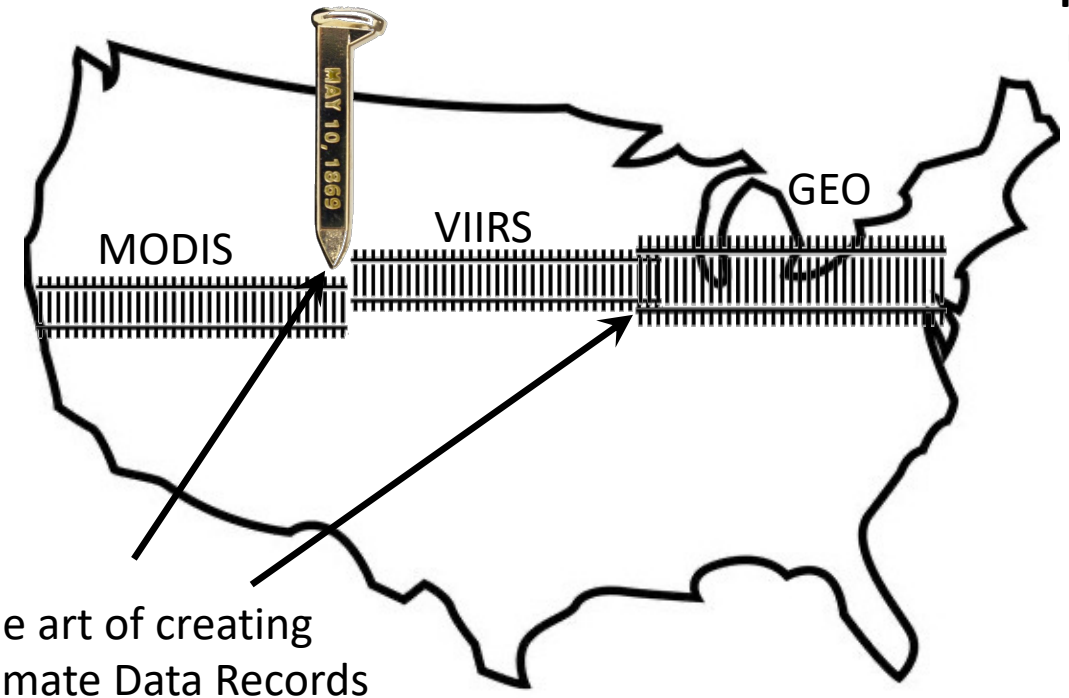
From MODIS to VIIRS: Continuity of NASA's Level 2 "Atmosphere" Products



The art of creating
Climate Data Records

Robert C. Levy (NASA-GSFC):
Dark Target aerosol product

with slides "stolen" from:

Christina Hsu (NASA-GSFC):
Deep Blue aerosol product
Kerry Meyer (NASA-GSFC)
Cloud properties product
Virginia Sawyer (SSAI)
Dark Target aerosol

Background

- With the operational lives of the Terra and Aqua satellites nearing their end, successors to key EOS-era (LEO) sensors are essential to achieve multi-decadal climate data records
- VIIRS (on SNPP and JPSS series) is the natural successor to MODIS. NASA is currently funding multiple algorithm teams for MODIS/VIIRS Atmosphere Discipline continuity product work (https://atmosphere-imager.gsfc.nasa.gov/) including:
  - Aerosols: VIIRS "Dark Target" AERDT and "Deep Blue" AERDB (MODIS MOD04 heritage)
  - Clouds: MODIS/VIIRS CLDMSK, CLDPROP (parallel to MODIS standard products MOD35, MOD06) – common algorithm using common subset of channels
- In addition to LEO continuity, we also think about quantifying diurnal cycles and rapid changing events via GEO. "Expanding" the data records

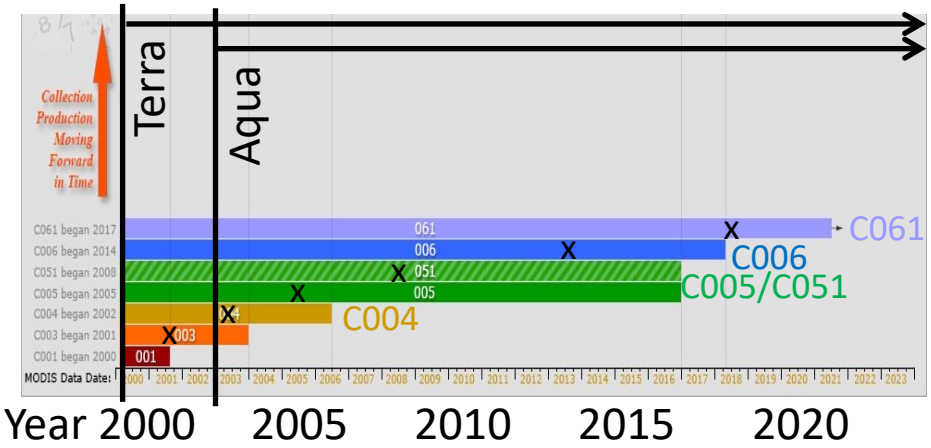
Outline of sorts

- History of algorithm development and sensors
- Discovery of offsets and biases between sensors
- Individual and team efforts to solve and mitigate
- Where we are now regarding MODIS → VIIRS
- Future into GEO

- Note: As Dark Target algorithm lead, most perspective is mine!!
- Also Note: I will skip some slides for time.

MODIS Collections

https://atmosphere-imager.gsfc.nasa.gov/collections/overview



Color	Collection	Production_Start	Description
	061	2017	Corrected issues in the input Level-1B (L1B) data -- with a few new L2 and L3 improvements added.
	006	2013	Collection 006 included many new science updates and improvements.
	051	2008	Key Update for the L2 Aerosol (04_L2) and L2 Cloud Product (06_L2) -- along with all of L3 to pick up L2 updates.
	005	2005	First Major Science Collection, which was widely distributed.
	004	2002	Second Major Update/Improvement, which went through 3 stages of Validation during it's tenure.
	003	2001	First Major Update/Improvement, however this was still considered "Provisional" Data.
	001	2000	Initial Testbed Collection.

Collection

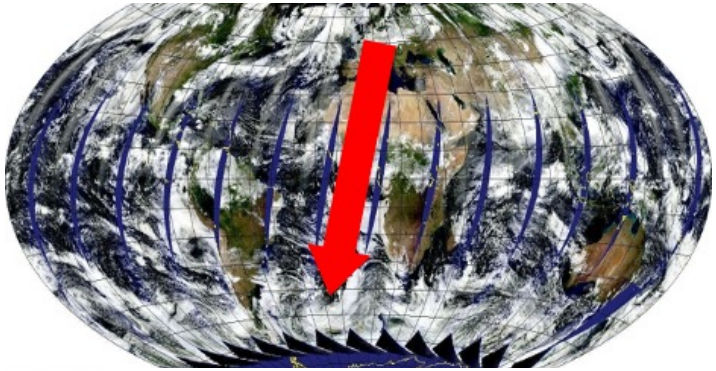
- = “very broad MODIS data version”
- Attempt to use the same version of the Science Algorithms and Program Executables (PGEs).
- Includes PGEs for creating L1B

HISTORY

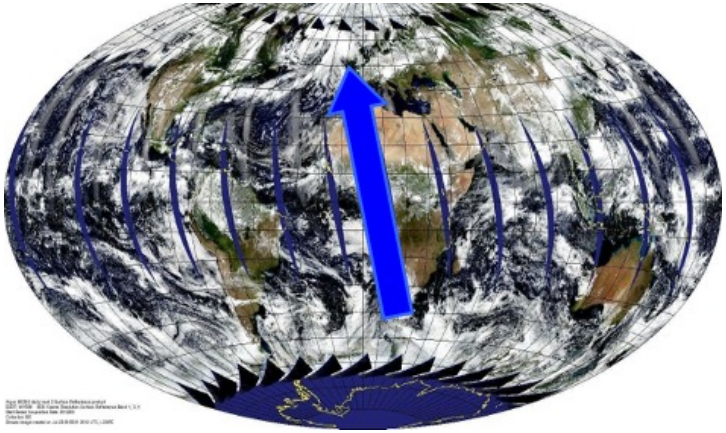
- C001: Initial algorithms at Terra launch
- C003: Provisional applied to both Terra and Aqua
- C004: First significant validation
- C005: First real “science”
- C006: Major upgrades to science
- C061: updates to the L1B.

C005: Long enough time series to be interesting

Terra (10:30, Descending)



Aqua (13:30, Ascending)

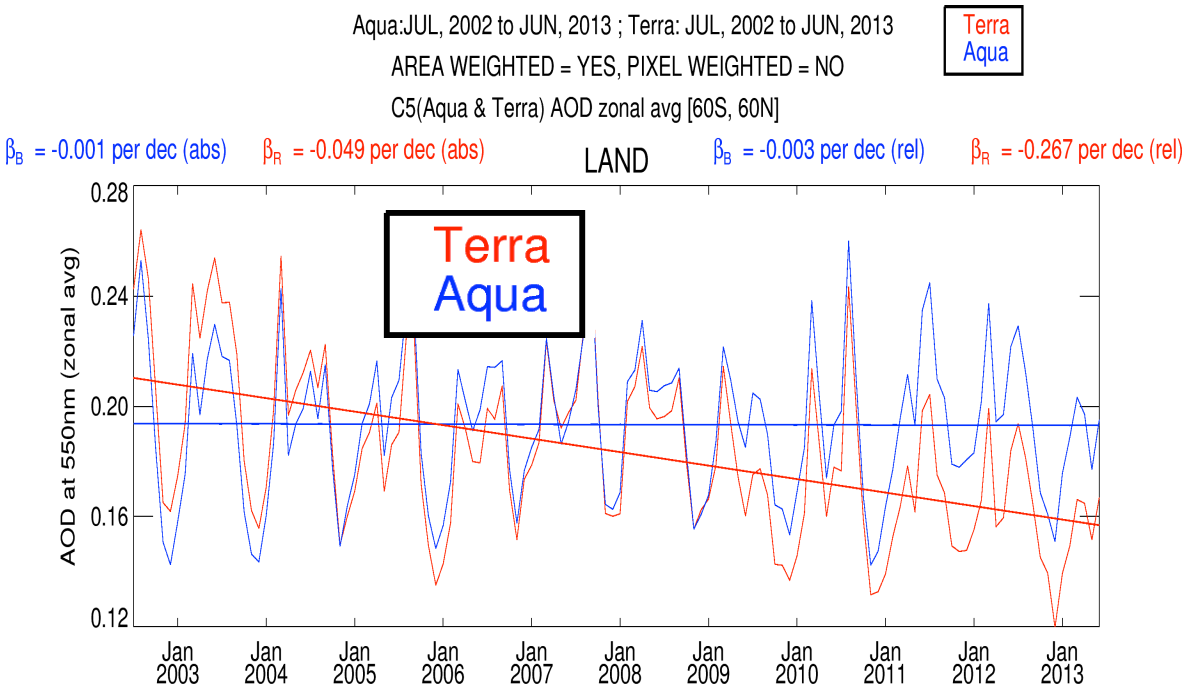


Terra vs Aqua

- Two sensors, essentially identical twins
- Roughly symmetrical around equator
- Assumption is they would observe approximately the same world? (minus the diurnal differences)

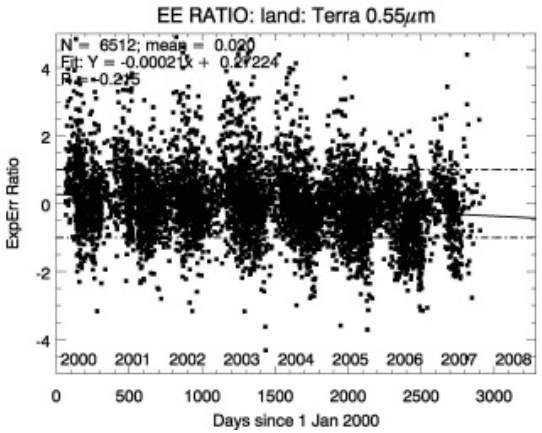
- Same L1B PGEs to both sensors
- Same L2 PGEs to both sensors

C005 Aerosol Trends: Terra ≠ Aqua!!



