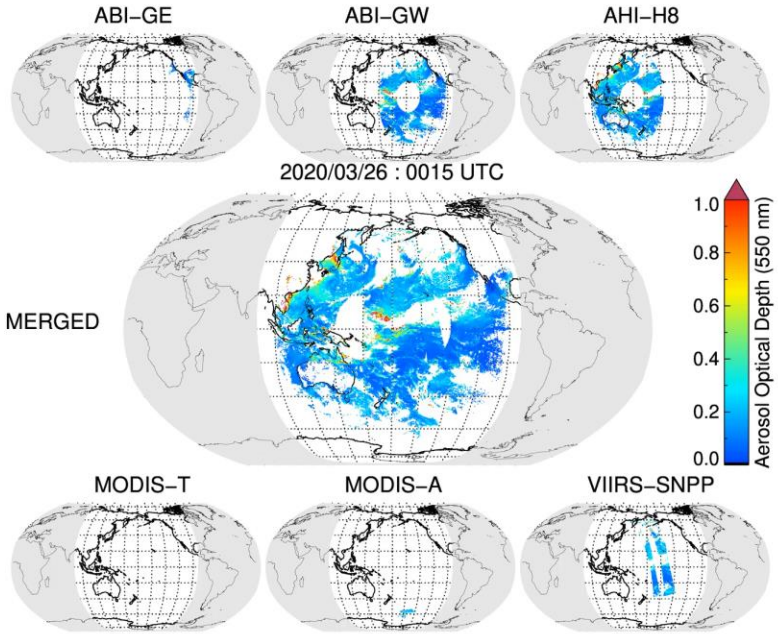
Dark Target Aerosol Retrieval Project

"Core" = R. Levy[1], S. Mattoo[2], V. Sawyer[2], V. Kiliyanpilakkil[2], Y. Shi[3], P. Gupta[4], 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.
[1]GSFC/613, [2]SSAI/613, [3]UMBC/613, [4]USRA/MSFC, [5]JCET/UMBC, [6]ORAU/NPP,
[7]GSFC/610, [8]ADNET/610, [9]SSEC/Uwisc, [10]GESTAR/614, [11]ESSIC/613, [12]U Iowa, etc.

6+ sensors + one algorithm = all daylight globe



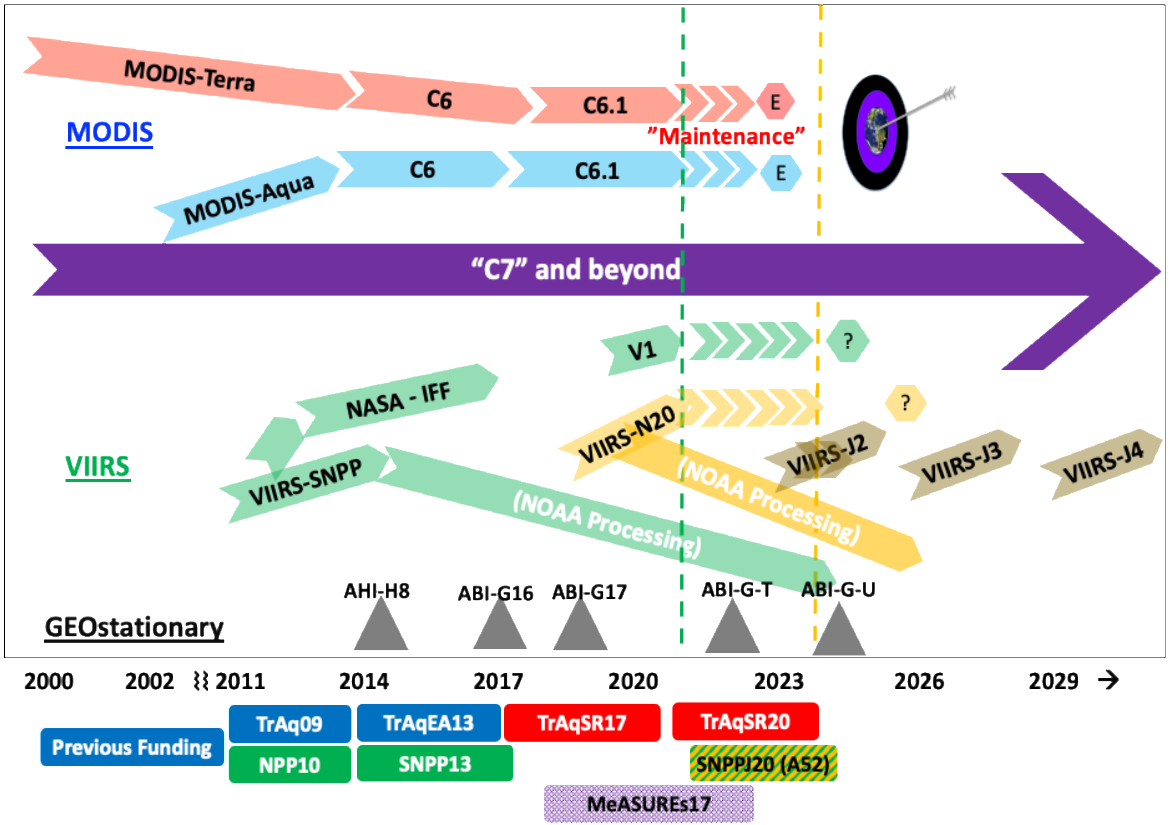
Objectives:

- **To retrieve or not to retrieve, that is the question.**
- Use a "consistent" algorithm to derive global aerosol climatology
  - Multi-decadal
  - Diurnal
- Work with product users to identify and report unusual aerosol conditions
- Simplify and document the algorithm to be used as a "basis" for other, more advanced algorithms on current / future sensors (e.g. PACE).

