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).

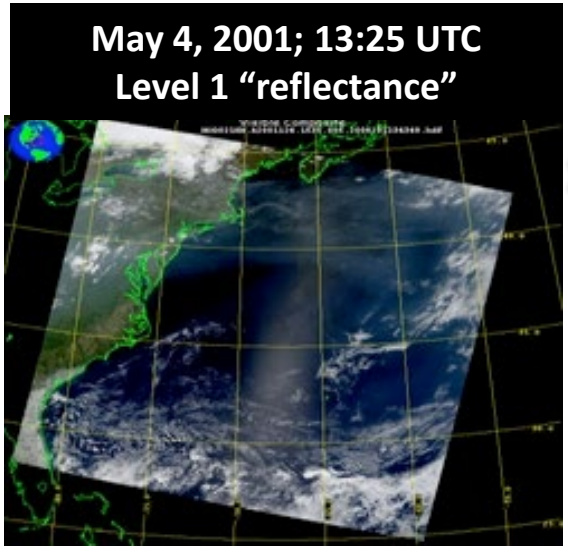
GODDARD EARTH SCIENCES

An outline of sorts

- The Dark Target algorithm on MODIS
- 20 years from MODIS
- Creating a global climate data record
  - Extending MODIS using VIIRS
  - Expanding MODIS using Geostationary
  - Integrating LEO and GEO
- Thoughts on a global constellation

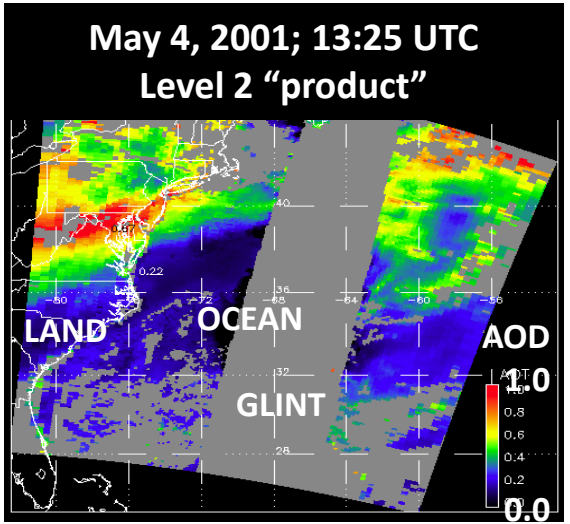
Dark-Target: A “Single View” aerosol algorithm (originally developed for MODIS – Terra/Aqua – as “polar orbiting")

What a sensor observes



DT

Attributed to aerosol (AOD)



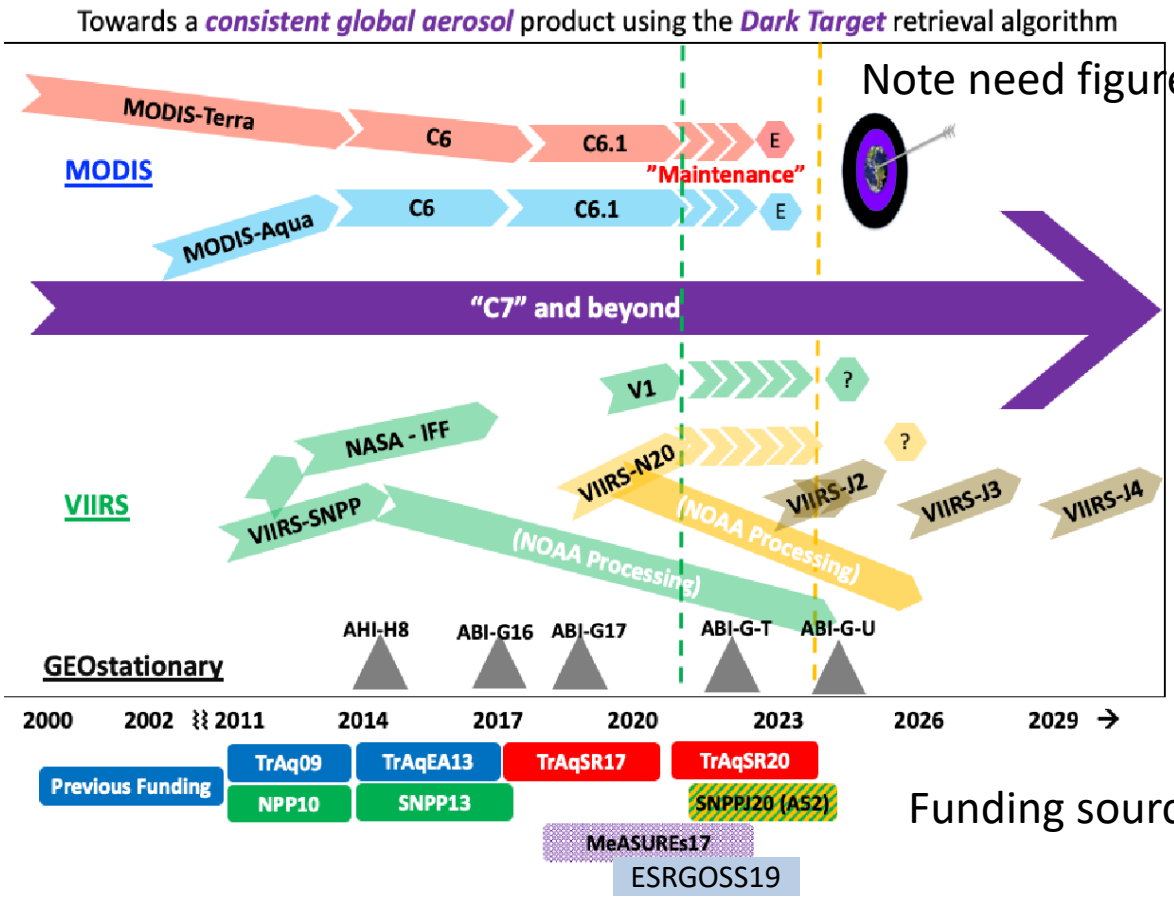
“Established 1997” by Kaufman, Tanré, Remer, etc)
“Modified 2005, 2010, 2013, 2015” by Remer, Levy, Gupta, etc

Separate logic over land and ocean

Retrieve: AOD at 0.55 μm, spectral AOD (AE), cloud-cleared reflectances, diagnostics, quality assurance

Dark Target Aerosol Retrieval Project

Cobbling together an integrated view of the world

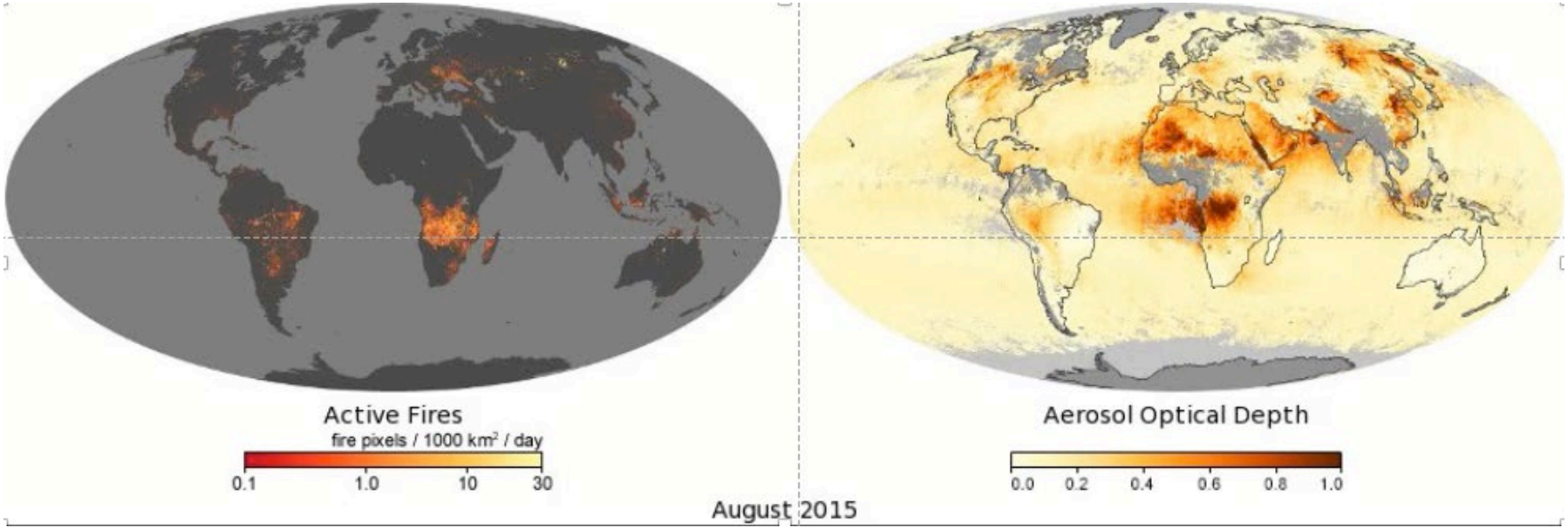


Note need figure update

Funding sources…

20+ years of fires and aerosols from MODIS (DT + DB)