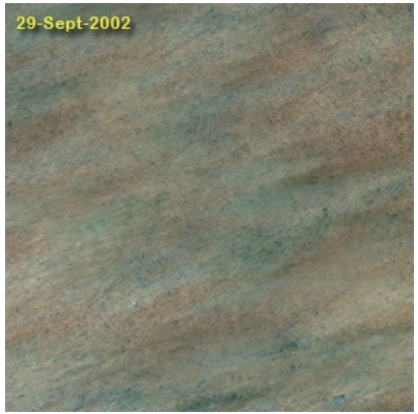
(from Lyapustin et al., 2014)

- Same retrieval over land
- Yet, Terra and Aqua disagreed on trends!



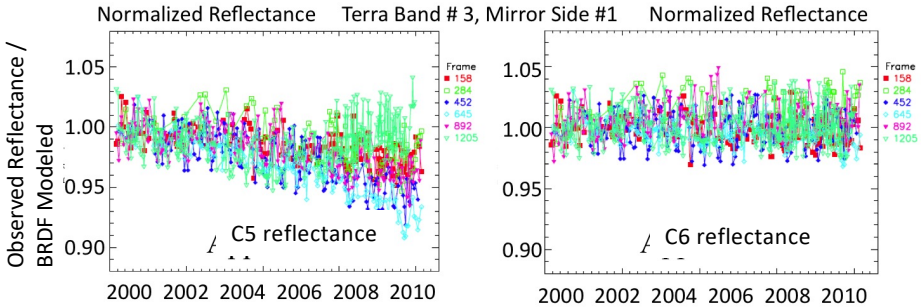
- And Terra also showed decreasing "quality" with respect to ground truth

Why? Calibration was culprit: Reflectance over desert sites: C005 → C006



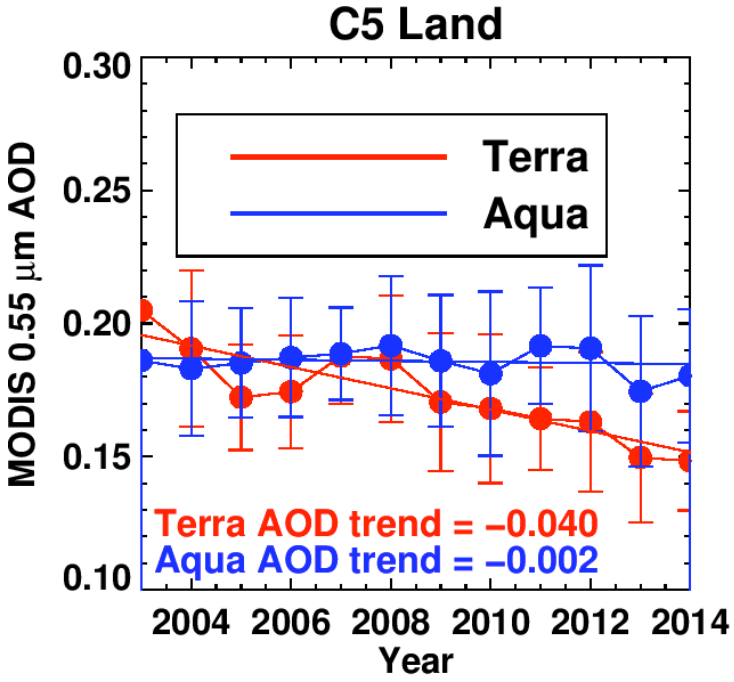
desert test sites

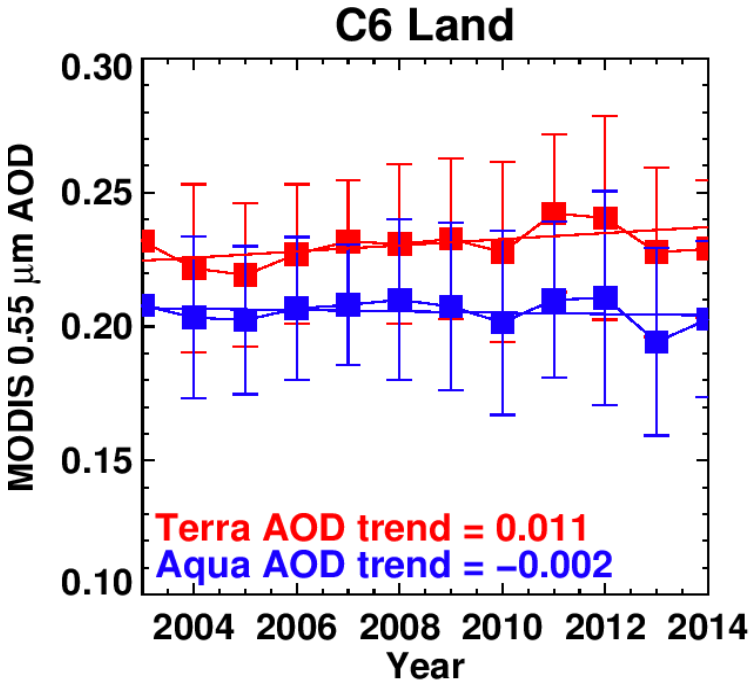
(1) Collect clear-sky MODIS data over desert sites
(2) Develop site-specific BRDF from first 3 years of mission
(3) MCST found that "observed" reflectance diverged from BRDF modeled reflectance over time



(1) Many bands were affected, including relevant aerosol retrieval ands.
(2) Terra much worse than Aqua
(3) MCST was able to "de-trend" the observations and
(4) Create a new L1B dataset for C6.

After de-trending calibration: C006



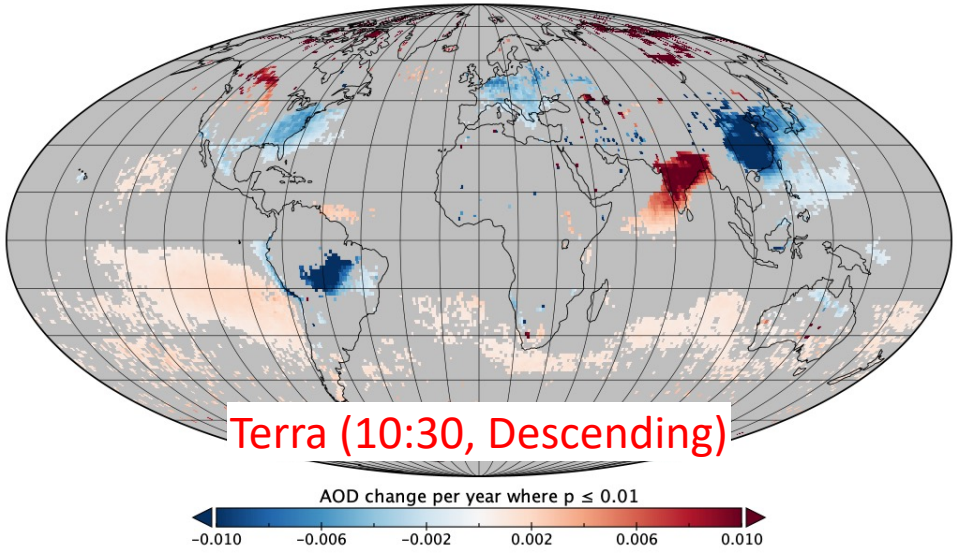


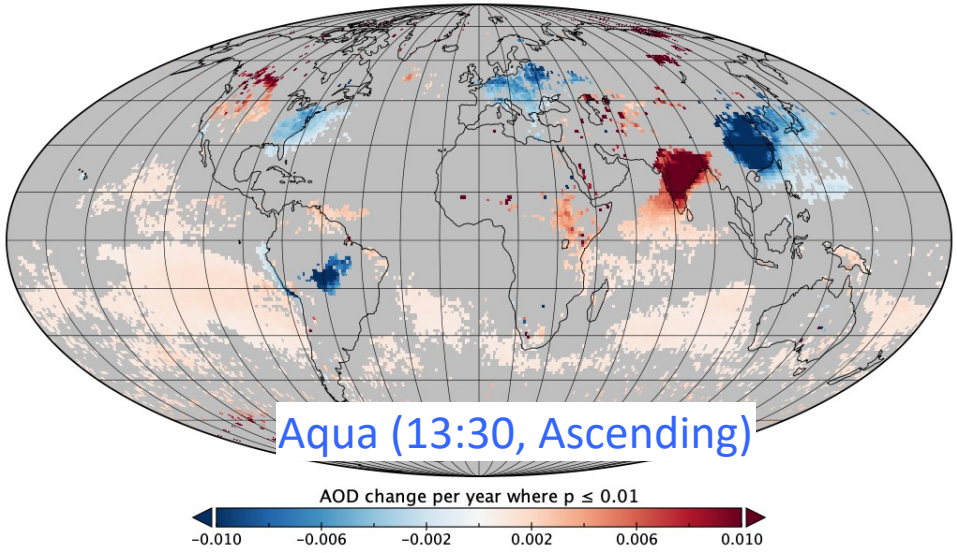
Good news: Strong $\Delta\tau$ negative "trending" is reduced in C6

Bad news: **0.15 offset remained between AM and PM? (noting offset was at beginning in 2003 as well!)**

MODIS C061: Terra and Aqua agree!

