Dark Target (DT) Aerosol Retrieval Project

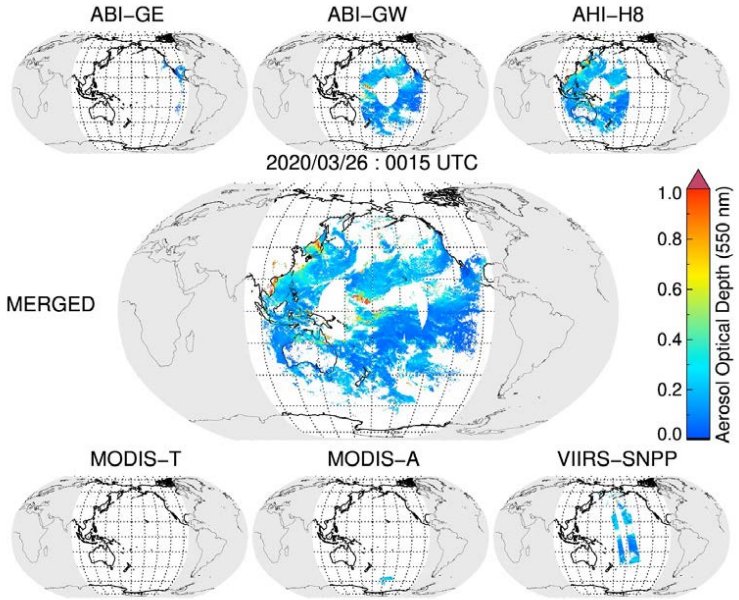
"Core" = R. Levy[1], S. Mattoo[2], V. Sawyer[2], V. Kiliyanpilakkil[2], Y. Shi[3], P. Gupta[1], Y. Zhou[3], L. Remer[5] , M. Kim[6], etc.

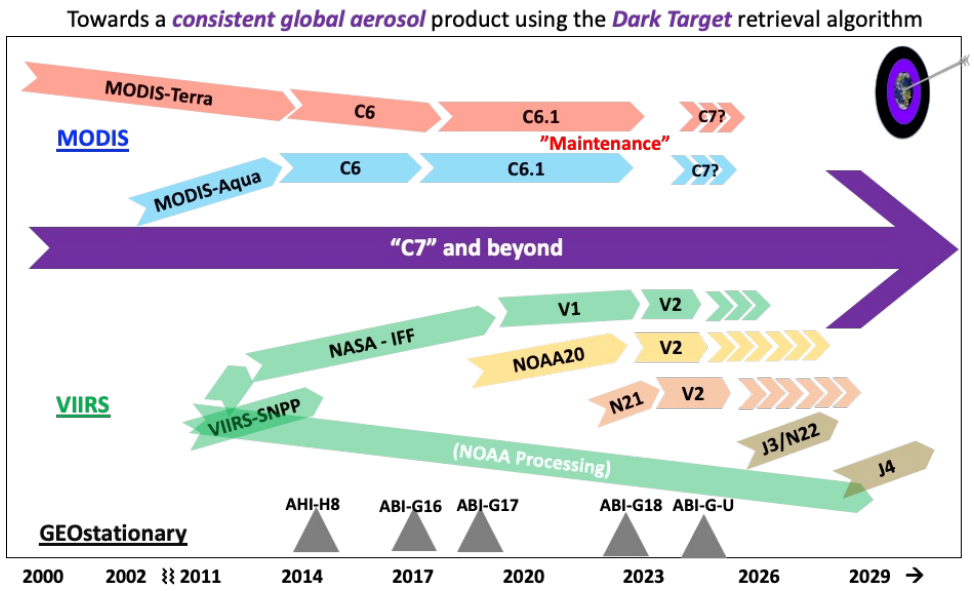
"Enhanced" = J. Wei[7], Z. Zhang[8], R. Holz[9], M. Oo[9], H. Jethva[10], R. Kleidman[2], S. Gassó[11], J. Wang[12], etc.

"Processing/Delivery" = B. Ramachrandan, S. Devadiga, C. Davidson, J.Z Wang, G. Cureton, S. Dutcher, etc.

[1]GSFC/613, [2]SSAI/613, [3]UMBC/613, [4]USRA/MSFC, [5]GESTAR2/UMBC, [6]GESTAR2/Morgan State U.,
[7]GSFC/610, [8]ADNET/610, [9]SSEC/Uwisc, [10]GESTAR2/614, [11]ESSIC/613, [12]U Iowa, etc.

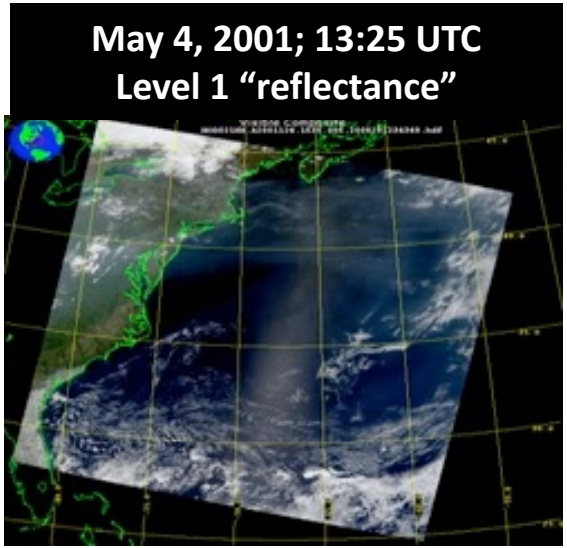
One algorithm + many sensors = **All daylight globe**





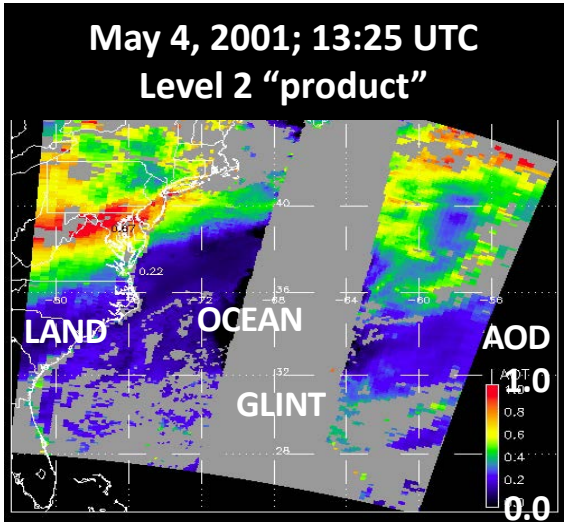
Dark Target Aerosol retrieval Algorithm
(originally developed for MODIS)

What a sensor observes



DT

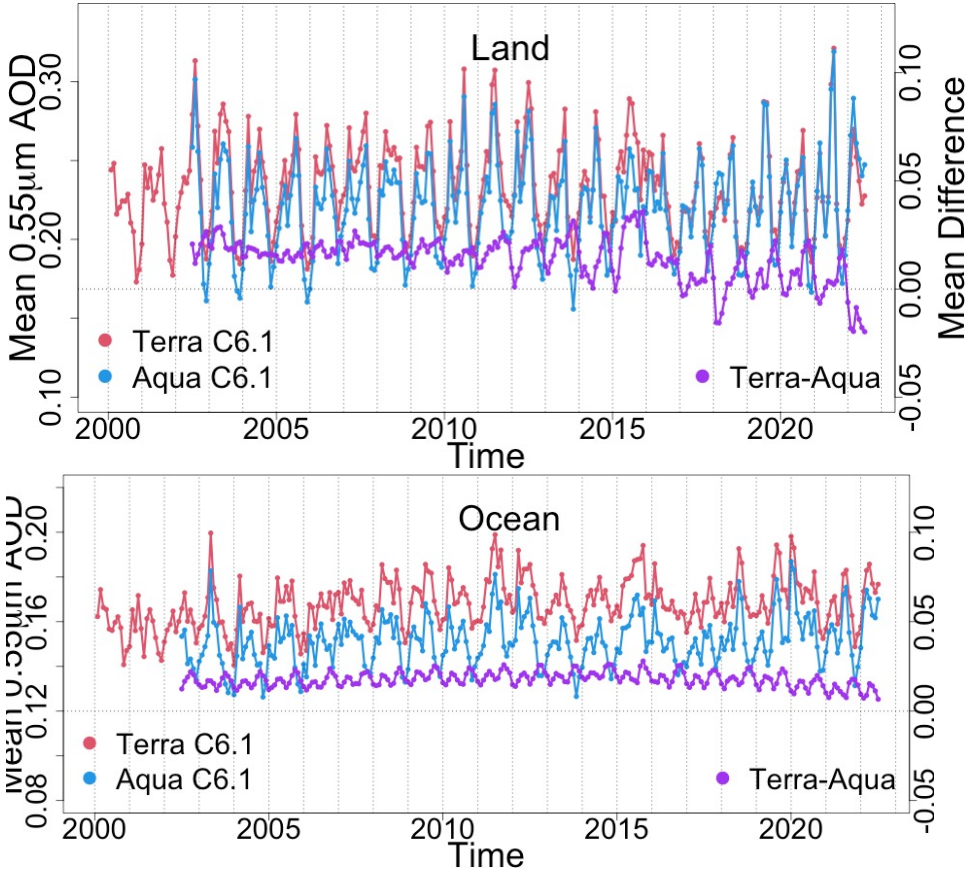
Attributed to aerosol (AOD)



- Established by Kaufman, Tanré, Remer, et al (1997)
- Modified by Remer, Levy, Gupta, Sawyer, Shi et al (2005, 2010, 2013, 2015, 2020, etc.)