Dark Target + Deep Blue algorithms



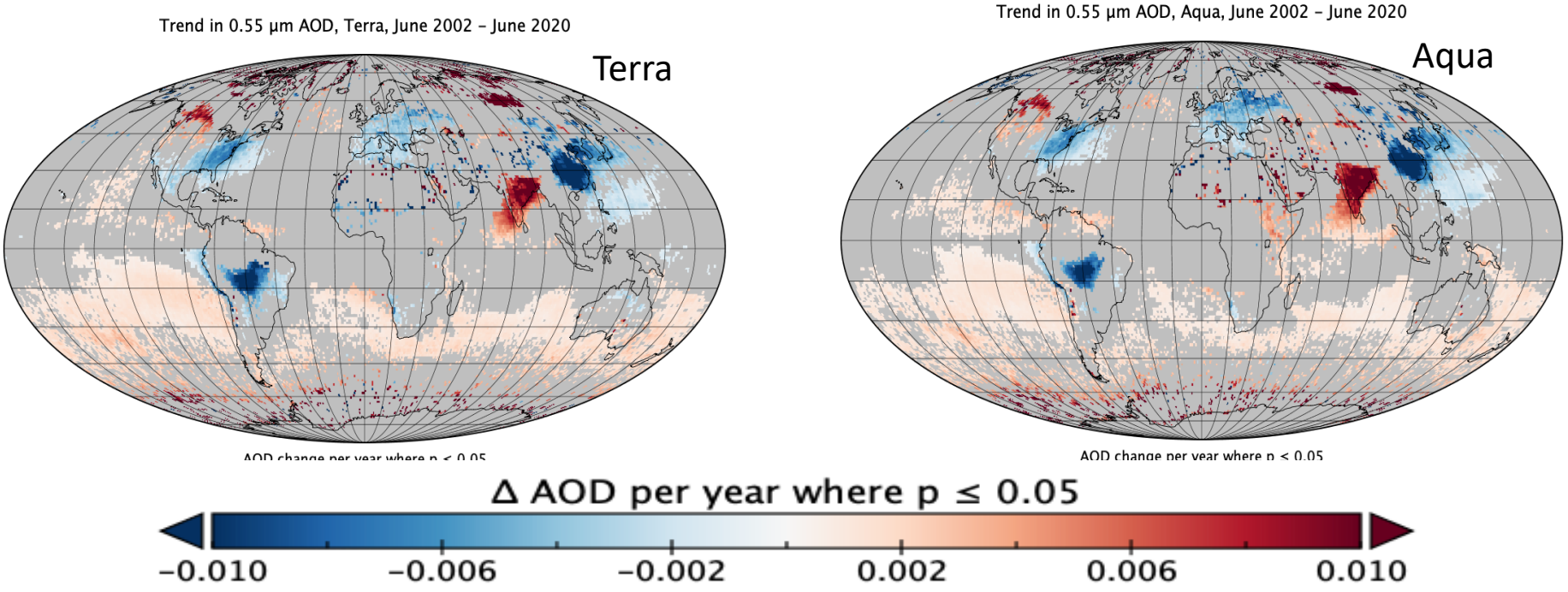
For a full animation (of monthly data) see:

https://earthobservatory.nasa.gov/global-maps/MODAL2_M_AER_OD/MOD14A1_M_FIRE

Connecting MODIS (Terra + Aqua) and VIIRS (Suomi-NPP and NOAA-20)

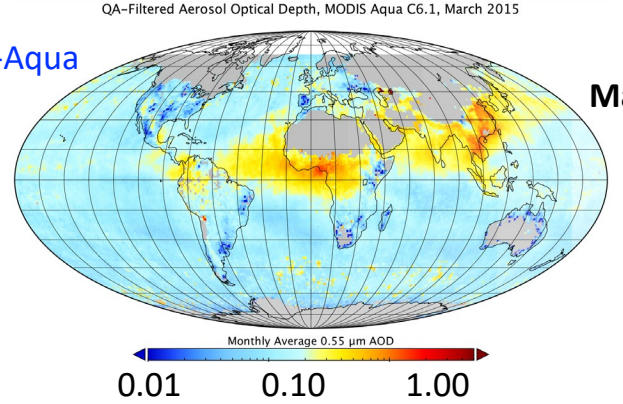
Virginia Sawyer et al..,

After all updates and calibration and such,
very consistent 'Trends' from Terra and Aqua MODIS (2002-2020)



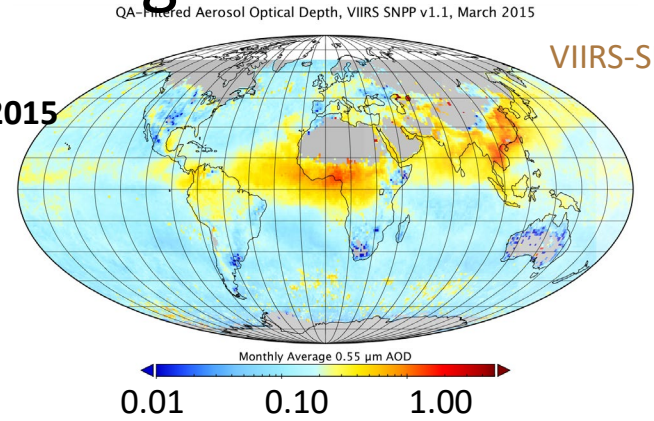
MODIS + VIIRS --> Long term data

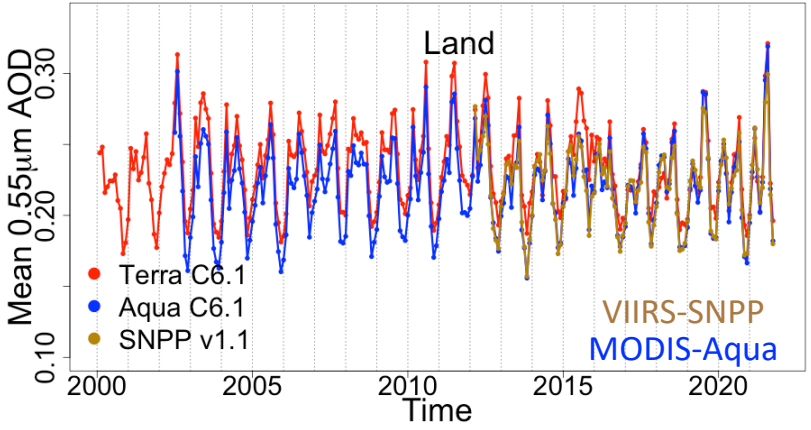
MODIS-Aqua

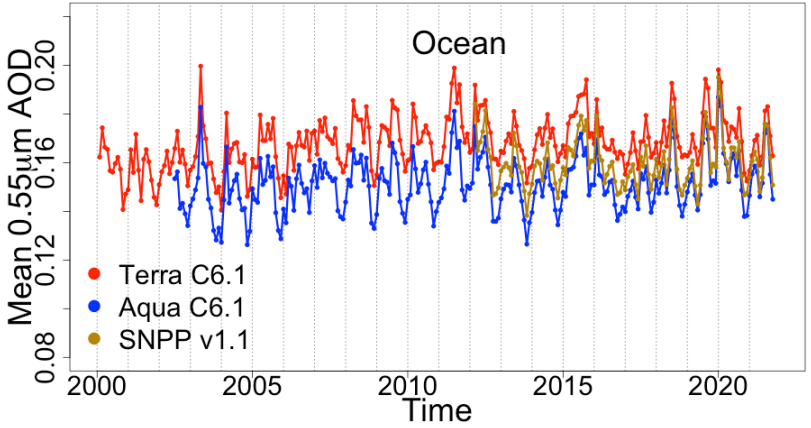


March 2015

VIIRS-SNPP

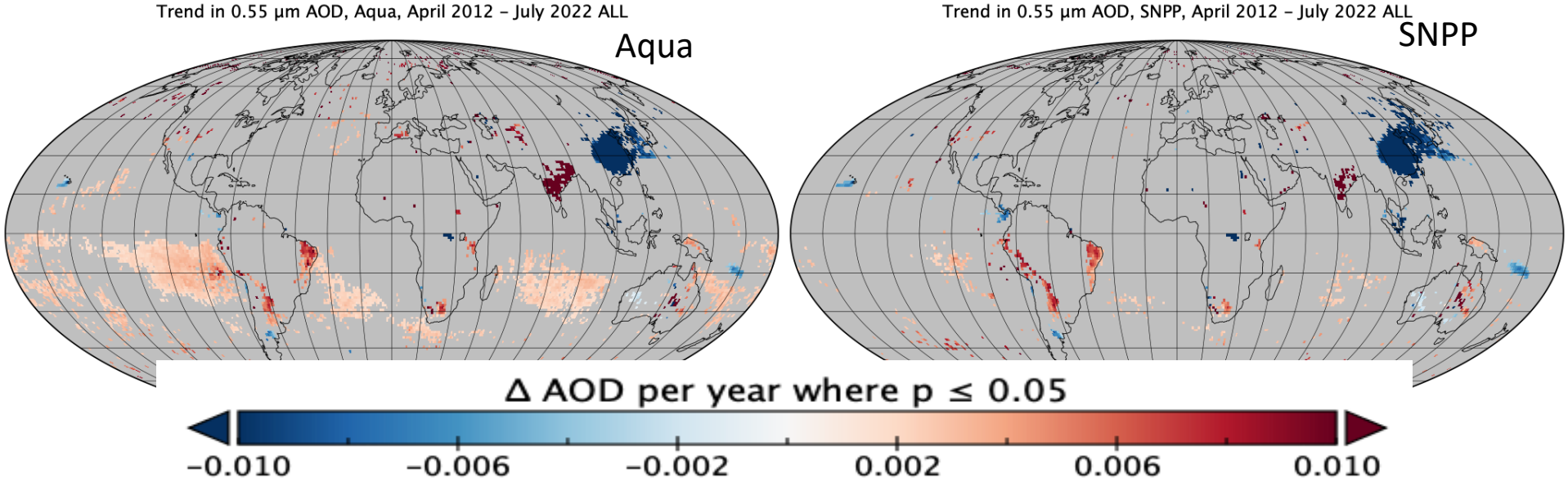






- With MODIS ending its nominal orbits in 2023, we look to VIIRS to continue the data record
- Note varying y-axis scales between Land and Ocean. VIIRS generally within 0.01 of MODIS.
- Additional spectral reflectance calibration factors (1-3%) may reduce differences.

