Updates and Trends in Dark Target for MODIS and VIIRS

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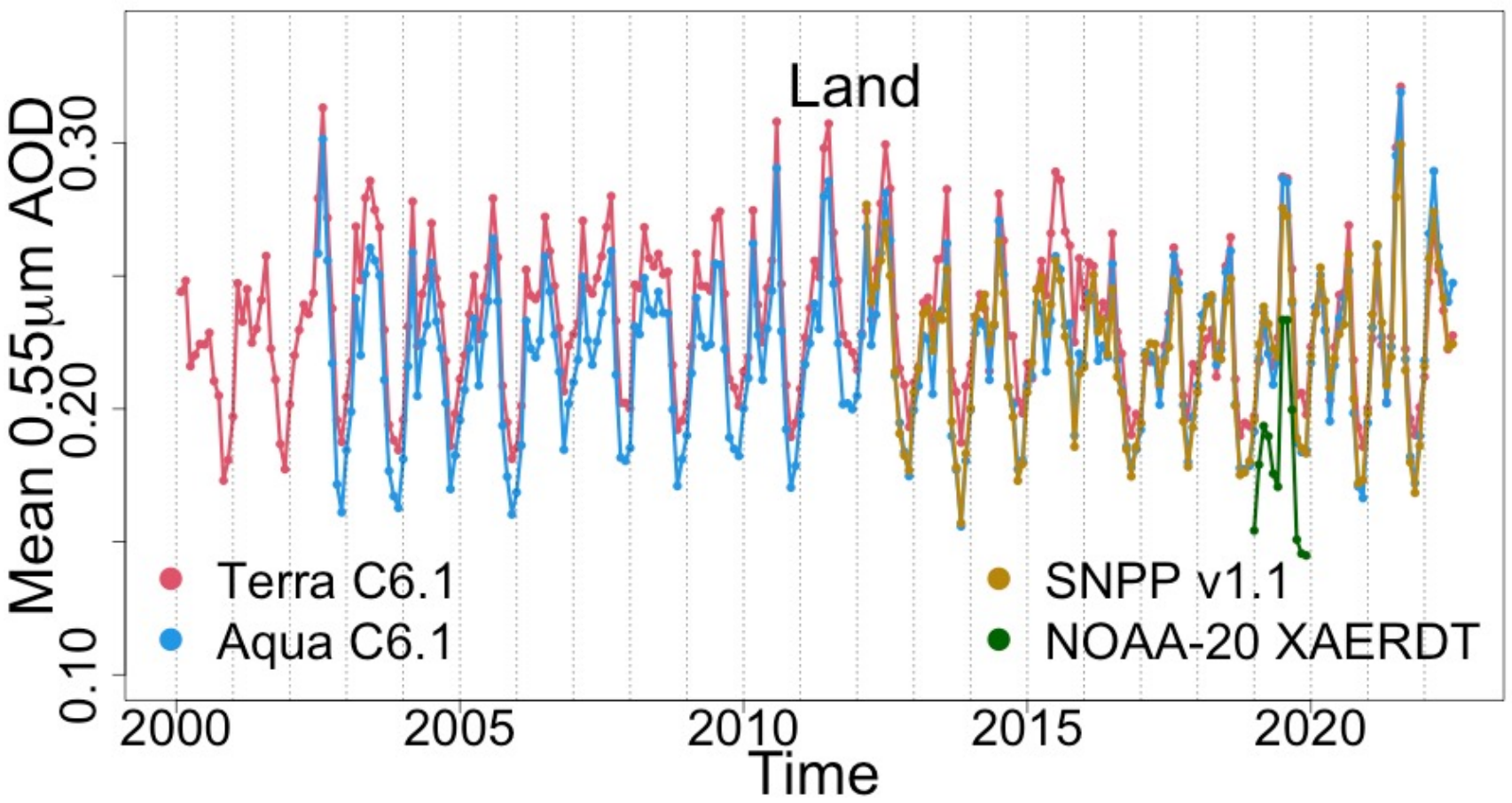
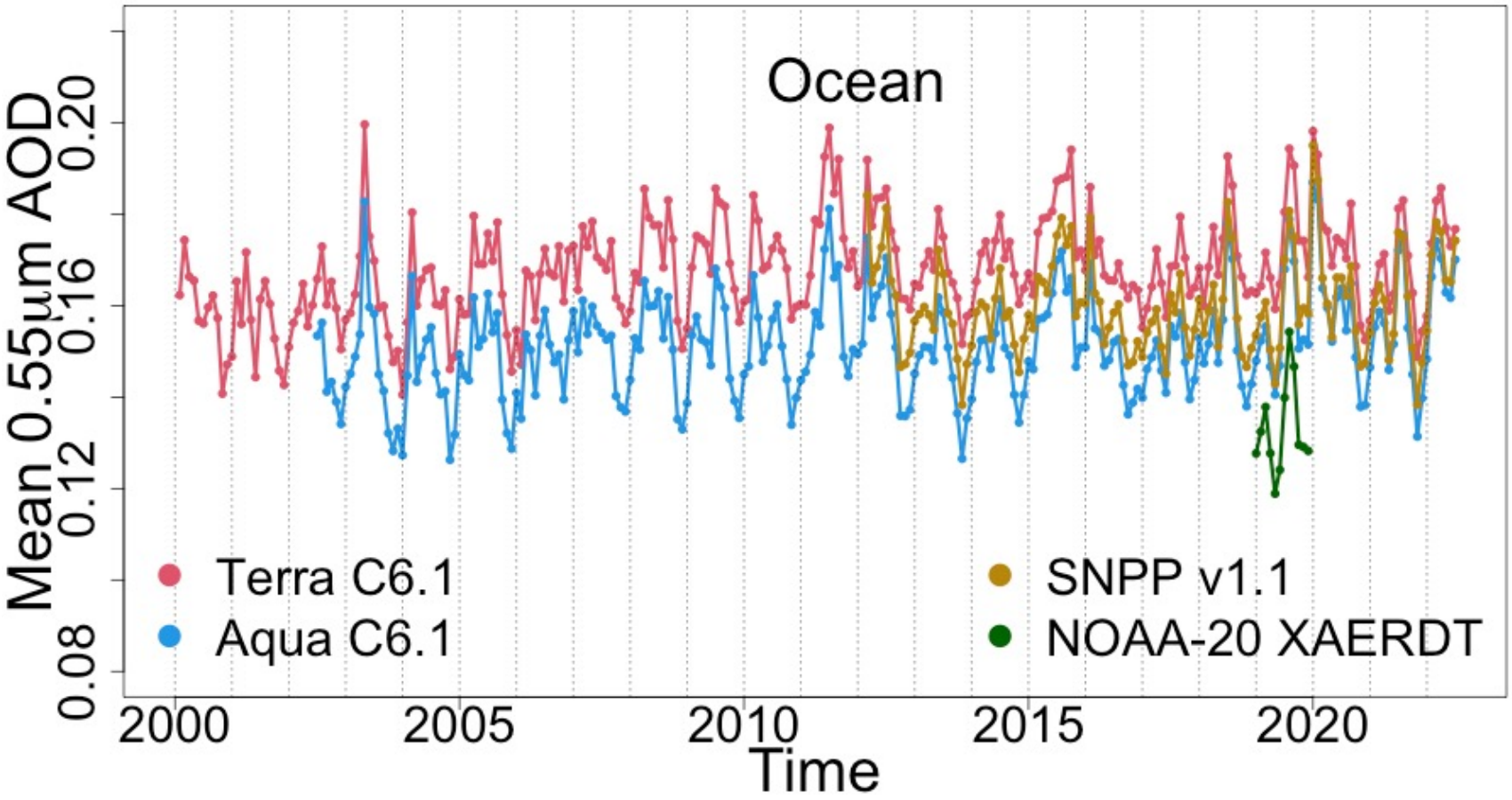
Aerosol Optical Depth as a Climate Data Record