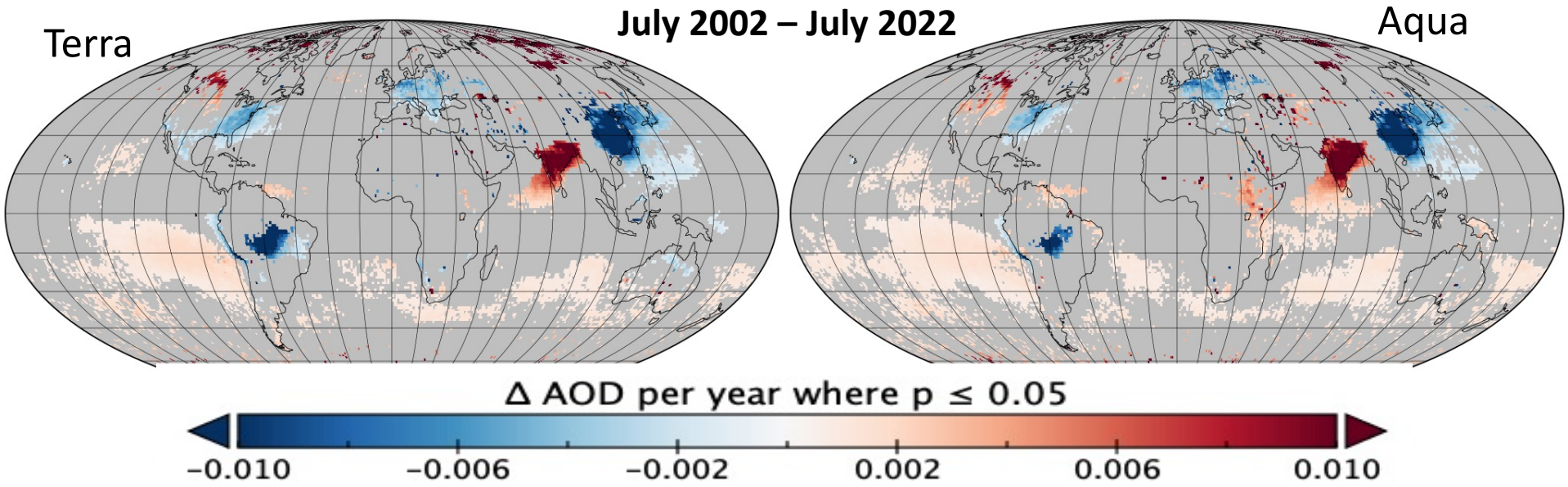
- **Requires:** Observations of spectral reflectance in selected bands between ”blue” and “SWIR” wavelengths (other bands help with cloud/surface masking and filtering)
- **Retrieves:** AOD at 0.55 μm, spectral AOD (AE), cloud-cleared reflectances, diagnostics, quality assurance

20+ years of MODIS: Terra vs Aqua time series



- With same algorithm, Terra offset high compared to Aqua by about 0.015.
- Drift of Terra – Aqua difference after 2017, especially over land.
- Yet, both within expected uncertainties
- Small calibration adjustments of 2% or less might help, but requires doing all wavelength bands and maybe also time-dependence

Consistency of Dark Target AOD Trends (Terra vs Aqua)



Slope of the linear regression for each 1°×1° grid cell (monthly mean QA-filtered AOD) plotted where p ≤ 0.01

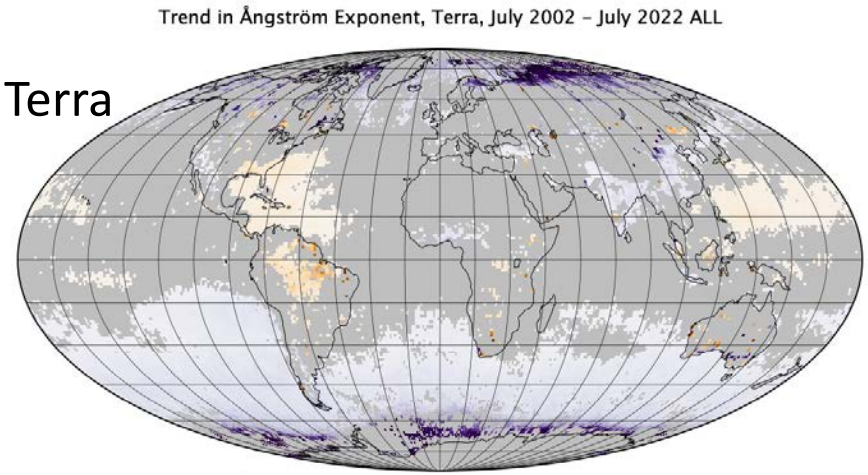
- Terra and Aqua agree on regions that show significant increase or decrease in AOD over time
- **Note:** simple linear regression has limitations, and temporal autocorrelation may make these results "overconfident" where month-to-month progression gives the illusion of a trend

Ångström exponents

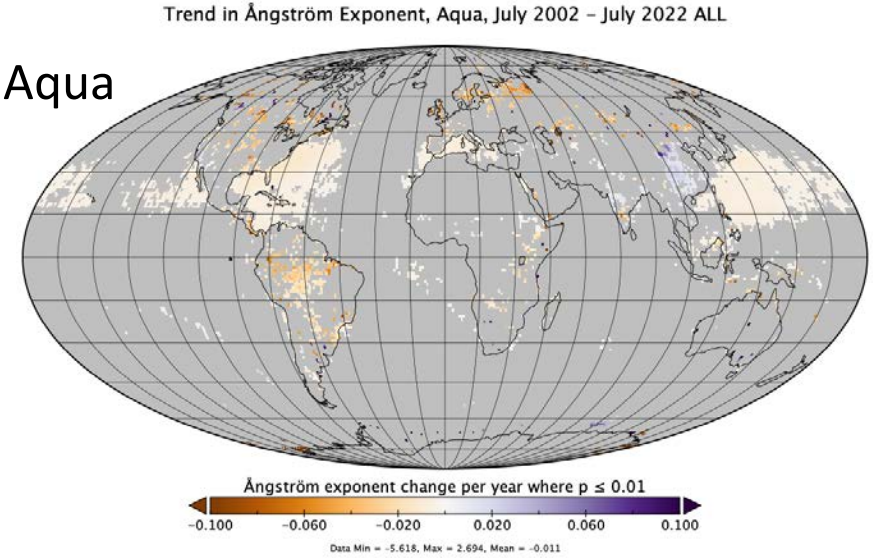
July 2002 – July 2022

- Trends in indicators of particle size could show whether aerosol sources or composition are also changing over the 20-year period
- Unfortunately, Terra and Aqua show much less agreement in Ångström exponent trends than they do in AOD
- May indicate 20 years of subtle, wavelength-specific sensor drift

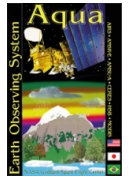
Terra



Aqua

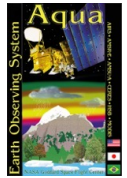


MODIS



- The bulk of the MODIS effort is funded under ”Senior Review – Algorithm Maintenance” (latest is 2020-2023)
- Since 2017, operating as “Collection 6.1”.
  - Standard products at 10 km and 3 km resolution
  - Near Real time (NRT) at both resolutions
  - Level 3 (1° x 1°) from 10 km standard product.
  - Merge with Deep Blue (Christina Hsu) for the 10 km resolution.

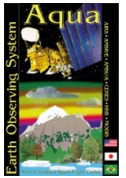
MODIS



- When searching ISI Web of Science for index terms “MODIS and Aerosol”, yields 5000 publications, H index of 186,
- 1000 publications since 2020!

- *Still relevant after all of these years…*

MODIS



- Recent proposal (March 2023) to continue under SR at 55% FTE effort.
- SR proposal includes finishing Collection 7
  - Level 2: Modernize to NetCDF Climate and Forecast file format and metadata conventions
  - Level 3: TBD, but will likely look much as does now (e.g. 1° x 1° grids at daily, 8 day and monthly).
  - Continued validation and documentation
  - Thoughts about “legacy” as MODIS missions (both Terra and Aqua) end
  - analyze how orbital drifts impact long term record (e.g. diurnal cycle of aerosols, clouds, sun angles, etc.)

The Level 2 DT-Package

A "platform independent" version of the retrieval code

- All outputs in NetCDF format.
- Modular, so that testing and updates are much easier
- Necessary some differences between "standard" MODIS algorithm logic →
- specific LUTs for specific sensors
- Making it available in Git.
- MODAPS can "run it"
- Currently exploring to work in Amazon cloud

Differences between DT-Package and standard applied to MODIS

Issue	MODIS C6.1	DT-Package (C7)
Data	L1B + geolocation + cldmask in native resolution	L1B + geolocation + cldmask downscaled to 500 m
Reading data	10 lines at a time	Entire granule into memory
Ocean cloud masking	3x3 stddev at 0.55 μm	3x3 stddev at 0.66 μm • GEO has no 0.55 • all sensors have red at 2x resolution of other bands
Land cloud masking	all tests at native pixel resolution	all tests at 500 m resolution
Snow mask	Uses 0.86 vs 1.24 μm	Uses 0.86 vs 1.63 μm tests • GEO has no 1.24.
Overall pixel masking	10 lines at a time (lines #0 and #9 set to values of #1 and #8).	Entire granule at once (lines #0 and #9 have their own values)

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

2000 ← MODIS → 2022

+

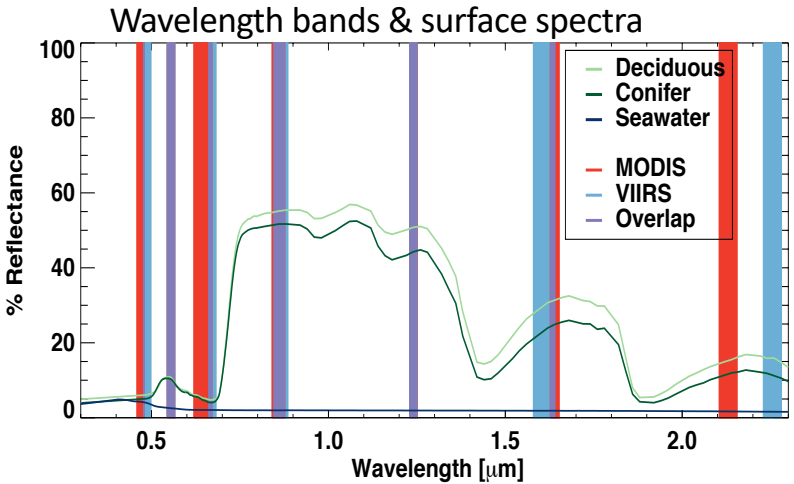
2011 ← VIIRS → 2030+

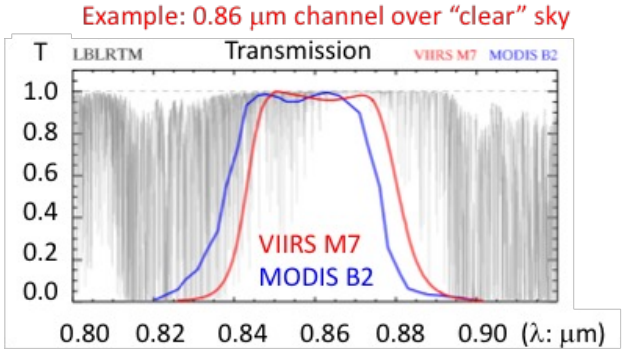
Target metric	Target
Horizontal Resolution	5-10 km, globally
Accuracy	MAX(0.03 or 10%)
Stability / bias	<0.01 / decade
Time Length	30+ years
Temporal Resolution	4 h