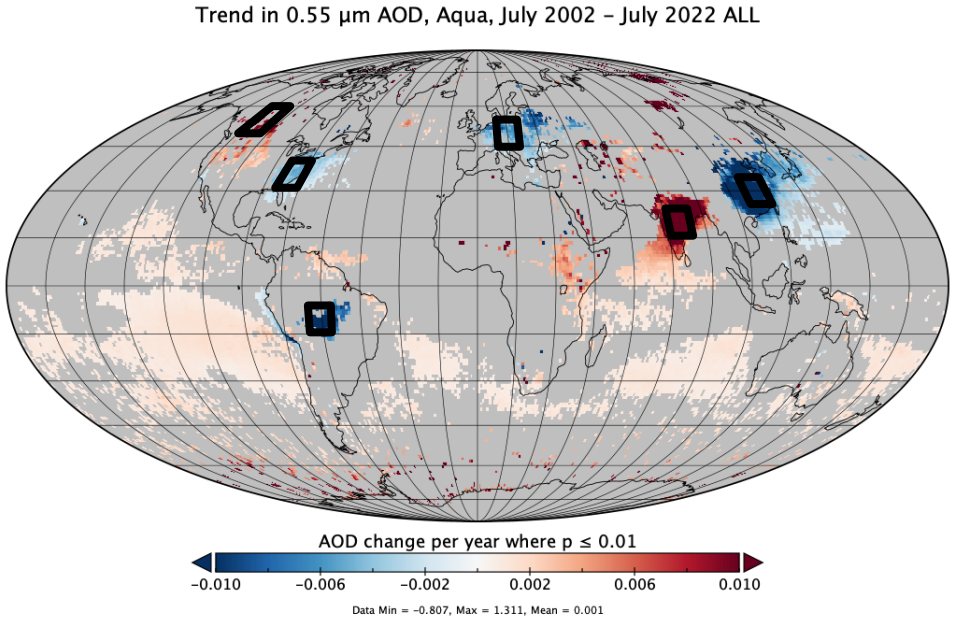
MODIS -> VIIRS overall consistent



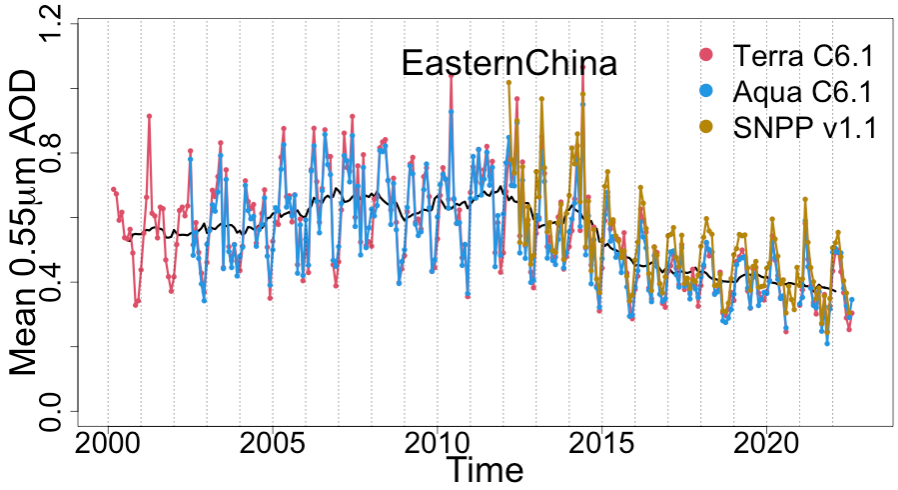
- For 10-year record since the start of VIIRS SNPP, half as much data = fewer grid cells meet a given significance threshold, generally sharper slopes where they do
- Note that the 20-year record found strong trends over India and eastern China for all four seasons, so they are easier to find in the shorter record
- However, not all of the 20-year regional trends continue in the same direction throughout the time interval: economic and policy changes happen in different years
- Nevertheless, SNPP sees the same world as Terra and Aqua, and may help in cases where they disagree

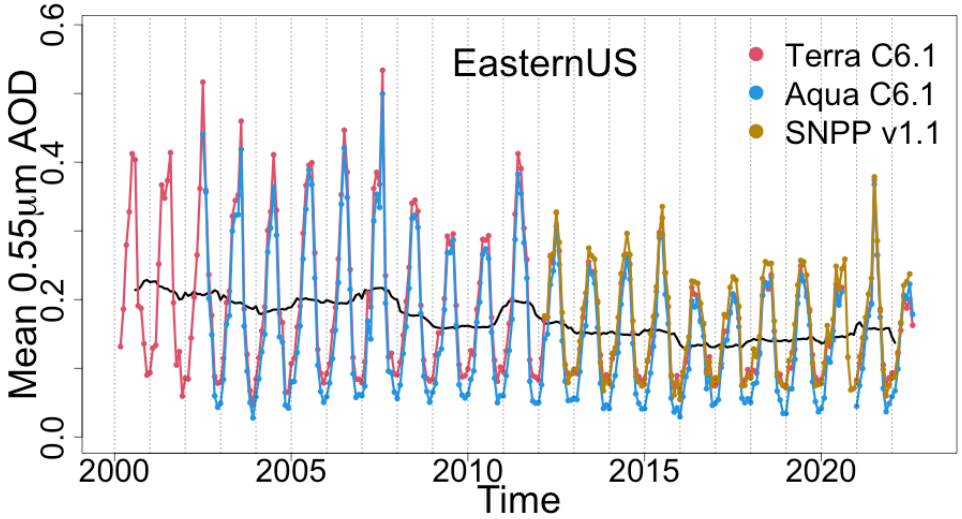
Regional trends from the 20-year record

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





2 example regions:

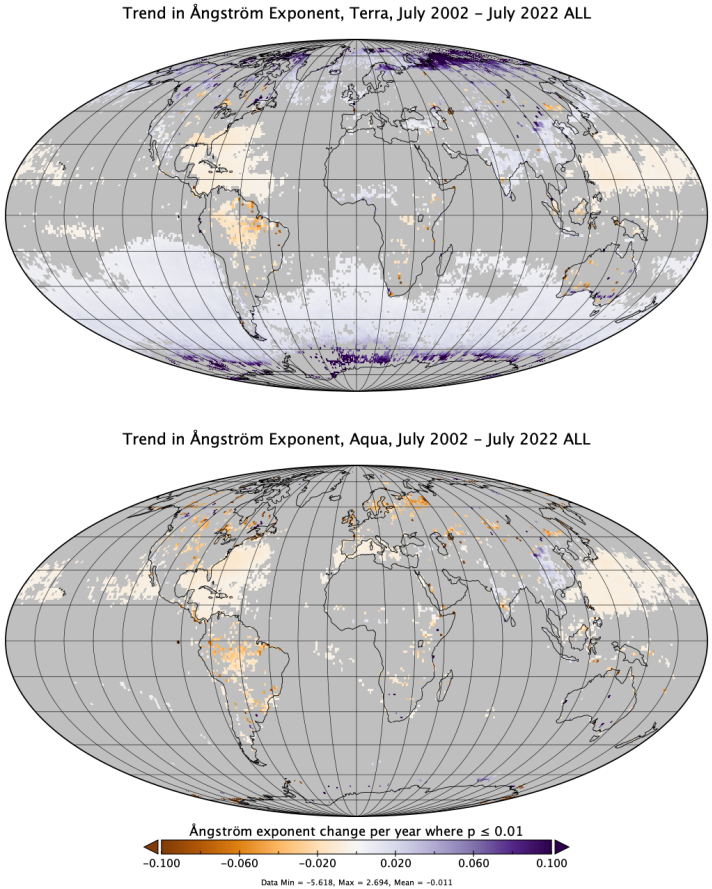
Eastern China:

- Coherent interannual change in all four seasons
- China began intensive efforts to improve air quality, and it shows as a turning point in the AOD record

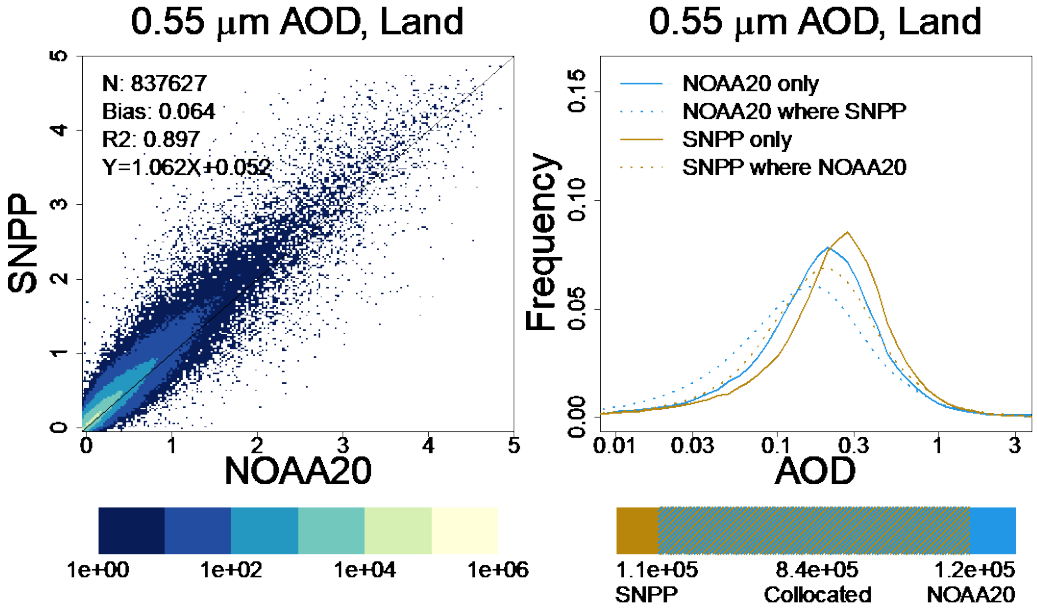
- Eastern US:
  - Possible flattening in the 2010s may help explain the lack of a significant AOD trend since SNPP
  - Why the spike in summer 2021?

