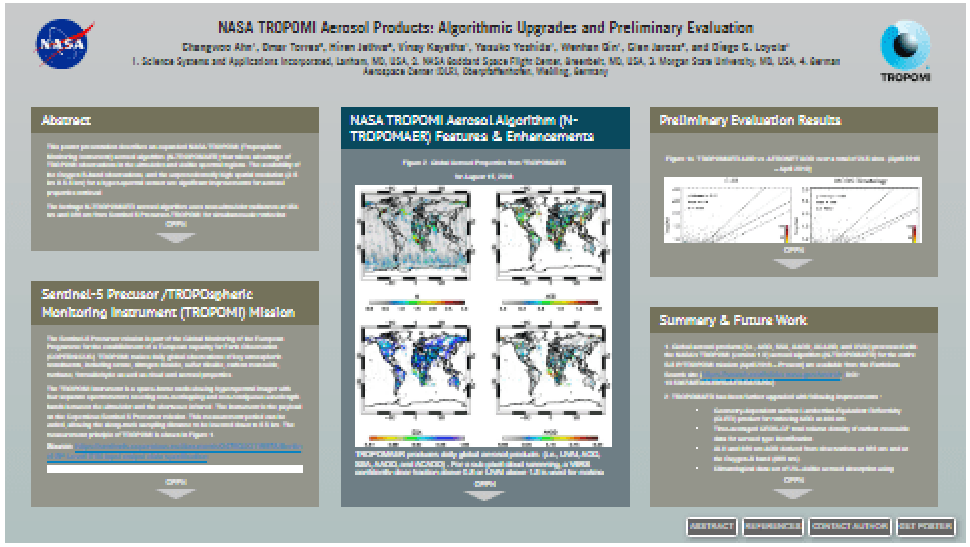
NASA TROPOMI Aerosol Products: Algorithmic Upgrades and Preliminary Evaluation



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TROPOMI

PRESENTED AT:

ABSTRACT

This poster presentation describes an expanded NASA TROPOMI (Tropospheric Monitoring Instrument) aerosol algorithm (N-TROPOMAER) that takes advantage of TROPOMI observations in the ultraviolet and visible spectral regions. The availability of the Oxygen B-band observations, and the unprecedentedly high spatial resolution (3.5 km X 5.5 km) for a hyper-spectral sensor are significant improvements for aerosol properties retrieval.

The heritage N-TROPOMAER aerosol algorithm uses near-ultraviolet radiances at 354 nm and 388 nm from Sentinel 5 Precursor-TROPOMI for simultaneously retrieving aerosol optical depth (AOD), single-scattering albedo (SSA), aerosol absorption optical depth (AAOD), and above-cloud aerosol optical depth (ACAOD) at 388 nm, along with the qualitative UV aerosol index (UVAI). We have expanded the inversion capability beyond the UV, to retrieve AOD at 466 nm and 680 nm. Surface reflectance effects at 466 nm are accounted for using a recently developed geometry-dependent surface Lambertian-equivalent reflectivity (GLER) product, which is derived from the top-of-atmosphere radiance computed with Rayleigh scattering and surface bidirectional reflectance distribution function (BRDF) for the exact viewing geometry at the sensor's spatial resolution. Aerosol layer height (ALH) and 680 nm AOD are simultaneously derived from observations at 680 nm and at the Oxygen-B band (688 nm). Another important upgrade is the use of time averaged total column carbon monoxide from the NASA GEOS-CF (Global Earth Observing System Composition Forecast) as a tracer of carbonaceous aerosols.

SENTINEL-5 PRECUSOR /TROPOSPHERIC MONITORING INSTRUMENT (TROPOMI) MISSION

The Sentinel-5 Precursor mission is part of the Global Monitoring of the European Programme for the establishment of a European capacity for Earth Observation (COPERNICUS). TROPOMI makes daily global observations of key atmospheric constituents, including ozone, nitrogen dioxide, sulfur dioxide, carbon monoxide, methane, formaldehyde as well as cloud and aerosol properties.

The TROPOMI instrument is a space-borne nadir-viewing hyperspectral imager with four separate spectrometers covering non-overlapping and non-contiguous wavelength bands between the ultraviolet and the shortwave infrared. The instrument is the payload on the Copernicus Sentinel 5 Precursor mission. This measurement period can be varied, allowing the along-track sampling distance to be lowered down to 5.5 km. The measurement principle of TROPOMI is shown in Figure 1.

Source: https://sentinels.copernicus.eu/documents/247904/3119978/Sentinel-5P-Level-01B-input-output-data-specification (https://sentinels.copernicus.eu/documents/247904/3119978/Sentinel-5P-Level-01B-input-output-data-specification)