} extend and expand MODIS data record

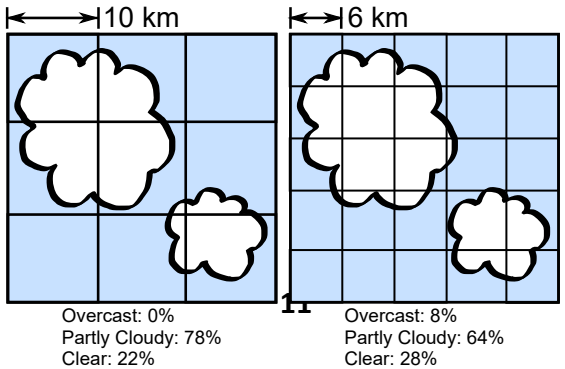
For aerosol continuity we can port the algorithms (Extending from MODIS→VIIRS)

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



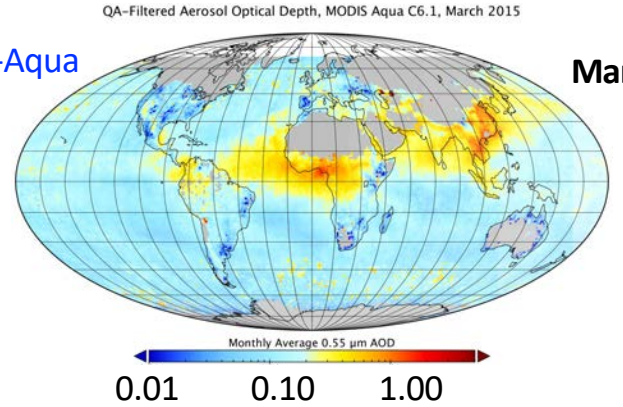


- Deal with differences in resolution, etc. (for cloud masking)