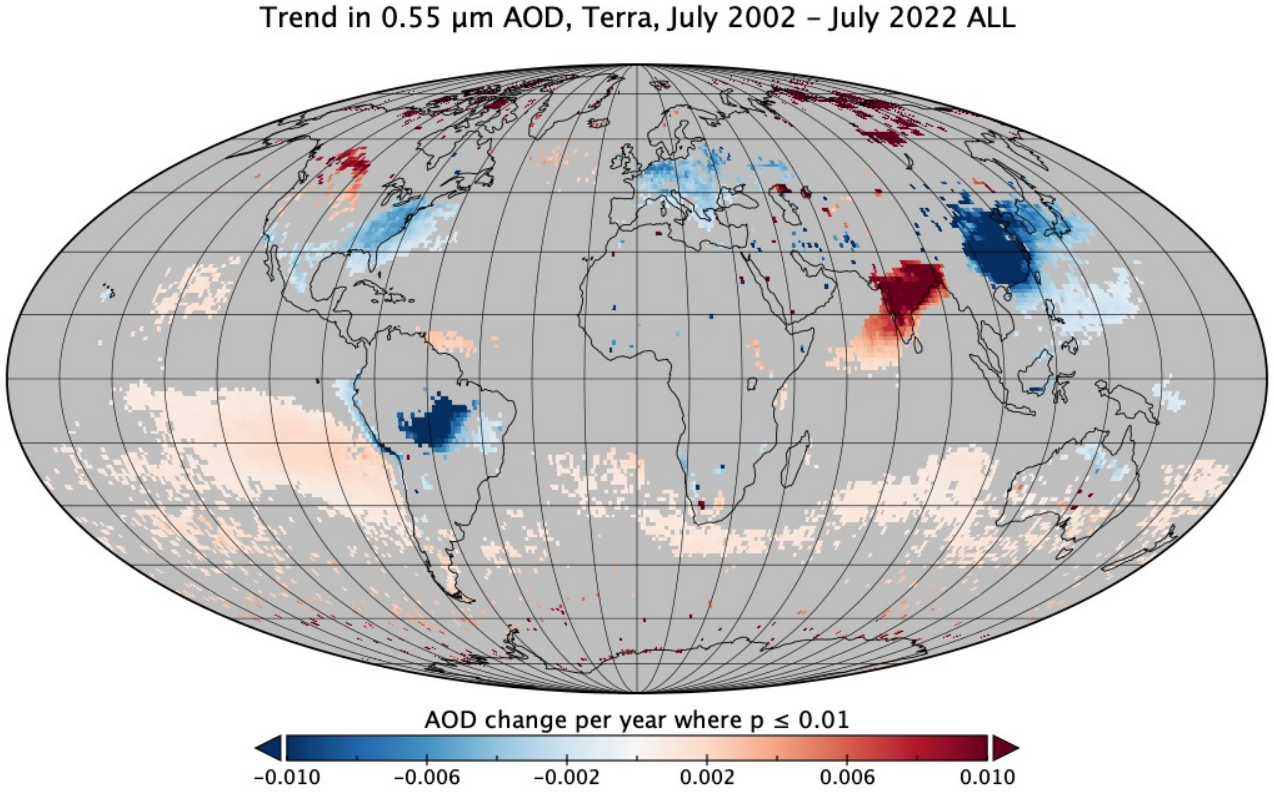


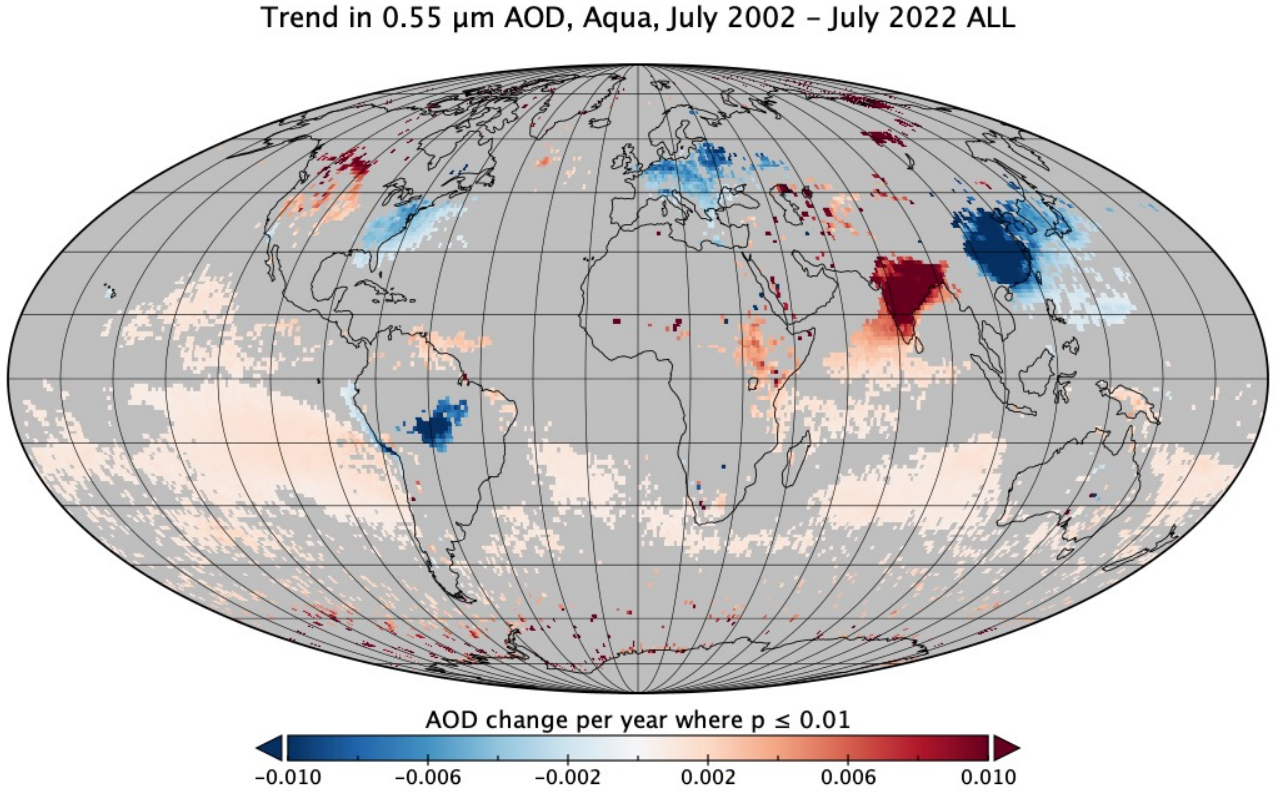
- Dark Target uses the same retrieval algorithm across multiple MODIS and VIIRS (and ABI and AHI) sensors
- Offsets in AOD caused by differences in instrument design, calibration, or degradation over time (Remer et al. 2020, Sawyer et al. 2020, Levy et al. 2018)
- Diverging Terra vs. Aqua trend in earlier collections was corrected for C6
- No long-term global average trend

Aerosol Optical Depth as a Climate Data Record



- MODIS Aqua reached 20 years and VIIRS SNPP reached 10 years in 2022, with MODIS Terra at 22
- Dark Target for VIIRS NOAA-20 and a major SNPP update are almost ready to release
- VIIRS NOAA-21 is operational as of Feb 2023
- Terra and Aqua crossing times are now drifting, and VIIRS must pick up the record after end of MODIS mission
- NOAA-20 seems offset “low”, but see validation later in this talk

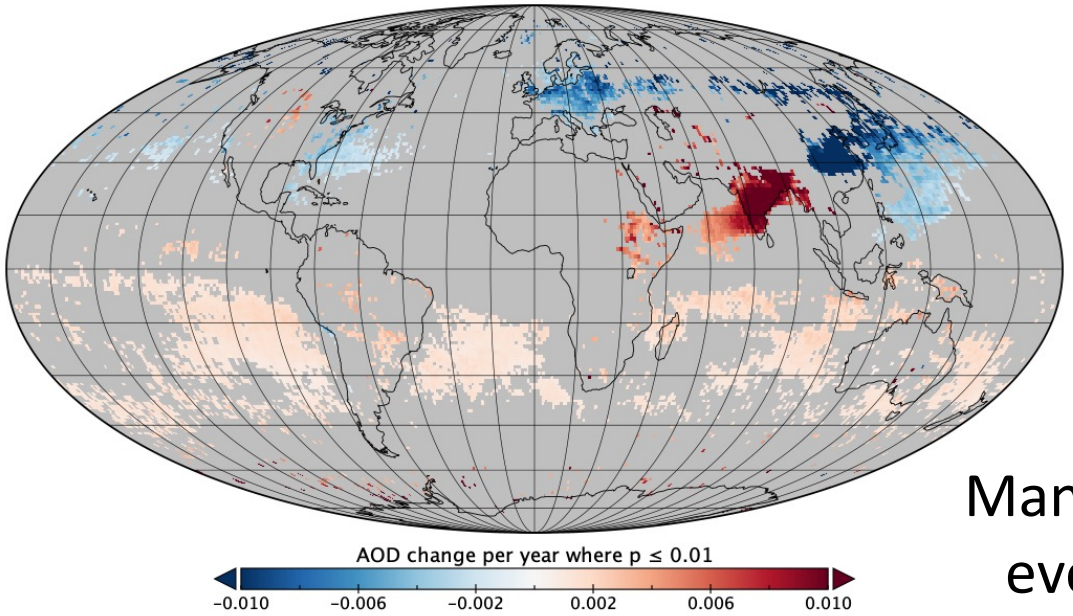




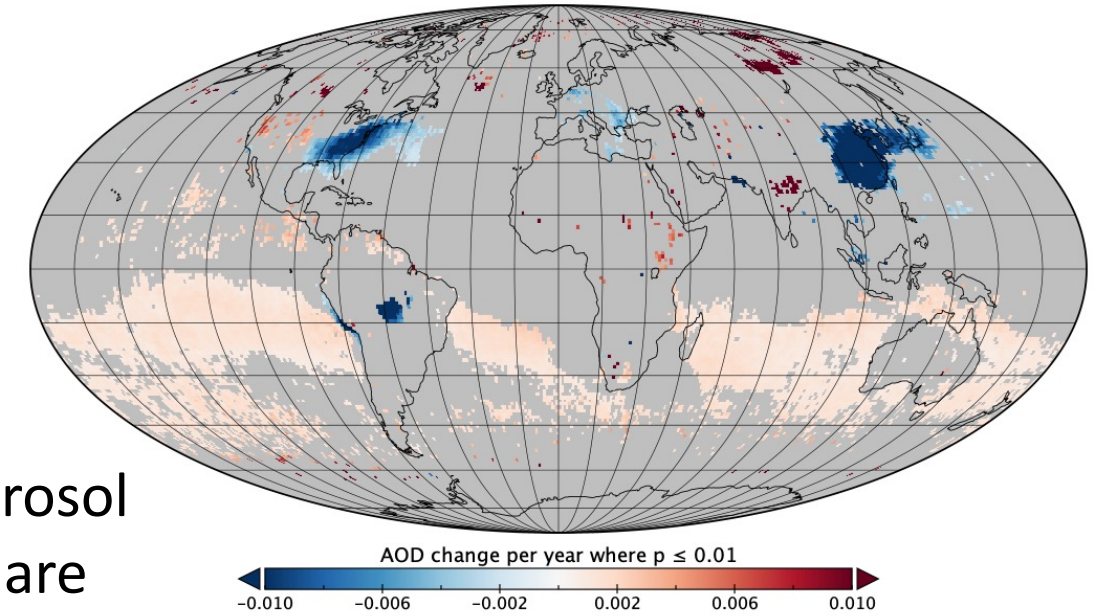
Slope of the linear regression for each 1°×1° grid cell (monthly mean QA-filtered AOD) plotted where p ≤ 0.01

- Time series show no change in globally averaged AOD, but GCOS requires a continuous 30+ year record
- However, since the Aqua launch in 2002, we have a 20-year record from two MODIS sensors
- 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