Dark Target Aerosol Retrieval Project

Cobbling together an integrated view of the world

Towards a ***consistent global aerosol*** product using the ***Dark Target*** retrieval algorithm



Multiple funding sources

Basic "DT" related (PI = Levy)

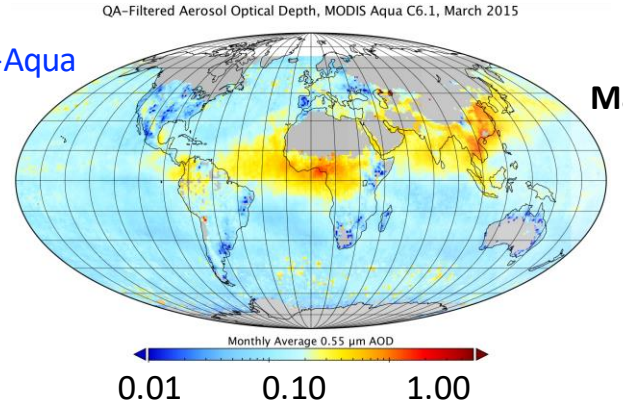
- TerraAqua Senior Review
- SNPP-JPSS (2020-A52)
- MEaSUREs (2017-A33)

Enhancements

- ESROGSS (2020: PI = C. Hsu)
- PACE (2020: PI = L. Remer)
- RST (2019: PI = R. Espinosa)
- HAQAST (2020: PI = P. Gupta)
- CommercialSat (PI = K. Meyer)

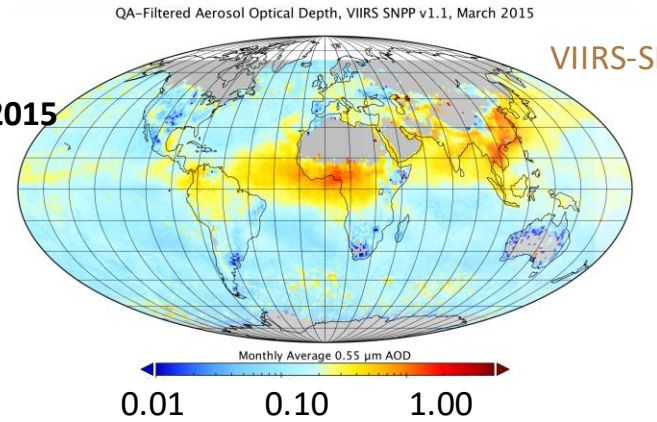
MODIS + VIIRS --> Long term climate

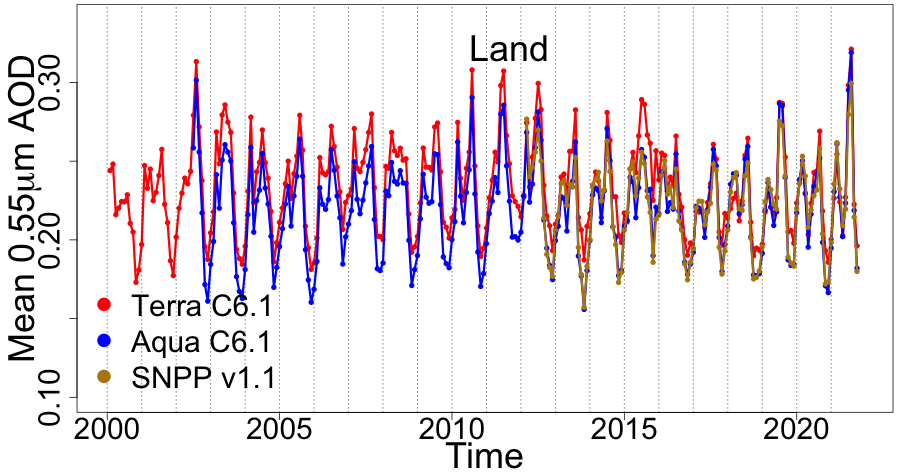
MODIS-Aqua



March 2015

VIIRS-SNPP





VIIRS-SNPP (V1.1)

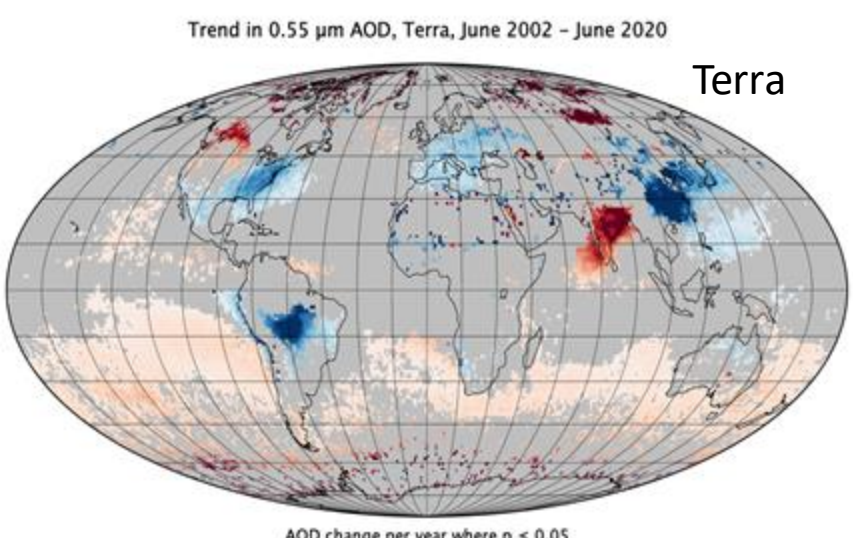
MODIS-Aqua (C6.1)

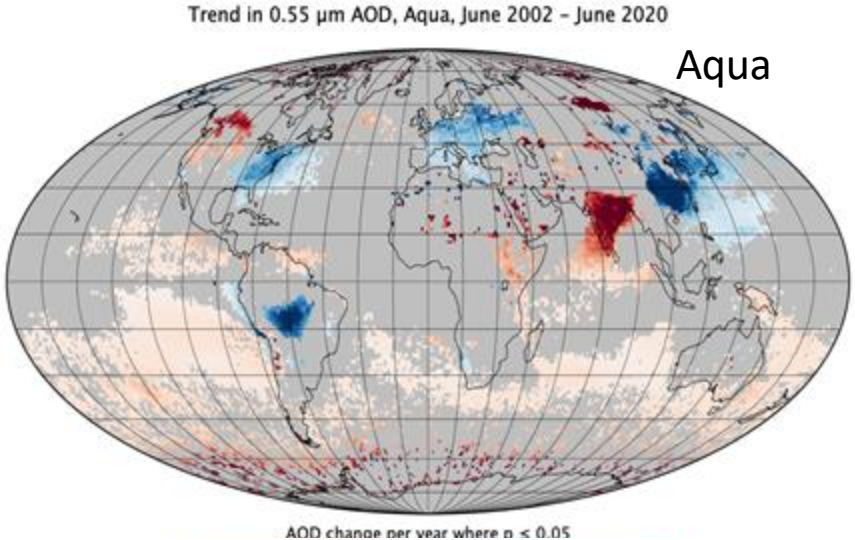
"funded" to continue on VIIRS-JPSS-1/NOAA20 (≥2021)

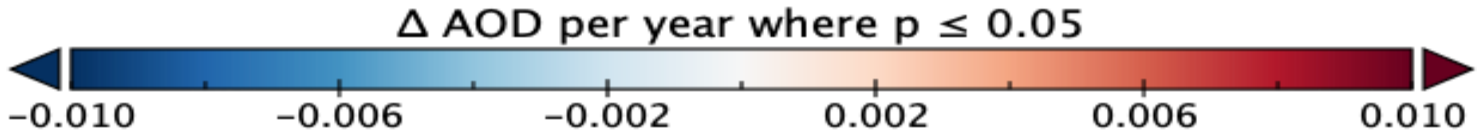
Consistency of Dark Target Trends

Virginia Sawyer, R. Levy, S. Mattoo, et al.,

very consistent 'Trends' from Terra and Aqua MODIS (2002-2020)



