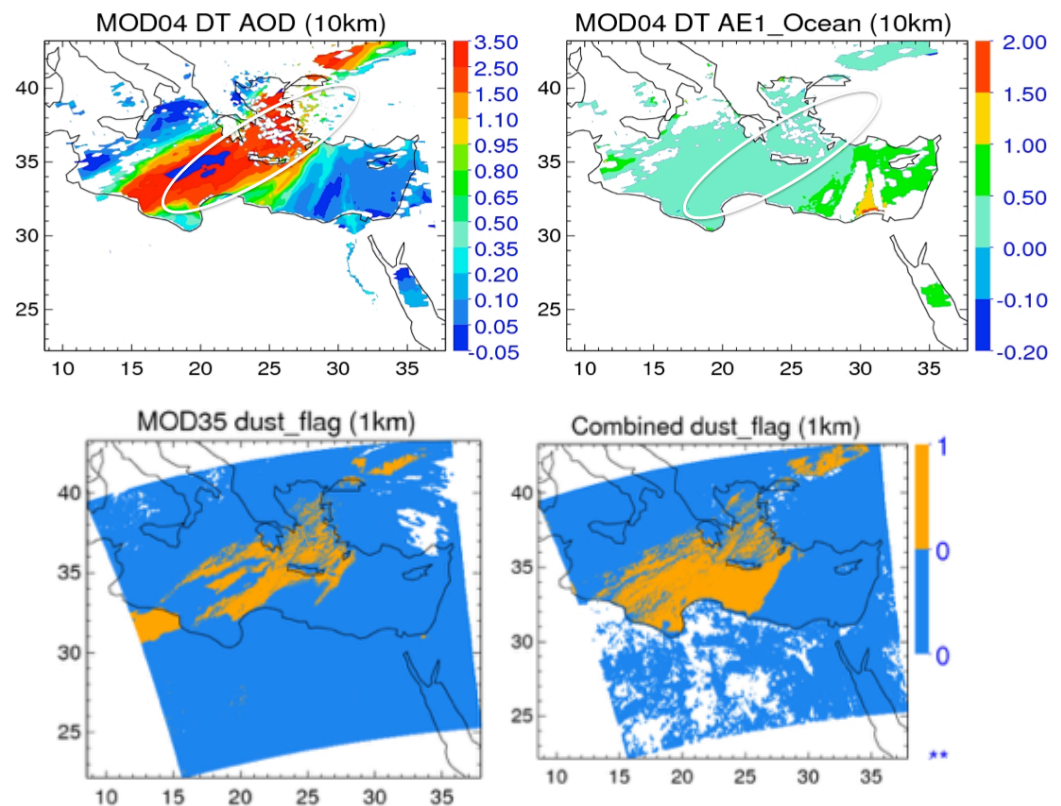
"MCI" uses TIR plus "DAI" that uses DB

New AOD retrieval over coastal turbid water
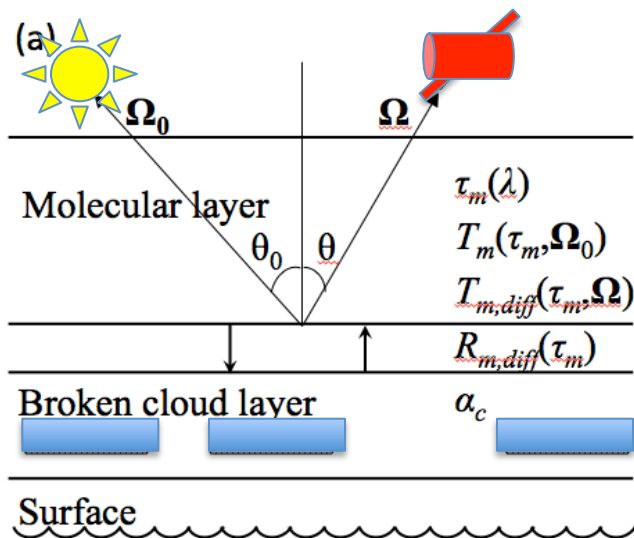
Yi Wang, Jun Wang (Univ. of Nebraska), Rob Levy

Standard product

Standard product + new retrieval

550 nm AOD

RMSE = 0.144   Validation
R = 0.85
NMB =   4.9%
N =   12

AOD (fit 2110 nm)

within   EE = 50.0%
above   EE = 41.7%
below   EE =   8.3%

aeronet AOD

0.00   0.40   0.80   1.20   1.60

Most people live near coastlines!