Trend in 0.55 μm AOD, Aqua, July 2002 – July 2022 MAM

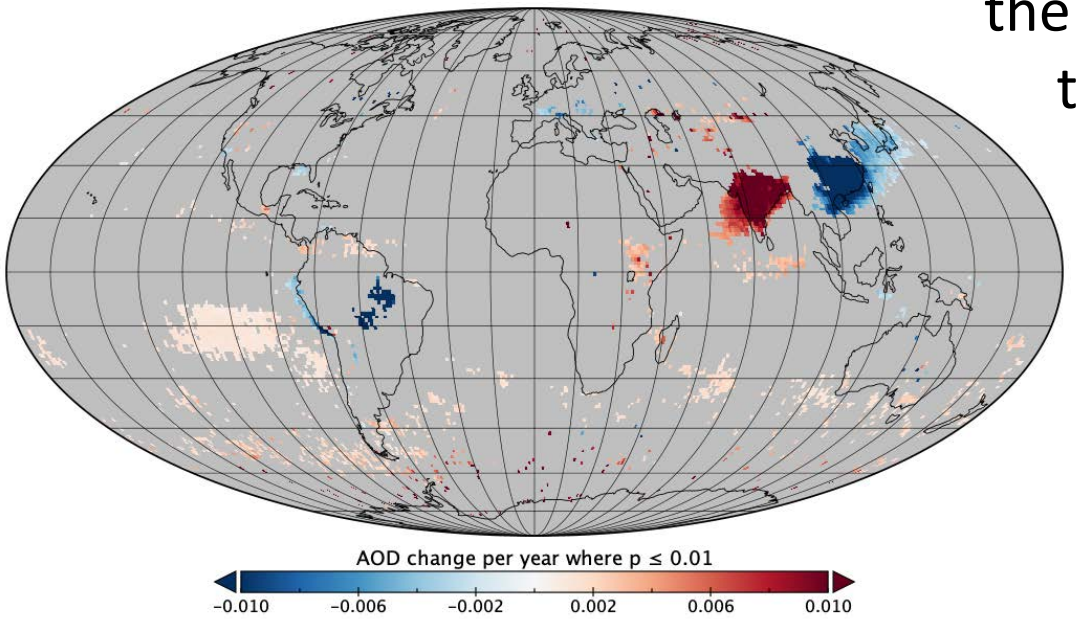


Trend in 0.55 μm AOD, Aqua, July 2002 – July 2022 JJA

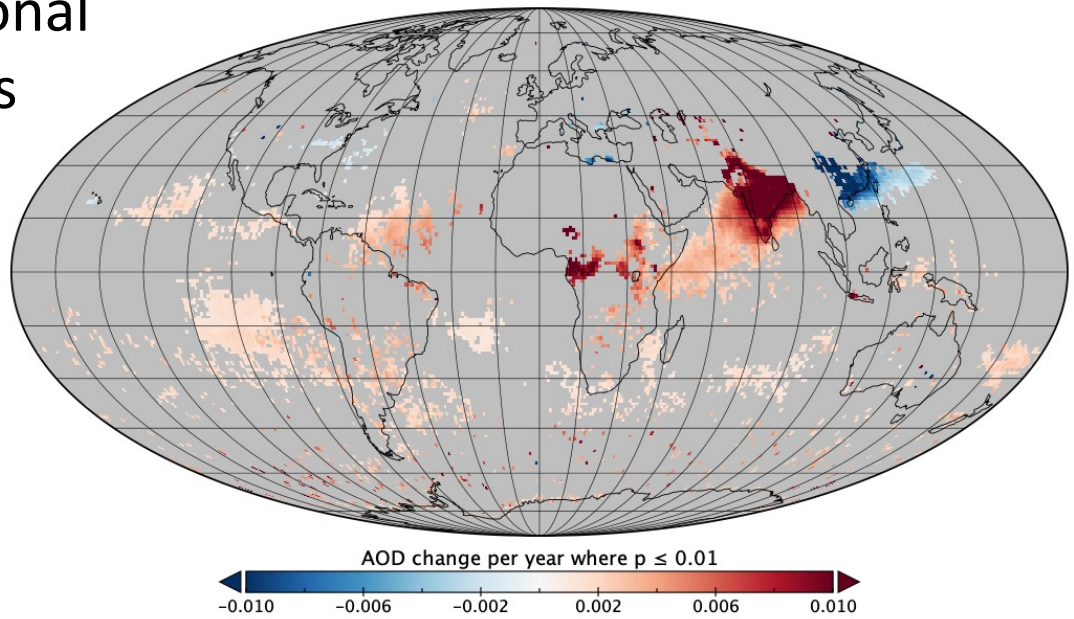


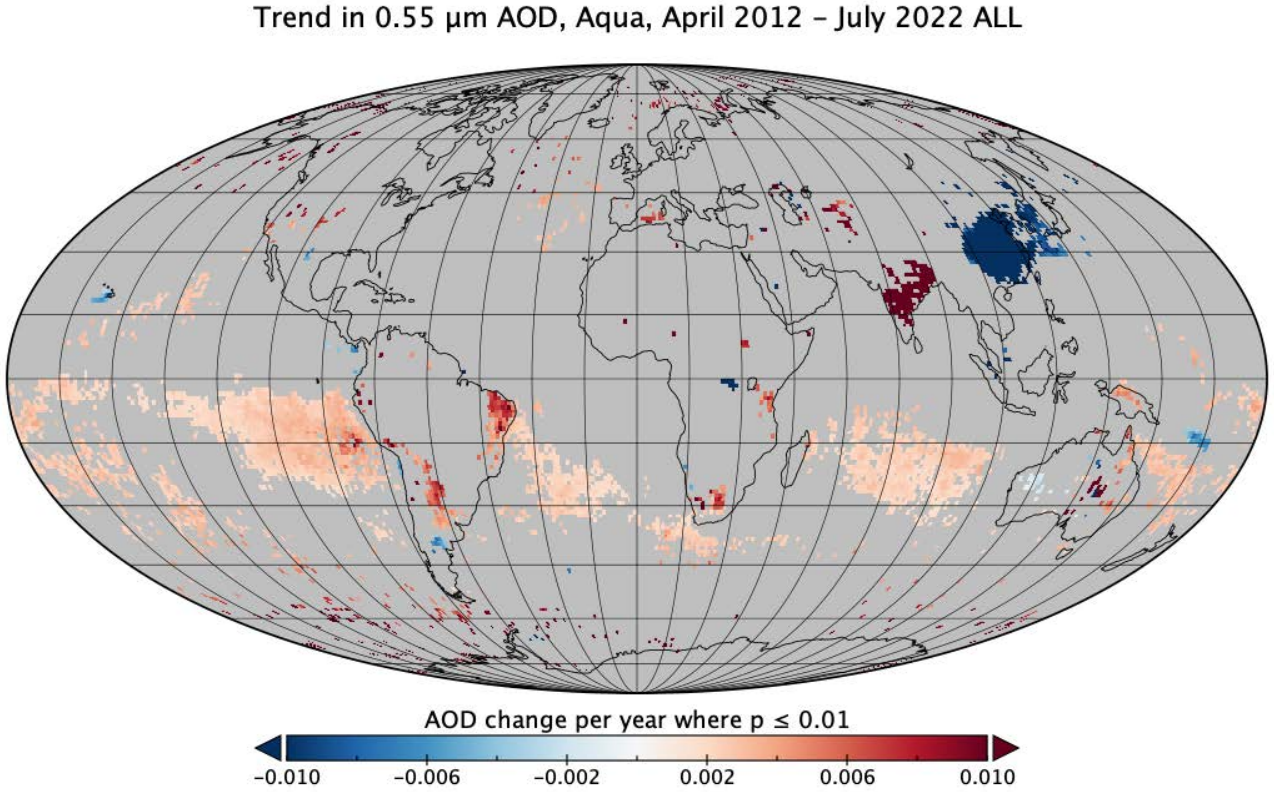
Many aerosol events are seasonal. So are the regional trends

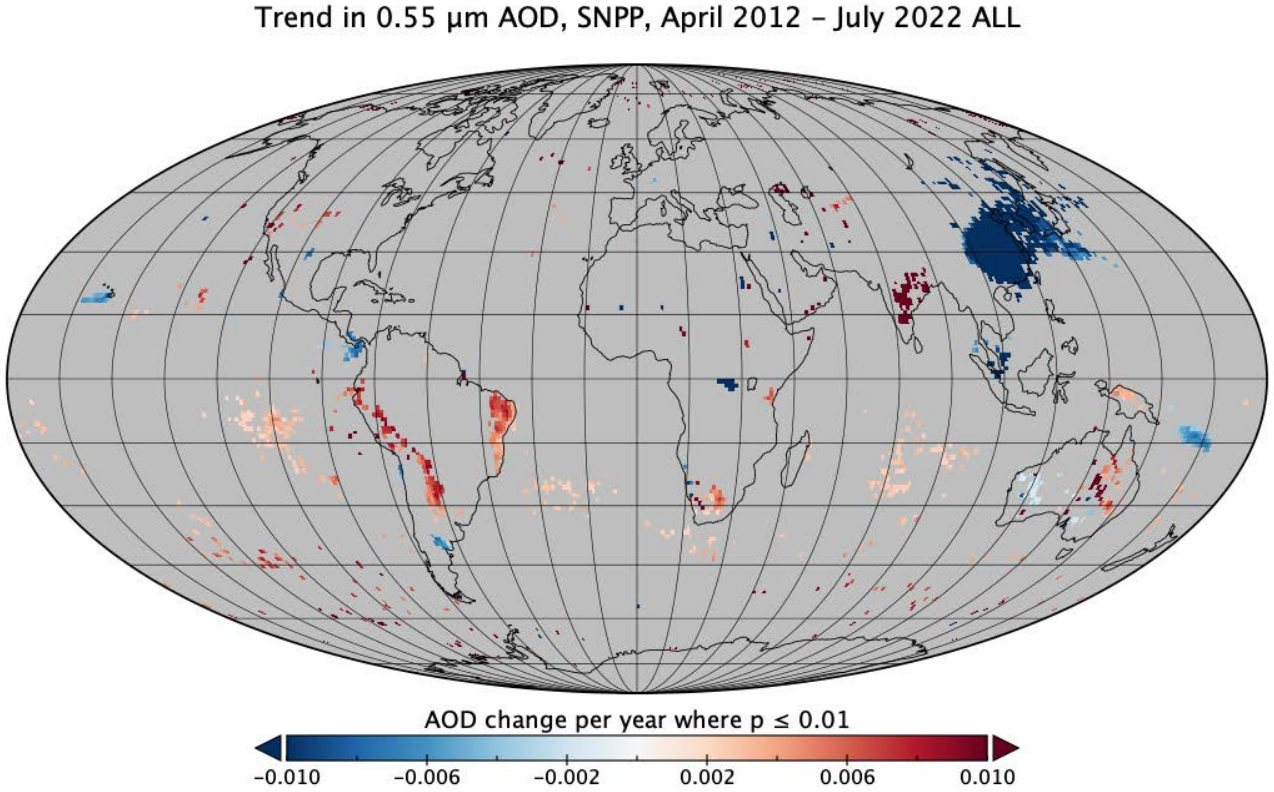
Trend in 0.55 μm AOD, Aqua, July 2002 – July 2022 SON



Trend in 0.55 μm AOD, Aqua, July 2002 – July 2022 DJF





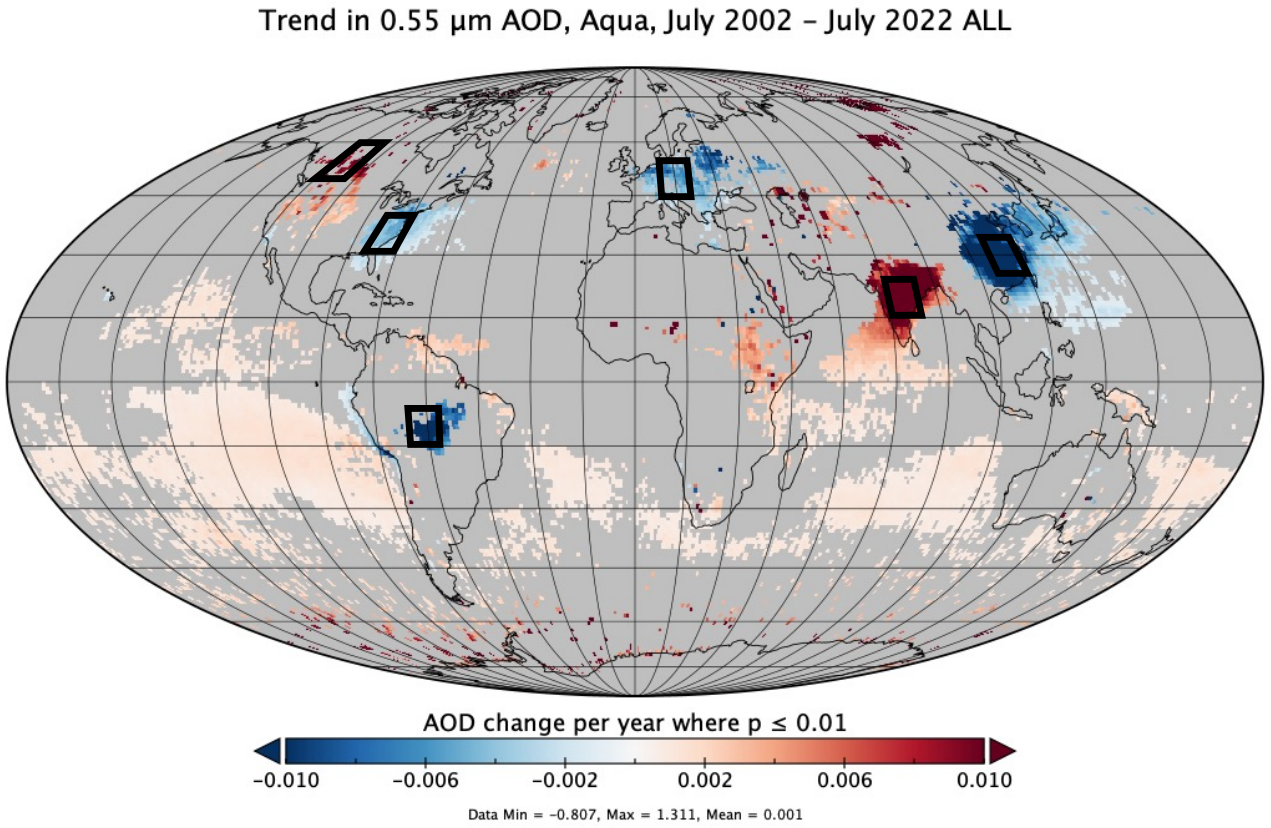


Slope of the linear regression where p ≤ 0.01, this time only since the beginning of the VIIRS SNPP record