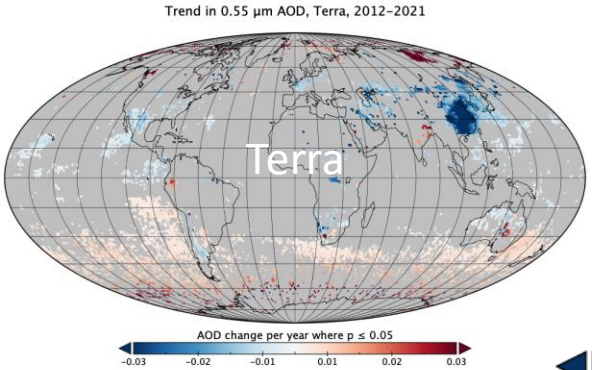


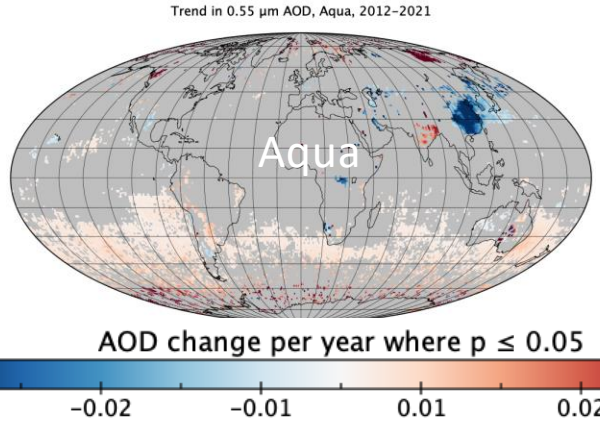


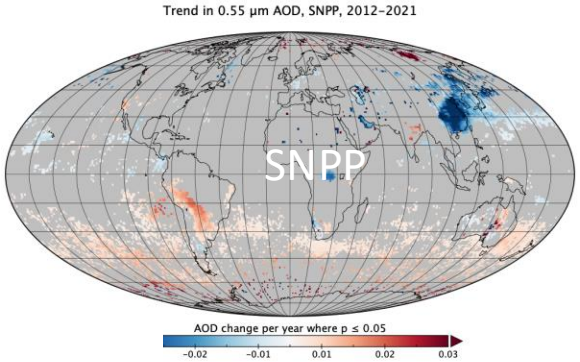
Trends: Terra + Aqua + SNPP (2012-2021)