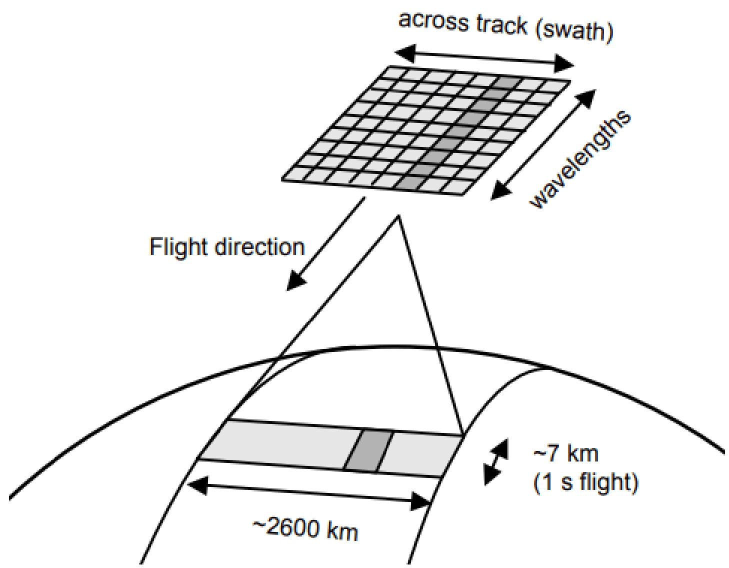


Figure 1: TROPOMI measurement principle

Spectrometer	**UV**		**UVIS**		**NIR**		**SWIR**	
Band ID	1	2	3	4	5	6	7	8
Performance range* [nm]	270–320		320–490		710–775		2305–2385	
Spectral range [nm]	267–300	300–332	305–400	400–499	661–725	725–786	2300–2343	2343–2389
Spectral resolution [nm]	0.45–0.5		0.45–0.65		0.34–0.35		0.227	0.225
Slit width* [μm]	560	560	280	280	280	280	308	308
Spectral dispersion [nm/pixel]	0.065		0.195		0.126		0.094	
Spectral magnification*	0.327	0.319	0.231	0.231	0.263	0.263	0.025	0.021

Table 1: Main spectral characteristics of the four TROPOMI spectrometers and the definition of the TROPOMI spectral bands with identifiers 1–8. Parameters marked with $\star$ are design values. The other values are listed as calibrated pre-flight.

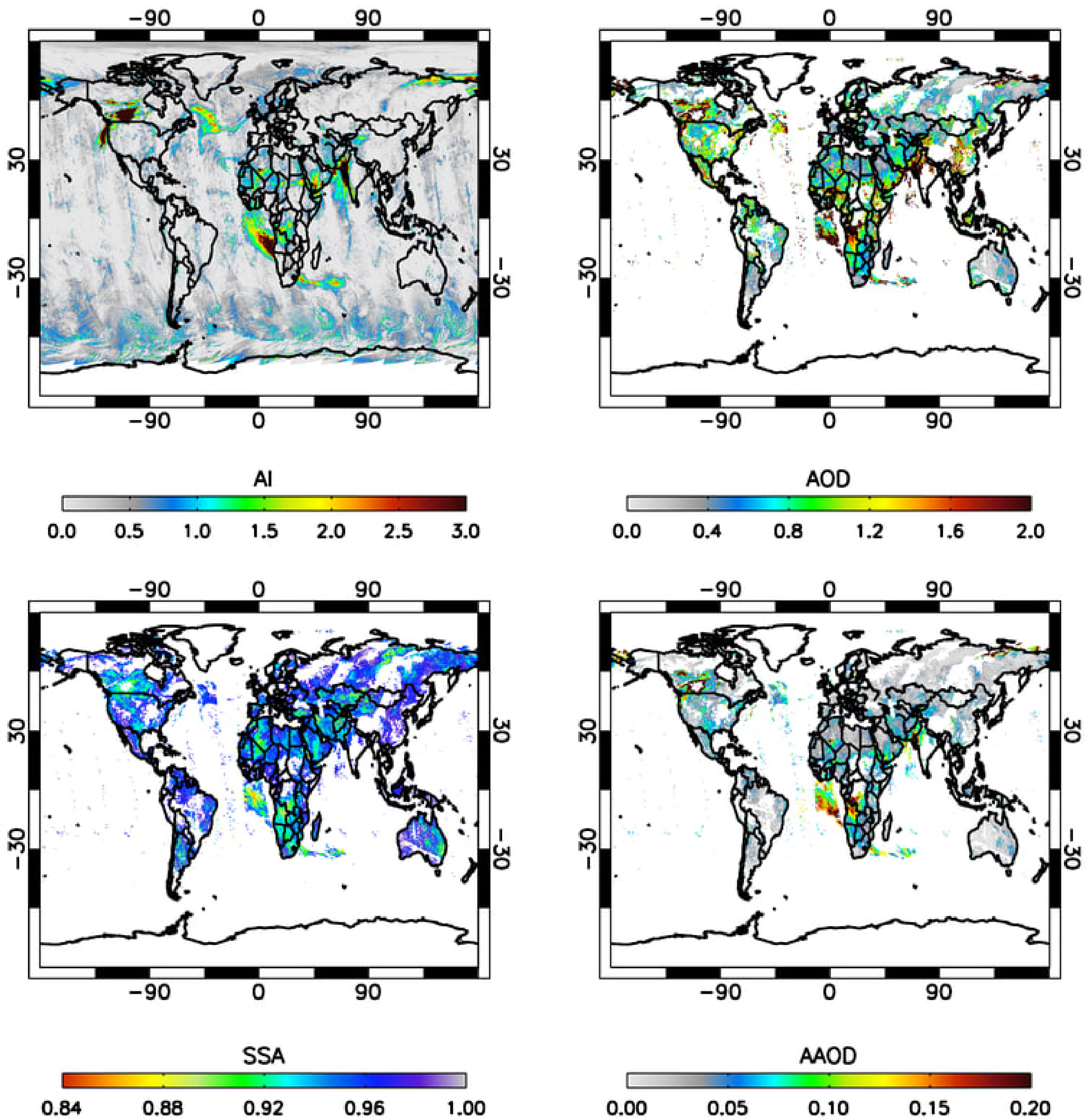
Band	DEM	Binning factor	Across-track ground pixel size
1	UV	4...16	28 ... 60 km
2	UV	1...2	3.5 ... 15 km
3	UVIS	1...2	3.5 ... 15 km
4	UVIS	1...2	3.5 ... 15 km
5	NIR	1...2	3.5 ... 15 km
6	NIR	1...2	3.5 ... 15 km
7	SWIR	n/a	7 ... 34 km
8	SWIR	n/a	7 ... 34 km