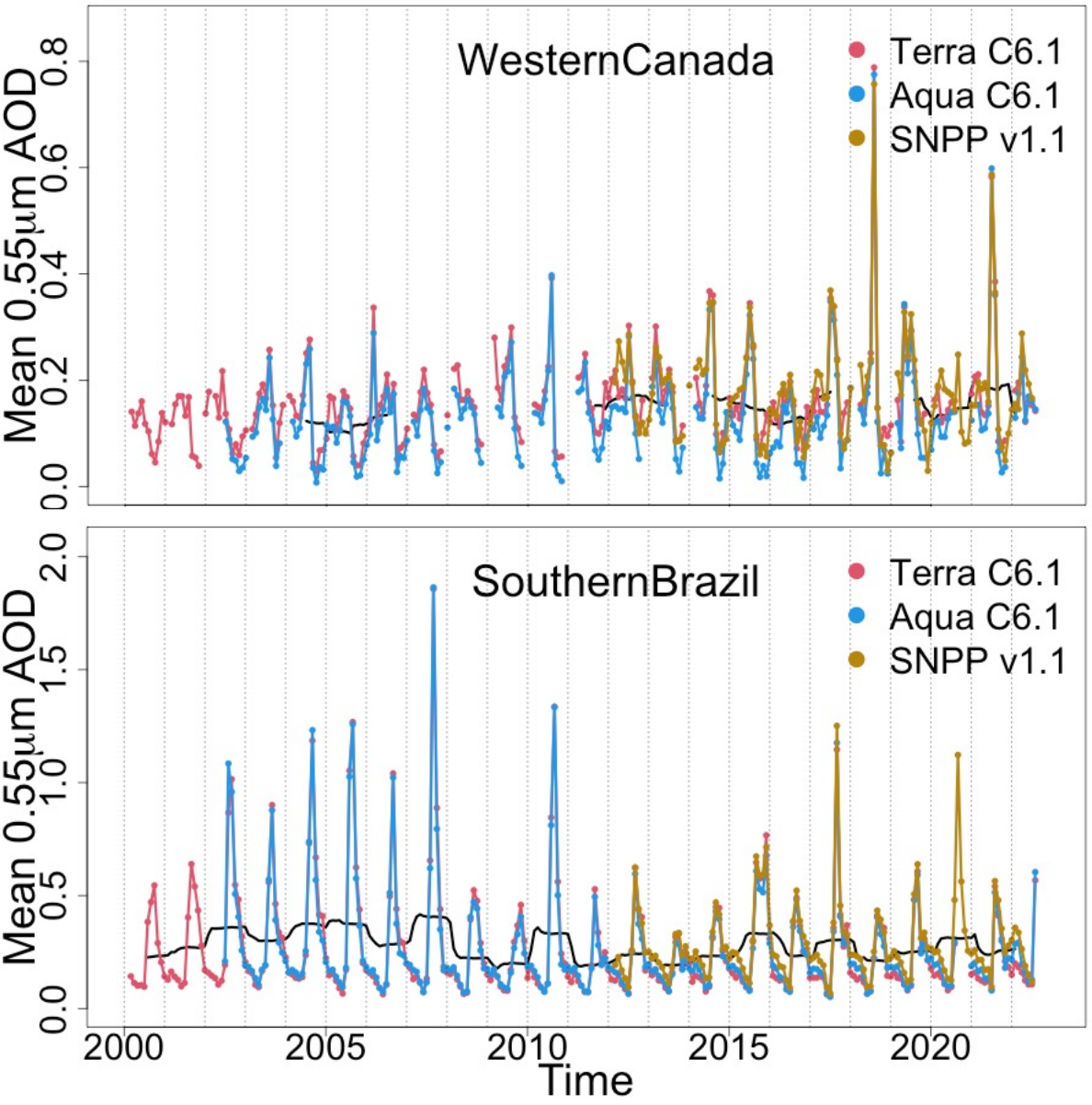
- For 10-year record, half as much data = fewer grid cells meet a given significance threshold, generally sharper slopes where they do
- Note that the 20-year record found strong trends over India and eastern China for all four seasons, so they are easier to find in the shorter record
- However, not 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 mostly agrees with Terra and Aqua, and can continue the record beyond MODIS