Ångström exponents (not clear)

- 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
- Are high-latitude aerosols made up of finer particles than before (Terra) or not (Aqua)?
- The 10-year trends have the same problems as the 10-year AOD plots, and SNPP's answer is between Terra's and Aqua's



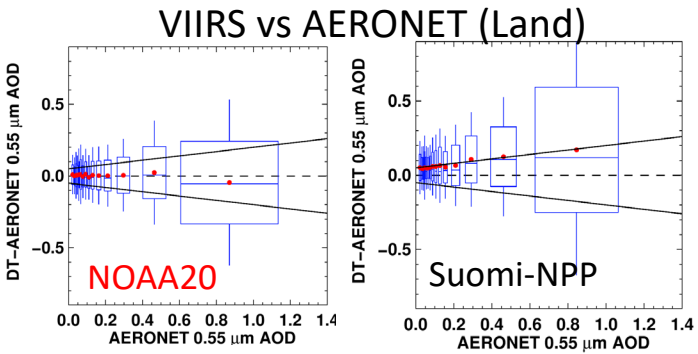
…now VIIRS on NOAA20!! (compare to SNPP)



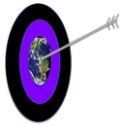
Suomi-NPP > NOAA-20

- Even when collocated within ±30 minutes
- Same story over ocean
- Consistent with community knowledge that Suomi-NPP "biased high" in some wavelength bands.

comparison (with AERONET) of NOAA-20 is darn good!



Status of standard Dark Target products (LEO)



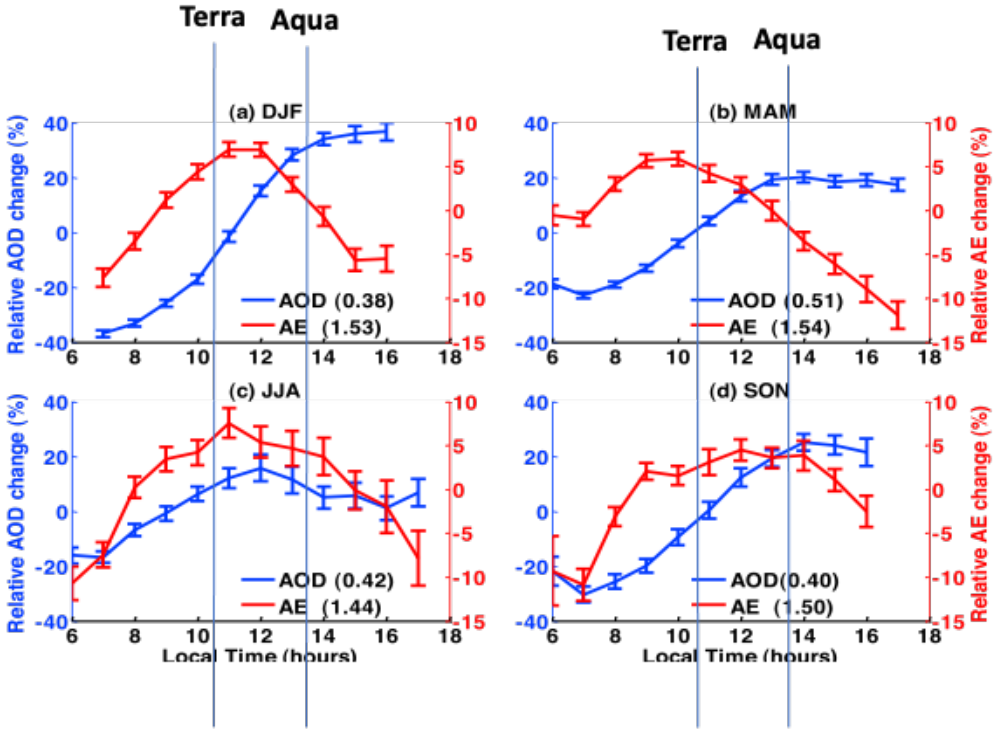
- **MODIS Collection 6.1 ('MxD04_L2' and 'MxD04_3K') : 2000 - present**
  - Data (2000-present) available in HDF4 format.
  - Includes Dark-Target / Deep Blue (DT/DB) merge product
  - **Includes 3 km resolution product (MxD04_3K)**
  - Collection 7 algorithm is in development – full reprocessing
- **VIIRS Version 1.1 Dark-Target ('AERDT_VIIRS_SNPP'): 2011 - present**
  - DT Data available in NetCDF4. Most output parameters same as MODIS
  - Deep Blue already ('AERDB') available since early 2019, and no current merge
  - Version 2.0 DT algorithm is being run for full reprocessing of both SNPP and NOAA20. (AERDT_VIIRS_NOAA20: 2017 - present) – fixes some bugs in V1.1.
  - Version 3.0 algorithm in development for SNPP, NOAA20 and JPSS-2:

MODIS + VIIRS Data currently available on LAADS.

- https://ladsweb.modaps.eosdis.nasa.gov/missions-and-measurements/science-domain/aerosol/

Near-Real Time products on LANCE / Worldview (https://worldview.earthdata.nasa.gov/)

LEO-Imager cannot see diurnally or more rapid aerosol changes!

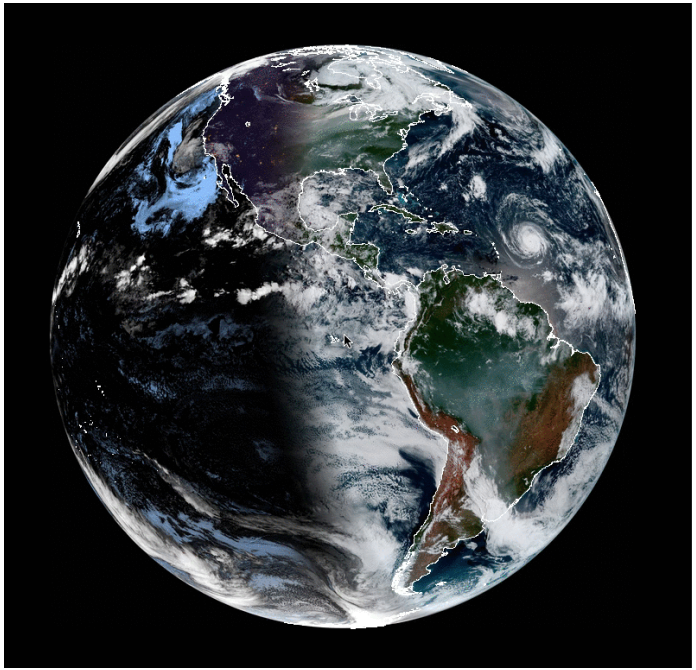


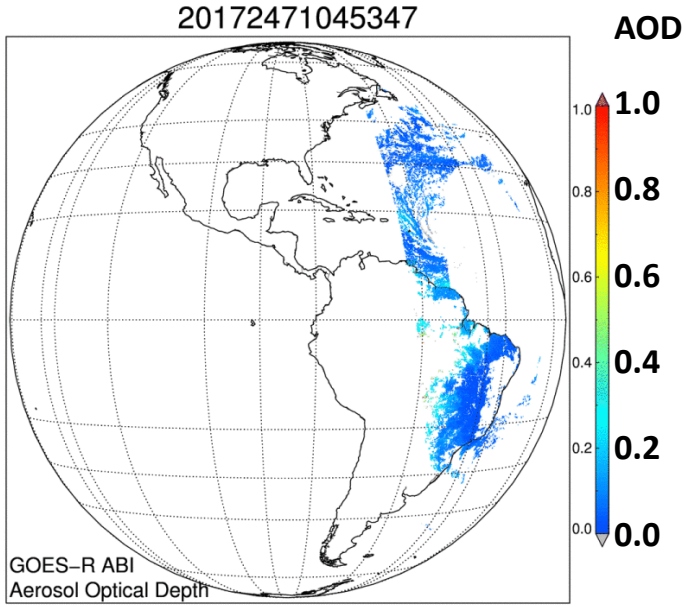
From: Zhang, Y., Yu, H., Eck, T. F., et al, (2012). Aerosol daytime variations over North and South America derived from multiyear AERONET measurements, *J. Geophysical Research*.

And can change rapidly
5 days of smoke from GOES-West

Retrieve from GEO-Imager data!