Consistent AOD trends, not so much for AE

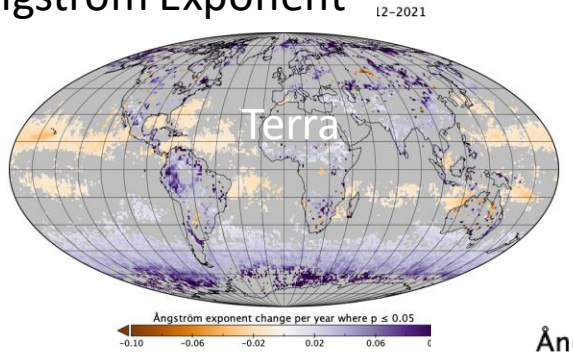
AOD

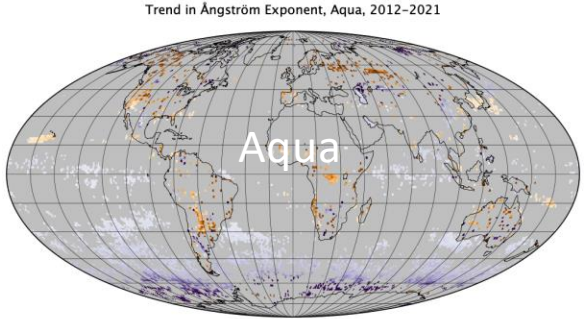


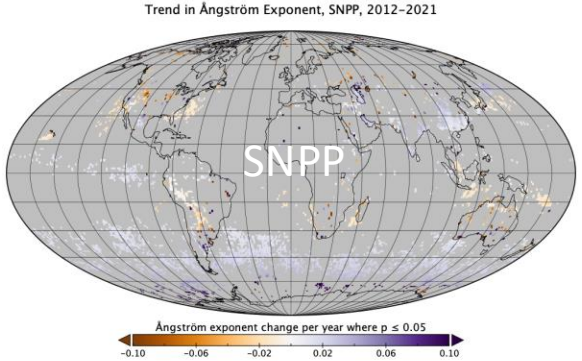




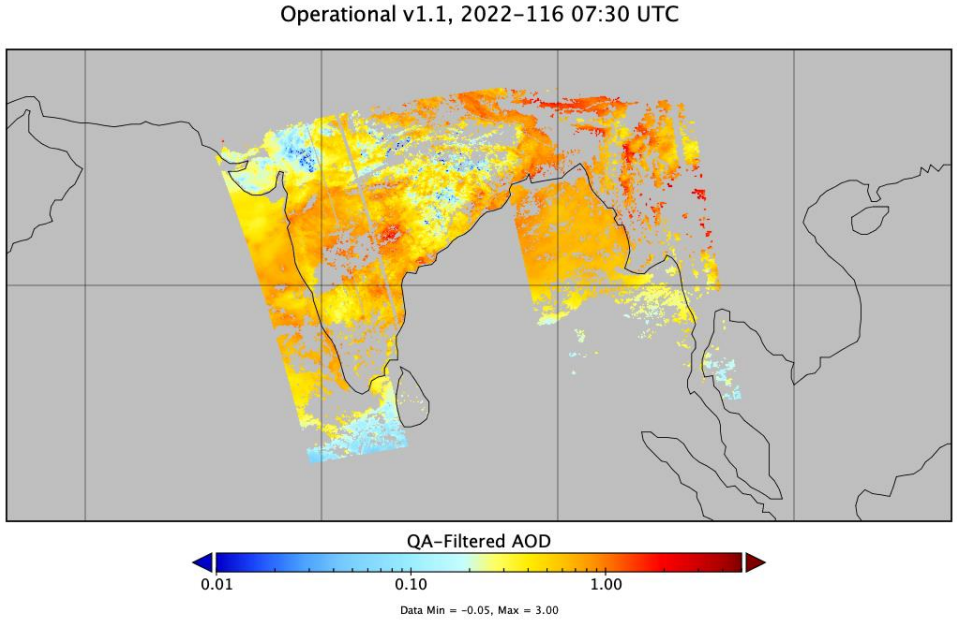
Angstrom Exponent

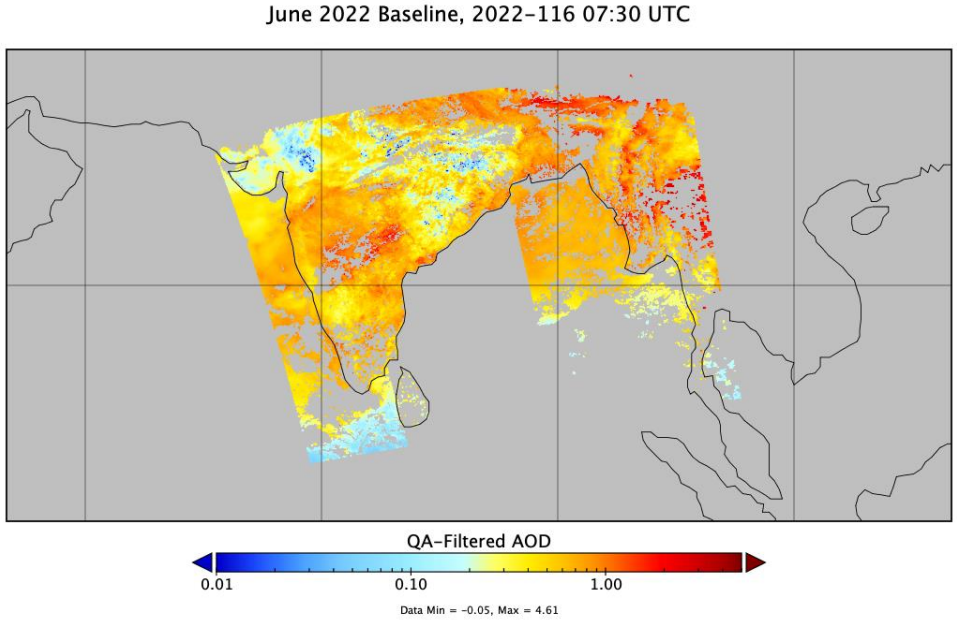






Update for VIIRS: (V1.2 bug fix and cloud mask)
Better cloud edge coverage, no more stripes





The DT-Package

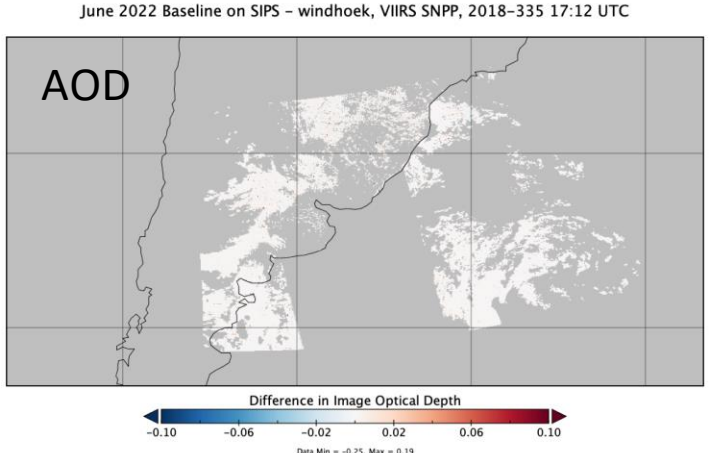
- A “platform independent” version of the retrieval code
  - Still needs working and accessible versions of NetCDF and other libraries.
  - Fortran and C compilers
  - Modular, so that testing and updates are much easier
  - Improved comments
  - Necessary some differences between C6.1 logic/science.
  - In theory, minimum number of “if-else” statements, only lookup tables for each sensor’s band/wavelength combo.

Issue	MODIS 6.1	DT-Package
Data	L1B + geolocation + MxD35 in native resolution	L1B + geolocation + MxD35 downscaled to 500 m
Reading data	10 lines at a time	Entire granule into memory
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)
Ocean cloud masking	-3x3 spatial variability at 0.55 μm -Other tests at native pixel resolution	-3x3 spatial variability at 0.66 μm (no 0.55 in GEO) -Other tests at 500 m resolution (including MxD35)
Land cloud masking	-all tests at native pixel resolution	-all tests at 500 m resolution
Snow mask	Uses 0.86 vs 1.24 μm	Has 0.86 vs 1.63 μm tests because GEO has no 1.24.

Aside: About ”infrastructure”

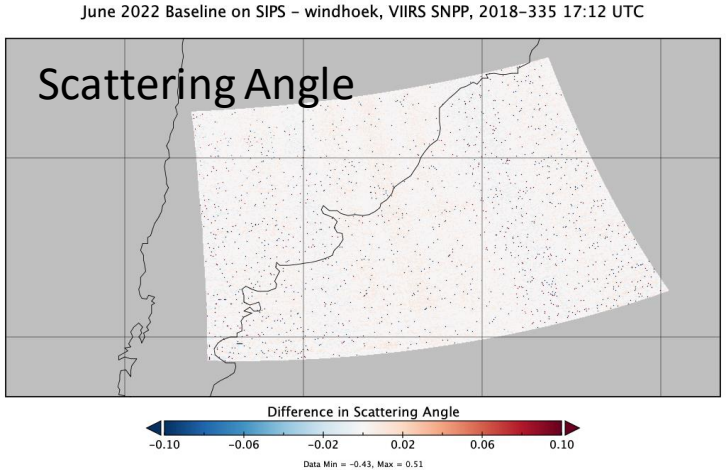
SIPS: Compiler library issues…

- All-new SIPS-specific makefile
- Needed to add a lib/ directory to the package itself, with updated netCDF libraries
- We had to use a compiler module SIPS considers outdated (GCC 4.9.2 instead of 10.2) which may cause problems for future versions if we can’t update Fortran syntax