Table 2: Binning factors and across-track ground pixel sizes for Earth radiance measurements.

NASA TROPOMI AEROSOL ALGORITHM (N-TROPOMAER) FEATURES & ENHANCEMENTS

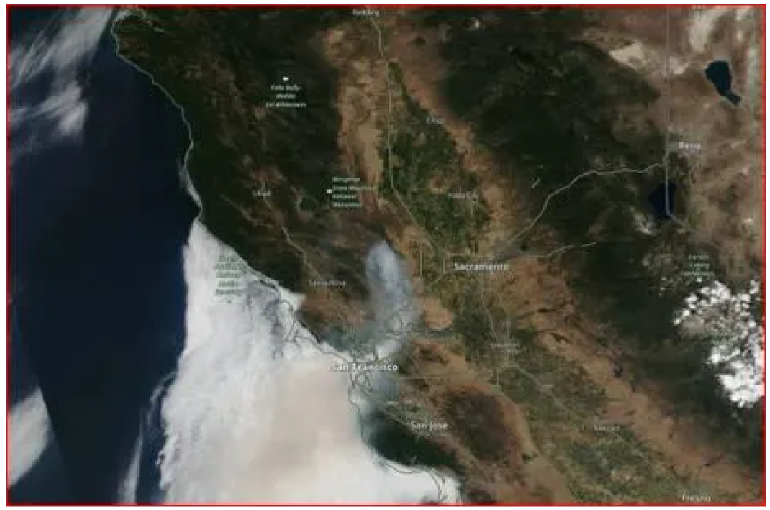
Figure 2. Global Aerosol Properties from TROPOMAER

for August 15, 2018



TROPOMAER produces daily global aerosol products (i.e., UVAI, AOD, SSA, AAOD, and ACAOD) . For a sub-pixel cloud screening, a VIIRS confidently clear fraction above 0.8 or UVAI above 1.5 is used for making AOD, SSA, and AAOD maps.

Figure 3a. Advatage of TROPOMI with a High Spatial Resolution for Detecting the Smoke Plume from Wildfires over the Bay Area in California for July 1, 2018



NASA World View Suomi NPP/VIIRS RGB Imagery for July 1, 2018.

Figure 3b. UVAI (TROPOMAER vs. OMPS)