RGB and AOD from ABI for Sep 4, 2017 (animation): Pre-operational GOES-16 Canada/Washington fires and smoke mega-event

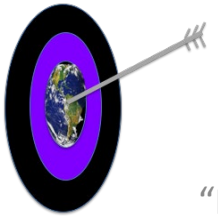




ABI = Advanced Baseline Imager

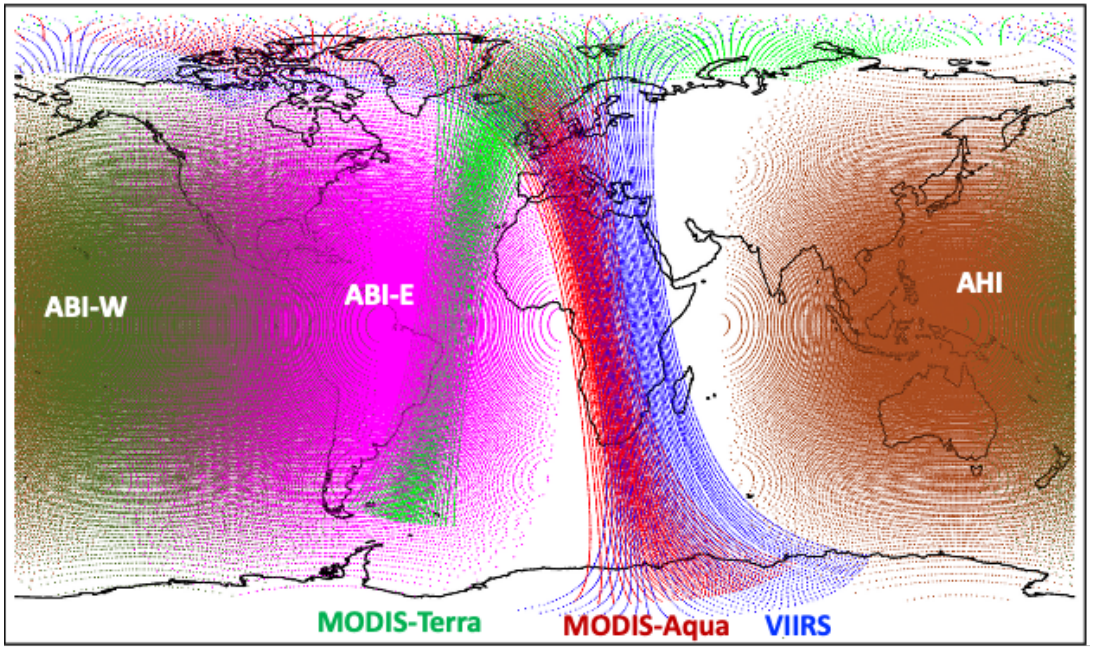
- Polar Orbiting Satellites: 1-3 observations per day, per sensor, cannot resolve diurnal cycle
- Current Geostationary Satellites: Every 10 min (Full Disk). Can resolve time

Dark Target specific: “XAERDT”



Funded under NASA-ROSES 2017

“Making Earth System Data Records Useful in Research Environments (MEaSUREs).



Note synergy of GEO and LEO

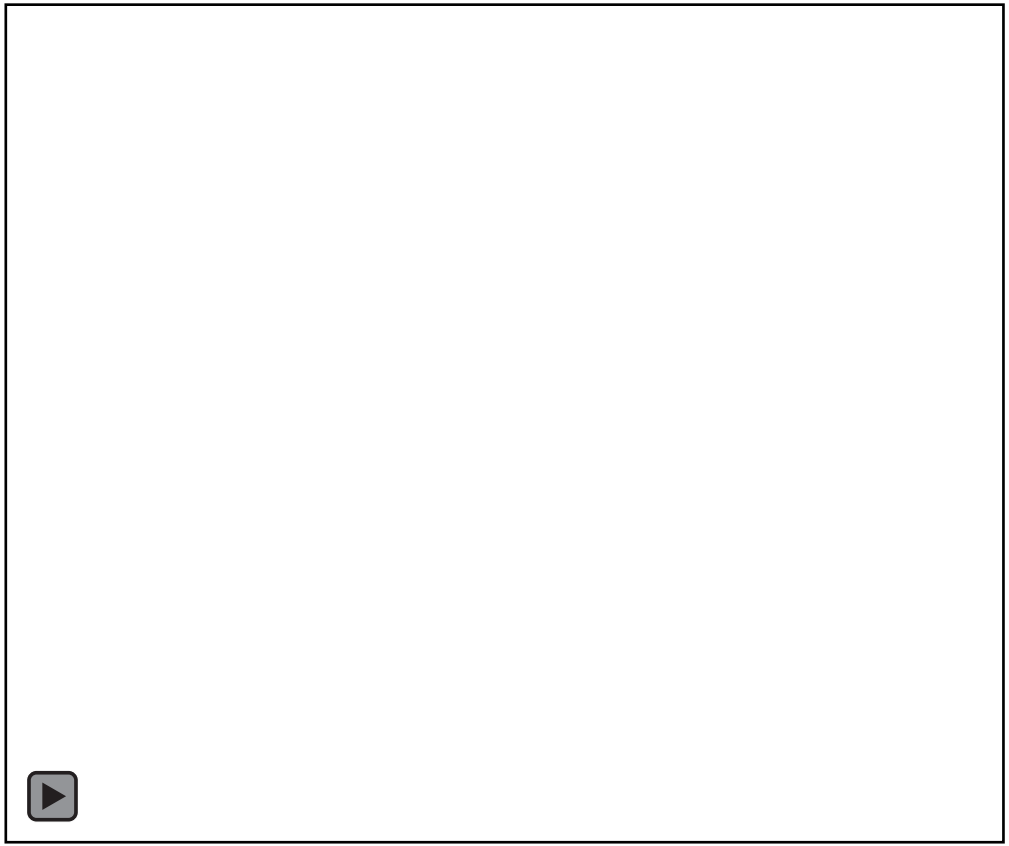
MODIS/VIIRS helps fill in Europe/Africa, poles, and “gaps” in GEO coverage

XAERDT: A joint LEO-GEO aerosol product

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

- 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



The DT-Package (Level 2)

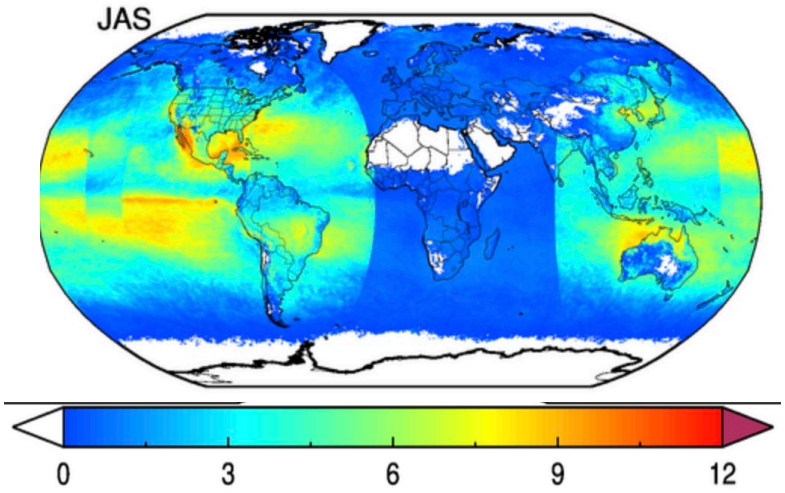
A "platform independent" version of the retrieval code

- All outputs in NetCDF format.
- Fortran and C compilers
- Modular, so that testing and updates are much easier
- Improved comments
- Necessary some differences between "standard" MODIS algorithm logic →
- If/then statements control specific LUTs for specific sensors
- Produces L2 cloud-cleared reflectance in sensor's native wavelengths.
- Aerosol retrieval at 0.55 μm.
- Currently exploring to work in Amazon cloud

Differences between DT-Package and standard applied to MODIS

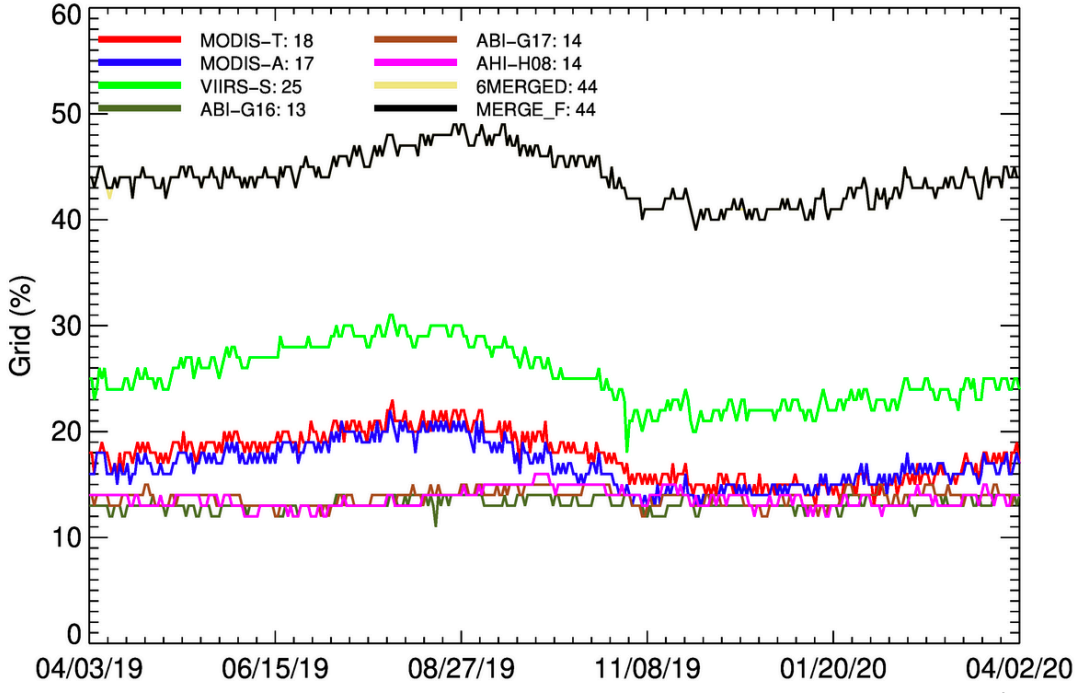
Issue	Standard MODIS	DT-Package
Data	L1B + geolocation + cldmask in native resolution	L1B + geolocation + cldmask downscaled to 500 m
Reading data	10 lines at a time	Entire granule into memory
Ocean cloud masking	3x3 stddev at 0.55 μm	3x3 stddev at 0.66 μm • GEO has no 0.55 • all sensors have red at 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)