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

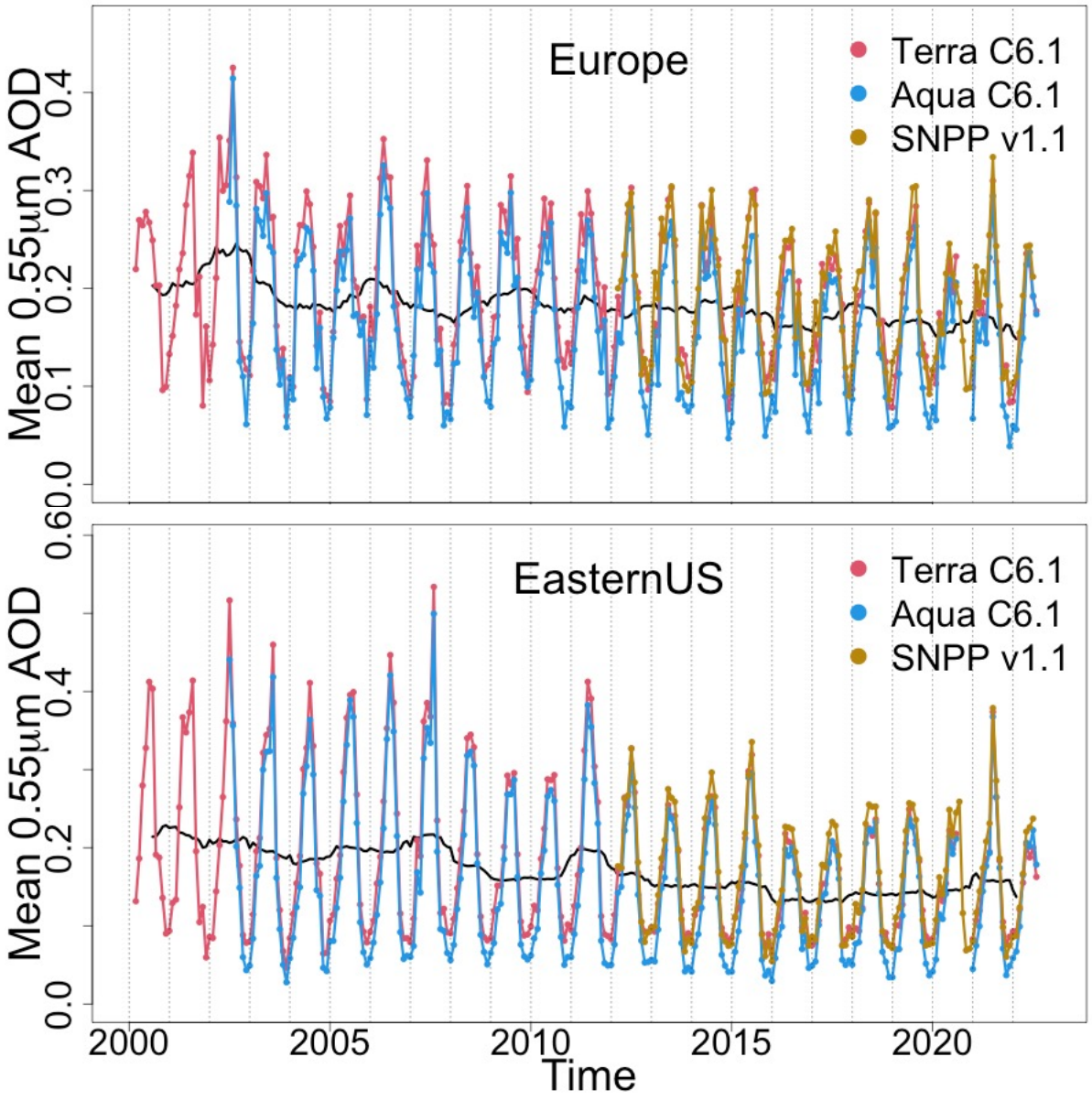


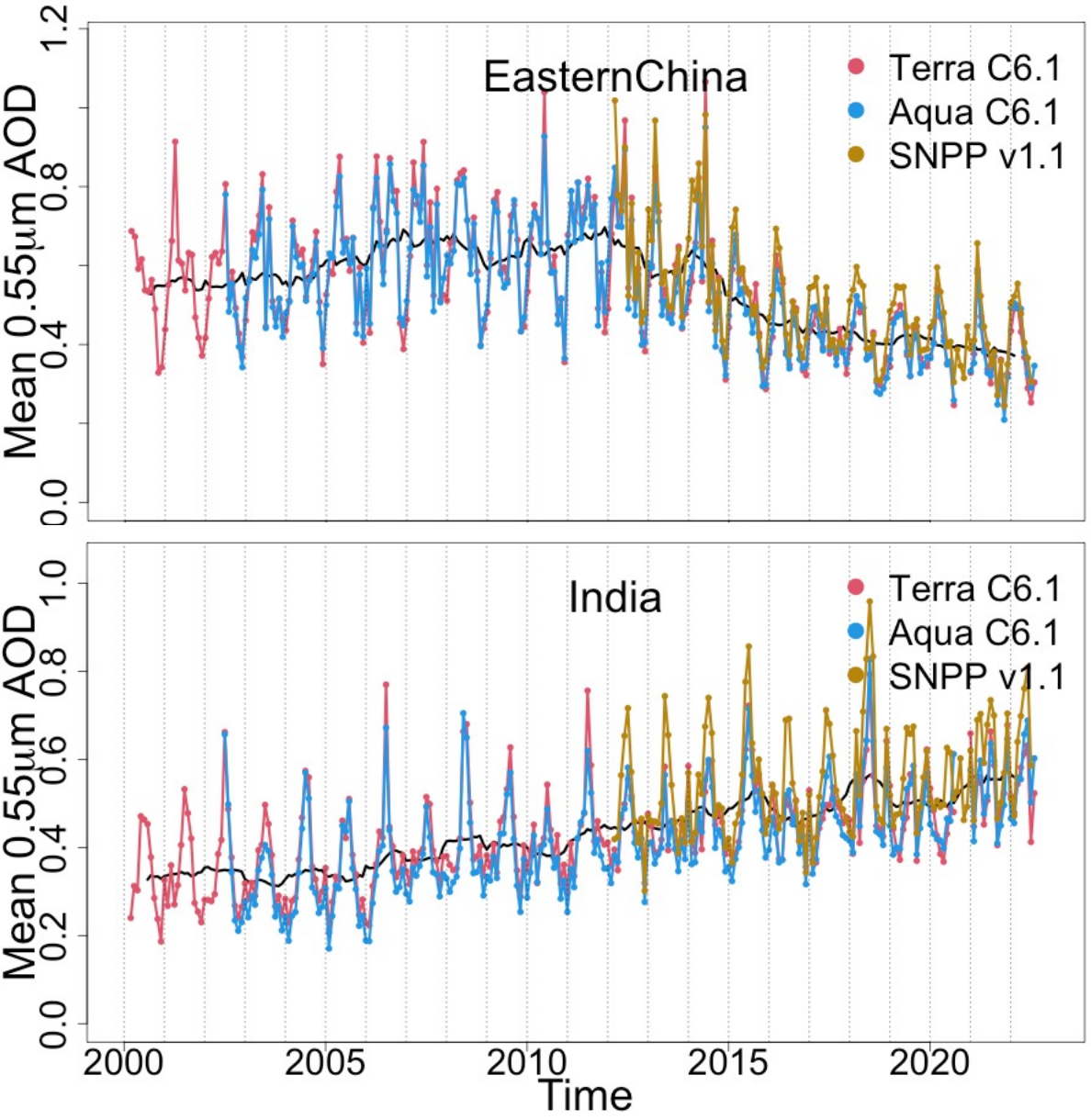
Wildfire seasons

- In western Canada and southern Brazil, the apparent 20-year trend is driven by extreme (boreal) summers or (austral) springs, respectively, in individual years
- Autumn and winter are nearly flat over time
- Interannual variability during fire season is much greater than the typical seasonal variability within one year
- Difficult to pick out the timing for policy changes, etc. during the 20-year period that could explain changes in AOD

Steady reductions

- Europe and the eastern US show high seasonality and low interannual variability
- Autumn and winter still show almost no trend, but spring and summer show a nearly linear decrease in AOD over time
- Both regions have been reducing industrial emissions since before the 2000s
- Possible flattening in the 2010s may help explain the lack of a significant AOD trend since SNPP
- Spike in summer 2021 may be wildfires



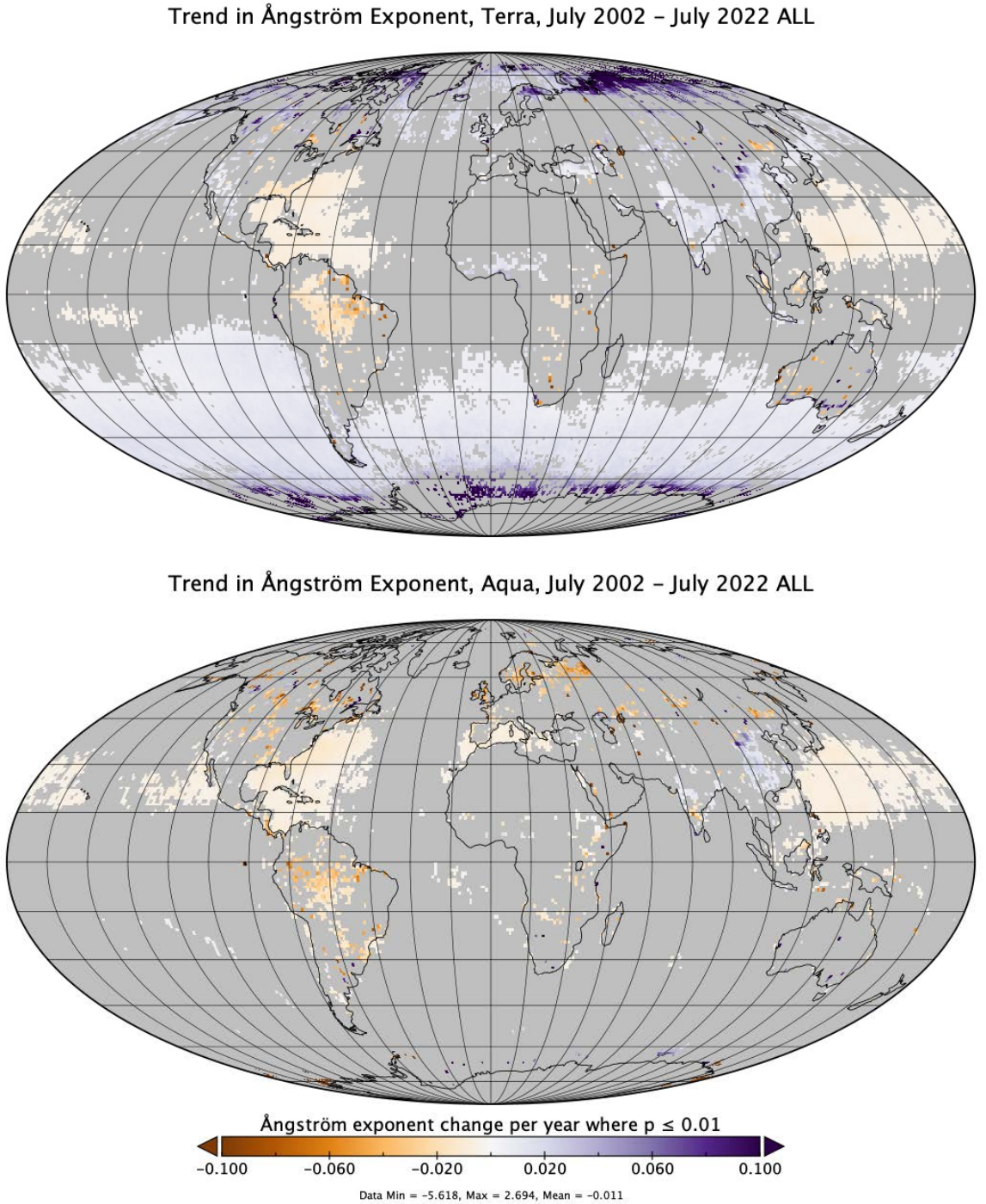


Strong four-season trends

- Eastern China and India show less predictable seasonal cycles than the four regions from previous slides
- Coherent interannual change in all four seasons
- China began intensive efforts to improve air quality c. 2010, and it shows as a turning point in the AOD record
- India shows emissions increase since before the 2000s, with increasing interannual variability since c. 2014

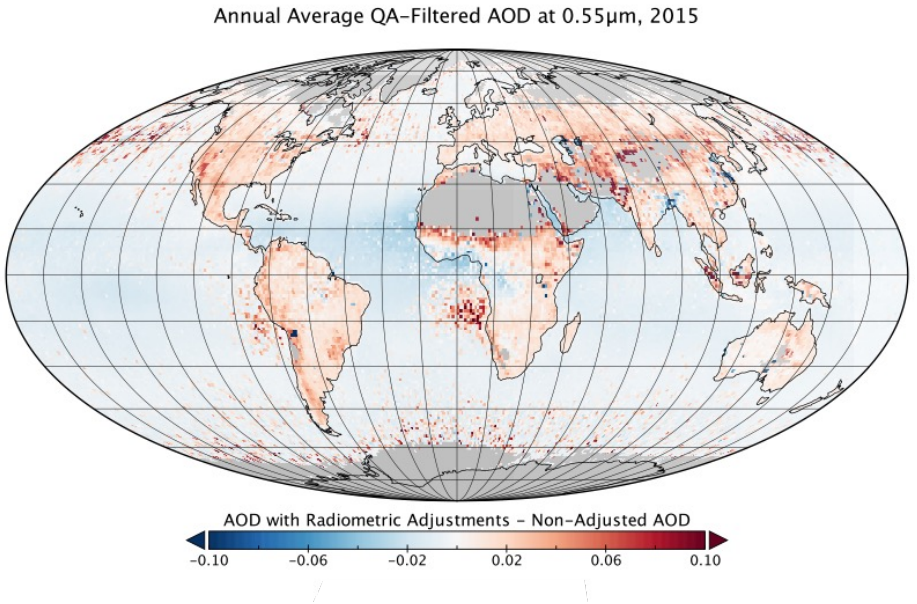
Ångström exponents

- 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
- May indicate 20 years of subtle, wavelength-specific sensor drift



Aqua/SNPP Calibration Adjustments

VIIRS SNPP Band	Sayer et al. (2016)
M3 (0.49 µm)	0.990
M4 (0.55 µm)	0.956
M5 (0.67 µm)	0.937
M7 (0.86 µm)	0.962
M8 (1.24 µm)	1.021
M10 (1.60 µm)	0.980
M11 (2.26 µm)	0.933

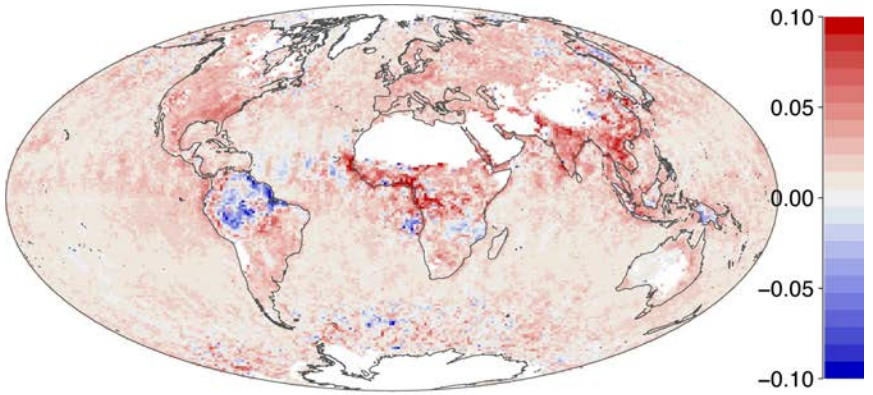


- Applying adjustment factors to L1b reflectances before retrieval can bring SNPP AOD closer to Aqua or NOAA-20, reducing the positive bias compared to AERONET
- Sayer et al. (2016) factors were almost constant over time but varied by wavelength
- New Lyapustin et al. (*Remote Sensing*, submitted) includes new adjustment factors and trend adjustment

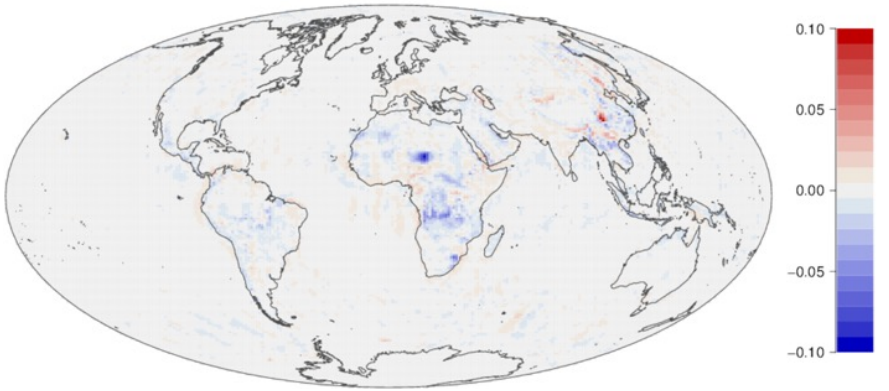
MODIS-VIIRS Continuity for the AOD Record