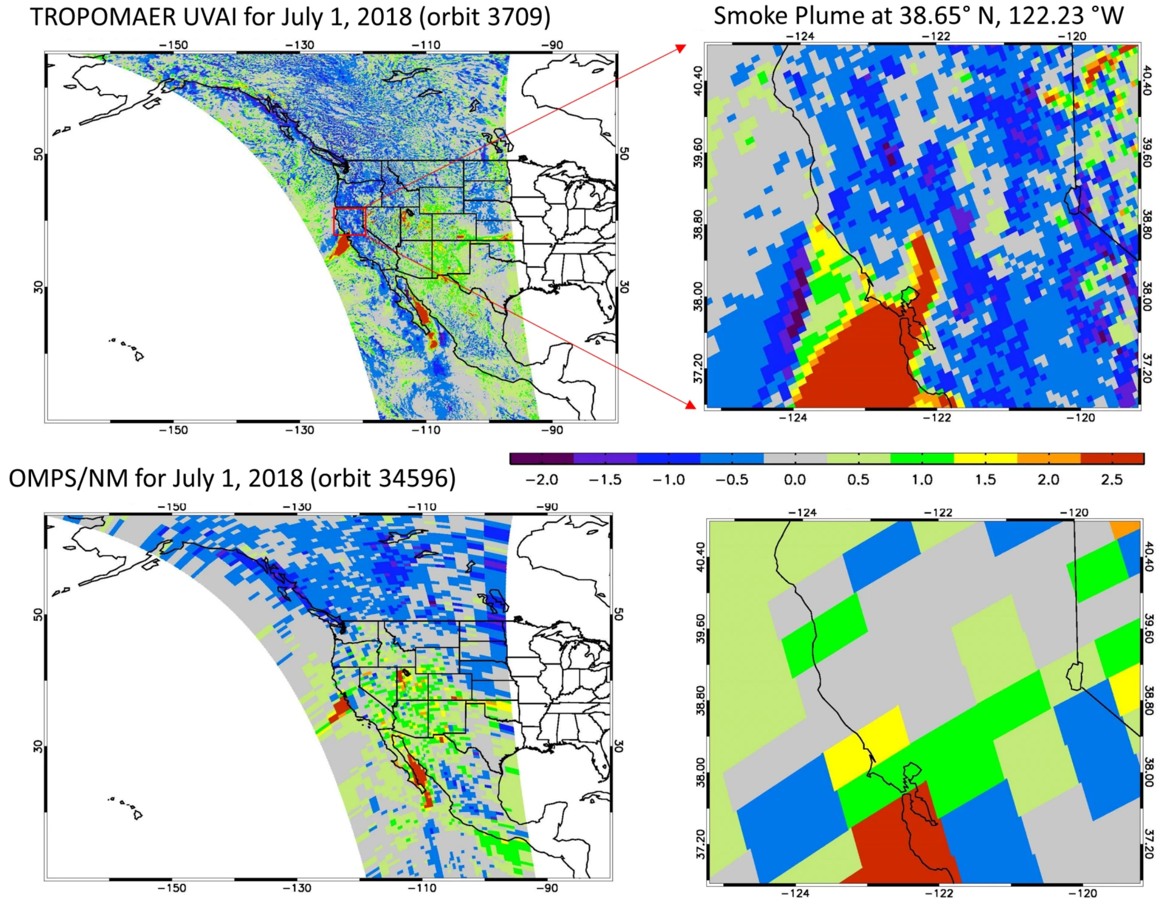


Figure 4. Time series of Monthly Average OMI 388 nm AOD over the Two regions for the last 17 years, along with the overlapping TROPOMI AOD Observations, illustrating the importance of the continuity of the long-term record.

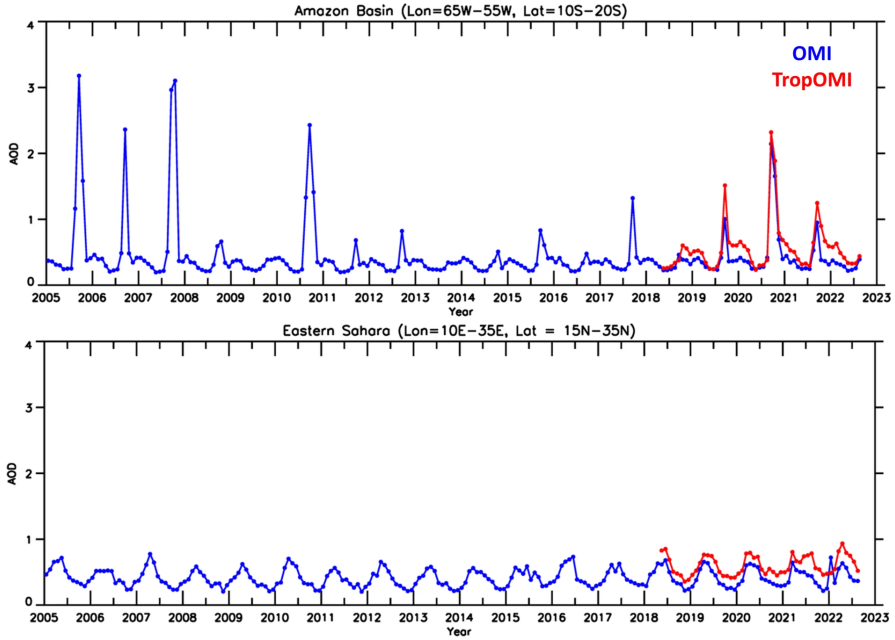
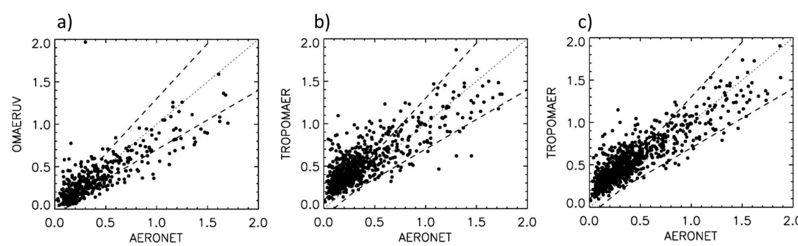


Figure 5. Validiation of OMI and TROPOMI AOD with AERONET AOD



AERONET–satellite comparisons of OMI-retrieved 388 nm AOD (a), TROPOMI using heritage cloud screening (b), and TROPOMI using VIIRS cloud mask (c). The dotted line indicates the one-to-one line, and dashed lines represent expected retrieval uncertainty (largest of 0.1 % or 30 %).

Table 1. AERONET sites used for the AOD validation analysis presented in this study.