DT: Daily Data Availability (6 sensors)

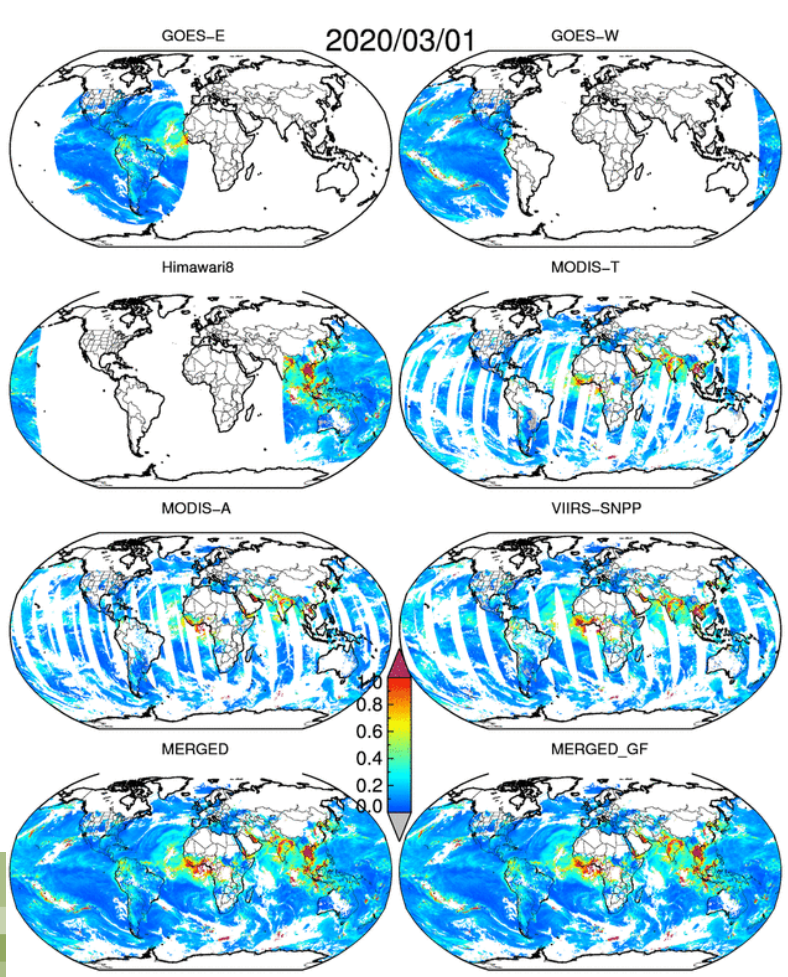


XAERDT_L3: number of hours (frequency) during JJA months that have valid AOD values at 0.25° x 0.25°

XAERDT_L3: % of global 0.25° grids covered by at least one satellite observation each day. Colored curves represent 6 sensors separately and Black curve is “all together”.



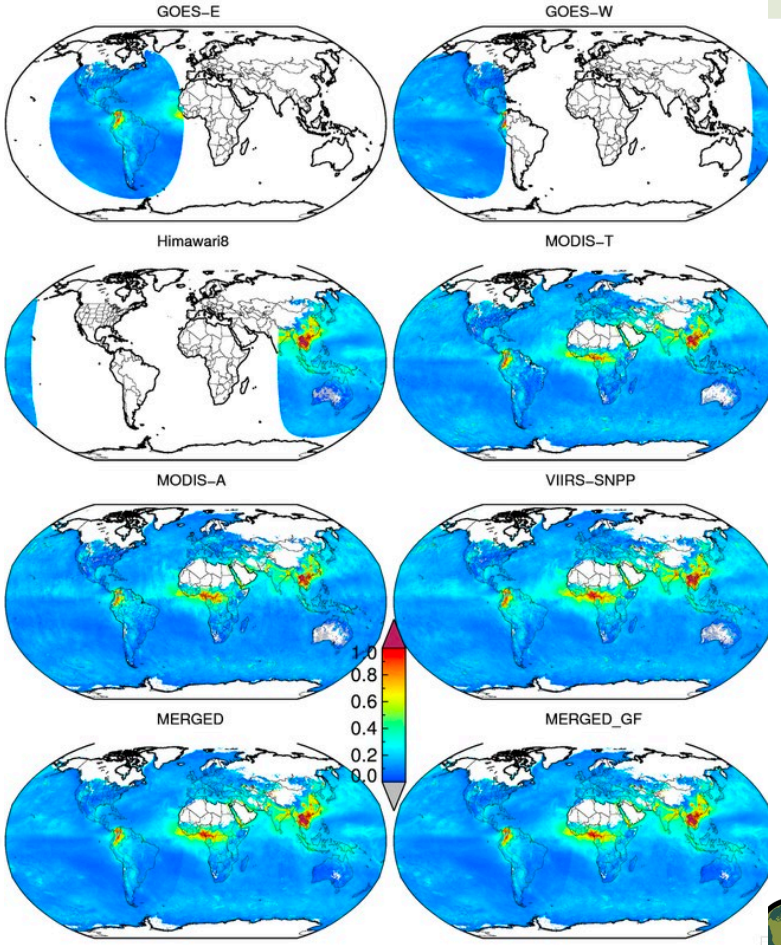
XAERDT Level 3 : Daily and Monthly coverage



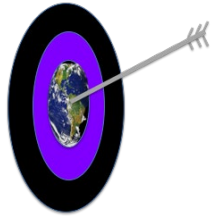
30-Minutes

Daily

Monthly



Status of GEO-LEO (XAERDT): Products



Level 2: Filename and product structure are finalized.

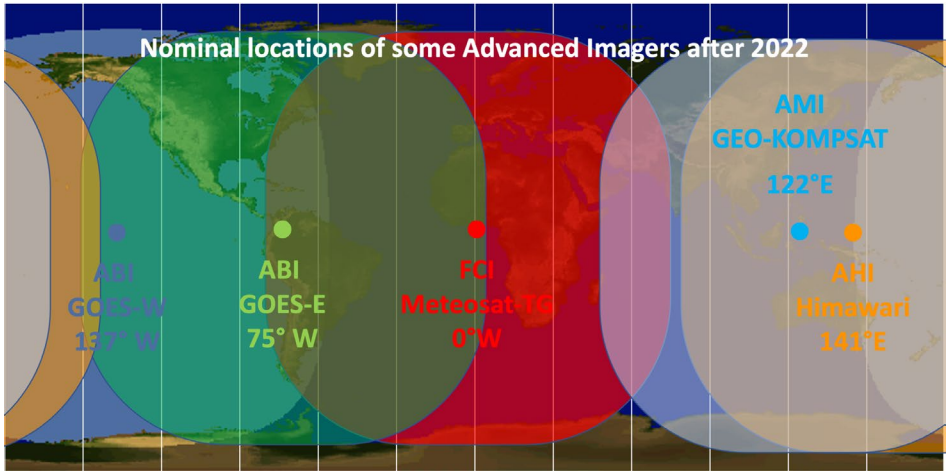
- XAERDT_L2_MODIS_Terra,"MODIS Terra Dark Target Aerosol 5-Min L2 Swath 10 km"
- XAERDT_L2_MODIS_Aqua,""MODIS Aqua Dark Target Aerosol 5-Min L2 Swath 10 km"
- XAERDT_L2_VIIRS_SNPP ,"SNPP VIIRS Dark Target Aerosol 6-Min L2 Swath 6 km"
- XAERDT_L2_VIIRS_NOAA20 ,"NOAA-20 VIIRS Dark Target Aerosol 6-Min L2 Swath 6 km"
- XAERDT_L2_ABI_G16, "ABI GOES-16 Dark Target Aerosol 10-Min L2 Full Disk 10 km "
- XAERDT_L2_ABI_G17, "ABI GOES-17 Dark Target Aerosol 10-Min L2 Full Disk 10 km "
- XAERDT_L2_AHI_H08, "AHI Himawari-8 Dark Target Aerosol 10-Min L2 Full Disk 10 km ”

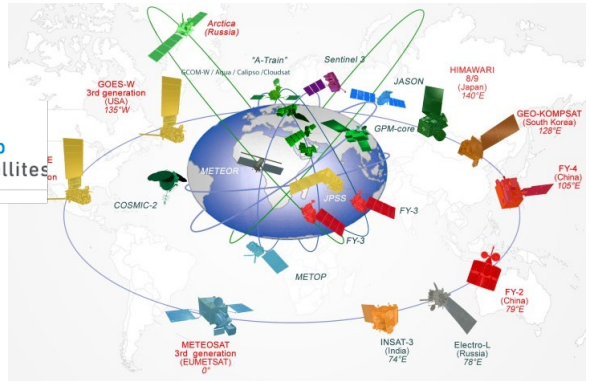
Level 3: Naming conventions not finalized.

- XAERDT_L3_30min, “Combined GEO-LEO Dark Target Aerosol 30-Min L3 Global 0.25x0.25 degree”
- XAERDT_L3_Daily, “Combined GEO-LEO Dark Target Aerosol Daily L3 Global 0.25x0.25 degree”

- All data will be served through NASA’s LAADS system (Needs “EarthData” login):
- Plan is for entire period (2019-2022) to be available early in 2023 and open for public download.
- Needs work on documentation, etc. What kind of papers to write?
- Currently available June-Oct 2019 representing the union of CAMP2EX and FIREX-AQ experiments (private download – ask me).
- Last few months of 2022: GOES-18 versus GOES-17? Himawari_9 versus Himawari_8?