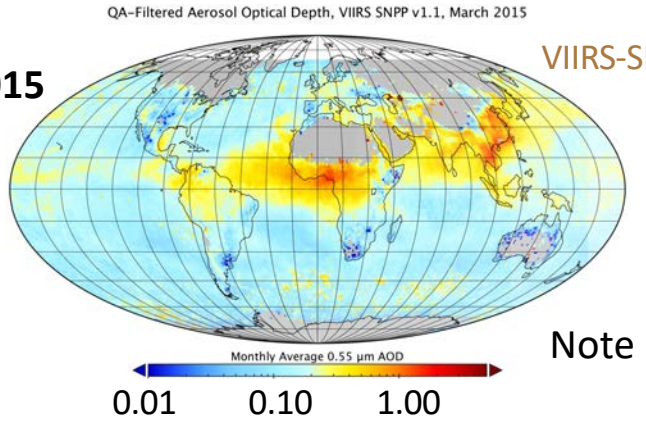


MODIS + VIIRS --> Long term climate

MODIS-Aqua

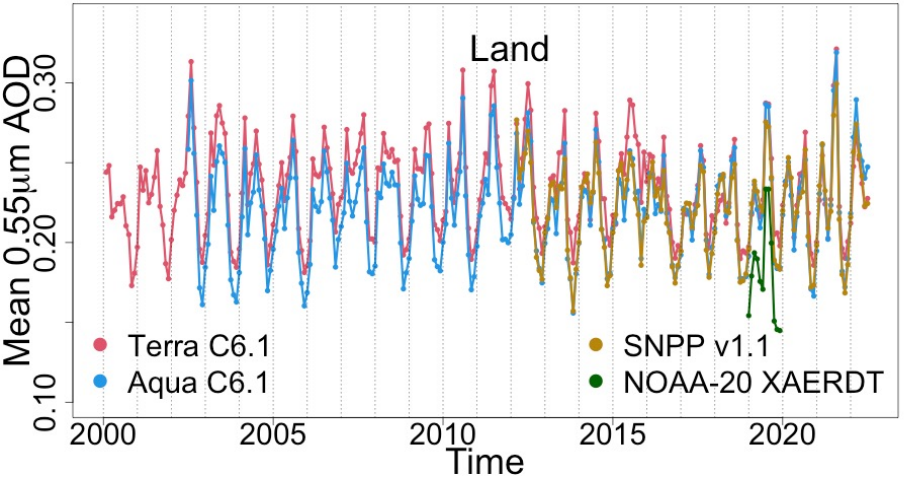


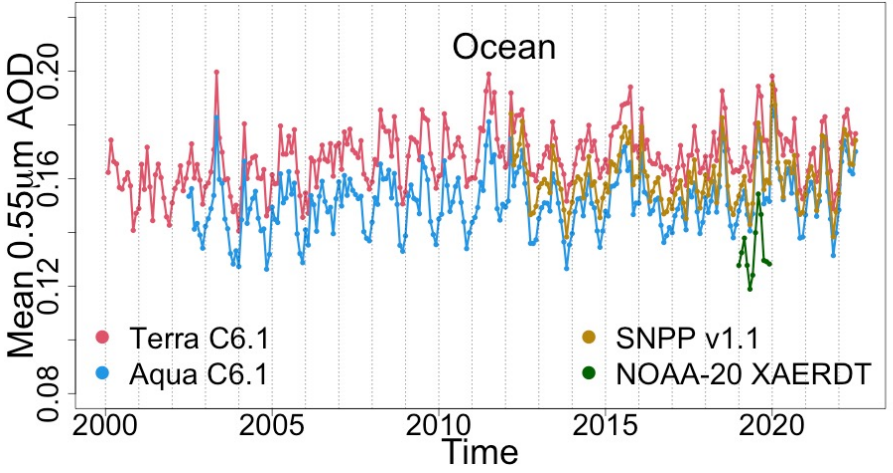
March 2015



VIIRS-SNPP

Note log scale



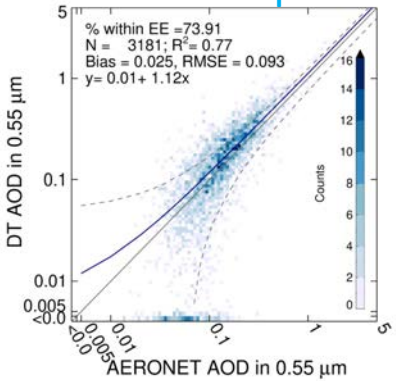


VIIRS-SNPP vs MODIS-Aqua comparison with AERONET

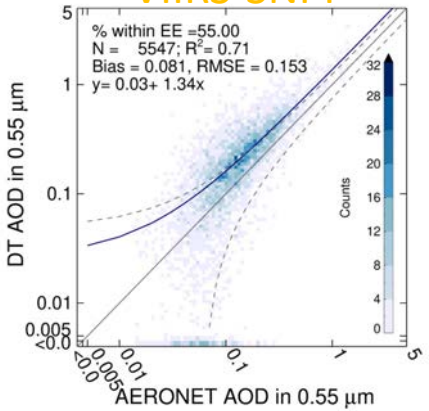
Jul – Oct 2019

Land

MODIS-Aqua

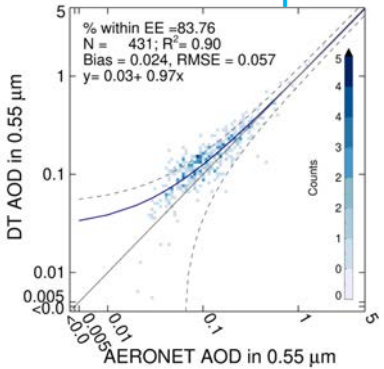


VIIRS-SNPP

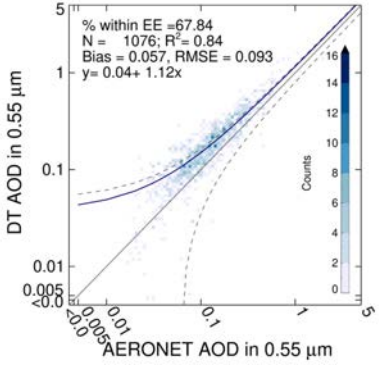


Ocean

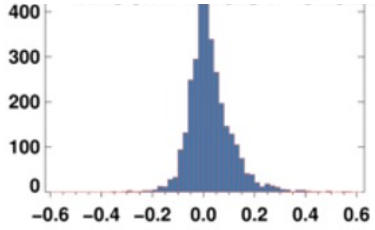
MODIS-Aqua



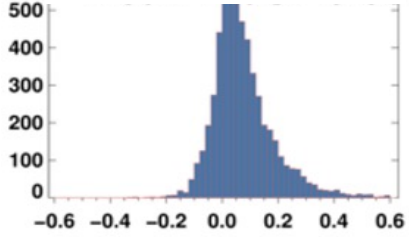
VIIRS-SNPP



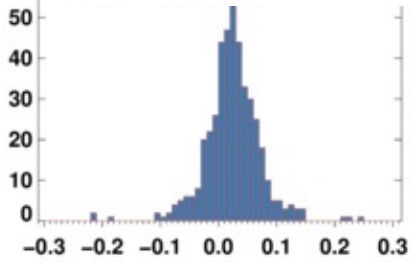
Mean Bias: 0.025



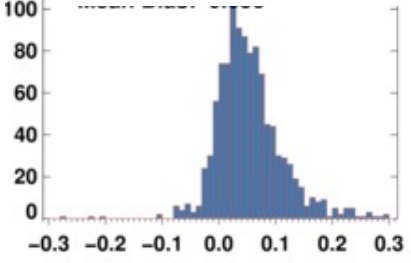
Mean Bias: 0.061



Mean Bias: 0.023

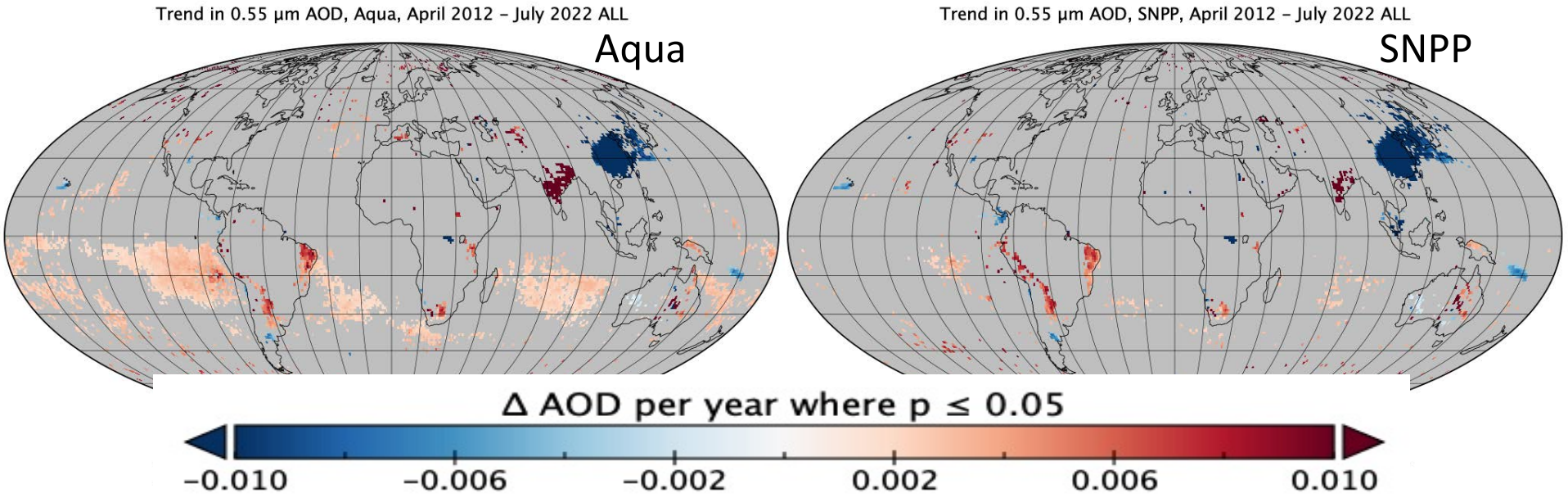


Mean Bias: 0.056



NOTE: We have *__not__* added calibration adjustments (for known high biases) for VIIRS

Consistency of Dark Target AOD Trends (SNPP vs Aqua): 2012-2022

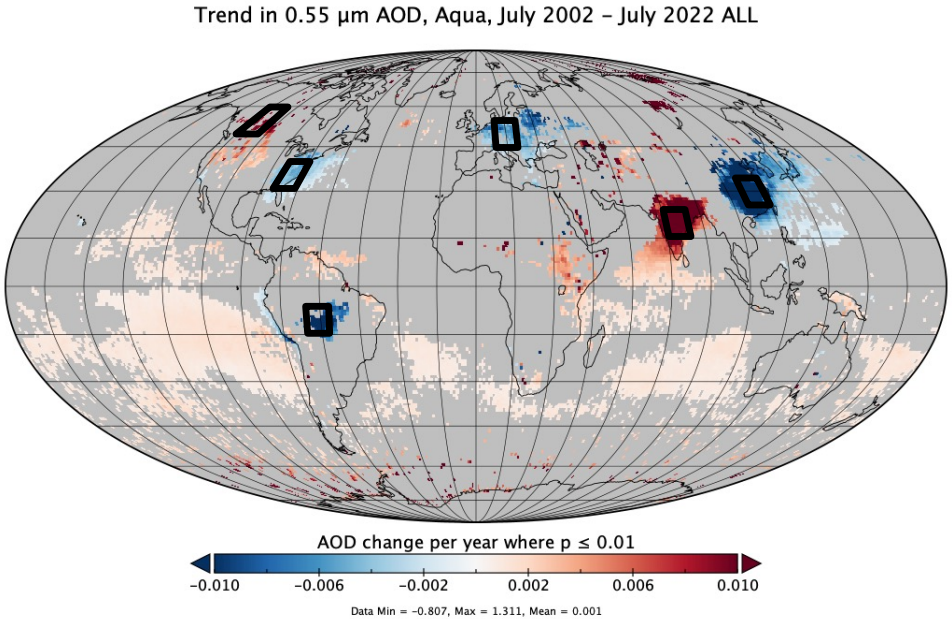


Slope of the linear regression where p ≤ 0.01, but only 10 years from 2012-2022.

- For 10-year record, half as much data = fewer grid cells meet a given significance threshold, but generally sharper slopes where they do
- Some places, the 10 year trends may be different than 20 year trends.
- Overall, SNPP sees the same world as Terra / Aqua (except for southern midlatitude ocean?)

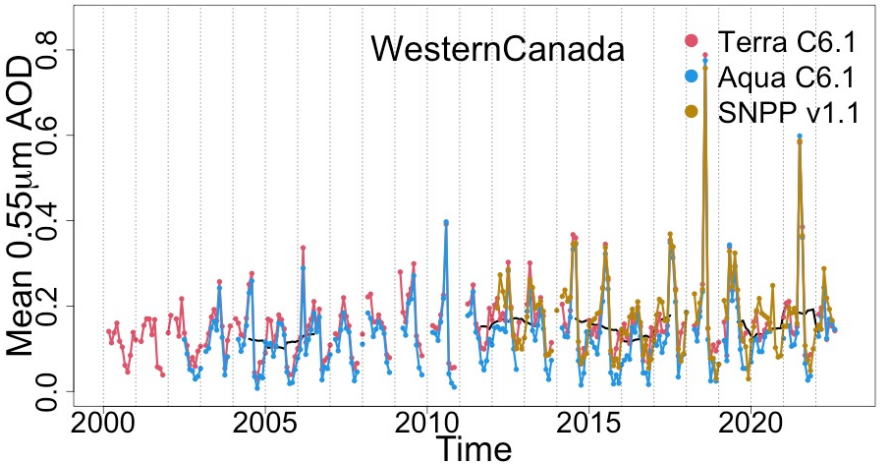
Regional trends from the 20-year record

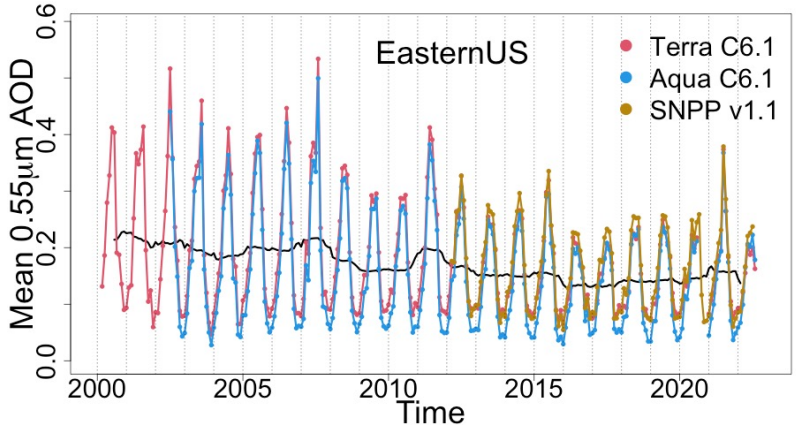
The area-weighted mean of the QA-filtered monthly AOD for each 10°×10° region below is used to construct regional time series for Terra, Aqua, and SNPP

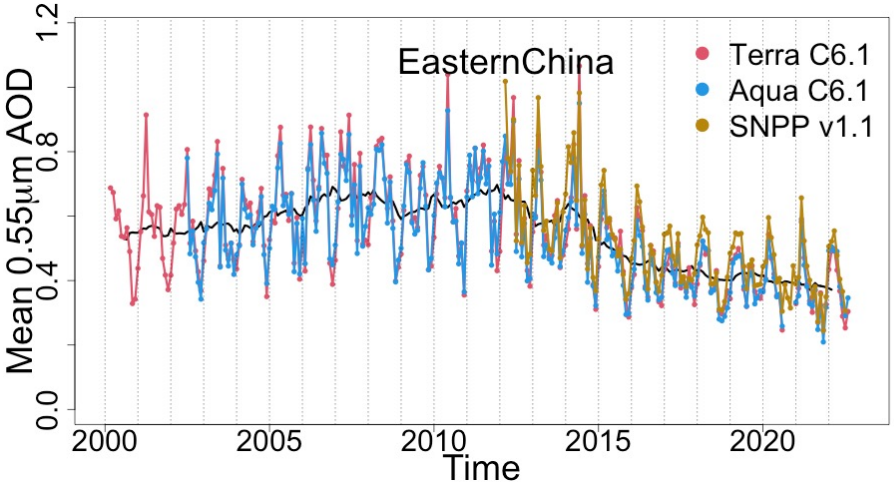


Region	Latitude	Longitude
Western Canada	50-60° N	110-120° W
Eastern US	30-40° N	75-85° W
Southern Brazil	5-15° S	55-65° W
Europe	45-55° N	10-20° E
India	15-25° N	75-85° E
Eastern China	25-35° N	105-115° E

Pick 3







- Wildfires in western Canada drive variability. Autumn/winter flat.
- Reductions seen in Eastern U.S. due to policy regarding emissions. But no trend during SNPP lifetime. Spike in 2021 due to fires
- Coherent interannual change in eastern China, strong decrease during SNPP period.

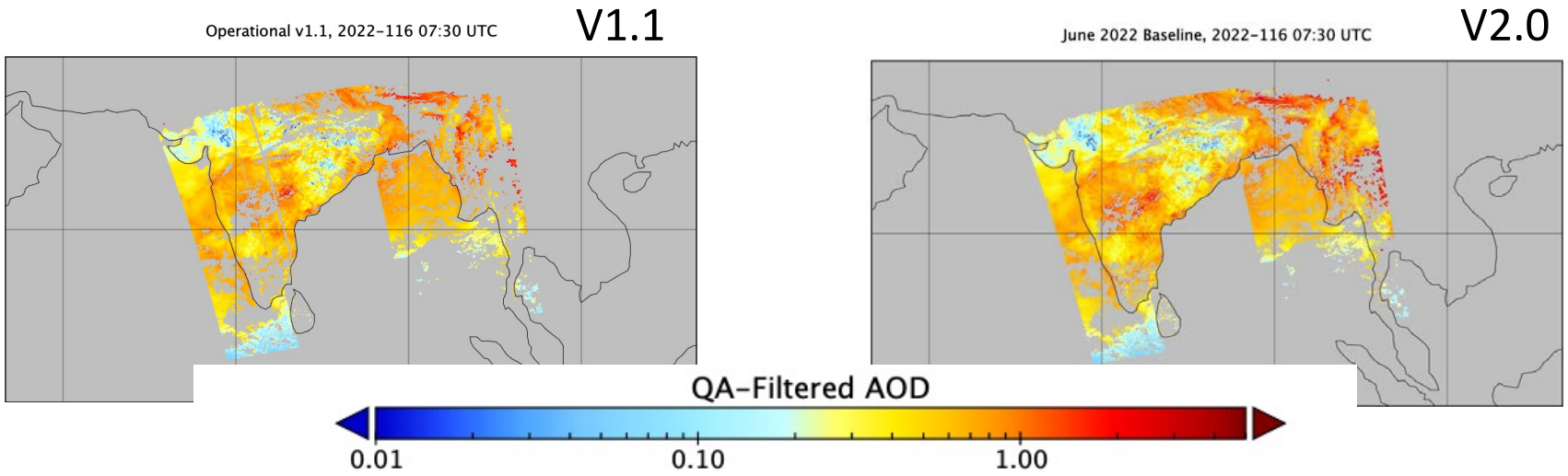
VIIRS

- Level 2 product known as “AERDT_L2_VIIRS”
- Since 2020, operating as “Version 1.1”.
- 2023: Delivered Version 2.0.
- This week: V2 Products getting ingested into LAADS!
  - AERDT_L2_VIIRS (SNPP since 2012 and NOAA20 since 2017)
  - Standard products at 6 km
  - Near Real time (NRT)
  - No calibration adjustment
  - Uses “DT-Package” so consistent with MODIS C7 framework

VIIRS

- ROSES 2020 proposal (work began in early 2022) included:
  - Delivering/processing Version 2 of Level 2
  - Level 3: Use of Wisconsin's Yori to create flexible grids and time periods.
  - Level 2: "big" science updates that requires new team members (but will not discuss today).
  - Level 2: revisit calibration adjustments.