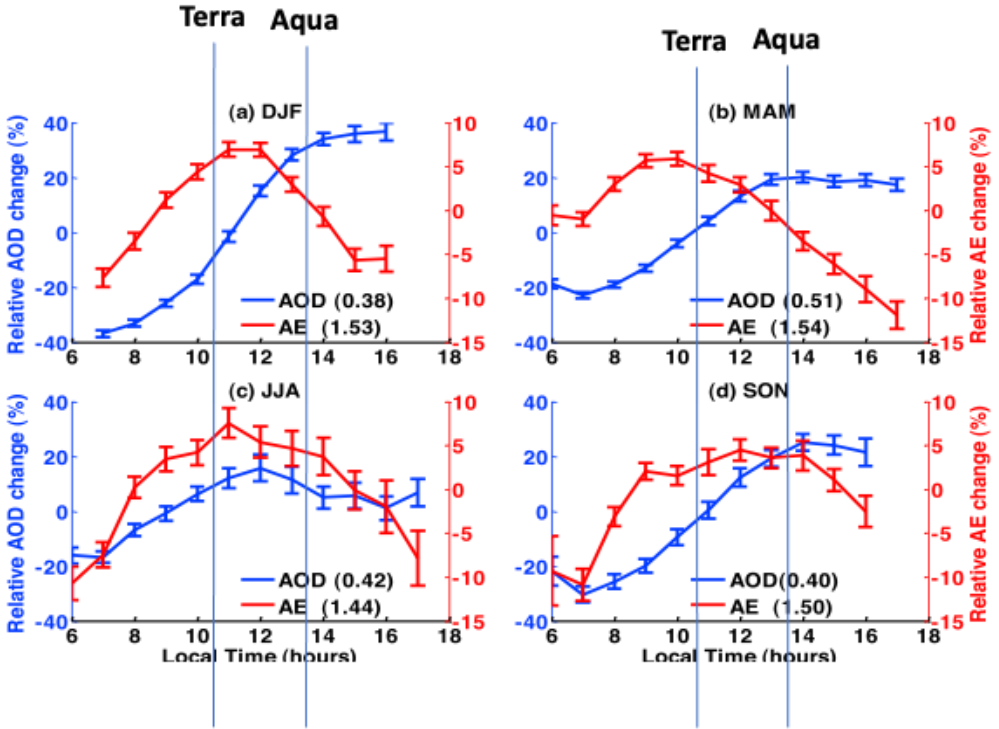


Windhoek: : Compiler library issues…

- Update to Ubuntu-20
- Killed libraries
- Similar issues as SIPS

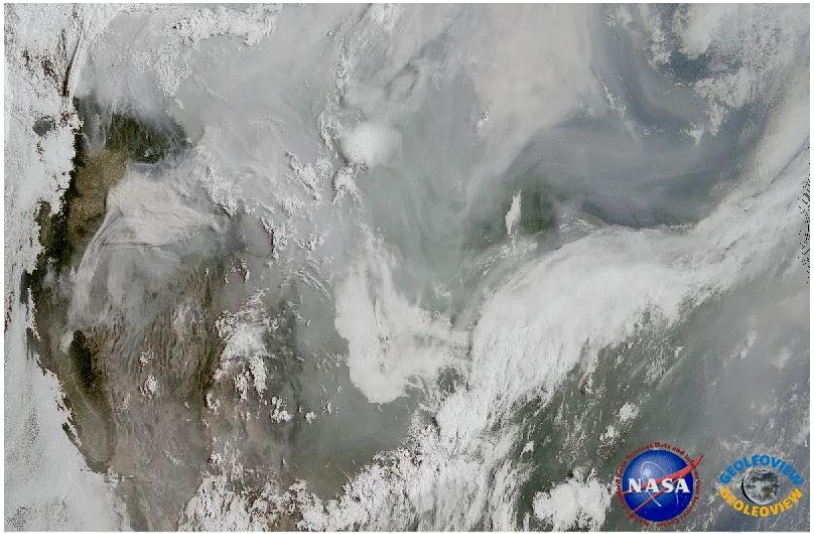


However, aerosol changes diurnally, and even more rapidly!



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

Status of Dark Target products (I)

- **'MxD04_L2' and 'MxD04_3K' = MODIS Terra and Aqua 10 km product (20x20 of 0.5 km)**
  - 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
  - ***DT-Package***
    - Using to create a separate MEaSUREs-consistent
    - Will be used to create **C7 product**
  - C7: Science updates (dust over ocean, heavy smoke, GMAO ancillary)
  - 3 km resolution product ('MxD04_3K') will have bow-tie/pixel "re-ordering"

- **'AERDT_VIIRS_SNPP'= VIIRS 6 km product (8x8 of 0..75 km)**
  - Version 1.1 DT Data available in NetCDF4 in LAADS dataset 5111. (2011-present)
  - NRT is V1.1-like
  - Delivery of bug-fix code (ASAP), Code for NOAA-20 ('AERDT_VIIRS_N20') for June 2022)

Status of Dark Target products (II)

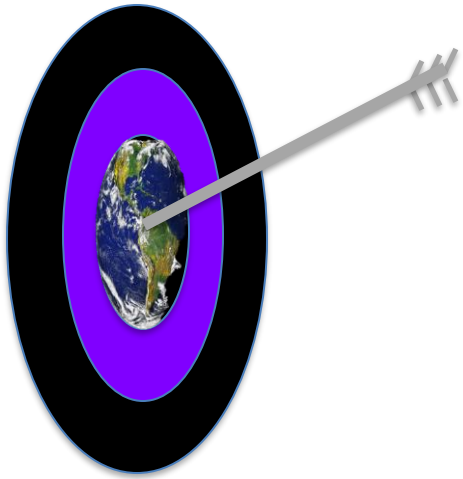
- **'AERDT_ABI_G16', 'AERDT_ABI_G17', 'AERDT_AHI_H08' = GEO 10 km products (10 x 10 of 1 km)**
  - Data are being processed 2019-2022 (and some earlier data).
  - DT Data available in NetCDF4 by request under LAADS dataset 5016. Public in early 2023?
  - Note that under C. Hsu's (ESROGSS-2020), we may work toward DT/DB merge.

- 'AERDT_EMAS' = MAS/eMAS products at 0.5 km (10 x 10 of 0.05 km).
  - Modern (C6+ processing) for SEAC^{4}RS (2019), and FIREX-AQ (2020)
  - DT Data available in NetCDF4 via LAADS
- 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°. Code exists via IDL, but working on computationally efficient code (maybe Yori-based?).

Conclusion

Currently, Dark Target retrieval algorithm works on

- **2 LEO sensors (MODIS, VIIRS)**
  - On 4 current satellites (Terra, Aqua, Suomi-NPP and NOAA20)
  - On future satellites (JPSS-2,3 and 4)
  - 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 Himarwi-8)
  - Similar sensors on future GOES, Himawari, and other agency satellites
  - Provide regional coverage at high temporal resolution
  - Working towards full climate data record.