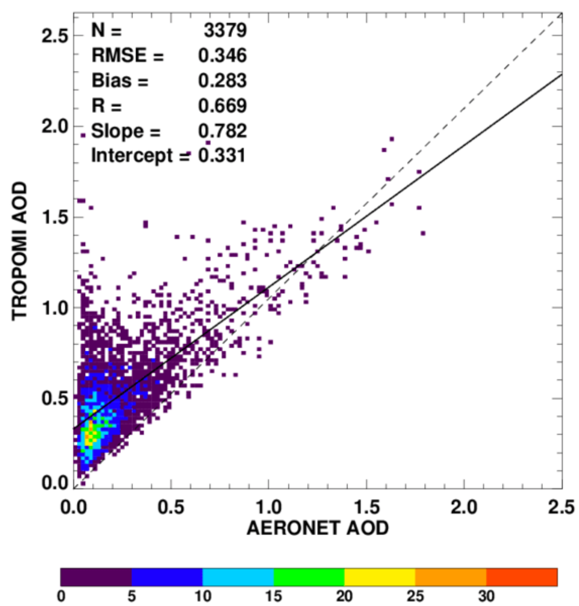
Site (country)	Lat., long.
Hohenpeissenberg (Germany)	47.8° N, 11.0° E
GSFC (USA)	39.0° N, 76.8° W
Lille (France)	50.6° N, 3.1° E
Beijing-CAMS (China)	39.9° N, 116.3° E
Thessaloniki (Greece)	40.6° N, 23.0° E
Fukuoka (Japan)	33.5° N, 130.5° E
Banizoumbou (Niger)	13.5° N, 2.7° E
Mongu (Zambia)	15.3° S, 23.3° E
Leipzig (Germany)	51.4° N, 12.4° E
Lumbini (Nepal)	27.5° N, 83.3° E
Yonsei University (South Korea)	37.6° N, 126.9° E
New Delhi (India)	28.6° N, 77.2° E

Table 2. Summary of statistics of comparisons between AERONET-measured and satellite-retrieved AOD at 12 locations (column 1) by the OMAERUV algorithm (column 2), TropOMAER heritage algorithm (column 3), and TropOMAER algorithm with VIIRS cloud mask (column 4).

	OMAERUV	TropOMAER (heritage cloud mask)	TropOMAER (VIIRS cloud mask)
Number of matchups	410	741	845
Correlation coefficient	0.62	0.82	0.89
Root mean square error	0.31	0.19	0.16

Ref: Torres, O., Jethva, H., Ahn, C., Jaross, G., and Loyola, D.G., TROPOMI Aerosol Products: Evaluation and Observations of Synoptic Scale Carbonaceous Aerosol Plumes during 2018-2020, Atmos. Meas. Tech., 13, 6789–6806, 2020, https://doi.org/10.5194/amt13-6789-202.

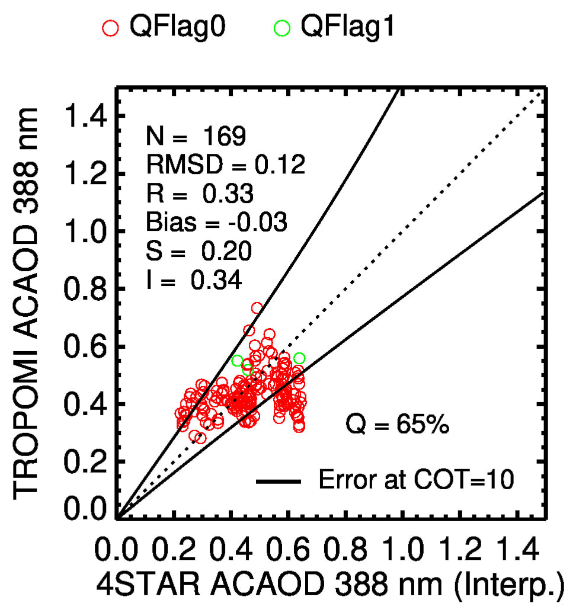
Figure 6. Scatter Density Plot of AOD between TROPOMI and AERONET at 14 Sites for the Entire Mission (2018 April - 2022 June)



(AgiaMarina_Xyliatou, Albergue_UGR, Alta_Floresta, Amazon_ATTO_Tower, Ames, Amsterdam_Island, Appalachian_State, Gangneung_WNU, Glasgow_MO, Gobabeb, Modesto, Moldova, Mongu_Inn, Monterey)

Figure 7. TROPOMAER Above-cloud AOD Retrievals against that measured from the 4STAR Sunphotometer