So any extra information is important!

Correcting for reflectance enhanced by low clouds

Guoyong Wen, Sasha Marshak, Tamas Varnai, Rob Levy

(a)

Molecular layer

θ_0 θ

Broken cloud layer

Surface

$\tau_m(\lambda)$

$T_m(\tau_m, \Omega_0)$

$T_{m,diff}(\tau_m, \Omega)$

$R_{m,diff}(\tau_m)$

α_c

Ω_0 Ω

- Clouds close to clear (aerosol retrieval) pixels tend to enhance reflectance toward sensor, leading to biased AOD retrieval
- These 3D effects include:
    a. Cloud / molecular interactions
    b. Cloud / surface interactions
    c. Cloud / aerosol interactions
    d. Etc.

- The goal is to develop "simple" models to estimate the the sum of these interactions.
- Re-submitted paper includes corrections for a and b.

- Must be done for all wavelengths.
- Can corrections for low cloud effects be applied to global MODIS aerosol retrieval?

DT retrieval: Fun stuff

- Retrieval at high resolution for aerosol/clouds
- Using UV wavelengths (motivated by PACE)
- Retrieval on geostationary platform
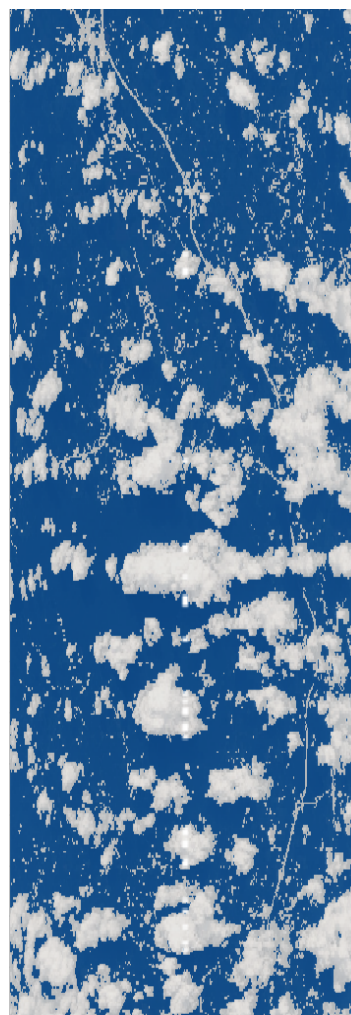
Using high-resolution to study aerosols near clouds

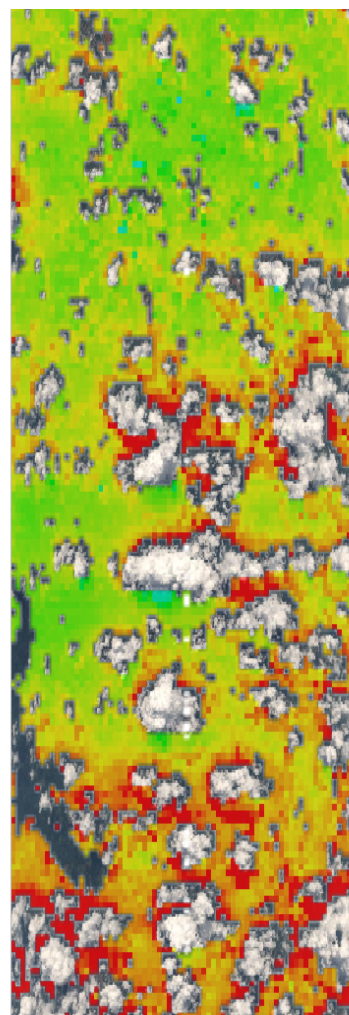Panels are 100 km by 37 km: DT aerosol retrieval at 500 m