AOD over 20 years! July 2002 – July 2022

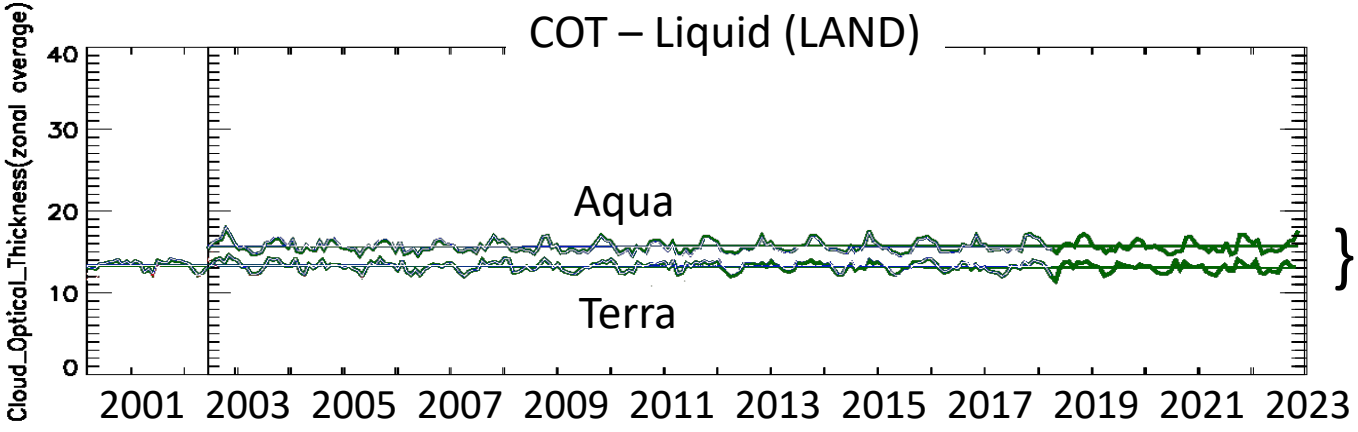




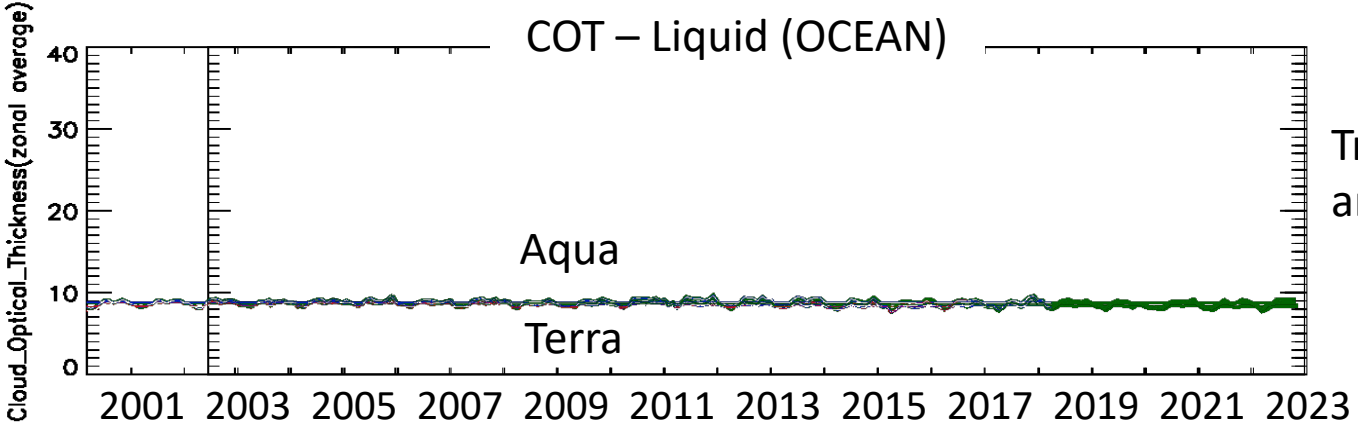
Slope of the linear regression for each 1°×1° grid cell (plotted where p ≤ 0.01)

- **Terra and Aqua agree on regions that show significant increase or decrease in AOD over time!**
- **Note1:** simple linear regression has limitations, and temporal autocorrelation may make these results "overconfident" where month-to-month progression gives the illusion of a trend
- **Note 2:** However, seasonal trends (e.g. Winter, Spring, Summer and Fall) each show consistency too.
- **Note 3:** After 2022, Terra and Aqua are drifting in orbits, so becoming unstable for longer trends.
- **Note 4:** All over-land and near-coastline trends fit expectation. Why the southern hemisphere ocean trends?

Cloud Optical Thickness : 25°N – 25°S



} Maybe diurnal diff?
Or calibration



Trends are nil,
and agree

https://modis-images.gsfc.nasa.gov/trend_web/

C061: Current MODIS

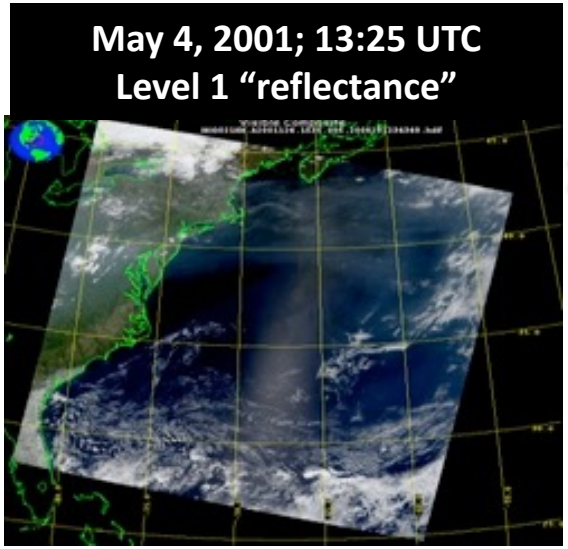
- Now, after de-trending of L1B, Terra and Aqua L2 trends agree.
- For Aerosol: Both Terra and Aqua – MODIS match to ground-truth within specs.
- And show same trends over 20 years! But can't continue much farther
- But with offsets remaining
  - Using many wavelengths at once, aerosol and cloud algorithms can be very sensitive
  - Correction factors of about 1-2% in relevant bands maybe do the trick.

GCOS requirements for an AOD climate data record (CDR)

Target metric	Target
Horizontal Resolution	5-10 km, globally
Accuracy	MAX(0.03 or 10%)
Stability / bias	<0.01 / decade
Time Length	30+ years
Temporal Resolution	4 h

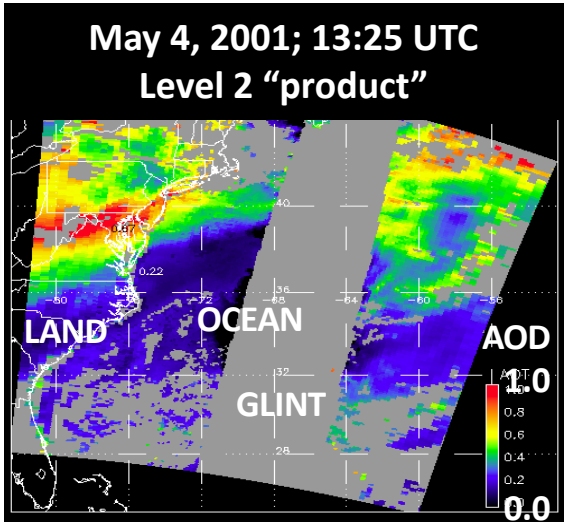
Dark Target Aerosol retrieval Algorithm
(originally developed for MODIS)

What a sensor observes



DT

Attributed to aerosol (AOD)

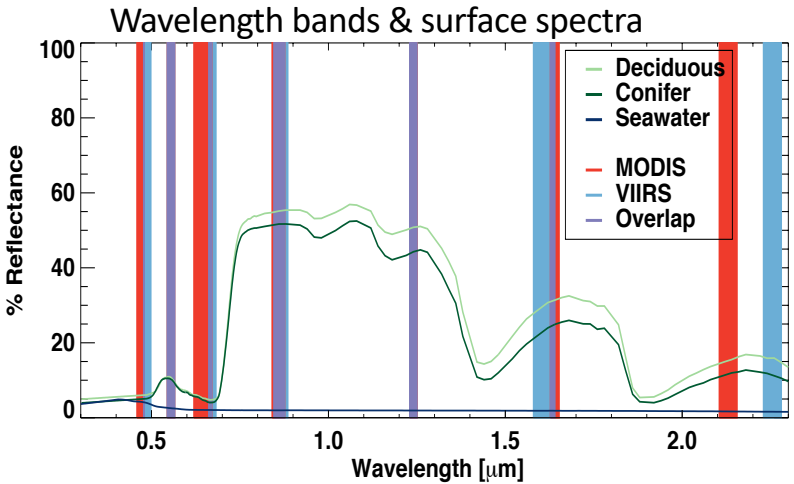


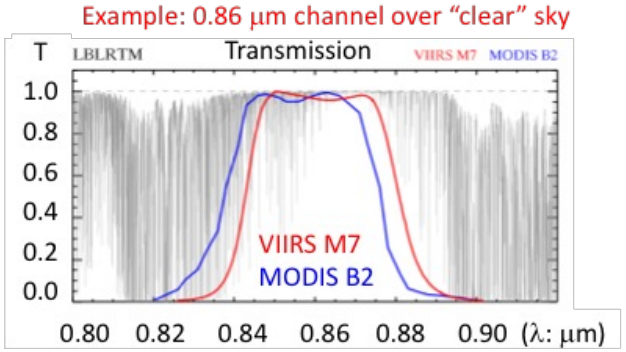
"Established 1997" by Kaufman, Tanré, Remer, etc)
"Modified 2005, 2010, 2013, 2015" by Remer, Levy, Gupta, etc

Separate logic over land and ocean
Retrieve: AOD at 0.55 μm, spectral AOD (AE), cloud-cleared reflectances, diagnostics, quality assurance

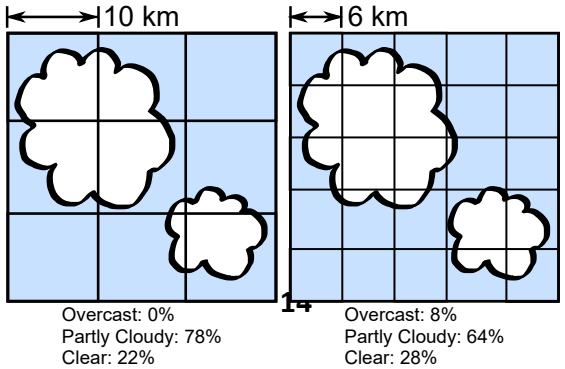
For aerosol continuity we can port the algorithms (Extending from MODIS→VIIRS)

- Create new LUTs for shifted wavelengths (gas corrections/Rayleigh, etc)