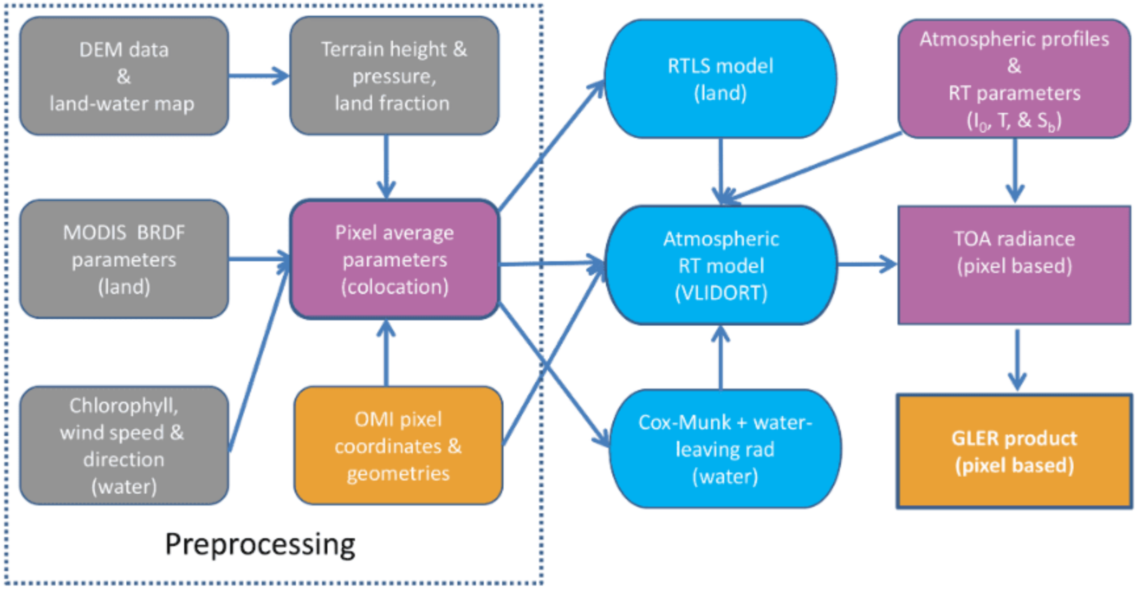
for the 2018 ORACLES Campaign



For evaluating the ACAOD , we have used airborne measurements acquired from Spectrometer for Sky-Scanning, Sun-Tracking Atmospheric Research (4STAR) sensor operated during NASA's ObseRvations of Aerosols above CLouds and their intEractionS (ORACLES) campaign conducted over the Southeastern Atlantic Ocean in 2018

Figure 8. TROPOMI Geometry-dependent surface Lambertian-Equivalent Reflectivity (GLER) product (S5PGLER) for Retrieving AOD at 466 nm

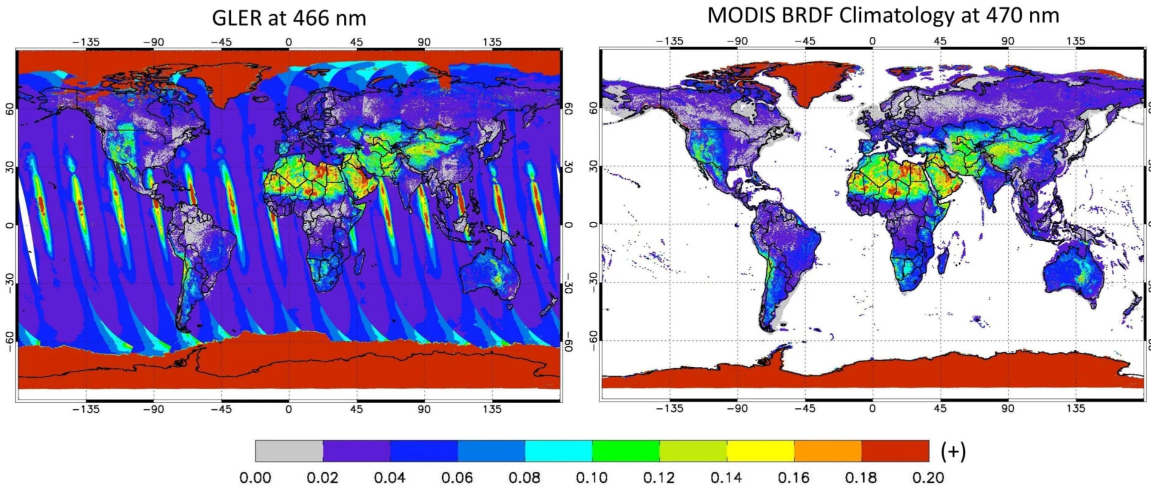
Flowchart of the GLER Processes



Grey for ancillary data for both land and water, purple for preprocessed input parameters or atmospheric input parameters, gold for sensor-dependent pixel-related inputs/output, and blue ovals for the physical models used. All input data are represented by the rounded rectangles and output product is shown in the box rectangle. DEM denotes digital elevation model. RTLS (Ross-thick/Li-sparse reciprocal function) consists of a linear combination of the weighted sum of an isotropic parameter and two kernels that characterize the scattering dependence on viewing and illumination geometry.