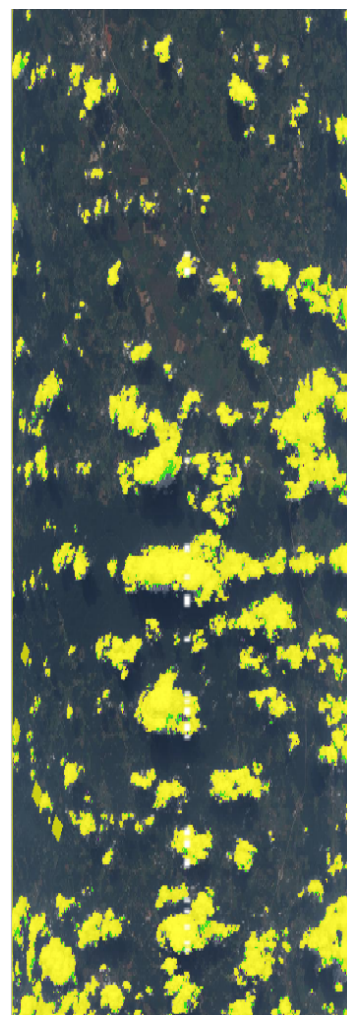Enhanced MODIS Airborne Simulator

RGB	Aerosol Cloud Mask	AOD	Wisc. Cloud Mask	1.88 μm Reflect

Segment is 19:21-19:26

Aerosol Cloud Mask — Cloudy / Clear — CPL identified cloud

AOD: 0.0 0.35 0.75 — CPL identified cloud

MOD35-like Cloud Mask — Conf. Cloud / Prob. Cloud / Prob. Clear — CPL identified cloud

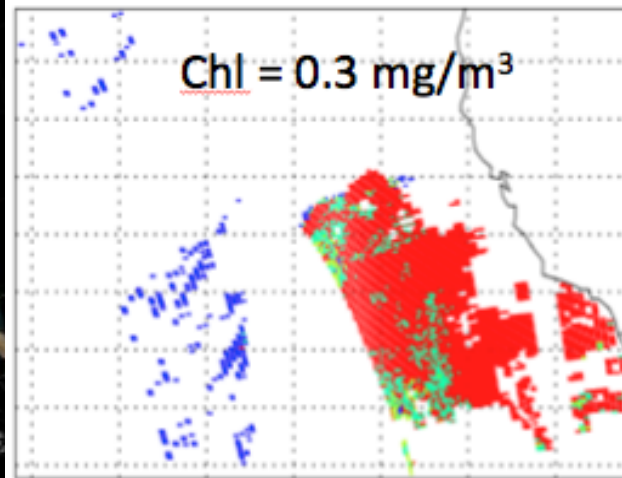0.0010 0.0100 0.1000 — 1.88 μm Reflectance — CPL identified cloud
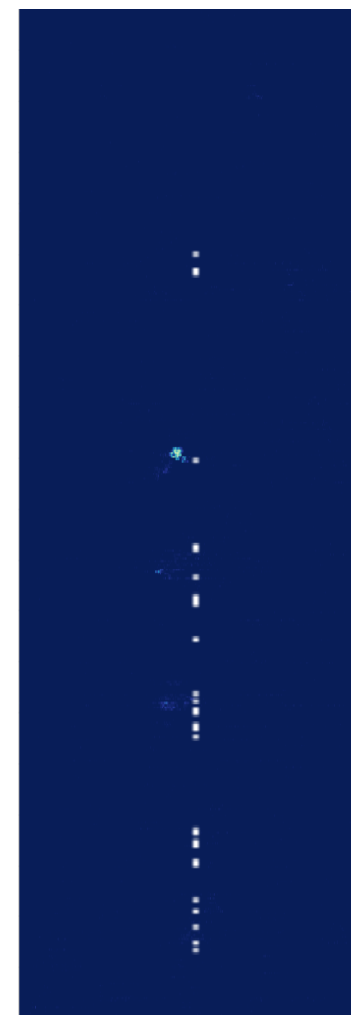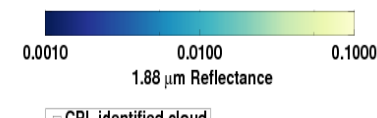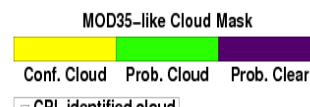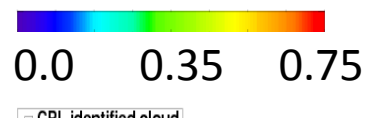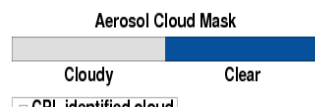
PACE development: Joining MODIS (VIS/NIR/SWIR) and OMI (UV) Sensitivity to aerosol absorption!