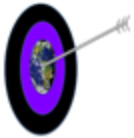


We are learning much about global aerosol from satellites

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

https://darktarget.gsfc.nasa.gov

Backup (+ science) stuff



Dark Target Aerosol Retrieval Project

Multiple Funding Sources (also funded roles)

Terra/Aqua Senior Review (2020-)
- MODIS "Maintenance"
- Currently in Collection 6.1
- Solve problems as needed
- Upkeep of Validation Tools (co-loc with AERONET)
- Development of the DT-Package (no Toolkits)
- Be "ready" for Collection 7 (including NetCDF format)
- Transition to GitLab or similar environment
- Mission End of Life concerns

SNPP-JPSS Continuity (2021-)
- Finish "porting" DT to VIIRS
- Consistent surface reflectance relationships (Mijin Kim/NPP Postdoc)
- Create NOAA-20 product
- Level 3 using Yori or alternative (Daily 1° X 1°)
- Add in "Coastal" retrieval (Jun Wang/U. Iowa)
- Add in "Aerosol Above Cloud" (Hiren Jethva / GESTAR II)
- Diagnostic uncertainties (Validation)
- "Quantify" continuity.

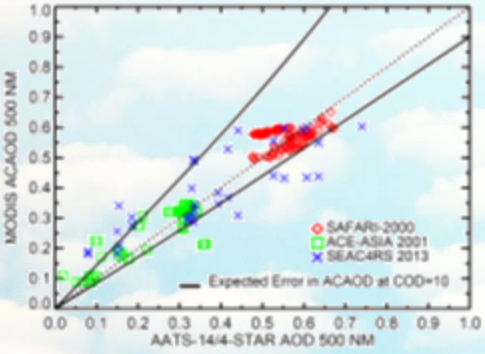
MEaSURES (2017-)
- Port to GEO (ABI on GOES-R, AHI on Himawari)
- L2 "Full Disk" every 10 minutes
- Consider impacts of "non-LEO" geometry/sampling
  - New angles / views
  - Near-limb perspectives
  - Constant view angles, etc.
  - Surface reflectance / BRDF constraints
- Integrated Level 3 product (½ hour x 0.25° x 0.25)
- Requires paralleziation for processing (Z. Zhang / ADNET)
- Useful visualizations and case studies (J. Wei / GESDISC)
- Processing at Wisconsin ≠ SIPS (R. Holz, M. Oo / U Wisc.)
- Insights from NOAA (S. Kondragunta, H. Zhang / NOAA-STAR)

Going beyond OMI… (Hiren Jethva)

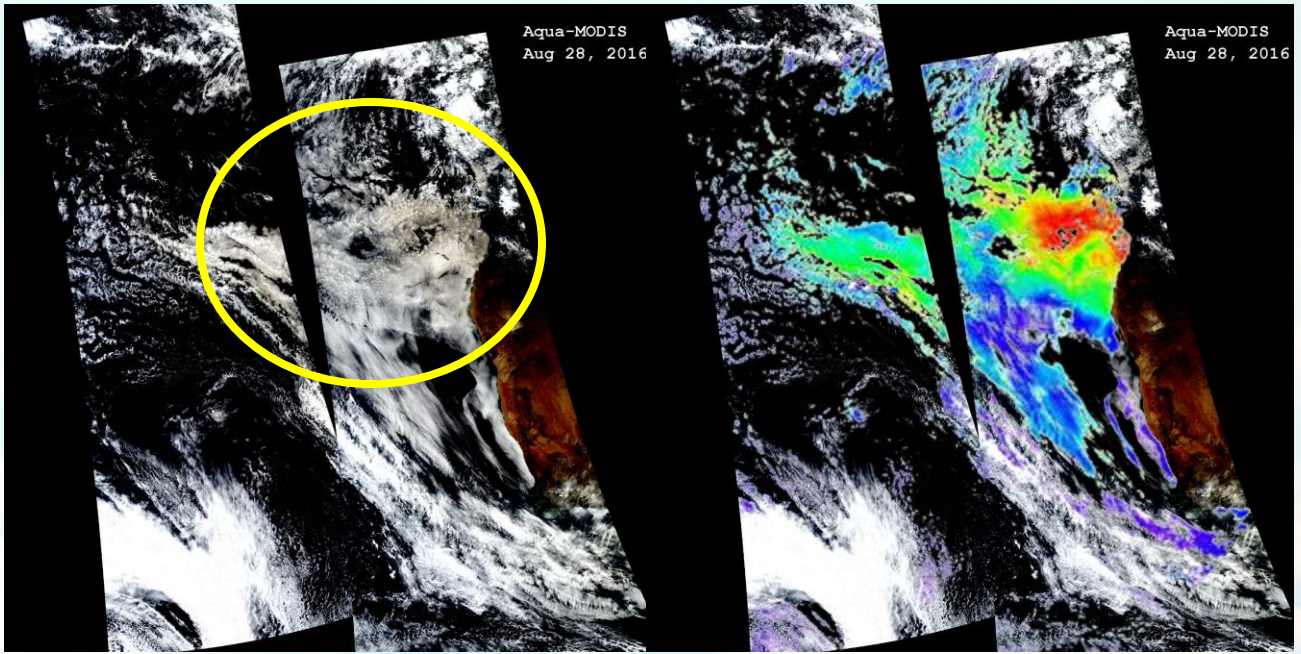
"Color Ratio" Method for Above-cloud AOD Retrieval from ***MODIS*** ***(we will test on VIIRS!)***

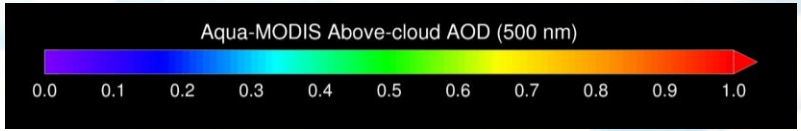
- **Aerosol absorption above cloud produces a strong "color ratio" effect in spectral TOA reflectance**
- **Use of two channels: 470 and 860 nm**
- **Simultaneous retrieval of above-cloud AOD and aerosol-corrected COD [*Jethva et al.* 2013 IEEE TGRS]**

Validation using airborne Sunphotometer meas.