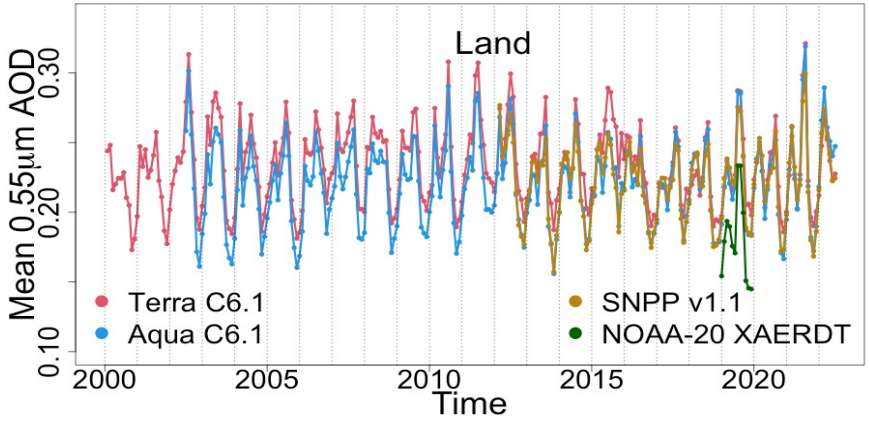


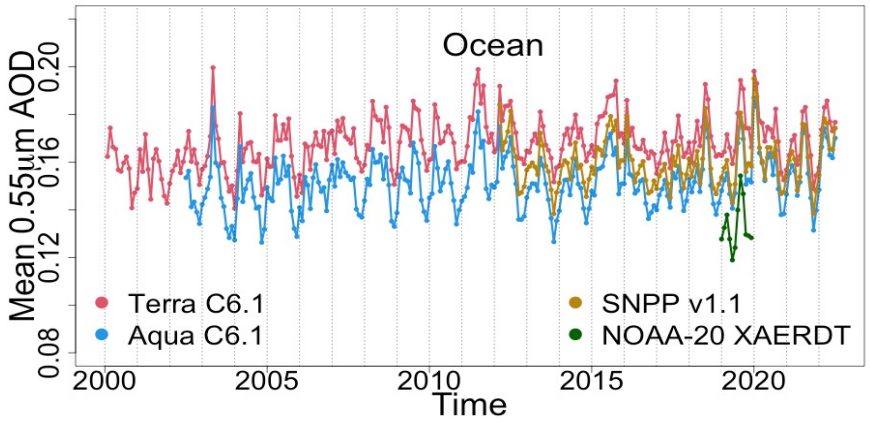


- Deal with differences in resolution, etc. (for cloud masking)



Results: Porting to VIIRS

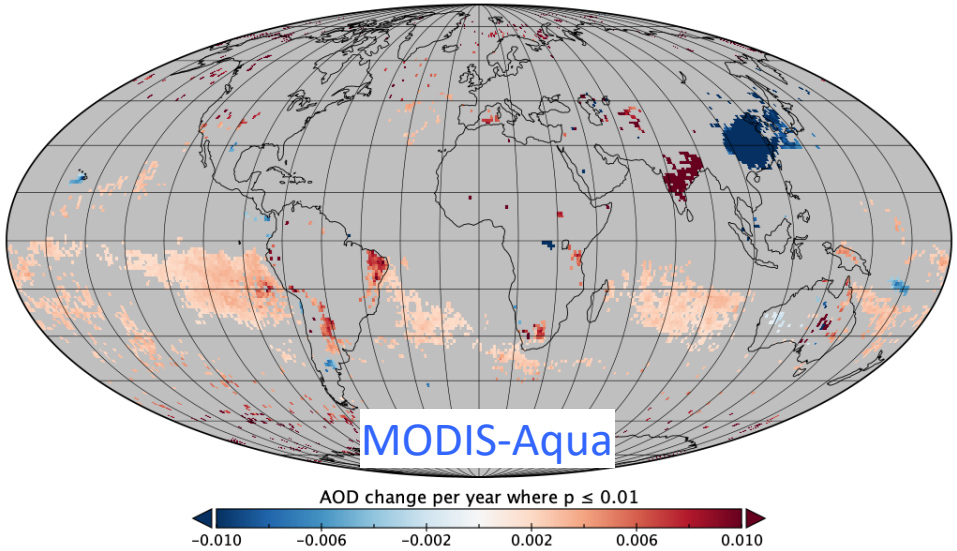


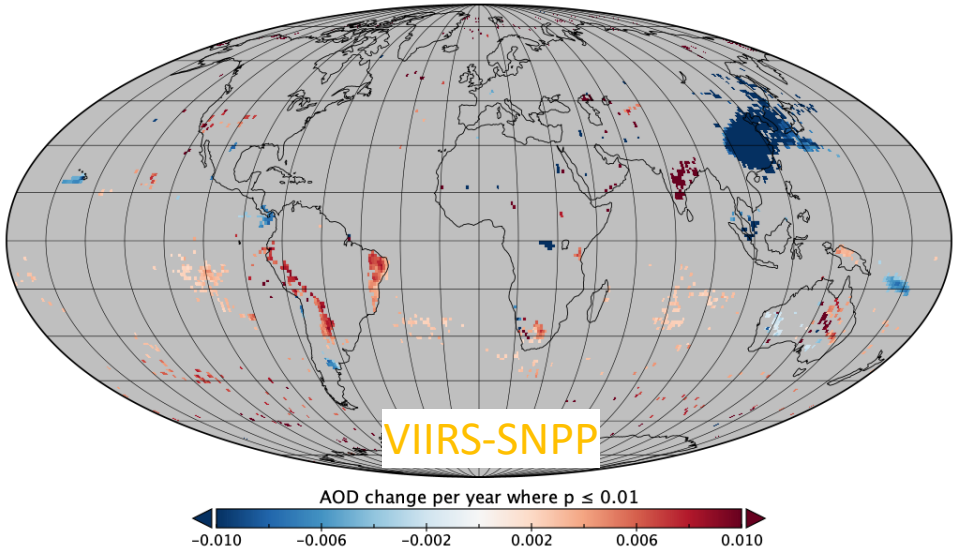


- Despite differences in instrument design, calibration, or degradation, Dark Target AOD shows agreement across LEO sensors
- SNPP between Terra and Aqua: NOAA-20 seems offset “low” but appears to fit ground-truth similar to Aqua.
- Update (V2: with bug fixes and cloud masking updates) for both SNPP and NOAA-20 are in production.
- VIIRS NOAA-21 launched in November, DT port can begin later this year

AOD Trending: VIIRS-SNPP vs MODIS-Aqua

AOD over 10 years! July 2012 – July 2022



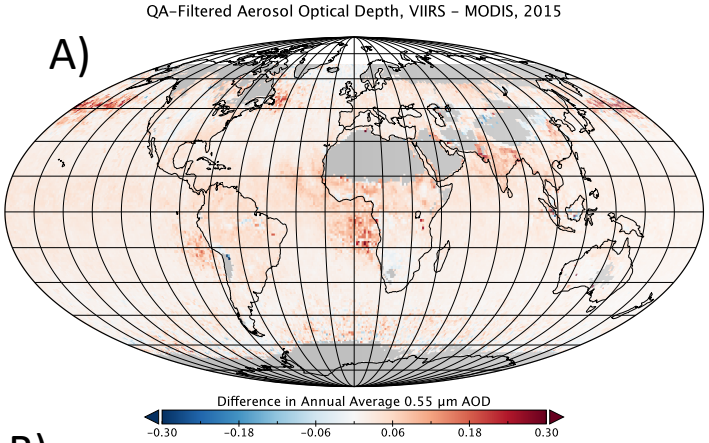


Slope of the linear regression for each 1°×1° grid cell (plotted where p ≤ 0.01)

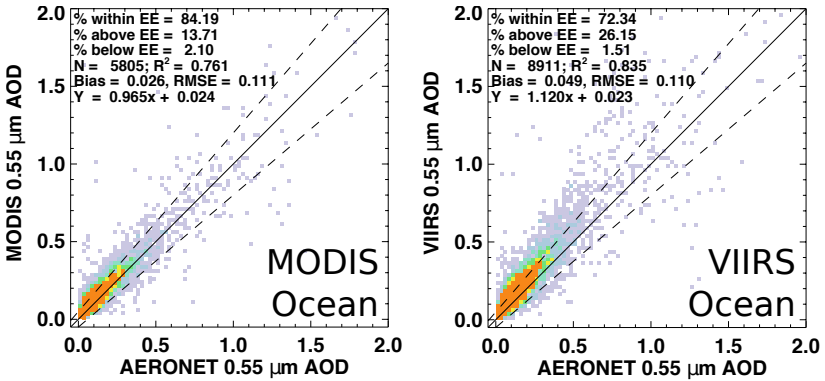
- Aqua and VIIRS ***mostly*** agree on regions that show significant increase or decrease in AOD over time!
- **Note 1:** For 10-year record, half as much data = fewer grid cells meet a given significance threshold, generally sharper slopes where they do
- **Note 2: S**trong trends over India and eastern China for all four seasons, are even more strong in the shorter record
- **Note 3:** Apparent increases in southern ocean are seen by Aqua (and Terra), but not VIIRS-SNPP.

AOD evaluation: VIIRS-SNPP vs MODIS-Aqua

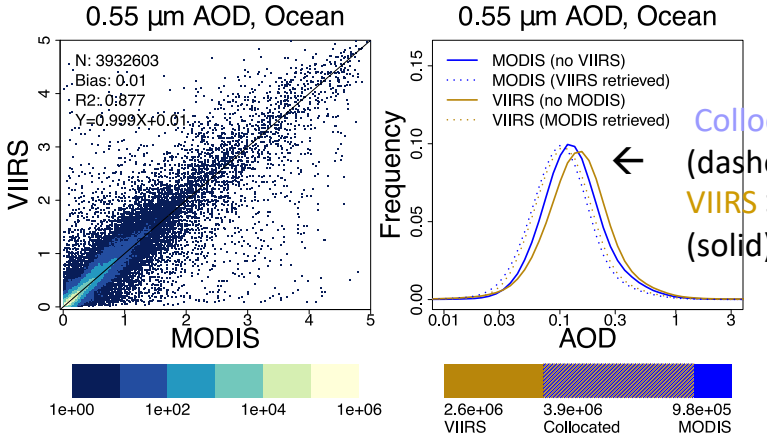
A)



B)



C)



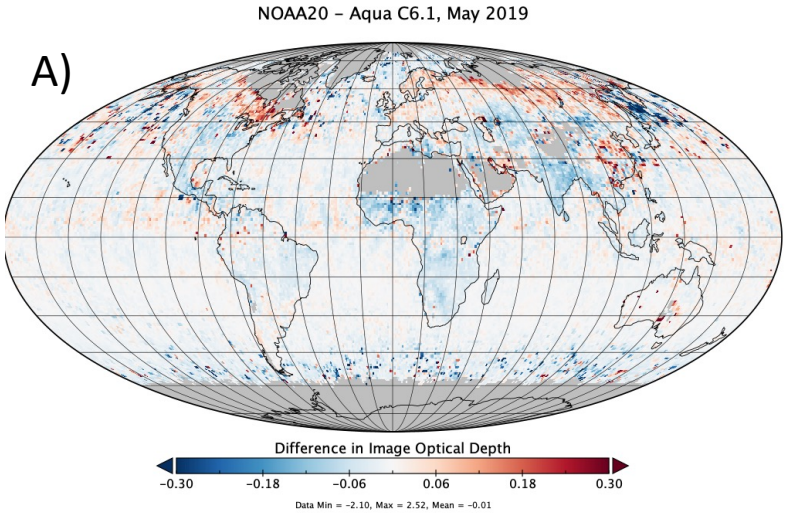
Collocated (dashed) and VIIRS > MODIS (solid)