Future GEO-Ring and Program of Record





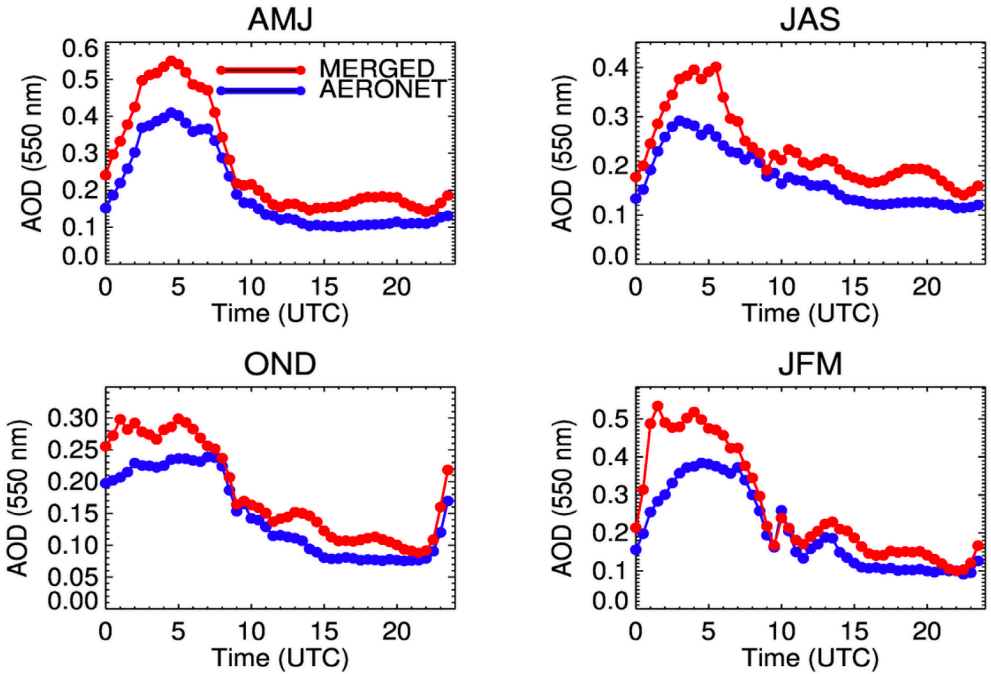
CGMS The Coordination Group for Meteorological Satellites

- The GOES series, Himawari, GEO-KOMPSAT, INSAT-3D/3DS, and METEOSAT 3rd Gen. will soon all be operational
  - advanced multi-spectral capabilities and ≤2km nadir spatial resolution (consistent aerosol retrieval)
  - International coordination that places all GEOs on same 10-minute cadence.
- All will contribute to our global understanding of aerosols and clouds.
- As the Program of Record, synergy with new missions (e.g. NASA's Atmosphere Observing System in 2027-2031?).
- Requires a new strategy on organizing data and Earth Information System? The cloud? Which cloud? And calibration needs to be a coordinated effort.

Some good, and needs improvement of DT-GEO (currently)

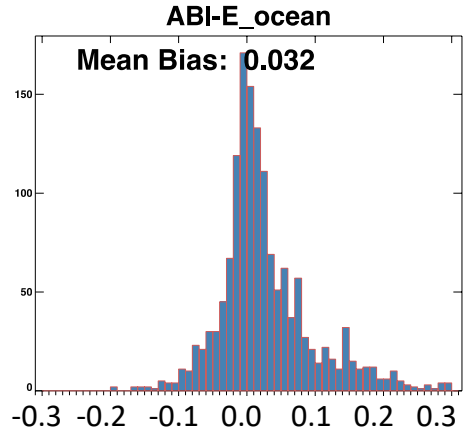
Diurnal Cycle - Spatial Variability

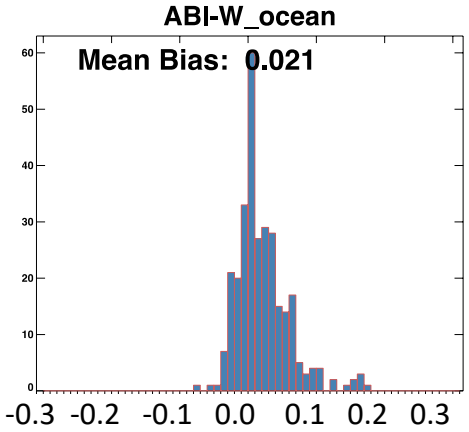
The global average for each UTC half-hour is calculated using collocated AERONET-MERGED datasets by season. Overall, XAERDT follows the AERONET but with a positive bias. We are further evaluating the diurnal cycle of AOD for local solar time.

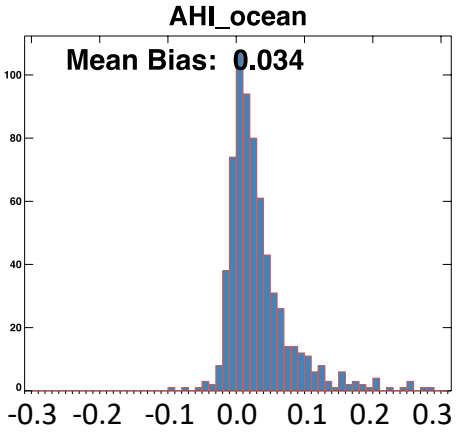


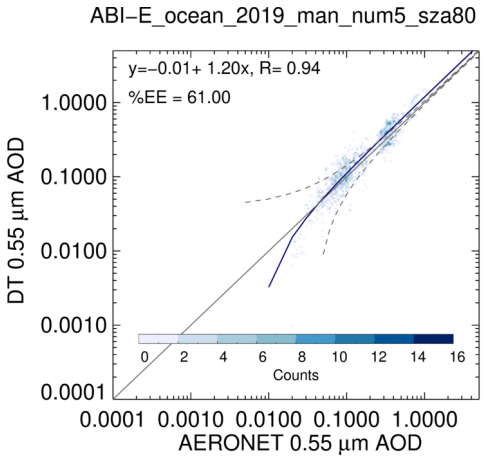
Understanding GEO validation (Y. Shi et al.,)

Ocean









Example for OCEAN:

Satellites versus MAN (Marine Aerosol Network)

Why do all three GEOs have a high bias?

- Issues with understanding GEO geometry?
  - Aerosol phase function?
  - Spherical atmosphere assumptions?
- Calibration?

Understanding **LAND** surface reflectance for GEO (Mijin Kim et al)