Jethva et al [2016] AMT





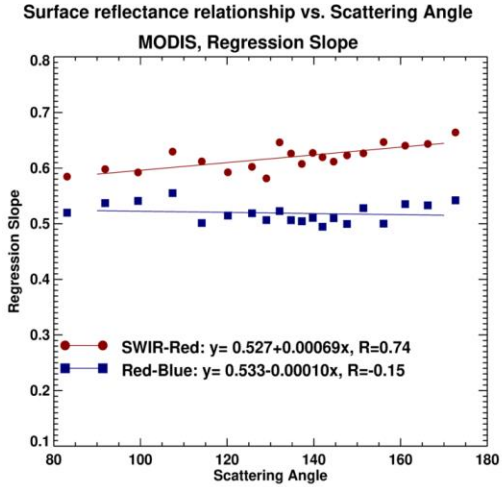
DT Surface reflectance relationships (Mijin Kim)

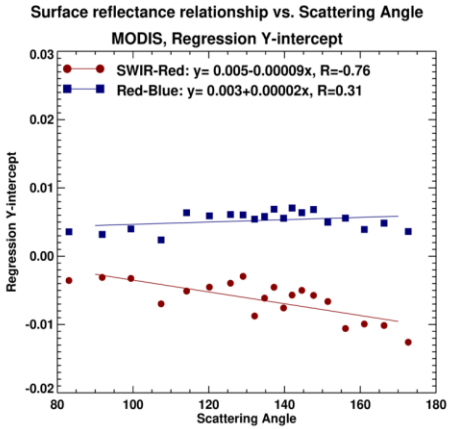
Atmospheric Correction near AERONET

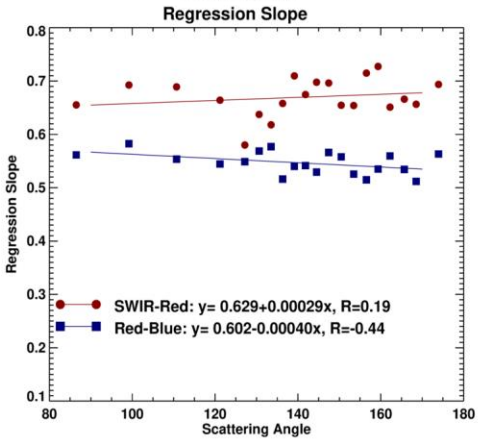
MODIS (Aqua)
(366 points for each bins)

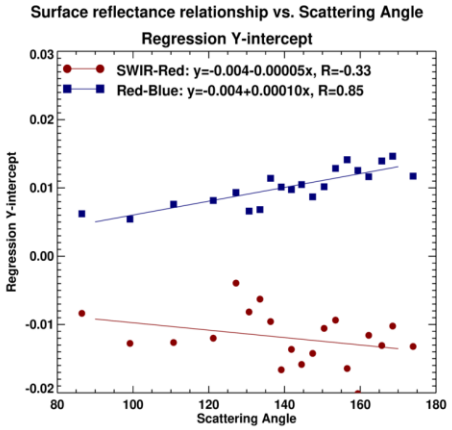
- ✓ The linear slope and y-intercept changes with scattering angle are shown in both MODIS and VIIRS SR relationship.
- ✓ Red/SWIR looks similar for both
- ✓ blue-red relationship looks different

VIIRS (SNPP)
(366 points for each bins)







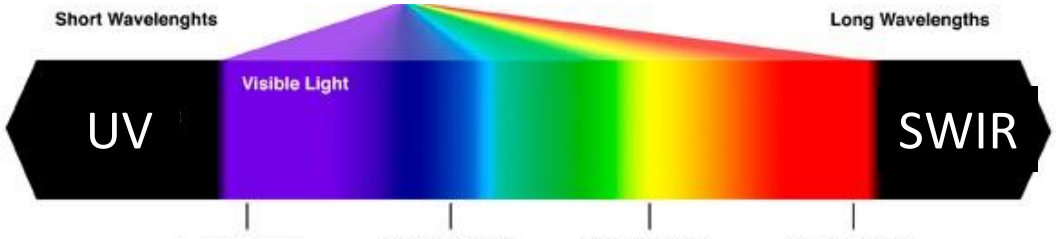


Also revisiting ”urban” corrections

PACE Unified Algorithm for aerosol characterization

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

Making use of the full solar spectrum measured by the PACE Ocean Color Instrument (OCI)

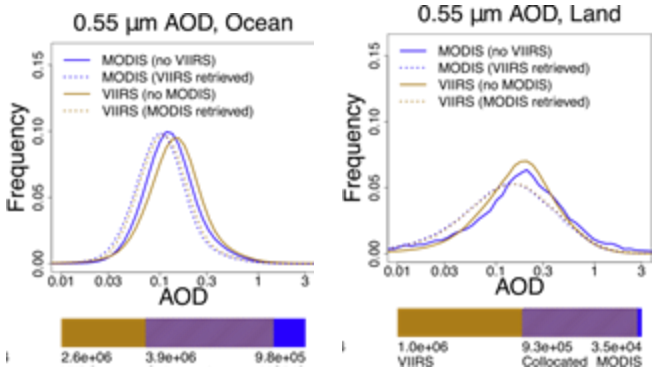


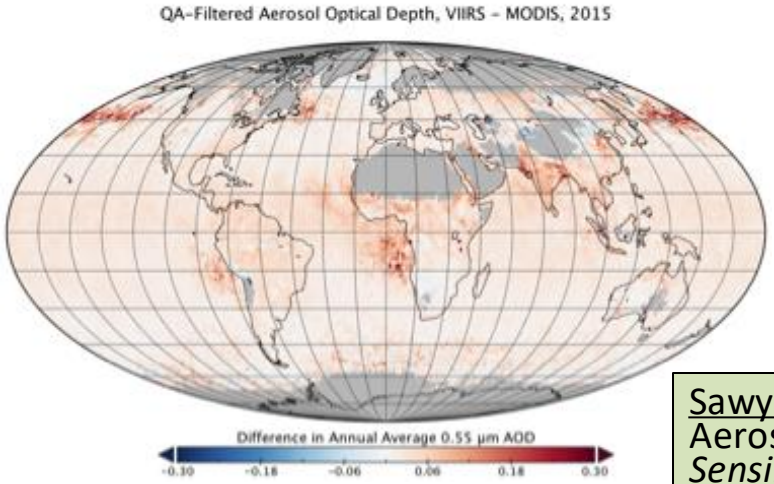
For the PACE observatory, to be launched January 2024

By combining the best of the
Dark Target (land and ocean),
Deep Blue (land) and
nearUV (TOMS/OMI heritage)

Using VIIRS SNPP to continue MODIS for a Climate Data Record

Virginia Sawyer, Robert C. Levy, Shana Mattoo, Geoff Cureton, Yingxi Shi, Lorraine Remer





Version 001: Compared to MODIS Aqua DT:

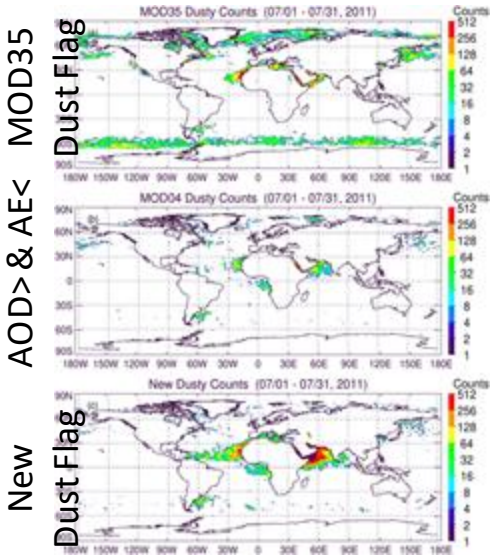
- Values of aerosol optical depth (AOD) are highly correlated with MODIS Aqua, and nearly identical where both sensors retrieve on the same day
- VIIRS is offset higher than MODIS because of solo-sensor retrievals
- Solo-sensor retrievals skew higher than collocated retrievals for both MODIS and VIIRS, but by different amounts for each sensor, and also by different amounts over land vs. ocean
- Most solo-sensor retrievals come from VIIRS rather than MODIS, because wider swath and finer resolution = more retrieved area per day