- Without calibration adjustment, VIIRS Dark Target AODs show offsets comparable to the offset between MODIS Terra and Aqua, which is mostly due to calibration rather than diurnal cycle differences in AOD or sampling
- Applications that already use mixed Terra and Aqua retrievals can consider SNPP and NOAA-20 in continuity with MODIS without adjustment
- Applications that require a single seamless record may need calibration adjustments to bring SNPP closer to a reference sensor
- The reference sensor must be current if adjustment factors change over time—SNPP/Aqua factors will become outdated after the end of the Aqua record
- Transition from MODIS Aqua to VIIRS NOAA-20 as the reference sensor would keep the calibration closest to AERONET

C6 Terra-Aqua 0.55 µm AOD, 2008

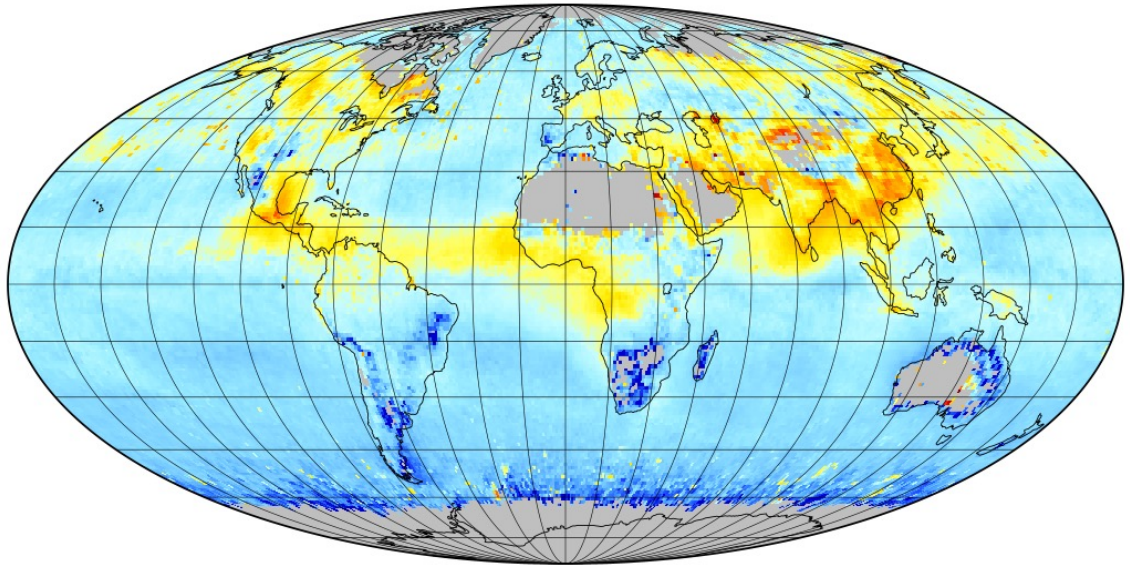


MERRA AM-PM on MODIS Swaths



Levy et al. 2018

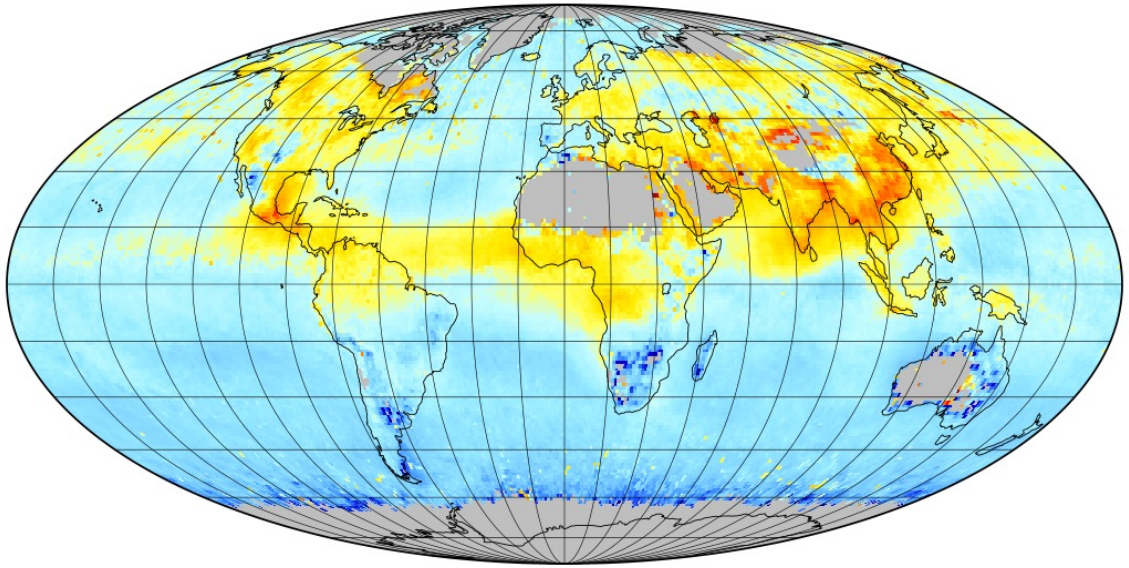
AERDT_L2_VIIRS_NOAA20 Test, May 2019



QA-Filtered Aerosol Optical Depth

0.01 0.10 1.00

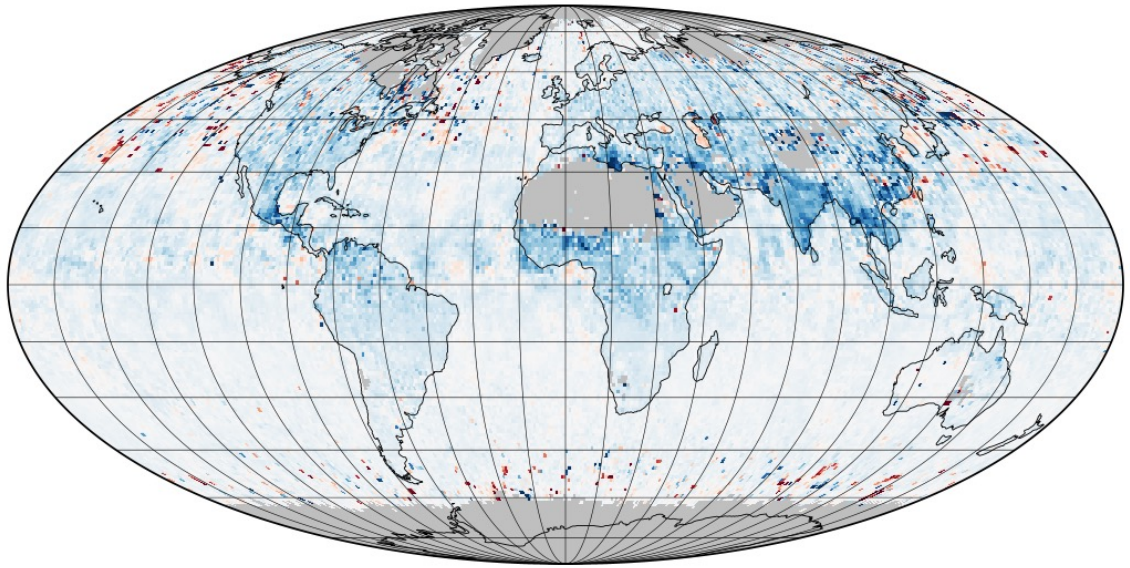
AERDT_L2_VIIRS_SNPP Update Test, May 2019



QA-Filtered Aerosol Optical Depth

0.01 0.10 1.00

AERDT Update Test NOAA20 – SNPP, May 2019



Difference in QA-Filtered Aerosol Optical Depth

-0.30 -0.18 -0.06 0.06 0.18 0.30

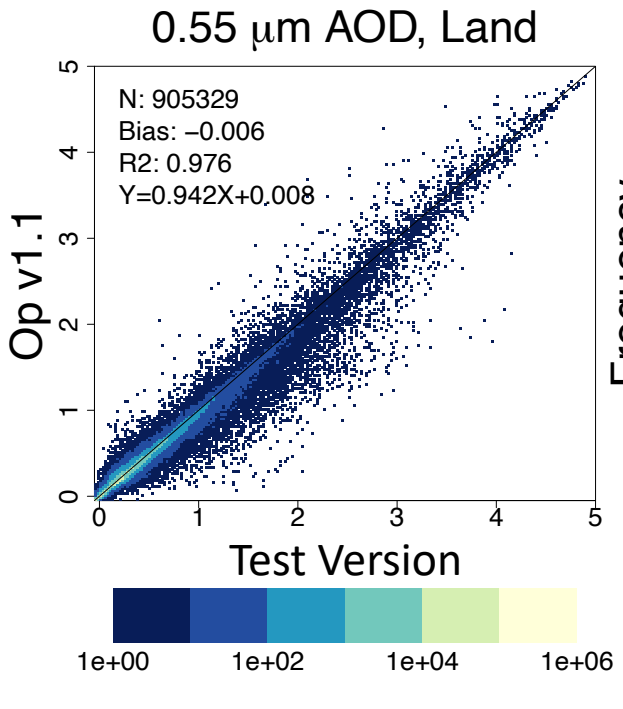
Monthly average AOD for test versions of Dark Target NOAA-20 and SNPP, May 2019

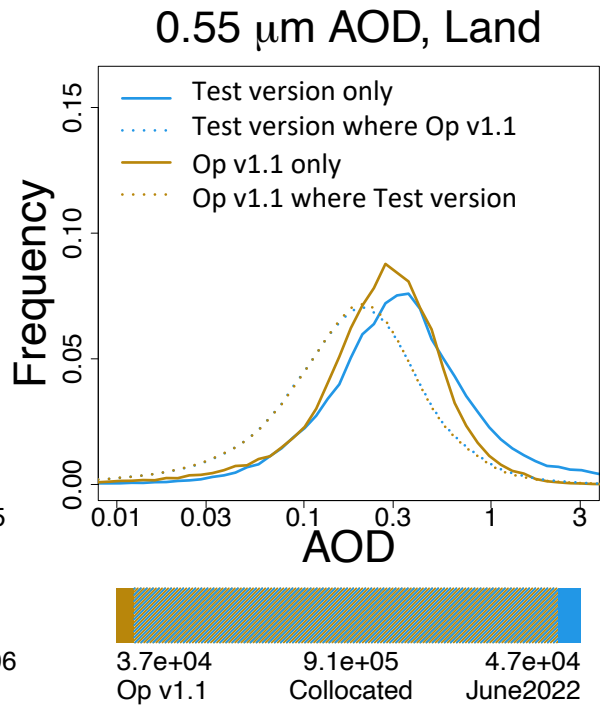
- Algorithm now uses image resolution L1b for cloud masking, GMAO for ancillary data, 1.64µm channel for snow mask
- Fixes several bugs, including blank stripes caused by cirrus flag/quality flag issue
- Now reports Mean_Reflectance_Land and STD_Reflectance_Land for all seven channels
- Metadata expansion and clarification