Update for VIIRS: (V2.0)
Better cloud edge coverage, no more stripes



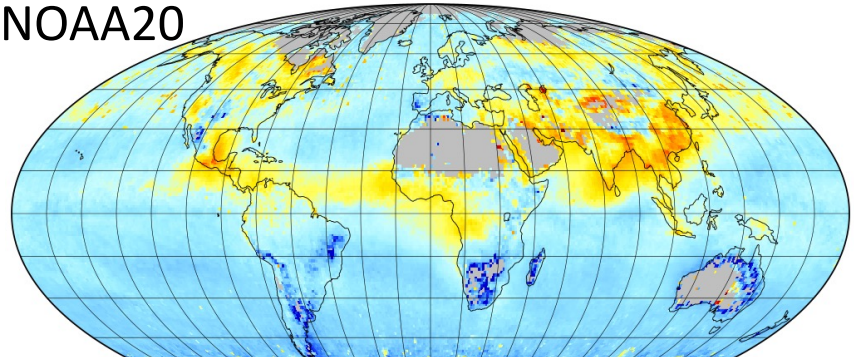
Highlights of V2.0

- S-NPP (2011-present) and N-20 (2017-present) and now being delivered to LAADS for archive
- Ancillary data is from GMAO/GEOS-IT rather than NOAA/GDAS
- Uses ”Image resolution” (375 m) bands for cloud masking.
- ”User guide” now available on Dark-Target web site
- Level 3: Testing of 1° x 1° archival version (daily and monthly only) that follows logic of MODIS

AOD: NOAA-20 vs SNPP, May 2019

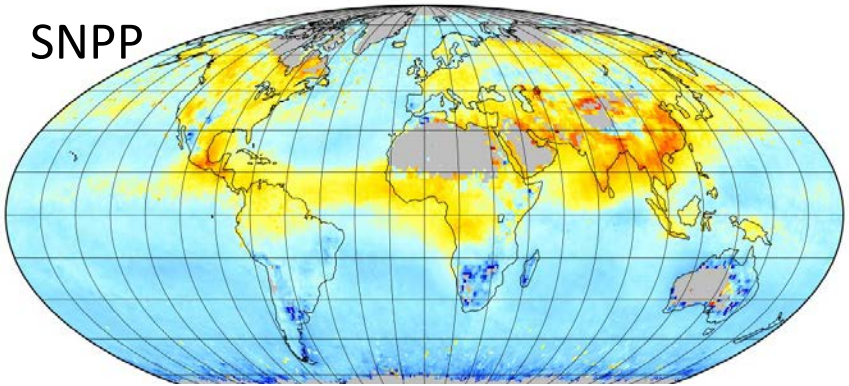
AERDT_L2_VIIRS_NOAA20 Test, May 2019

NOAA20

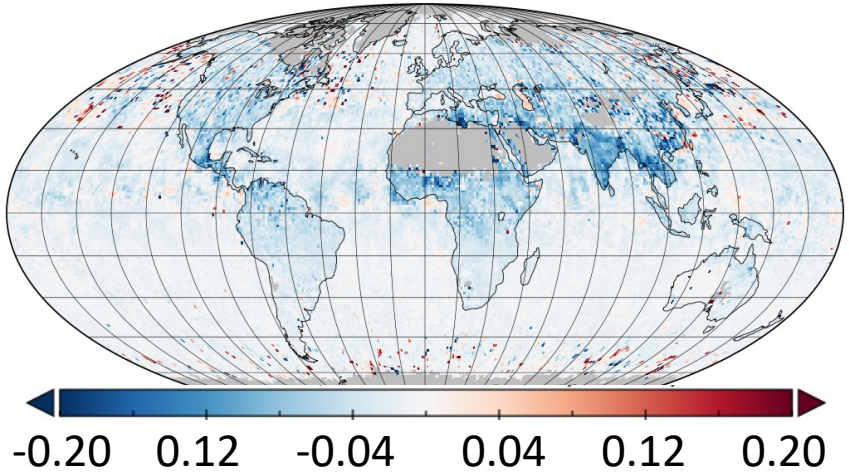


AERDT_L2_VIIRS_SNPP Update Test, May 2019

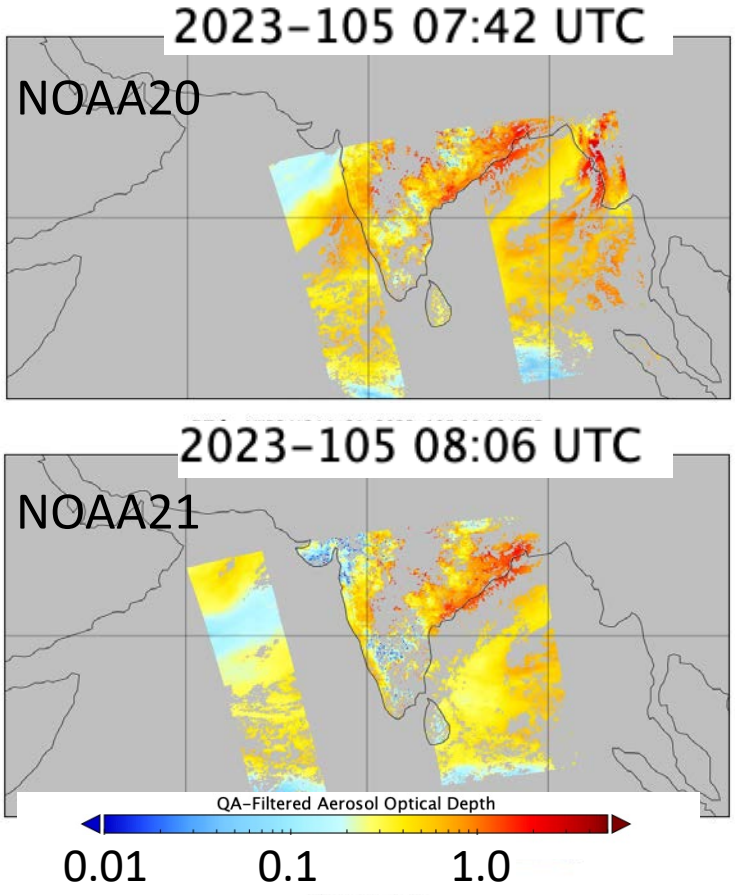
SNPP

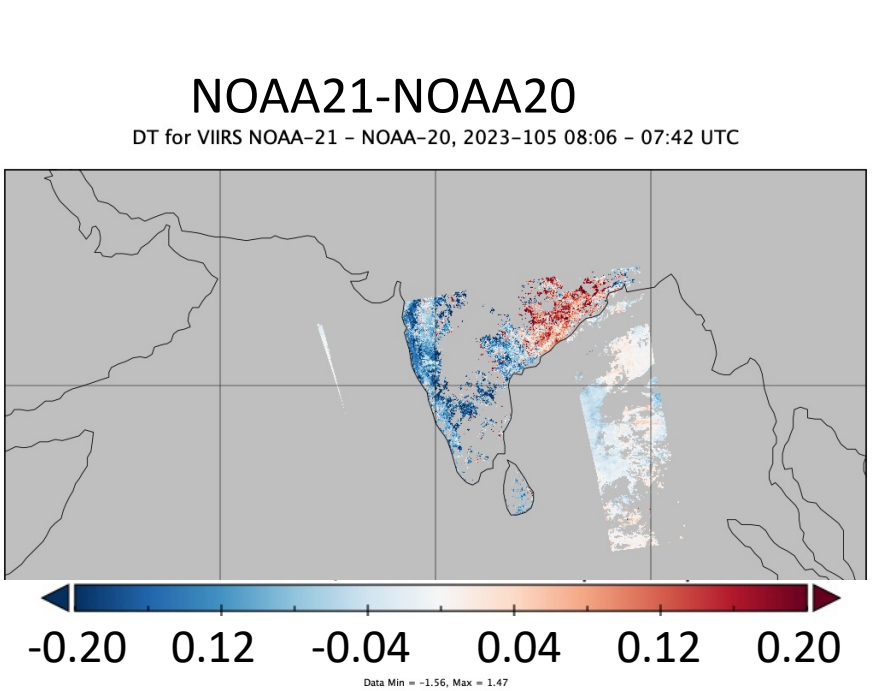


NOAA20 - SNPP



AOD: NOAA21 vs NOAA20! (Preliminary)