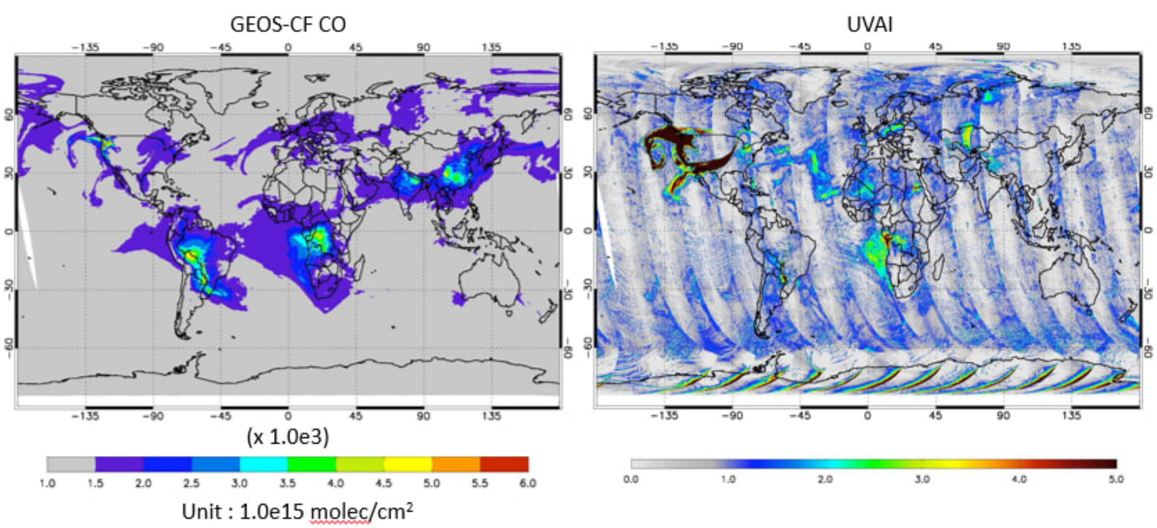
Ref : Qin W., Fasnacht Z., et al., A geometry-dependent surface Lambertian-equivalent reflectivity product for UV–Vis retrievals – Part 1: Evaluation over land surfaces using measurements from OMI at 466 nm, Atmos. Meas. Tech., 12, 3997–4017, 2019 https://doi.org/10.5194/amt-12-3997-2019.

Figure 9. TROPOMAER GLER at 466 nm and MODIS BRDF Climatology at 470 nm for September 12, 2020



Ref : Schaaf C., Gao F., et al., First operational BRDF, albedo nadir reflectance products from MODIS, Remote Sensing of Environment 83 (2002) 135–148.

Figure 10. TROPOMAER collocated GEOS-CF Total Column Density of Carbon Monoxide (CO) and UVAI for September 12, 2020



Time-averaged GEOS-CF CO files (xgc_tavg_1hr_g1440x721_x1) are avaiaible from the NCCS data portal site (https://portal.nccs.nasa.gov/datashare/gmao/geos-cf/v1/das/ (https://portal.nccs.nasa.gov/datashare/gmao/geos-cf/v1/das/)).

Figure 11. TROPOMAER Aerosol Layer Height (ALH)

from the Oxygen-B Band (688 nm)

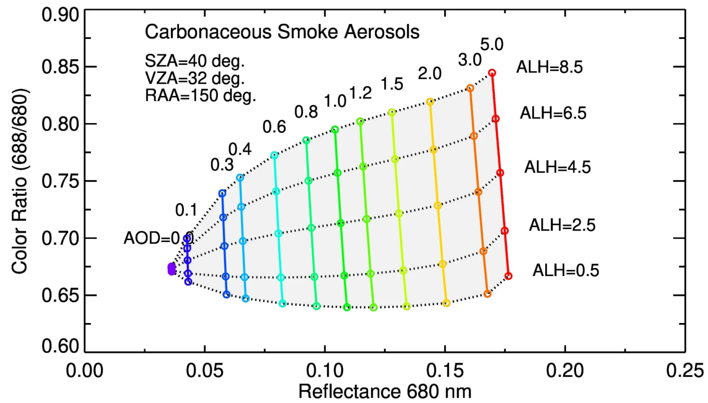
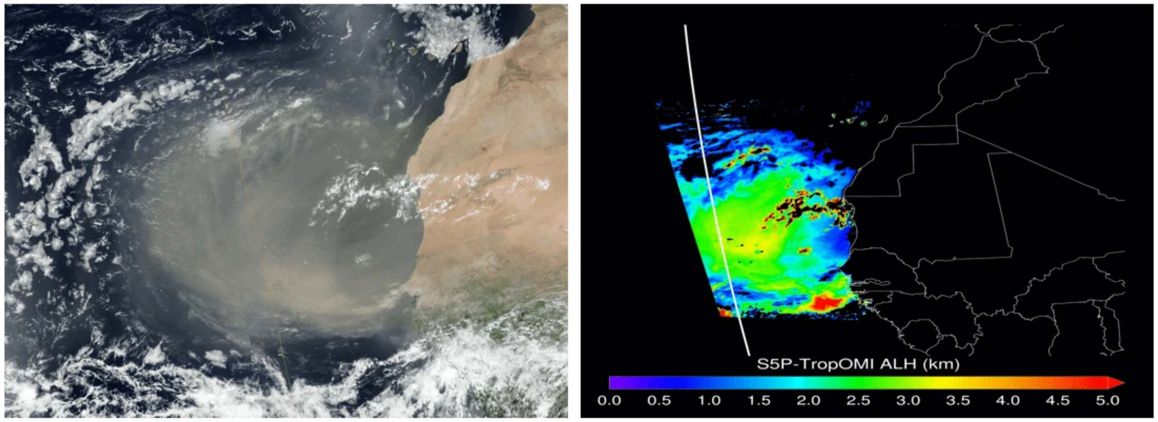


Figure 12. TROPOMAER O2B ALH for Dust Storm over the Atlantic Ocean for July 31, 2018 (VIIRS RGB imagery source : NASA WorldView)