Smoke example

Absorption model

See Remer and Mattoo poster!
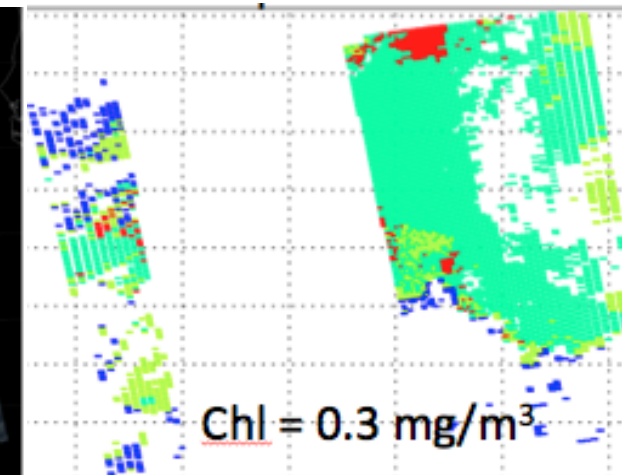
Chl = 0.3 mg/m^3

Dust example

Chl = 0.3 mg/m^3

NA   Du   C1   C2
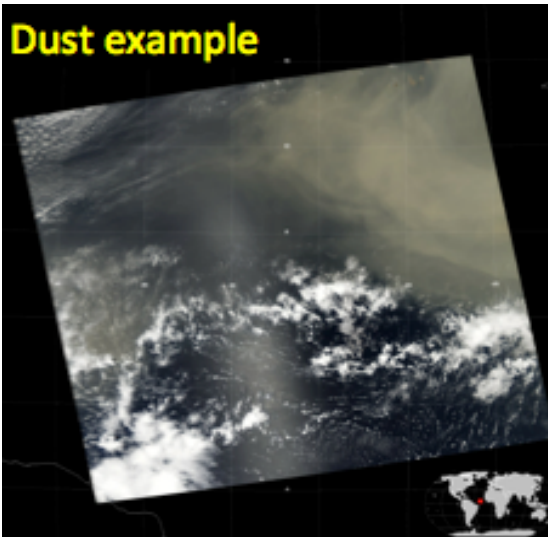
Use MODIS ocean retrieval to constrain AOD and aerosol model.

Use OMI UV reflectances to choose one of 4 absorption scenarios.
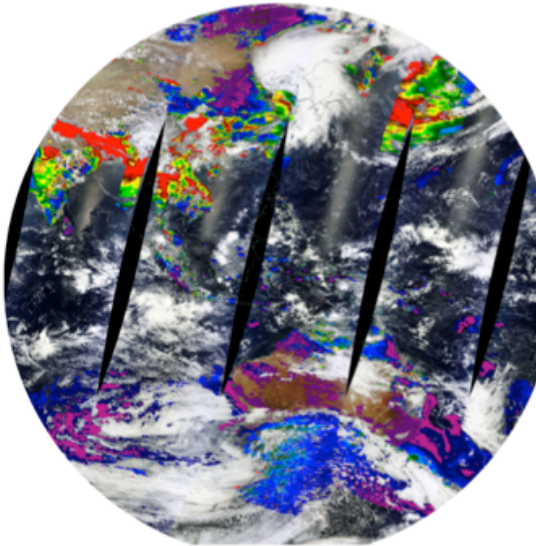
Chooses mostly combustion (C2) for smoke case. [SSA_400~0.89]