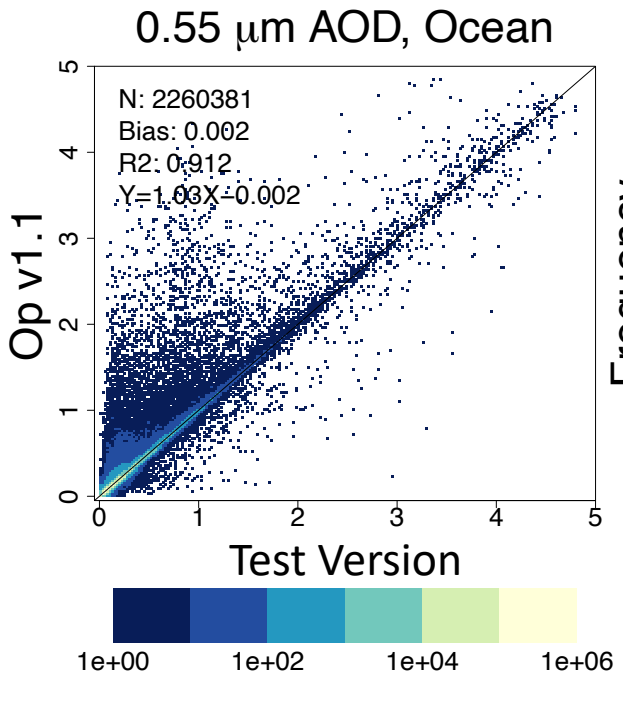
Differences between Dark Target versions

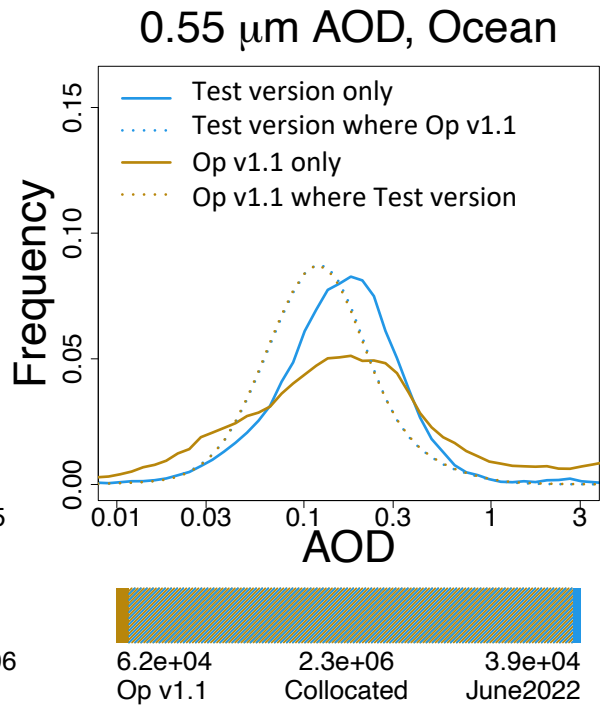
Scatter plots and histograms taken from 1°×1° gridded daily average AODs, May-Aug 2019

- Overall distribution of QA-filtered AOD values remains the same
- Higher-resolution cloud mask can retrieve closer to cloud edges with less cloud contamination
- No significant change to spatial coverage on the grid scale
- Other algorithm changes have less impact on AOD distribution
- Grid cells where both versions retrieve have nearly identical AOD distribution
- Grid cells where only one version retrieves are rare, especially over ocean, and both tend toward higher AODs





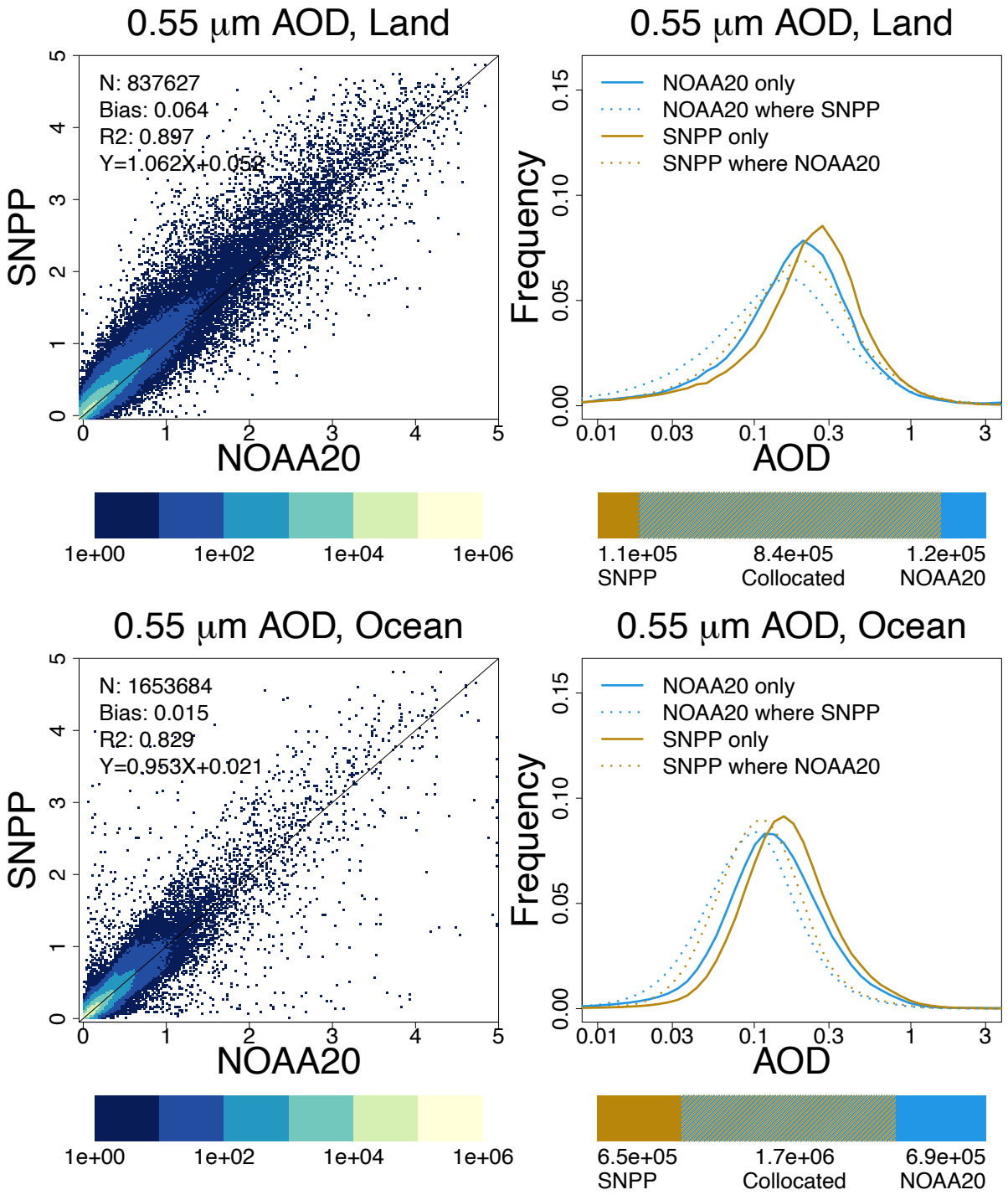




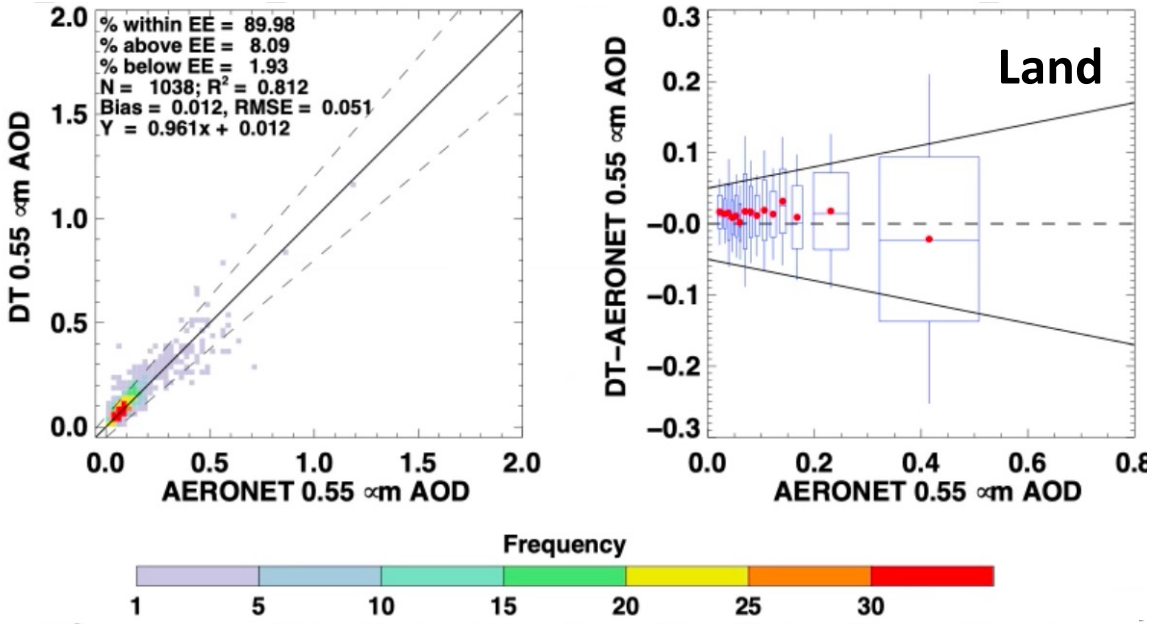
Differences between VIIRS sensors

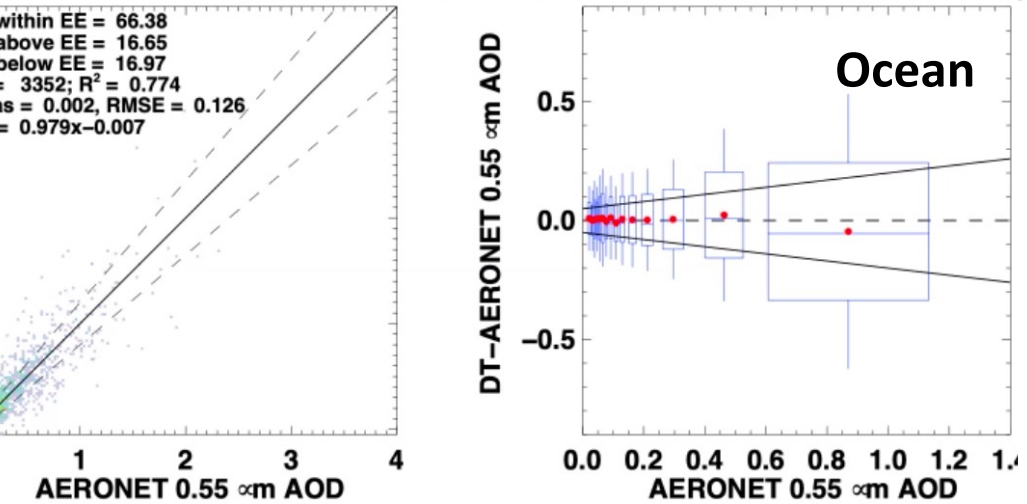
Scatter plots and histograms taken from 1°×1° gridded daily average AODs, May-Aug 2019

- SNPP and NOAA-20 have the same equatorial crossing time but fly half an orbit apart, so true collocation is rare
- Matched grid cells may come from multiple orbits, especially at swath edges
- Single-sensor retrievals are more common
- Correlation is as expected for Dark Target on different sensors
- AOD distribution is higher for SNPP than for NOAA-20, whether for matched grid cells or single-sensor retrievals
- SNPP is biased high compared to AERONET. Is NOAA-20 too low, or just low enough?