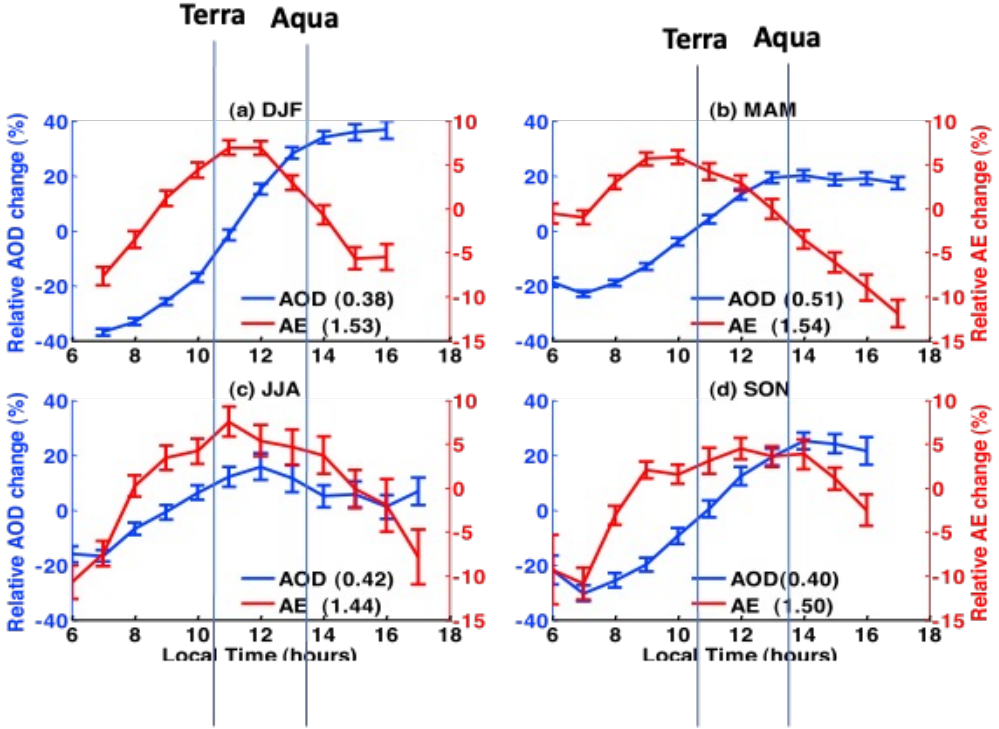




Summary of LEO-based aerosol

- MODIS has been providing very important AOD data record
- Data record transferred to VIIRS (for most part)
  - Regional trends are very consistent between SNPP and MODIS
  - SNPP offset high compared to MODIS, but maybe reducible with VIS/NIR/SWIR calibration adjustments
  - Based on experience with Terra vs Aqua, transfer of Angstrom Exp may be difficult.
- “DT-Package” makes it much easier to transfer to new sensors (NOAA-20, 21).
- Challenge will be continued validation and updates as funding is reduced.

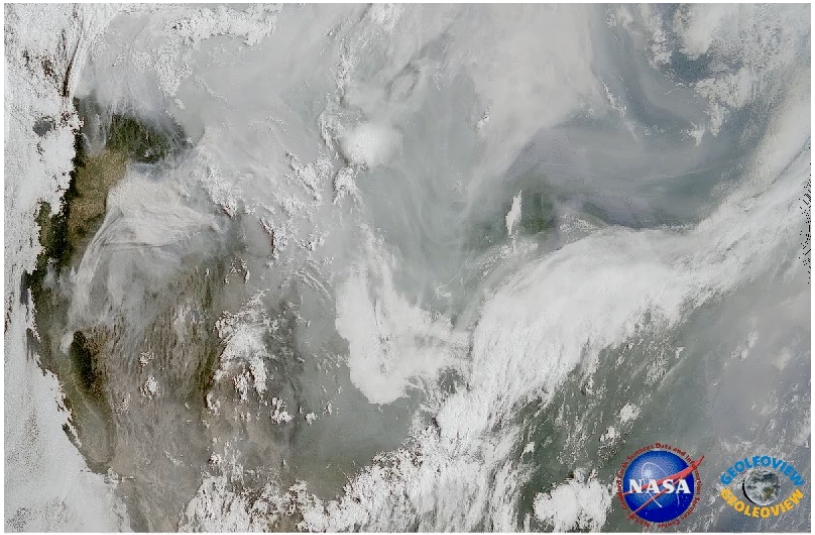
But LEO isn't enough:
Aerosol changes diurnally, and even more rapidly!



From: Zhang, Y., Yu, H., Eck, T. F., et al, (2012). Aerosol daytime variations over North and South America derived from multiyear AERONET measurements, *J. Geophysical Research*.

And can change rapidly

5 days of smoke from GOES-West

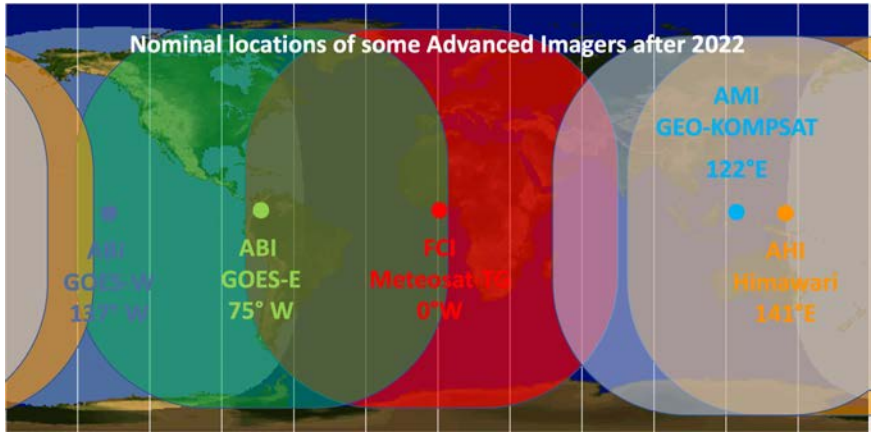


ABI_G17 Fire Smoke 2021/07/16 14:00Z

Global Climate Observing System (GCOS)
requirements for **Aerosol Optical Depth (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**

MODIS + VIIRS is not enough to capture **time-dependence**



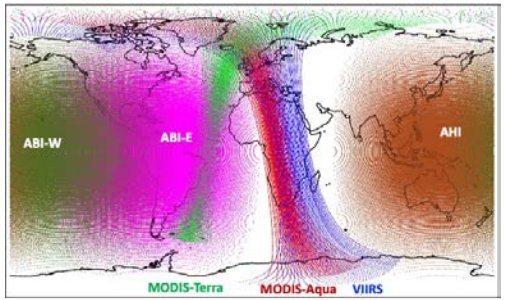
Need GEOstationary!!

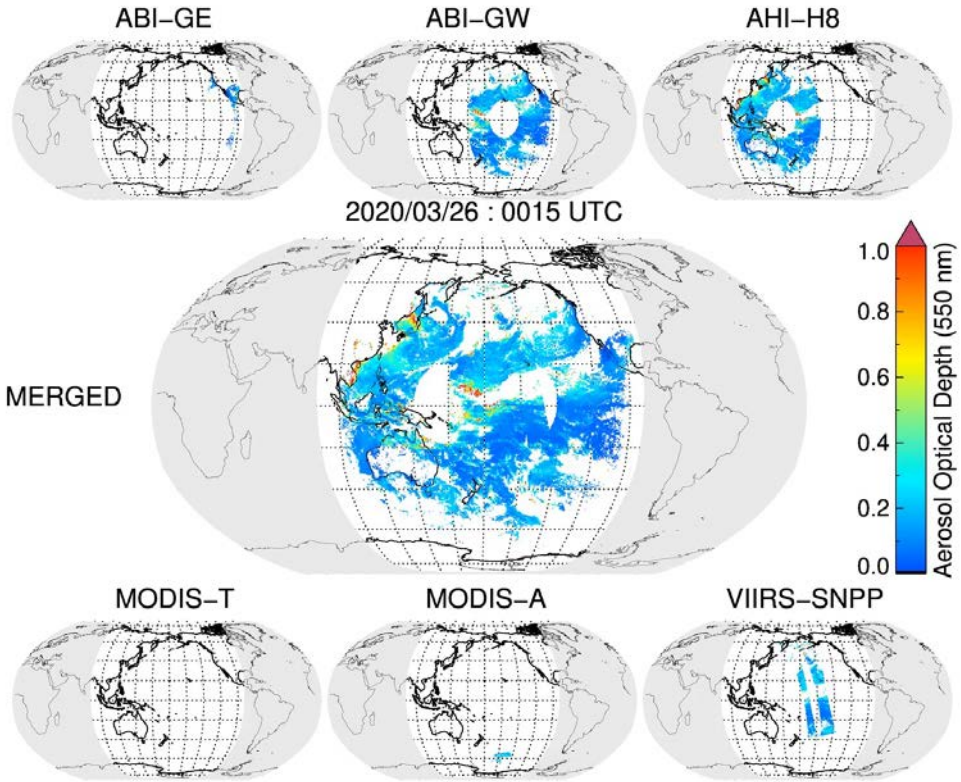
(and noting need as Program of Record)

XAERDT: A joint GEO-LEO aerosol product

A NASA "MeASUREs" (Making Earth Data Useful -2017) project

- **Uses DT-'package'**
- **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)**
- **Level 3:**
  - **30-minute intervals**
  - **Global 0.25° x 0.25° grid**





Status of Dark Target products (I)

- **MODIS:**
  - Collection 6.1 Data (2000-present) available in HDF4 format thru LAADS.
  - NRT is C6.1-like (uses forecast meto fields, rather than re-analysis)
  - Includes Dark-Target / Deep Blue (DT/DB) merge product
  - ***Towards C7***
    - DT package developed for MEaSUREs (XAERDT) is baseline for C7
    - C7 3 km resolution product ('MxD04_3K') will have bow-tie/pixel "re-ordering"
    - Will use GMAO rather than GDAS ancillary

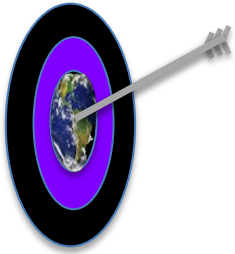
- **VIIRS:**
  - Version 2.0 DT Data NOW AVAILABLE in NetCDF4 in LAADS dataset 5200. (2011-present)
  - NRT will be processed as V 2.0.
  - Code for NOAA-20 ('AERDT_VIIRS_N20') is same code, but with different LUTs.
  - Using same code to run "XAERDT" for MEaSUREs

Status of Dark Target products (II)

- **GEO**
  - Data are being processed 2019-2022 (and some earlier data).
  - XAERDT_MODIS and XAERDT_VIIRS created with consistency.
  - DT Data available in NetCDF4 by request under LAADS dataset 5019. Public soon.
  - Note that under C. Hsu's (ESROGSS-2020), we are working toward DT/DB merge.

- Level 3 products
  - MODIS: Traditional aggregations of Level 2 (10 km) into daily and monthly 1°x1° (on LAADS)
  - VIIRS: Plans are for daily and monthly 1°x1°. It will "look" like MODIS, but use Wisconson – Yori
  - GEOLEO: Combined LEO (3 sensors) + GEO (3 sensors) at half-hourly and 0.25°x0.25°.