A) VIIRS-SNPP > MODIS-Aqua globally

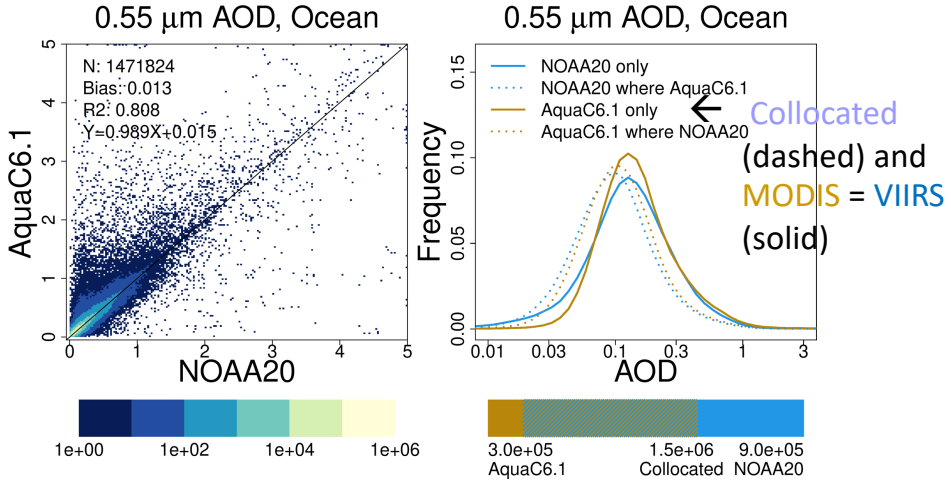
B) **Independently** compared to ground-truth, VIIRS appears high, whereas MODIS is perfect (over Ocean)

C) Yet, if **both** MODIS and VIIRS retrieve, they agree perfectly (scatterplot and dotted lines on histogram). Difference comes from VIIRS choosing to retrieve extra pixels VIIRS no MODIS > MODIS no VIIRS

AOD evaluation: VIIRS-N20 vs MODIS-Aqua



C)



Collocated (dashed) and MODIS = VIIRS (solid)

VIIRS-NOAA20 and MODIS-Aqua compare well globally, (except scatter). Note this is only 1 month of data.

A more systematic approach: Matchfiles

Goal

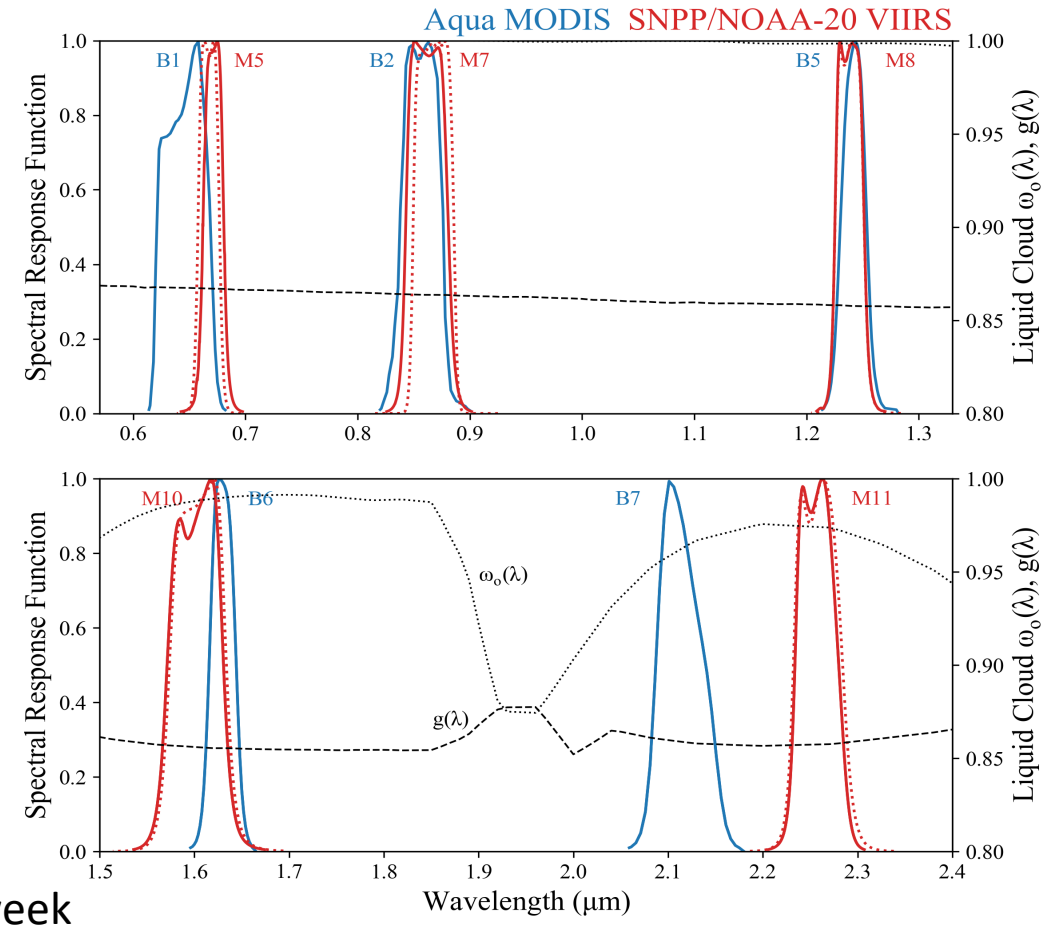
Use Aqua MODIS as a reference imager to derive spectral radiometric adjustments for SNPP and NOAA-20 VIIRS

Challenge #1:

Even though VIIRS and Aqua are “similar” orbits (~13:30) differences in swath widths and orbit altitudes mean that true matchups are hard to find.

Challenge #2

The analogous spectral channels on both imagers used for aerosol or cloud retrievals in some cases still are quite different, particularly in spectral regions where cloud single scattering properties vary strongly (e.g., for liquid clouds at right), and land surface properties (previous page).



Kerry Meyer will detail later this week

“Matchfiles”

- Developed by processed by the Atmosphere Science Investigator-led Processing System (A-SIPS) at U. Wisconsin
  - VIIRS Atmosphere Discipline production center
- Co-locate the Aqua and VIIRS data (M-bands)
- Look for homogeneous ground/cloud targets, strict angle matching, etc.
- Inversion approach:
  - Use Radiative Transfer (RT) to calculate multiple sets of LUTs: one for MODIS-Aqua wavelengths, one each for VIIRS on SNPP and VIIRS on JPSS (NOAA-20)
  - Assume MODIS-Aqua reflectance/radiance is “truth”,
  - do retrieval on MODIS: get aerosol or cloud properties
  - Invert to find out what reflectance “should” be for VIIRS
  - Calculate “correction factors”

Cloud and Aerosol uses of matchfiles

Open Access Article

Derivation of Shortwave Radiometric Adjustments for SNPP and NOAA-20 VIIRS for the NASA MODIS-VIIRS Continuity Cloud Products

by Kerry Meyer [1,*], Steven Platnick [1], Robert Holz [2], Steve Dutcher [2], Greg Quinn [2] and Fred Nagle [2]

[1] Earth Sciences Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA
[2] Space Science and Engineering Center, University of Wisconsin, Madison, WI 53706, USA
* Author to whom correspondence should be addressed.

Remote Sens. **2020**, *12*(24), 4096; https://doi.org/10.3390/rs12244096

Meyer et al (clouds) uses “bright clouds”

Atmos. Meas. Tech., 10, 1425–1444, 2017
https://doi.org/10.5194/amt-10-1425-2017
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Research article 13 Apr 2017

Cross-calibration of S-NPP VIIRS moderate-resolution reflective solar bands against MODIS Aqua over dark water scenes

Andrew M. Sayer[1,2], N. Christina Hsu[2], Corey Bettenhausen[2,3], Robert E. Holz[4], Jaehwa Lee[2,5], Greg Quinn[4], and Paolo Veglio[4]

[1]Goddard Earth Sciences Technology And Research (GESTAR), Universities Space Research Association (USRA), Columbia, MD, USA
[2]NASA Goddard Space Flight Center, Greenbelt, MD, USA
[3]Adnet Systems, Inc, Bethesda, MD, USA
[4]Space Science and Engineering Center, University of Wisconsin, Madison, WI, USA
[5]Earth Systems Science Interdisciplinary Center (ESSIC), University of Maryland, College Park, MD, USA

Sayer et al (Deep Blue aerosols) uses ”dark ocean”

VIIRS Wavelength (Band Designation)			0.67 µm (M5)	0.87 µm (M7)	1.24 µm (M8)	1.61 µm (M10)	2.25 µm (M11)	
Radiometric Adjustment Factor	N-20	vs MODIS C6.1	1.0	1.01	1.02	1.02	0.99	← N-20 ok, or needs slight increase
		vs MODIS C6.1	0.95	0.97	0.99	0.98	0.97	← SNPP needs reduction
	SNPP	vs MODIS C6	0.94	0.96	0.98	0.98	0.97	← Consistent with values for C006
		Deep Blue Gain Factors	*0.94*	*0.96*	*1.01*	*0.98*	*0.93*	← Uncertainty for longer bands

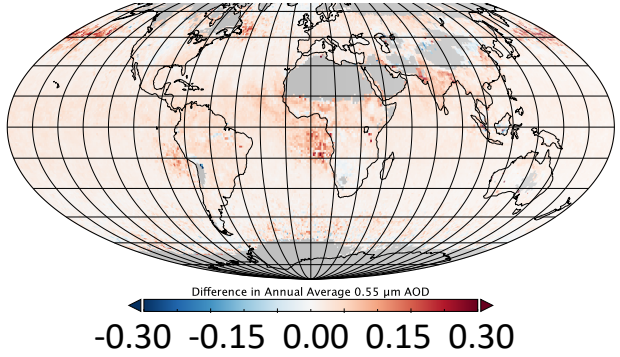
(Note Sayer et al., also calculated adjustments for blue bands)

Dark Target: Calibration adjustments

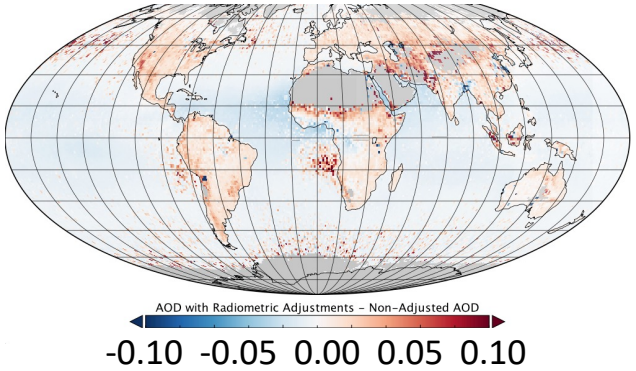
- *Meyer et al*. works for clouds, *Sayer et al.* works for DB aerosols.
- Does either choice work for DT aerosols?
  - The short answer is "sort of" (recalling mutual retrievals are already good!).
  - makes it worse over land?
  - Is the difference is related to pixel selection/cloud masking?
- Have considered other corrections: *Uprety et al*., *Doelling et al*, etc.