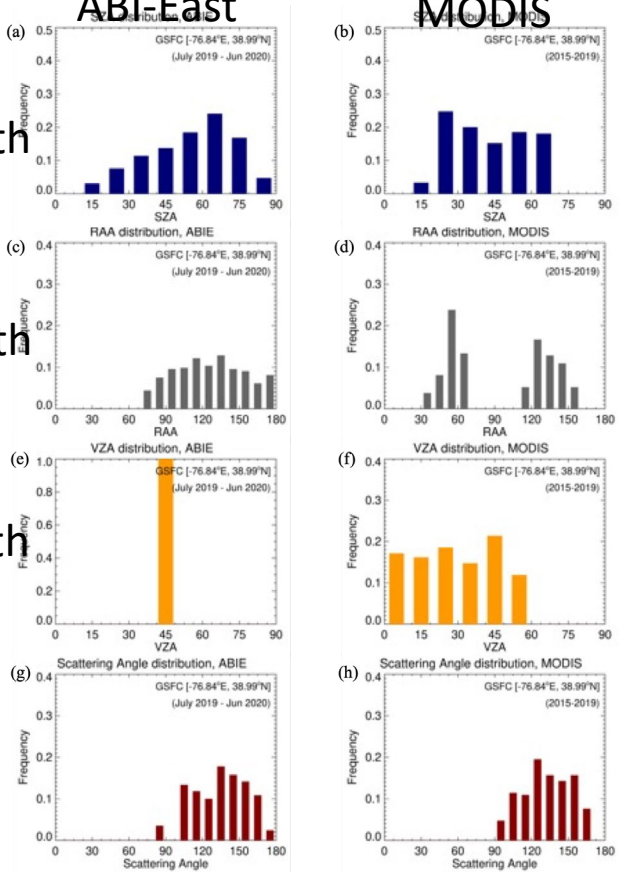
@ GSFC

Solar Zenith

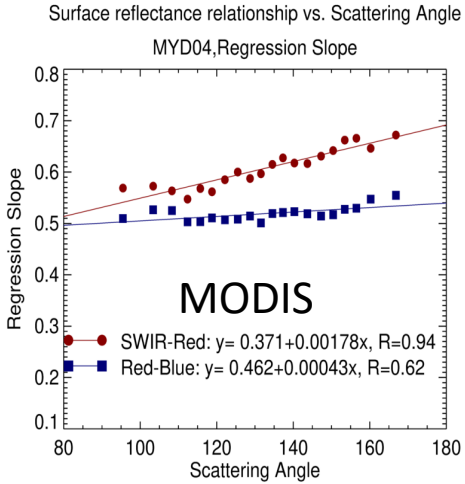
Rel Azimuth

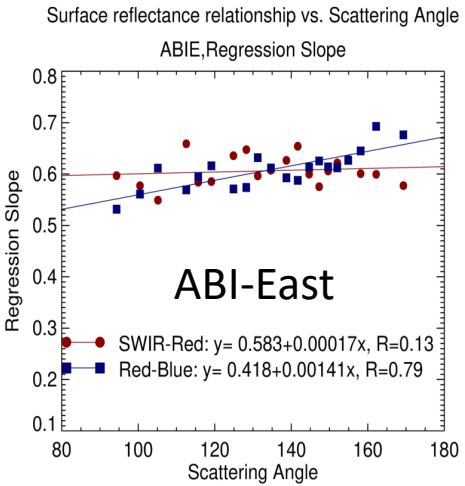
View Zenith

Scat Angle



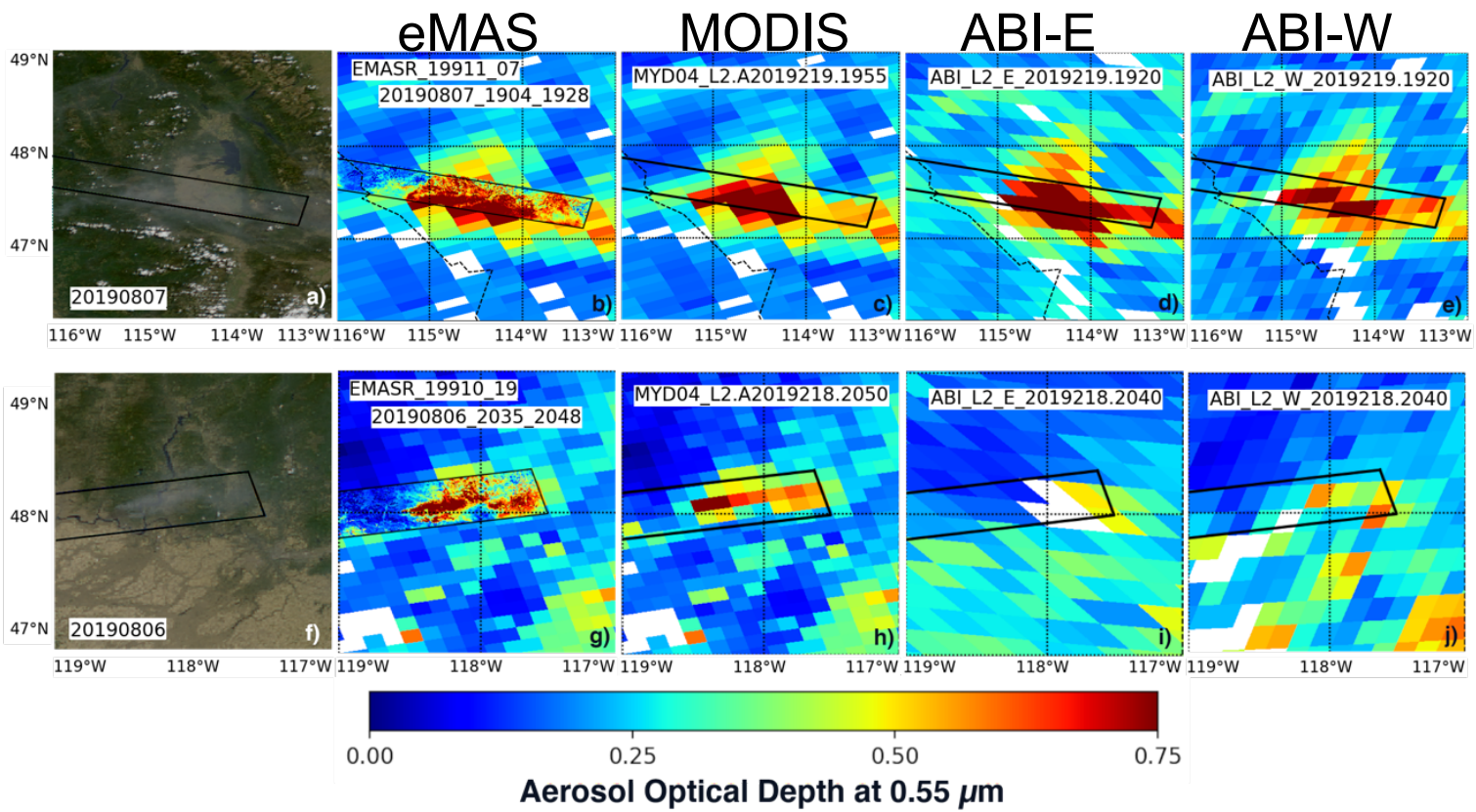
- ✓ LEO and GEO have entirely different geometries and spatial sampling
- ✓ Leading to different surface reflectance (red vs SWIR, blue vs red)





super interesting…

Investigating the Spatial and Temporal Limitations of Satellite Characterization of Wildfire Smoke Using Satellite and Airborne Imagers During FIREX-AQ (Yingxi Shi et al.,)

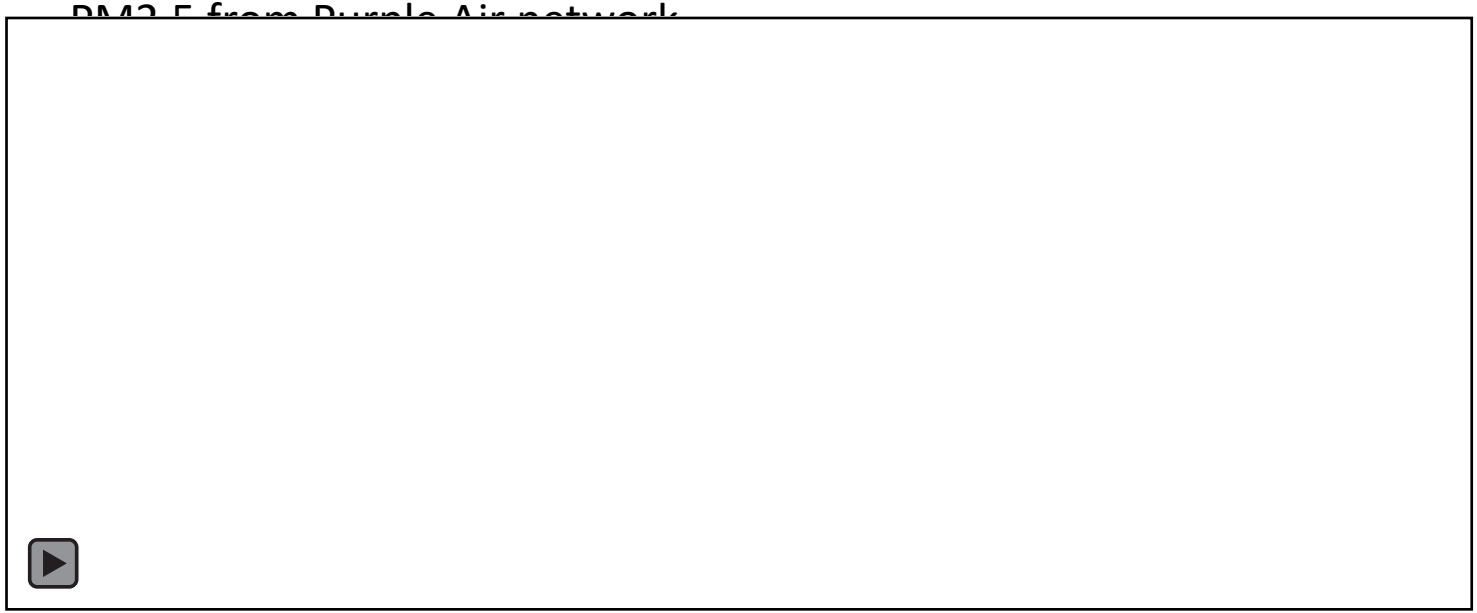


Playing with temporal and spatial resolutions!

Yes, biases perhaps…

But very consistent at scales.

Connecting the spatial/temporal co-variability of AOD and surface PM2.5 (Pawan Gupta et al.,)

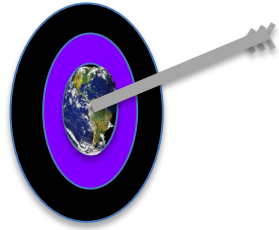


On 9 March 2020, a prescribed burn was set near Quantico, VA.

Smoke from this burn tracked over the Washington and then Baltimore Metro areas.

It was seen from satellite, and by low cost AQ sensors near the ground.

Where we are:



GODDARD EARTH SCIENCES

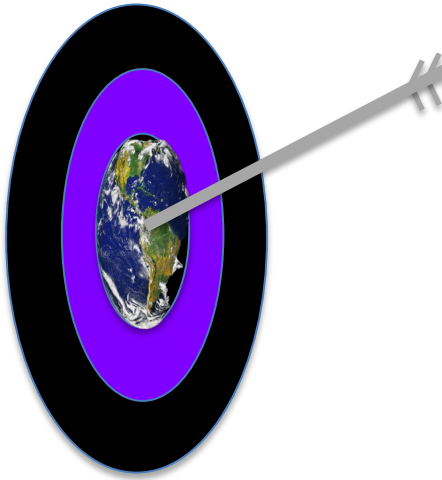
- **XAERDT: GEO-LEO fusion for a gridded/global/30 minute cadence product**
  - **Funded by NASA - MEaSUREs.**
  - DT-Package code development
  - GEO Level 2: 10 km x 10 km resolution every 10 minutes. (Full Disk)
  - Level 3: 0.25 x 0.25° every 30 minute.
  - It's "BIG" data, so data processing and archival is an order-of-magnitude more than MODIS or VIIRS
  - Possibility to expand to future GEO-LEO imager ring.
  - 2019-2022: All data will be served through NASA's LAADS system (Needs "EarthData" login):

- **Also plan to work with Christina Hsu (Jaewha Lee) for how we might combine DT and Deep Blue for GEO (NASA –ESROGSS-2019). Norm Loeb (CERES lead at LaRC) wants DT/DB for CERES reprocessing.**

- Still many retrieval issues (calibration/etc.) we need to work out. (after release of first version)?

- **My concern:** How do we (me) continue this work beyond MEaSUREs-2017 and ESROGSS - 2020?
- How are we funded?

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 4 current satellites (GOES-16/17/18 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.
- **1 Airborne sensor (eMAS)**
  - 10x better spatial resolution
  - Modern (C6+ processing) for SEAC^{4}RS (2019), and FIREX-AQ (2020)

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