Summary

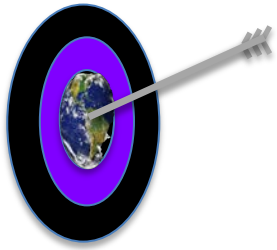


Currently, Dark Target retrieval algorithm works on

- **2 LEO sensors (MODIS, VIIRS)**
  - On 4 current satellites (Terra, Aqua, Suomi-NPP, NOAA20, soon NOAA21)
  - Provide global coverage
  - 20+ year history of aerosol optical depth and other aerosol properties
- **2 GEO sensors (ABI, AHI),**
  - on 3 current satellites (GOES-E/W and Himarawi-8)
  - Tested for GOES-18 and Himawari-9.
  - Similar sensors on future GOES, Himawari, and other agency satellites
  - Provide regional coverage at high temporal resolution
- **Working towards full climate data record (length and width).**

https://darktarget.gsfc.nasa.gov

Conclusion



We are learning much about global aerosol from DT algorithm

- Seasonal hot spots
- Trends
- Effects including air quality, climate, radiation, etc.

But challenges

- Homogenization of calibration
- Leveraging of funding
- Use as Program of Record for future missions

https://darktarget.gsfc.nasa.gov

Intended Science updates for VIIRS (ROSES-2020)

Hopefully can find opportunity to “back port” to MODIS!

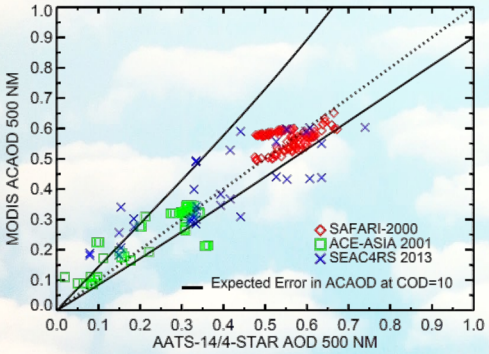
(skip for time)

“Color Ratio” Method for Above-cloud AOD Retrieval

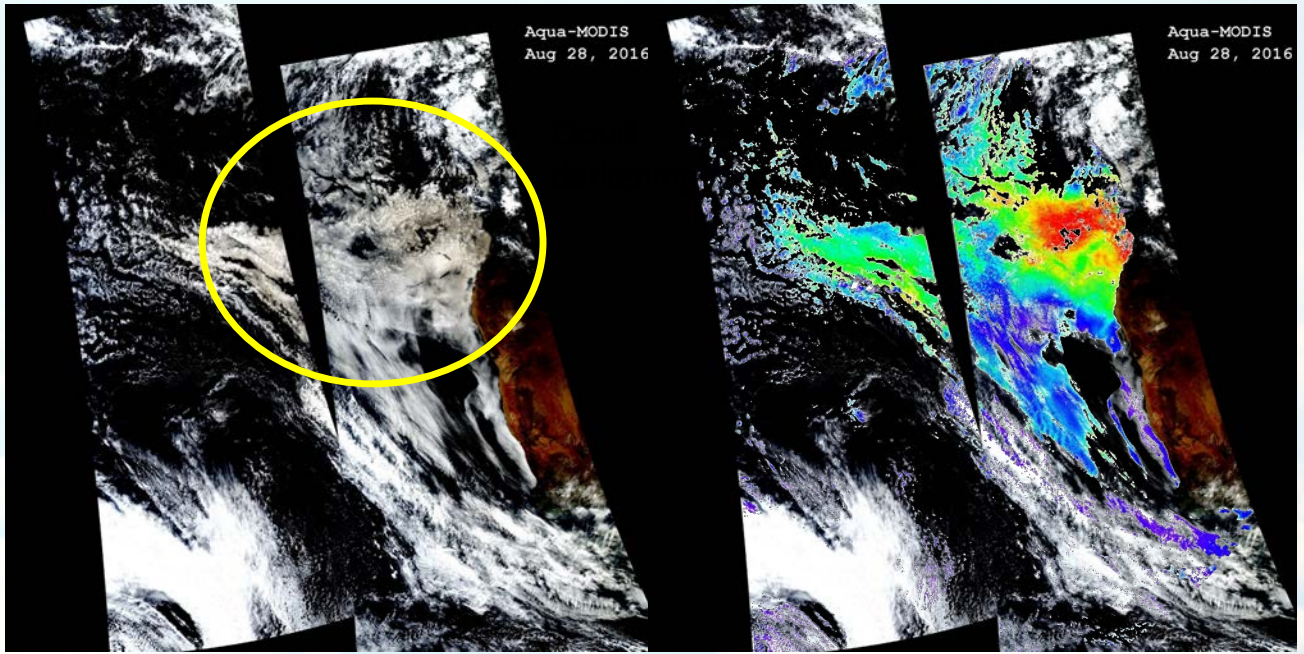
Hiren Jethva et al.,

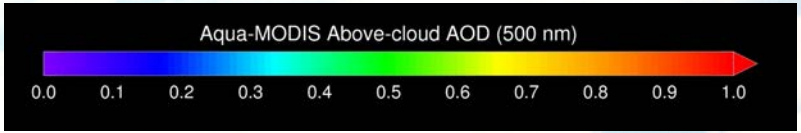
- **Aerosol absorption above cloud produces a strong “color ratio” effect in spectral TOA reflectance**
- **Use of two channels: 470 and 860 nm**
- **Simultaneous retrieval of <u>above-cloud AOD</u> and <u>aerosol-corrected COD</u> [*Jethva et al.* 2013 IEEE TGRS]**

Validation using airborne Sunphotometer meas.



Jethva et al [2016] AMT





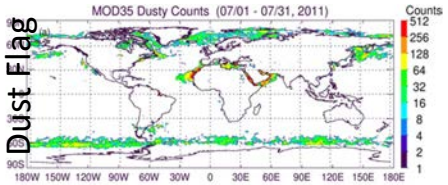
Dust detection and dust model for DT ocean algorithm

Yaping Zhou et al.,

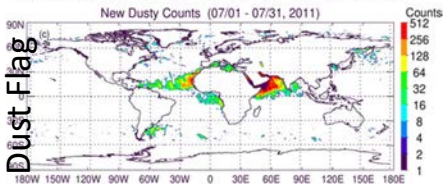
Dust detection:

MOD35 Dust Flag

AOD> & AE<



New Dust Flag

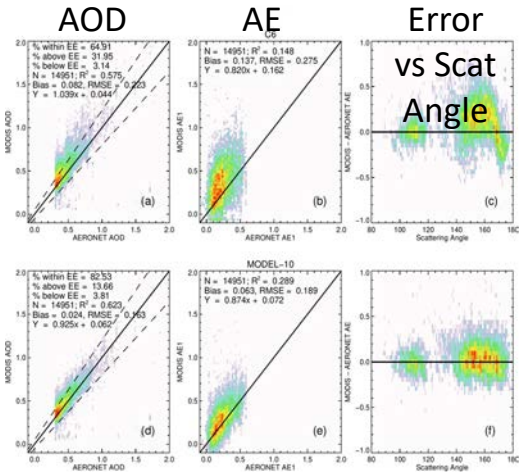


The DT algorithm for dust over ocean has long-standing biases due to assuming spheres, instead of non-spheres. Solution is:

- Detect 'likely' dust using series of visible/NIR/IR tests.
- Apply non-spherical model (collection of spheriods)

Result is improved (AOD), fine mode fraction (FMF) and angstrom exponent (AE).

Dust retrieval

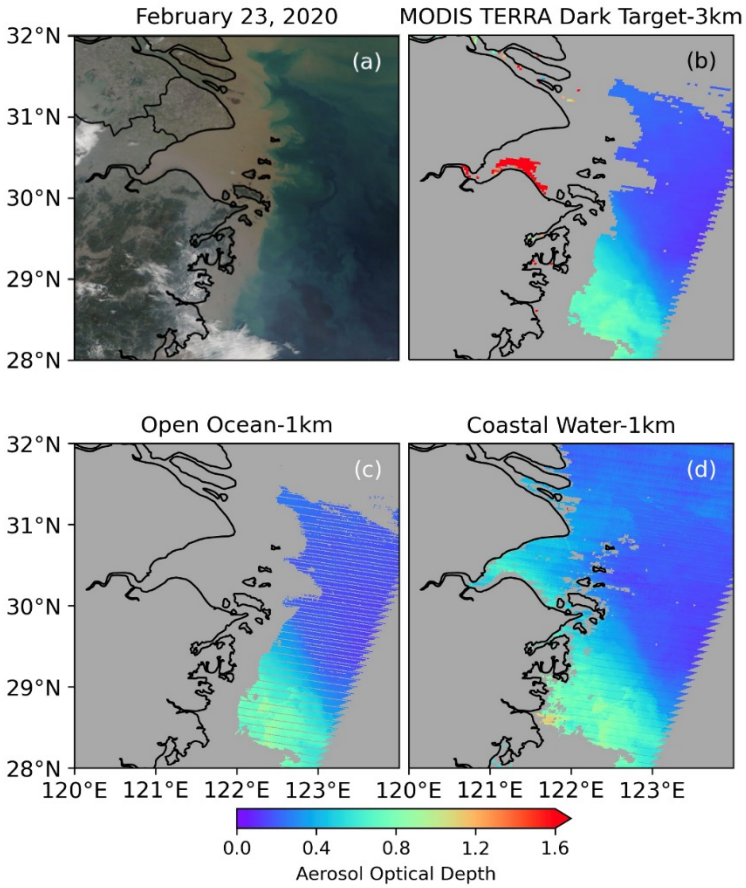


- Zhou, Y., et al. Dust Aerosol Retrieval over the Oceans with the MODIS/VIIRS Dark Target algorithm. Part I: Dust Detection (http://dx.doi.org/10.1029/2020EA001221)
- Zhou, Y. et al. Dust Aerosol Retrieval Over the Oceans with the MODIS/VIIRS Dark Target algorithm. Part II: Non-Spherical Dust Model (http://dx.doi.org/10.1029/2020EA001222).