Sawyer, V., et al., 2020. "Continuing the MODIS Dark Target Aerosol Time Series with VIIRS." *Remote Sensing*, [10.3390/rs12020308]

Dust detection and dust model for DT ocean algorithm

Yaping Zhou, Robert C. Levy, Shana Mattoo, Lorraine A. Remer, Yingxi Chen, Reed Espinosa, Chenxi Wang

Dust detection:

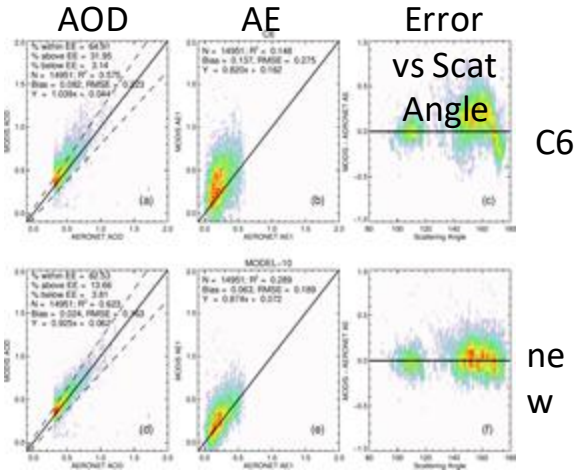


The DT algorithm for dust over ocean has long-standing biases due to assuming spheres, instead of non-spheres. Solution is:

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

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

Dust retrieval

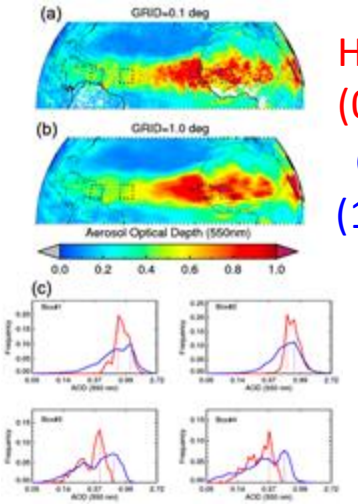


- Zhou, Y., et al. Dust Aerosol Retrieval over the Oceans with the MODIS/VIIRS Dark Target algorithm. Part I: Dust Detection (http://dx.doi.org/10.1029/2020EA001221)
- Zhou, Y. et al. Dust Aerosol Retrieval Over the Oceans with the MODIS/VIIRS Dark Target algorithm. Part II: Non-Spherical Dust Model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

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?

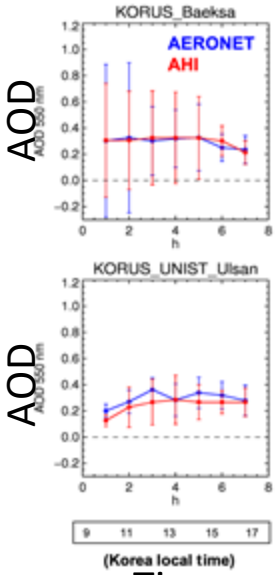


HRG (0.1°)

C6 (1.0°)

Monitor dust transport across the Atlantic Ocean during June 2018.

Using GEO to study diurnal cycle

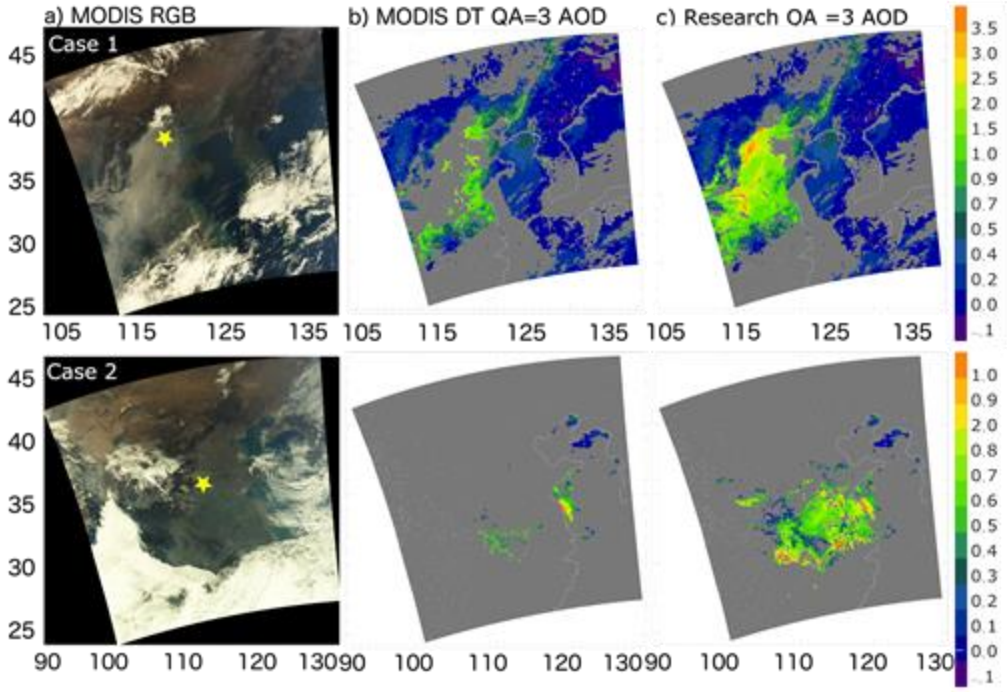


Time

- 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]

A Dark Target research aerosol algorithm for MODIS observations over eastern China: Increasing coverage while maintaining accuracy at high aerosol loading

Yingxi R. Shi, Robert C. Levy, Leiku Yang, Lorraine A. Remer, Shana Mattoo, and Oleg Dubovik



DT algorithm fails over heavy haze, such as over Beijing and northeast China during Winter season

- Failure from 'inland water mask' and 'snow mask'
- AOD errors due to:
  - Beijing aerosol at H<1km rather than assumed H=2km
  - SSA ~ 0.95 rather than assumed 0.9
- Develop 'research' algorithm that has improved masks and new aerosol optical model

Research product increases coverage and accuracy.