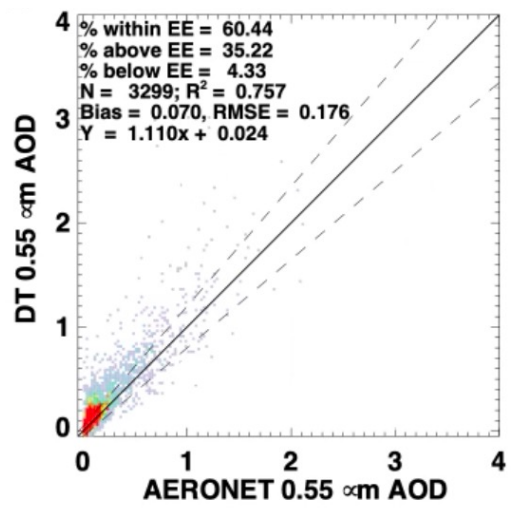


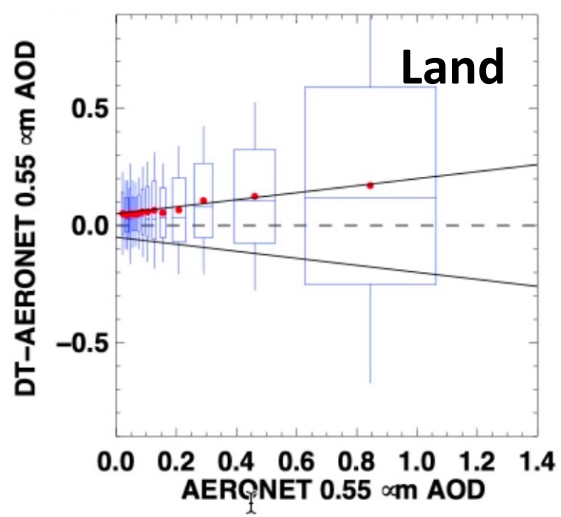
NOAA-20 DT vs. AERONET, Jan-Feb 2019

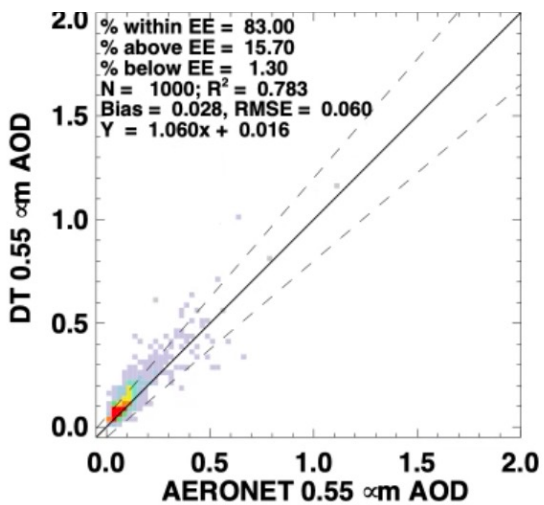


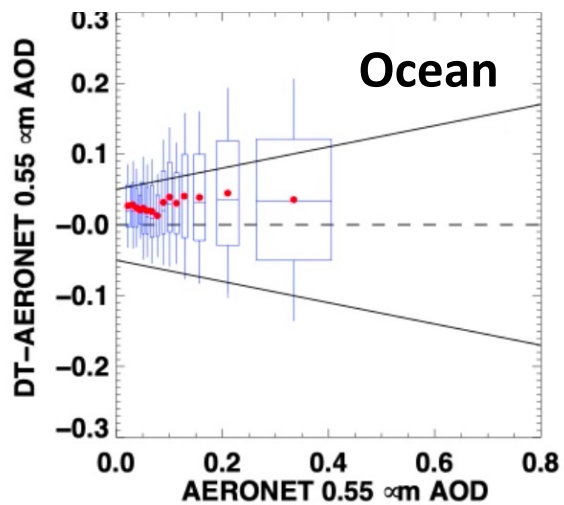


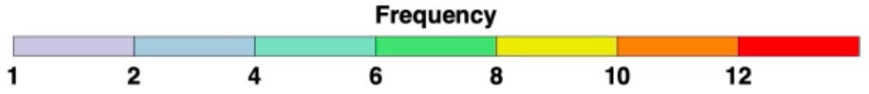
SNPP DT vs. AERONET, Jan-Feb 2019

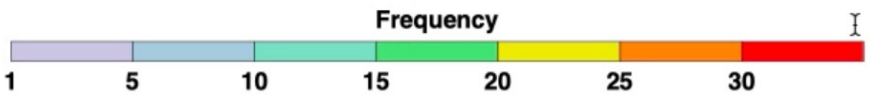






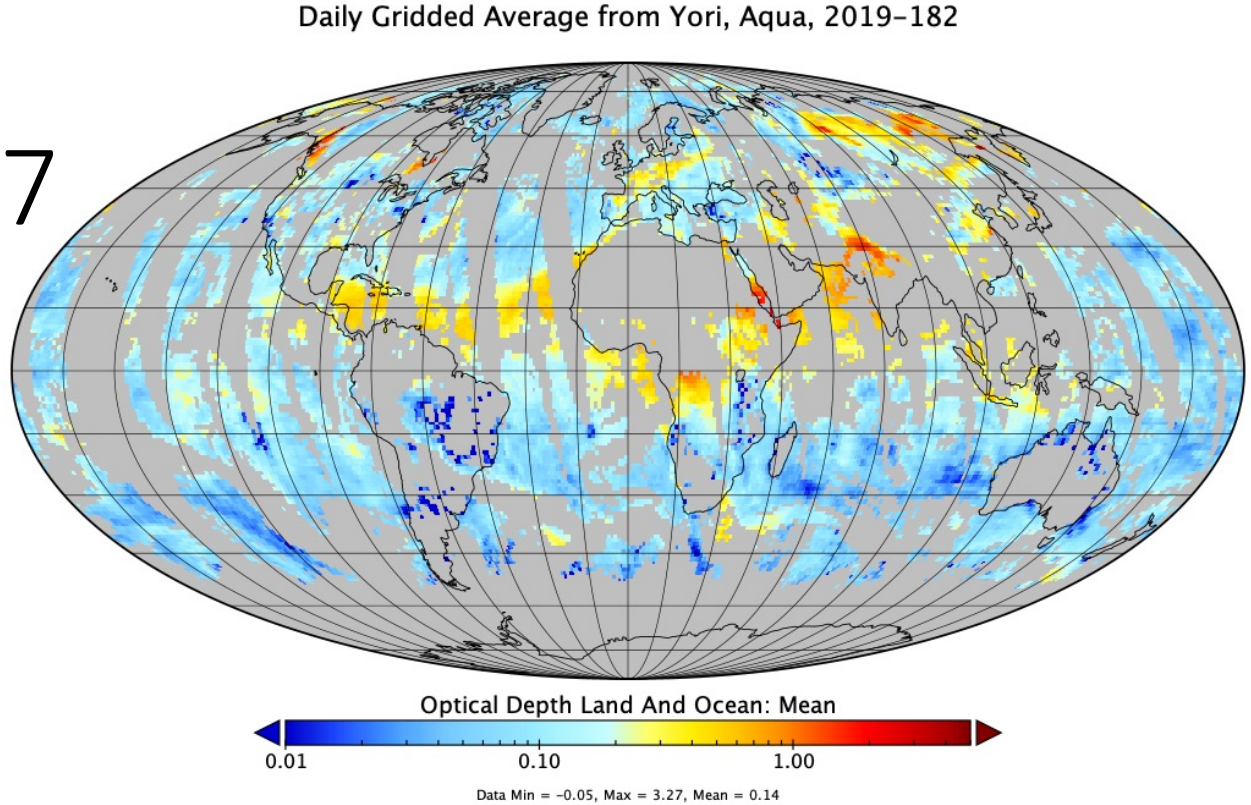


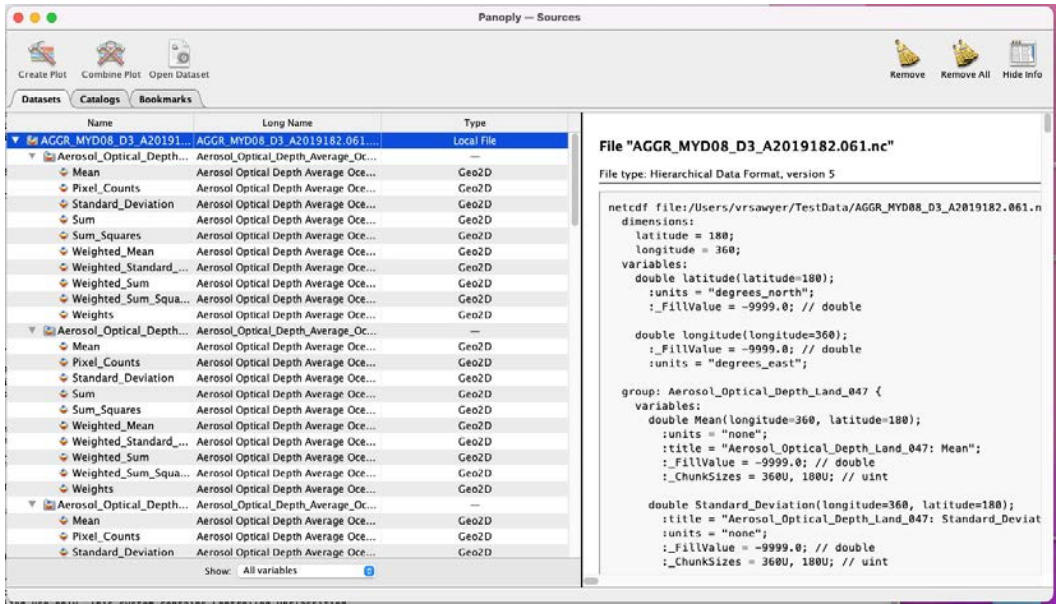




VIIRS v2.0 and MODIS C7

- Dark Target algorithm development now uses a single “package” for all sensors
- Output format is netCDF4, with the same file structure for all sensors and sensor-specific differences only in metadata
- All algorithm updates for VIIRS v2.0 will also apply to MODIS C7 (using MODIS high-resolution bands, etc.)
- L3 daily and monthly gridded averages under development via Yori, for both VIIRS v2.0 and MODIS C7
- VIIRS v2.0 will be released this spring
- VIIRS NOAA-21 just became operational and should require minimal changes for the DT port
- MODIS C7 release: TBD





Conclusions

- The data record for MODIS aerosol optical depth is not yet long enough to detect global trends, but it is long enough to see regional trends with good agreement between Terra and Aqua
- Although fewer significant trends are visible in the 10-year record, sensor agreement extends to SNPP
- AOD time series from specific regions with significant trends line up with known changes in aerosol emissions, such as wildfire seasons and economic and policy changes
- The lack of agreement in Ångström exponent trends shows the importance of wavelength-specific calibration differences, which adjustment factors can improve
- Dark Target for VIIRS can extend the record beyond the end of MODIS, and has a major update coming this spring for SNPP and NOAA-20 (and NOAA-21 soon after)
- NOAA-20 is calibrated lower than SNPP, and may be a better match to AERONET
- MODIS C7 will use the same algorithm “package” as VIIRS and includes all algorithm updates from VIIRS v2.0