(Sawyer et al., 2020)

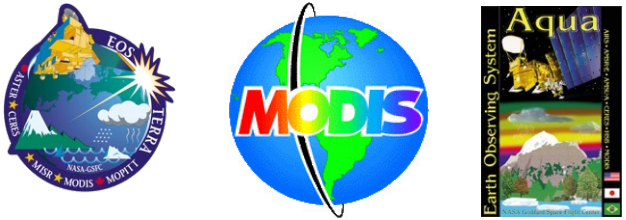
AOD: VIIRS-SNPP – MODIS-Aqua



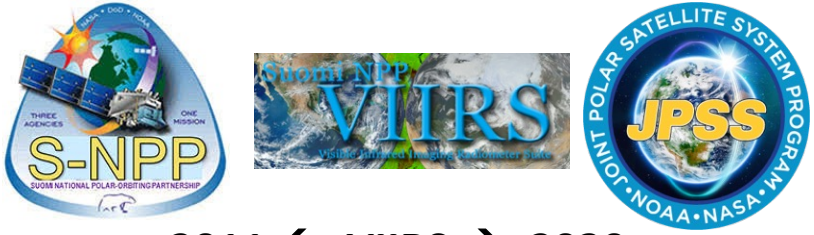
AOD: VIIRSwSayer – VIIRS



Global Climate Observing System (GCOS) requirements for **Aerosol Optical Depth (AOD)** climate data record (CDR):



2000 ← MODIS → 2022



2011 ← VIIRS → 2030+

Target metric	Target
Horizontal Resolution	5-10 km, globally
Accuracy	MAX(0.03 or 10%)
Stability / bias	<0.01 / decade
Time Length	30+ years
Temporal Resolution	**4 h**

} With a long LEO time series (MODIS + VIIRS) we can meet 1st four requirements for aerosol observations

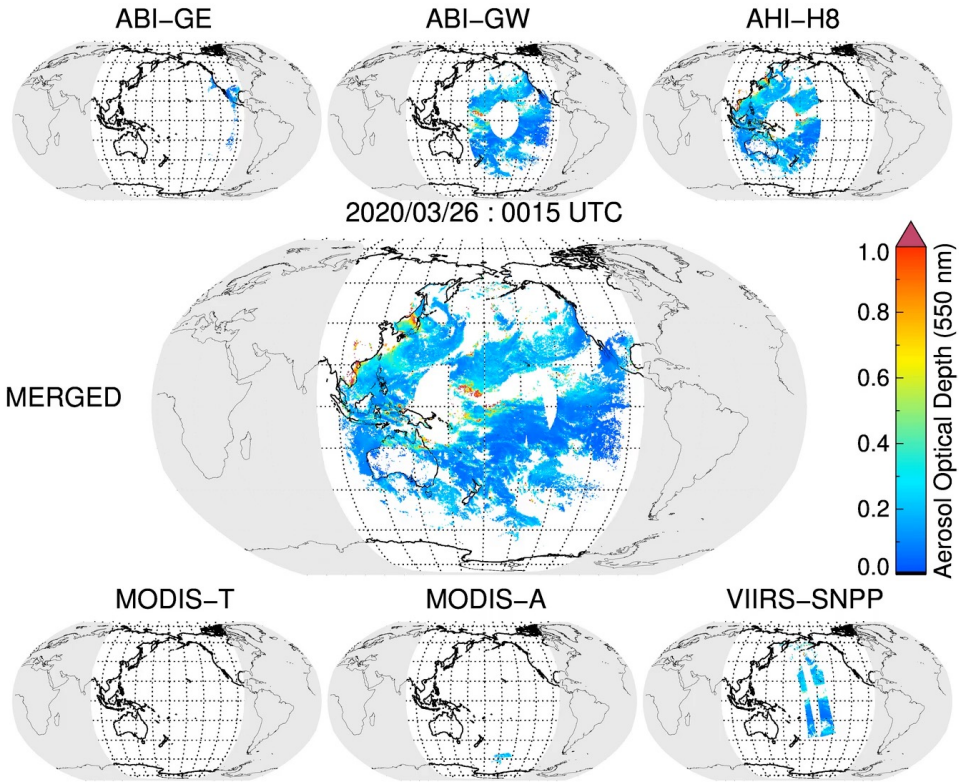
Pointing out obvious

- Calibration is important
- Calibration from different teams may give different results
- Consistency across all light levels (darkest ocean and brightest cloud) is necessary.
- GSICS is solution?

XAERDT: Joining LEO and GEO retrievals

- Level 2: 6 Individual sensors
  - MODIS on Terra (10 km)
  - MODIS on Aqua (10 km)
  - VIIRS on Suomi-NPP (6 km)
  - ABI on GOES-East (10 km)
  - ABI on GOES-West (10 km)
  - AHI on Himawari (10 km)
- Uses DT-package to derive all L2
- QA/QC filtered
- Level 3:
  - 30-minute intervals
  - Global 0.25° x 0.25° grid

- 2019 – 2022



What if?

Goal

Use Aqua MODIS as a reference imager to derive spectral radiometric adjustments for SNPP and NOAA-20 VIIRS

Challenge #1:

Even though VIIRS and Aqua are "similar" orbits (~13:30) differences in swath widths and orbit altitudes mean that true matchups are hard to find.

Challenge #2

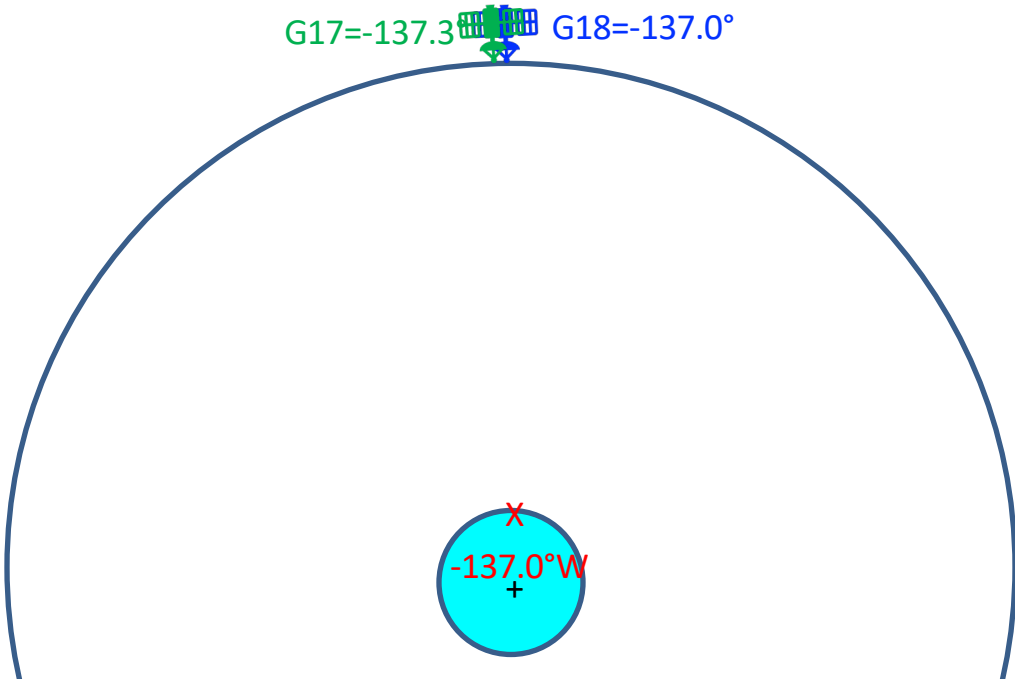
The analogous spectral channels on both imagers used for aerosol or cloud retrievals in some cases still are quite different, particularly in spectral regions where cloud single scattering properties vary strongly (e.g., for liquid clouds at right), and land surface properties (previous page).

Wouldn't it be nice if these were

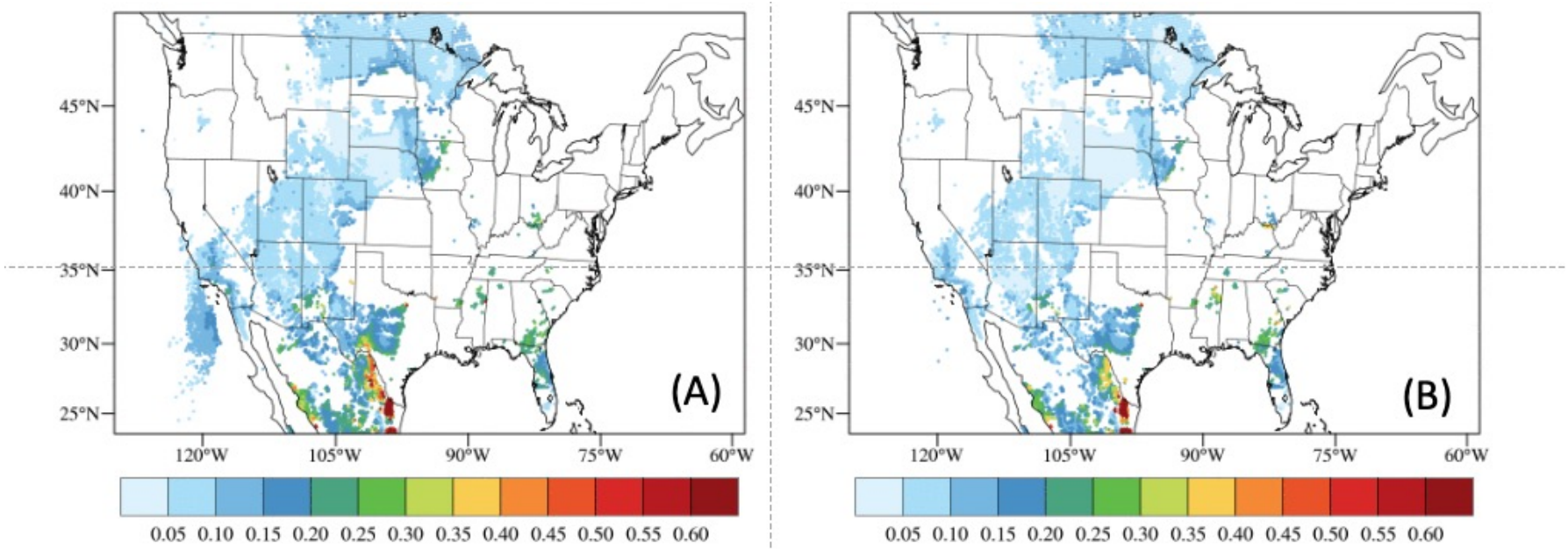
- the **same sensors**,
- in the **same orbits**?