Chooses mostly dust (Du) for dust case. [SSA_400~0.83]
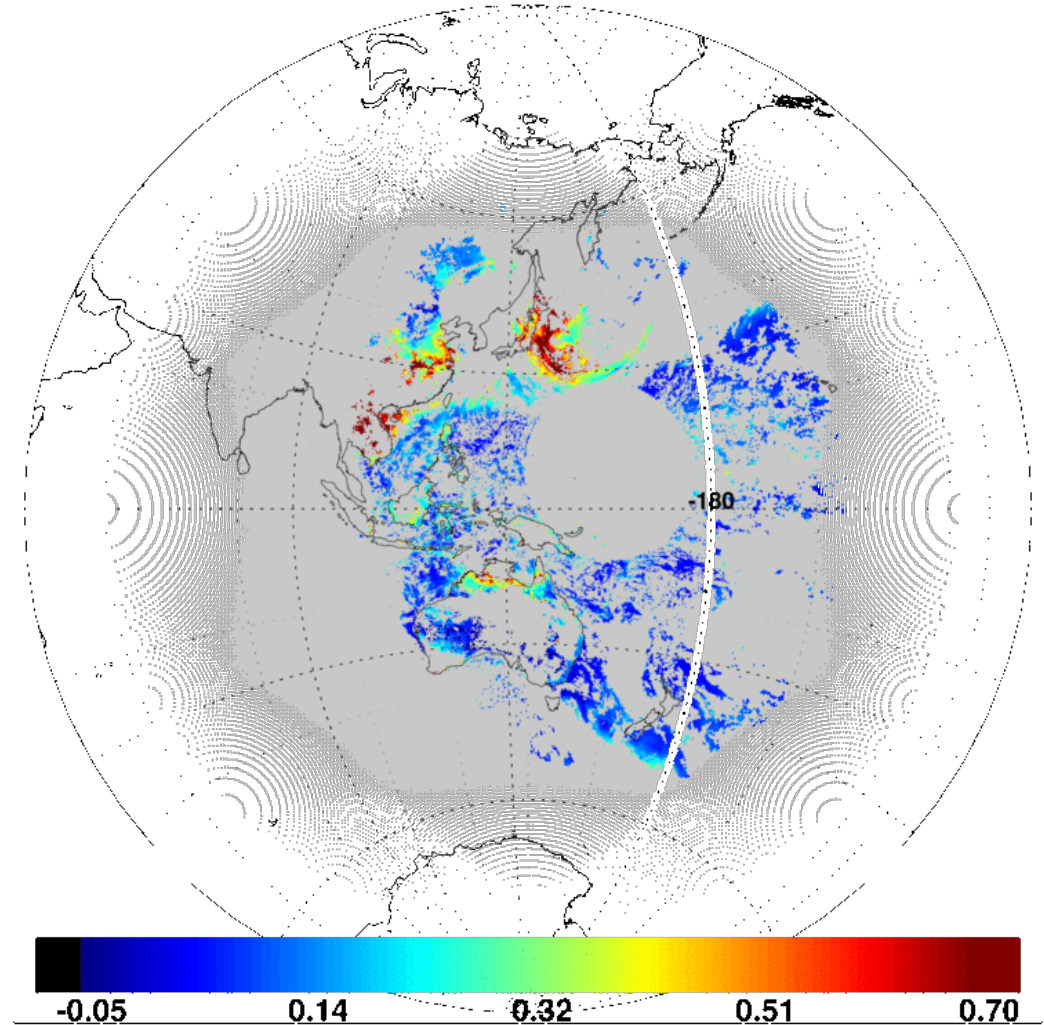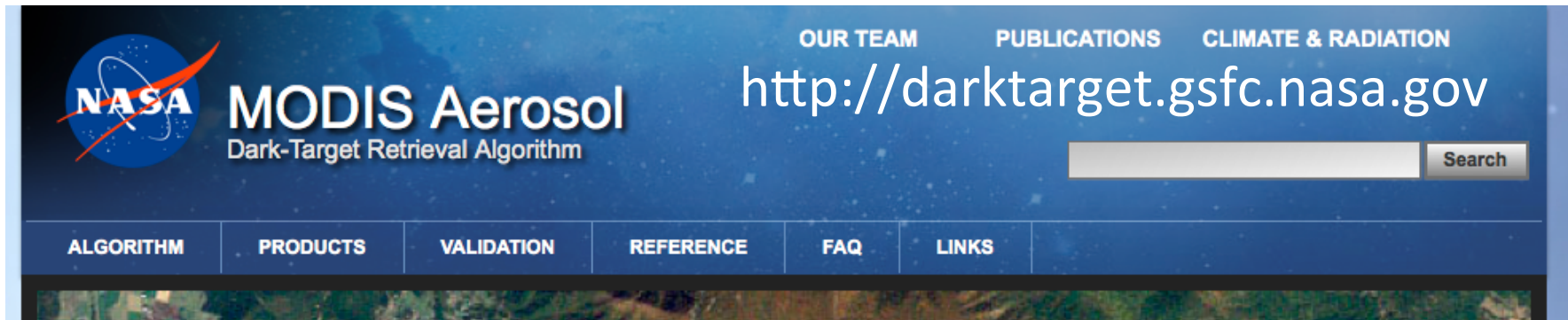
DT: Geostationary? and diurnal cycles
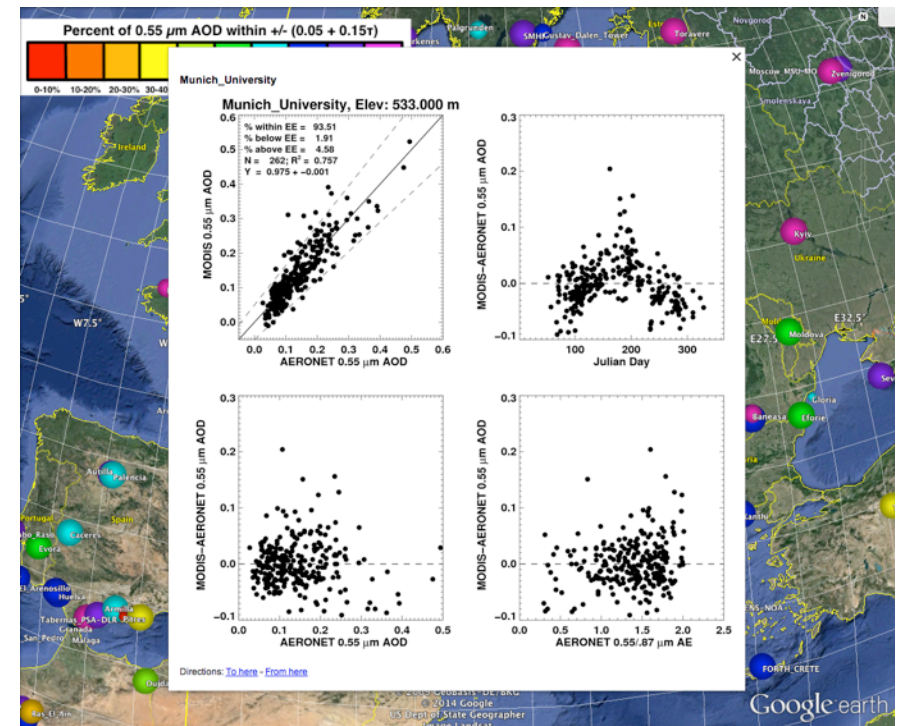
Himawari-8
May 3, 2016

MODIS-Terra (from WorldView)

HIMAWARI.A2016124.0000.hdf11.Image_Optical_Depth_Land_And_Ocean

OUR TEAM   PUBLICATIONS   CLIMATE & RADIATION

NASA

MODIS Aerosol
Dark-Target Retrieval Algorithm

http://darktarget.gsfc.nasa.gov

Search

ALGORITHM   PRODUCTS   VALIDATION   REFERENCE   FAQ   LINKS

- Reference for all things "dark target"
  - The algorithms and assumptions
  - Examples
  - Validation
  - Primary publications
  - Educational material
  - FAQ
  - Links to data access

THANK YOU!