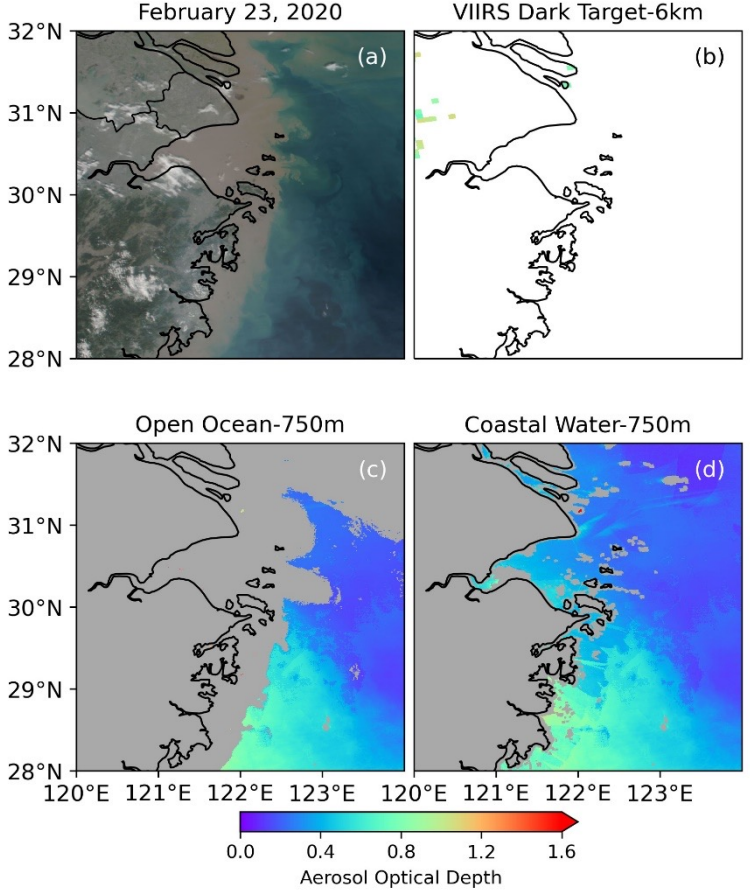
Coastal AOD over turbid waters

Jun Wang (U. Iowa) et al.,

MODIS/Terra



VIIRS



Coastal water retrieval filling the gap of operational VIIRS Dark Target algorithm

Larger spatial coverage

Updates/science for all sensors

DT Surface reflectance relationships (Mijin Kim)

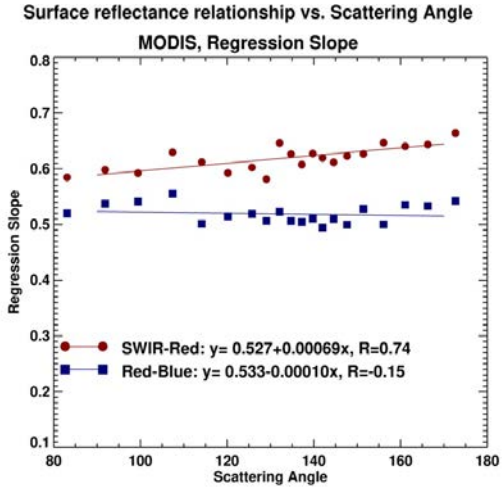
Atmospheric Correction near AERONET

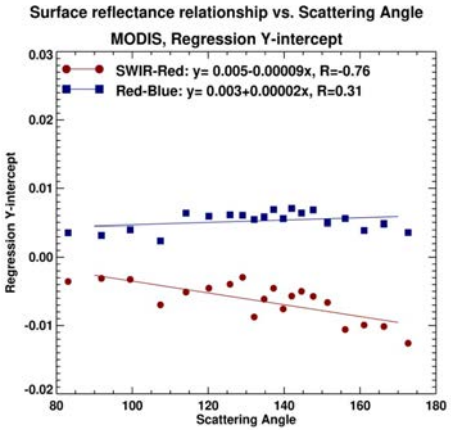
MODIS (Aqua)
(366 points for each bins)

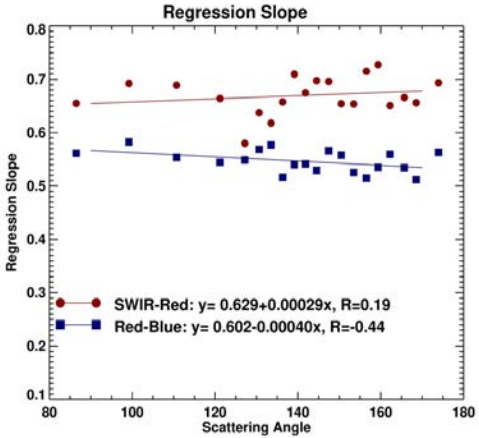
- ✓ The linear slope and y-intercept changes with scattering angle are shown in both MODIS and VIIRS SR relationship.
- ✓ Red/SWIR looks similar for both
- ✓ blue-red relationship looks different

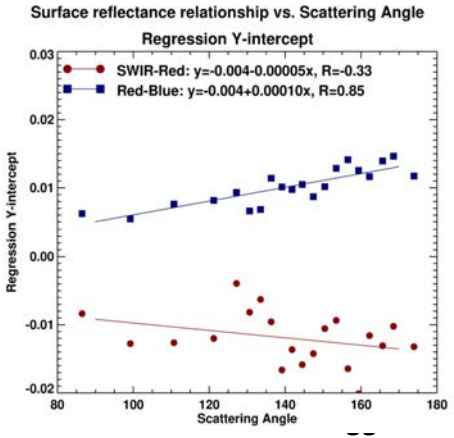
VIIRS (SNPP)
(366 points for each bins)

Also revisiting ”urban” corrections



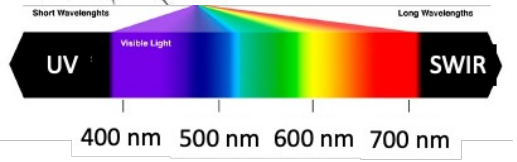




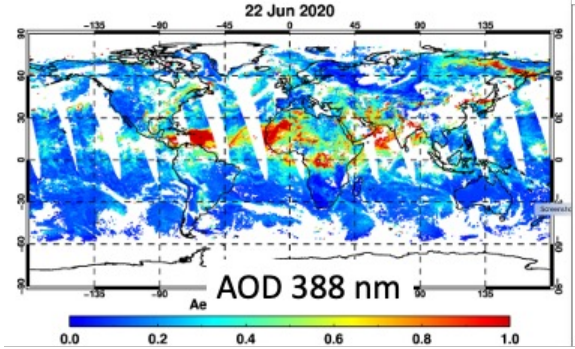


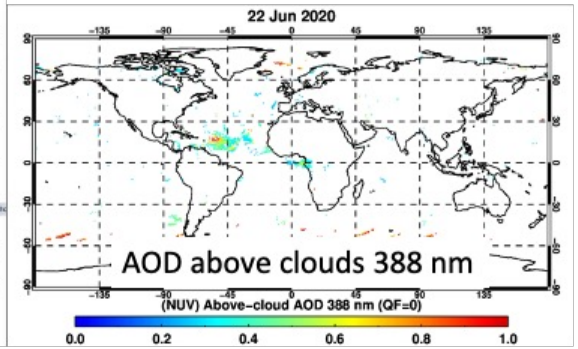
PACE Unified Algorithm for aerosol characterization

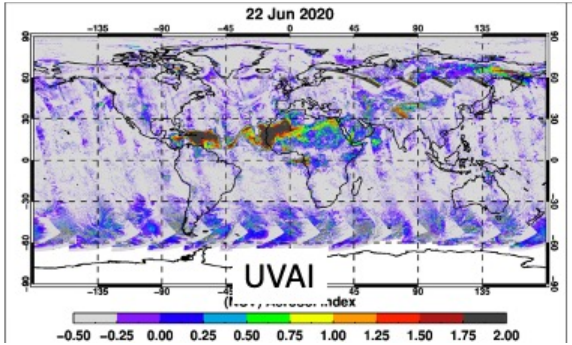
Remer, Mattoo, Torres, Levy, Hsu, Kayetha, Kim, Shi, Jethva

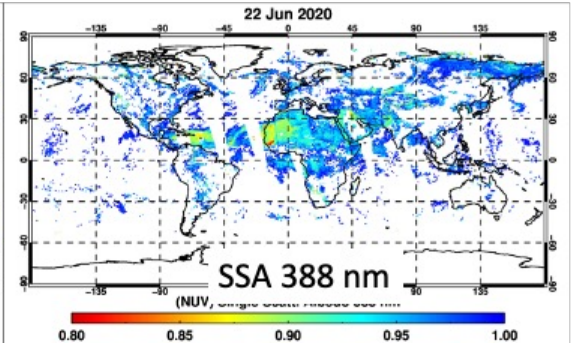


Use full solar spectrum measured by the PACE Ocean Color Instrument (OCI), to be launched Jan 2024: Combine DT, DB, and OMI heritages







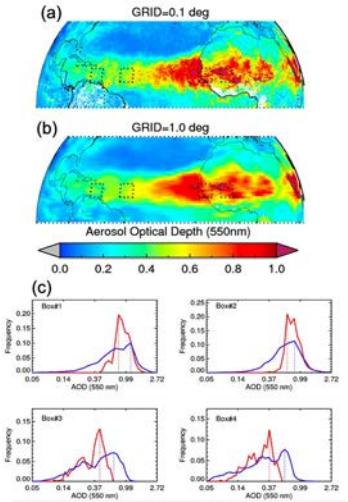


Unified Algorithm for PACE
1-day retrievals using VIIRS + TropOMI as proxy data
For PACE OCI

Towards integration of GEO and LEO

P. Gupta, R. Levy, S. Mattoo, S. Christopher, L. Remer, R. Holz, A. Heidinger, et al.

What resolution should we compare products?

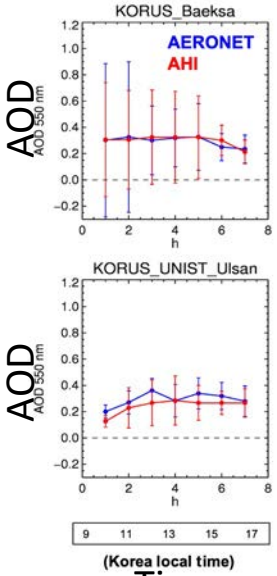


HRG (0.1°)

C6 (1.0°)

Monitor dust transport across the Atlantic Ocean during June 2018.

Using GEO to study diurnal cycle



- Gupta, P., et al., 2020. "High-Resolution Gridded Level 3 Aerosol Optical Depth Data from MODIS." Remote Sensing, 12 (17): 2847 [10.3390/rs12172847]
- Gupta, P., et al. 2019. "Retrieval of aerosols over Asia from the Advanced Himawari Imager: Expansion of temporal coverage of the global Dark Target aerosol product." Atmos. Meas. Techniques, [10.5194/amt-12-6557-2019]