GOES18 vs GOES17

- Prior to, and during “interleave”, GOES-18 was sitting at 137.0° right next to GOES-17 at 137.3°
- Both G18 and G17 are reprojected onto the surface as GOES-W (137.0°W)
- July 25th GOES-18 L1B reached provisional status, which includes a bias correction for Band #2 (red band).
- If GOES-18 and 17 are twins, how does L1B look? How does it impact Level 2 aerosol retrieval?

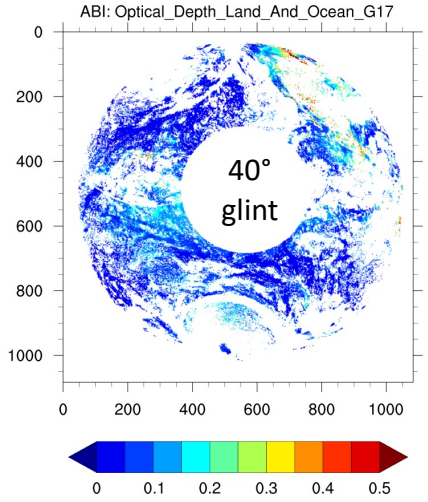


“Dark Target” Aerosol Optical Depth Retrieval

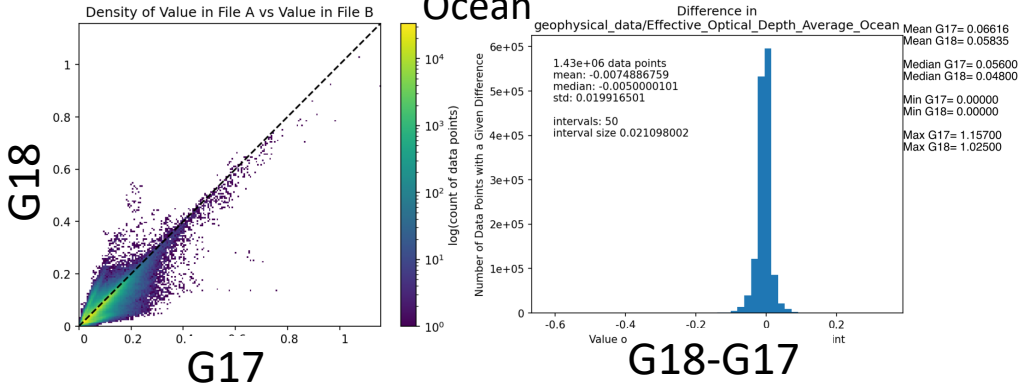


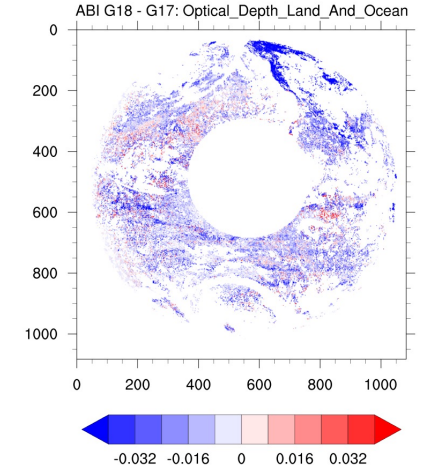
My eyes can’t tell the difference: How about “quantitatively”?

Aerosol Optical Depth (AOD)
Aug 24 2022 @ 20:50 UTC, (Day 236)
(Note Provisional G18 Data)

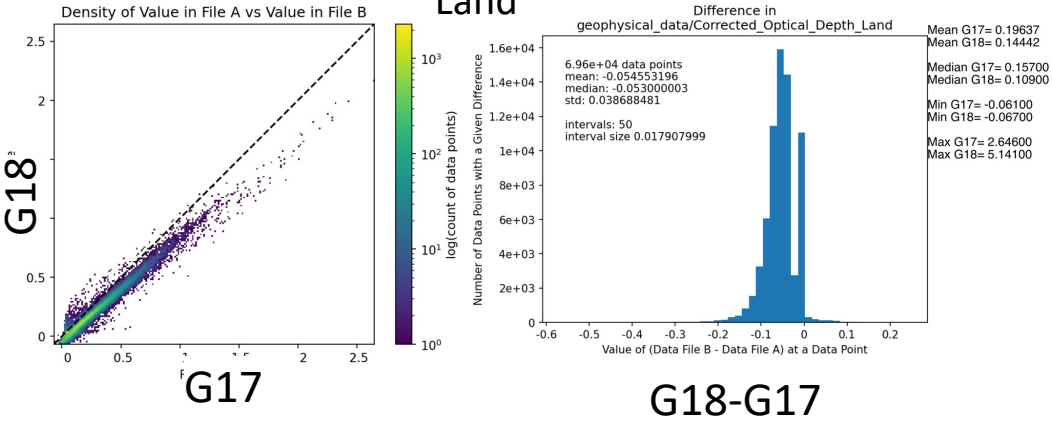


Ocean





Land



Using “Dark Target” (DT) aerosol retrieval algorithm to retrieve AOD, using ABI Bands 1-6 and 14.

retrieval over ocean uses different subset of ABI bands than does retrieval over land

- AOD over ocean: noisy but unbiased G18 ≈ G17
- AOD over land: G18 < G17.

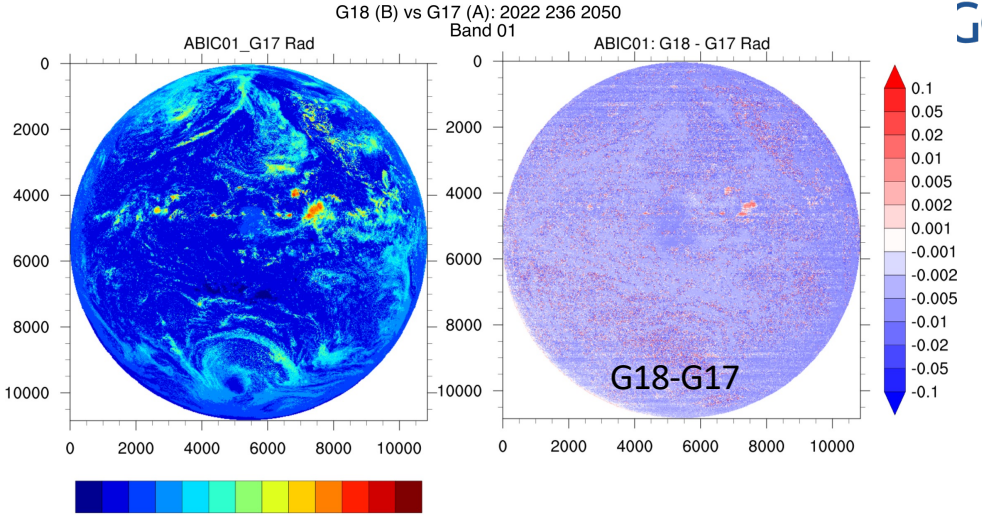
Let’s look at the L1B!

Why do these differences exit?

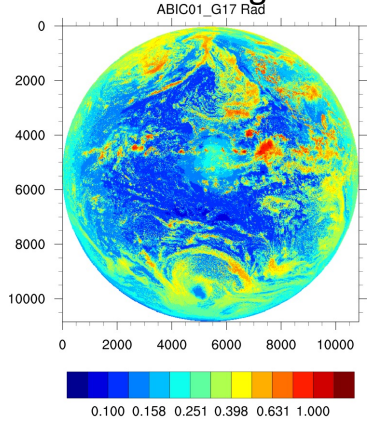
- Let’s look at L1B.
- I admit this is a naïve way!

Band 1 (0.47)

G17

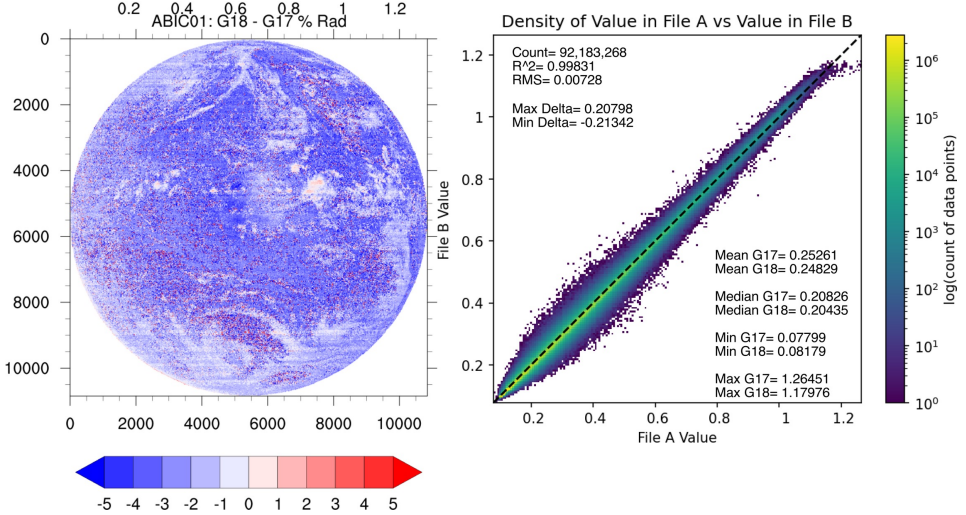


G17 on log scale



% Diff

100*(G18-G17)/G17



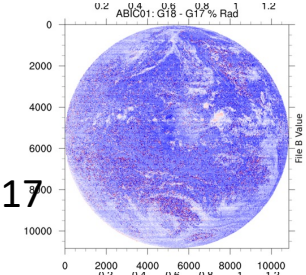
Small differences

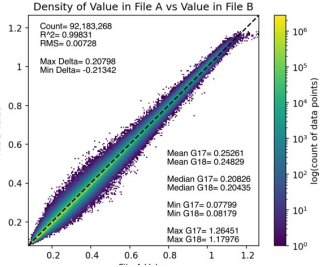
G18 < G17 by 1-2%

Some bands used for our DT retrieval

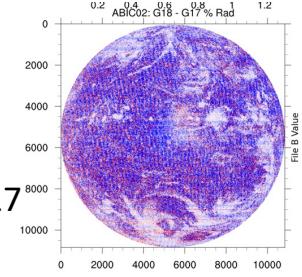
% diff

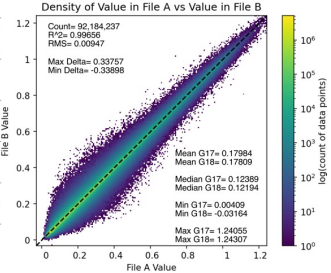
G18 vs G17



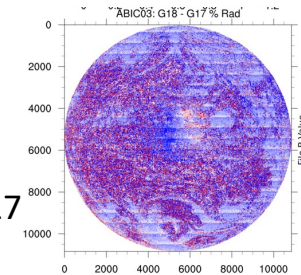


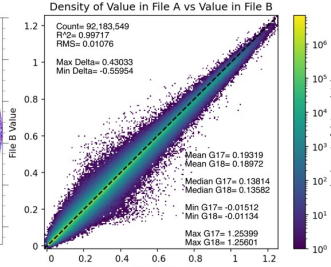
Band 1
(0.47)
G18 < G17



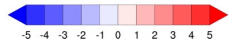


Band 2
(0.64)
G18 ≃ G17



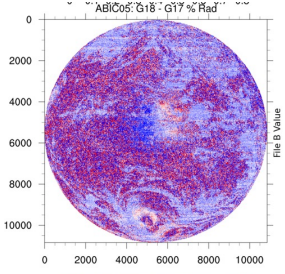


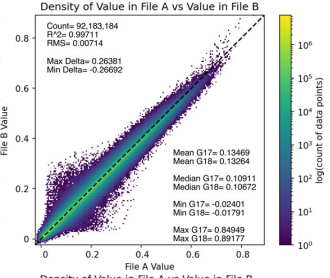
Band 3
(0.87)
G18 < G17



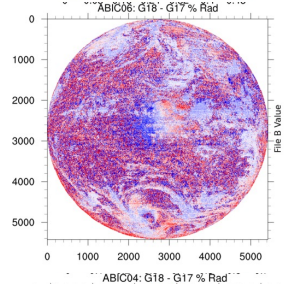
% diff

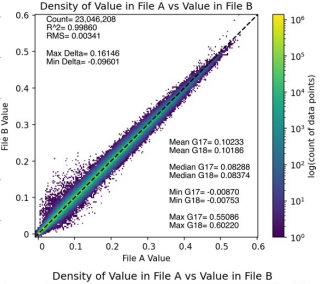
G18 vs G17



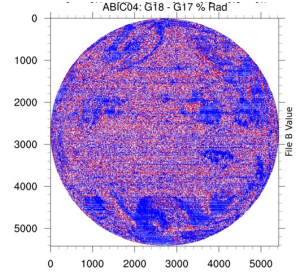


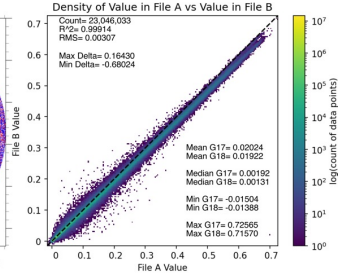
Band 5
(1.60)
G18 ≃ G17
+ noisy





Band 6
(2.26)
G18 ≃ G17



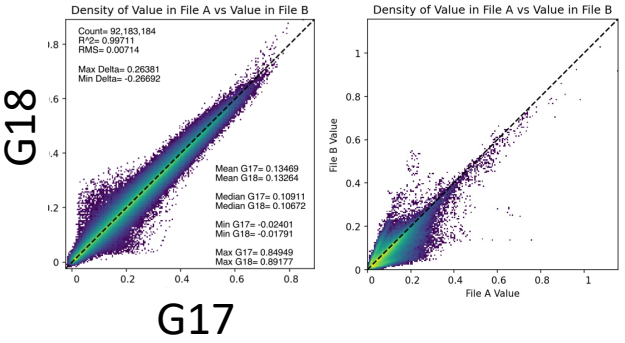


Band 4
(1.37)
Cirrus
Slope < 1.0

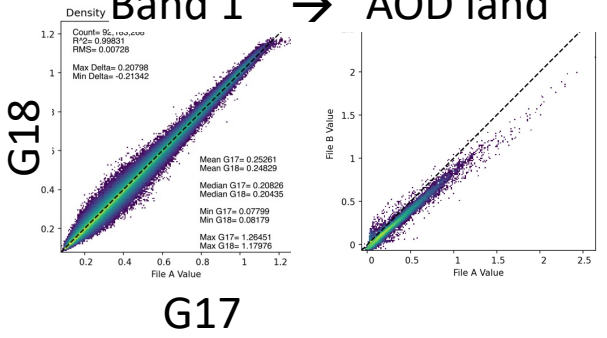
Summary

- Bands 2, 3, 5 and 6 appear to be close to 1-1 at lower reflectance levels
- For nearly all bands, G18 < G17 at high reflectance values.
- Band 1 (0.47 μm) appears to be lower for G18 by about 1-2% or on order of 0.002.
  - This results in low bias for our over land retrieval
- Band 5 (1.60 μm) appears to be noisy at low levels
  - This results in scatter for our over ocean retrievals
- Band 4 (cirrus = 1.37 μm) is interesting.
  - maybe affecting our cloud masking / pixel selection!)

Band 5 → AOD ocean



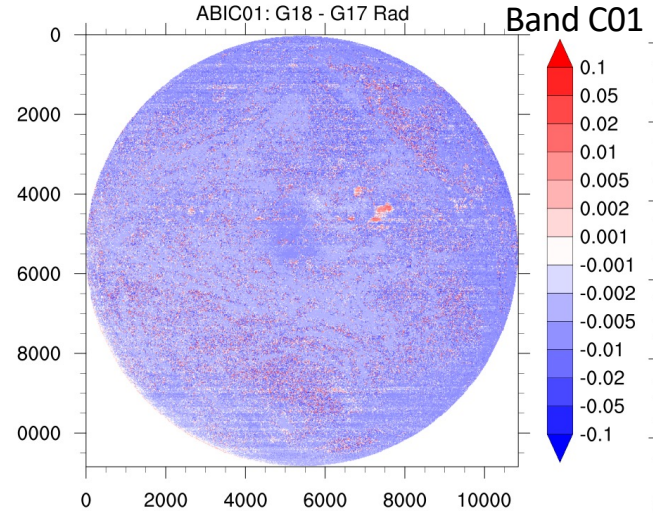
Band 1 → AOD land



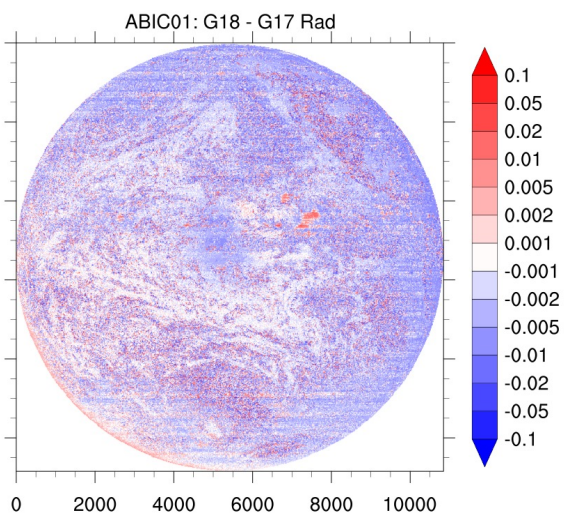
For fun:

- Can I make G18 look more like G17 for AOD retrieval?
  - Yes, I can!!
- Note Blue band #01 is only used for AOD over land.
- Correction factor of only 1%.

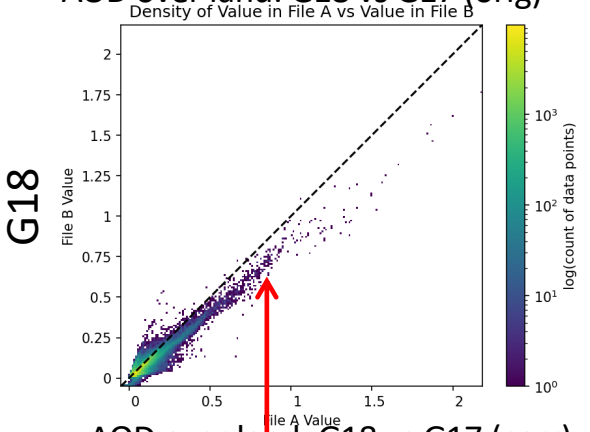
Original G18-G17



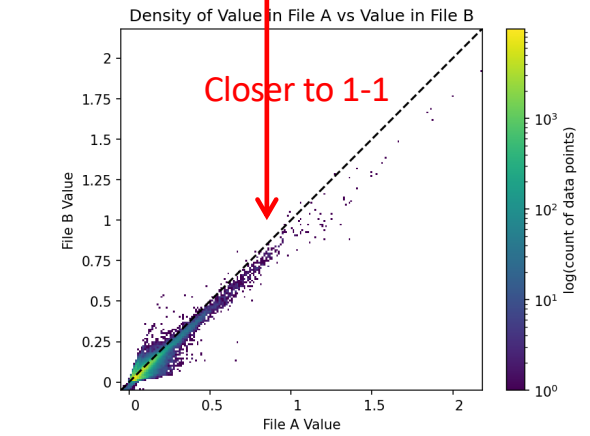
corrG18: 1.01*G18 – 0.001



AOD over land: G18 vs G17 (orig)



AOD over land: G18 vs G17 (corr)



G17

Summary (NASA-Atmospheres experience)

- With 20+ year record of MODIS on Terra, we have the beginnings of a Climate Data Record for Aerosols and Clouds.
- Entrance of MODIS on Aqua in 2002 invoked Segal's Law: " A man with one watch always knows what time it is. A man with two watches is never sure".
  - With addition of new calibration and bright-surface detrending exercises, 20-year aerosol and cloud trends agree extremely well in Collection 6.1.
  - Some Terra-Aqua offset remain, but maybe related to diurnal cycles?
- Entrance of VIIRS on Suomi-NPP in 2011 added a new model of watch
  - Ported retrieval algorithms were giving some inconsistent results, even with VIIRS and Aqua at similar observing times
  - Systematic efforts by aerosol and clouds teams, using "matchfile" processing have led to radiometric adjustments that reduce offsets for some retrieval products. (But not all!)
  - More teamwork is needed to reach consensus and consistency on all products.
  - Yet at least between 2012-2022, VIIRS-SNPP and MODIS-Aqua trends agree pretty well
- Entrance of VIIRS on NOAA-20 in 2017 seems to sometimes lead to better matches with Aqua. Noting that CERES team and other "continuity" efforts appear to be happier stitching NOAA-20 directly to MODIS-Aqua
- NASA's MODIS and VIIRS Atmosphere teams are recently interested in applying consistent retrieval algorithms to GEO sensors such as ABI.
  - These are very different instruments with very different geometry than LEO (a whole new species of watch!)
- With GOES-18 in near-exact orbit of GOES-17 for about 6 months of 2022-2023, one can nearly remove the uncertainties of wavelength differences and sampling differences to testing calibration and algorithms.
  - Meaning one can directly relate differences in G18 vs G17 L1B to differences in G18 vs G16 L2.

- More teamwork is needed to reach consensus and consistency on all products. GSICS?