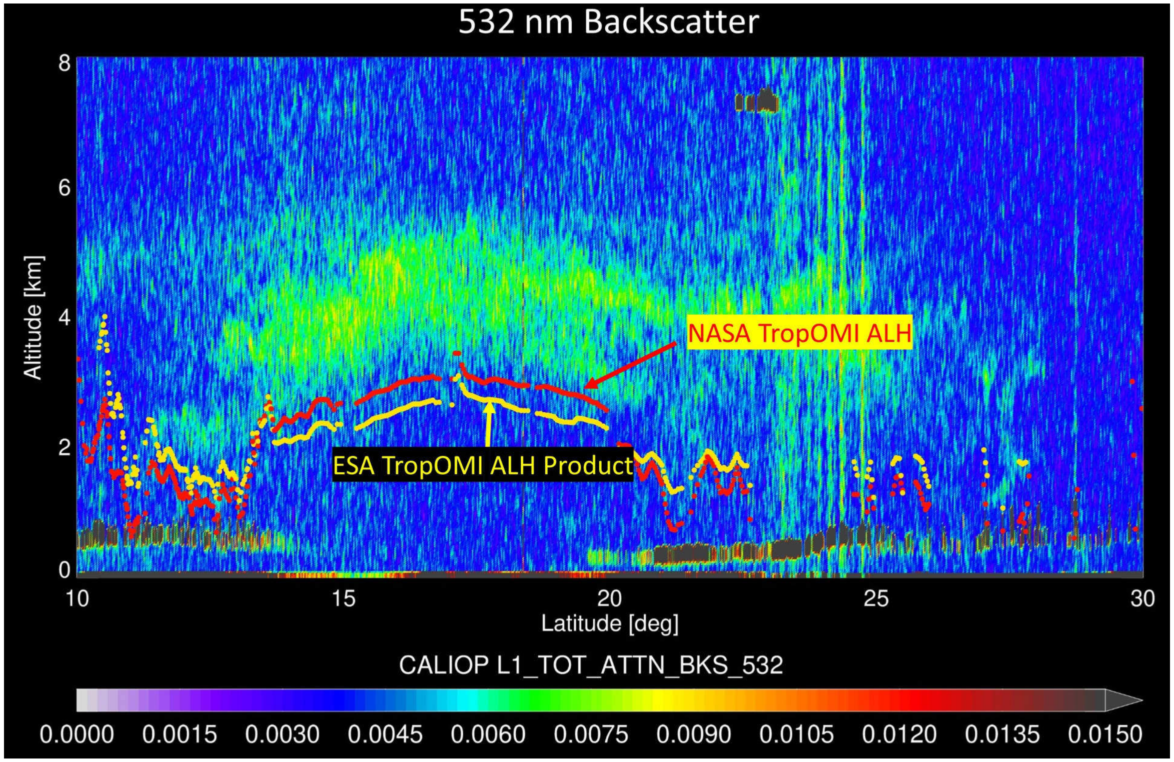
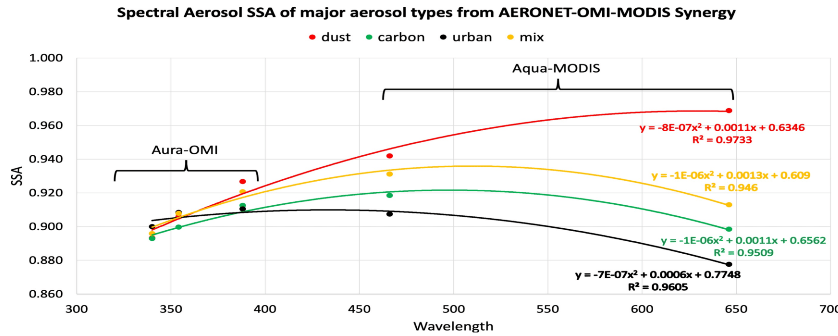
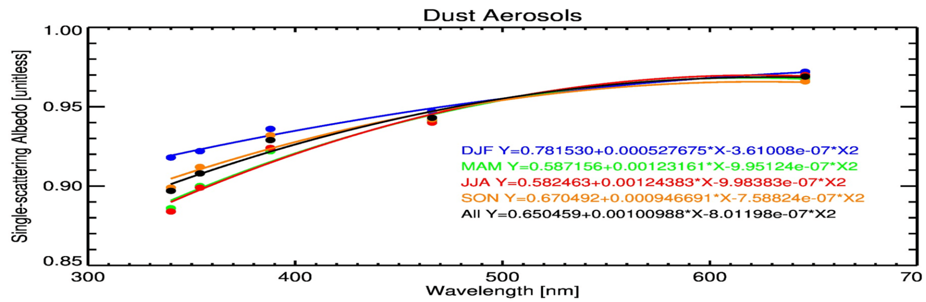


Figure 13. Inferring Aerosol Absorption in the Visible from UV-retrieved Single Scattering Albedo





Ref: Kayetha , V., Torres O., and Jethva, H., Retrieval of UV-Visible aerosol absorption using AERONET and OMI-MODIS synergy: Spatial and temporal variability across major aerosol environments, Atmos. Meas. Tech., 15, 845–877, 2022 https://doi.org/10.5194/amt-15-845-2022.

PRELIMINARY EVALUATION RESULTS

Figure 14. TROPOMAER AOD vs. AERONET AOD over a total of 245 sites (April 2018 – April 2019)

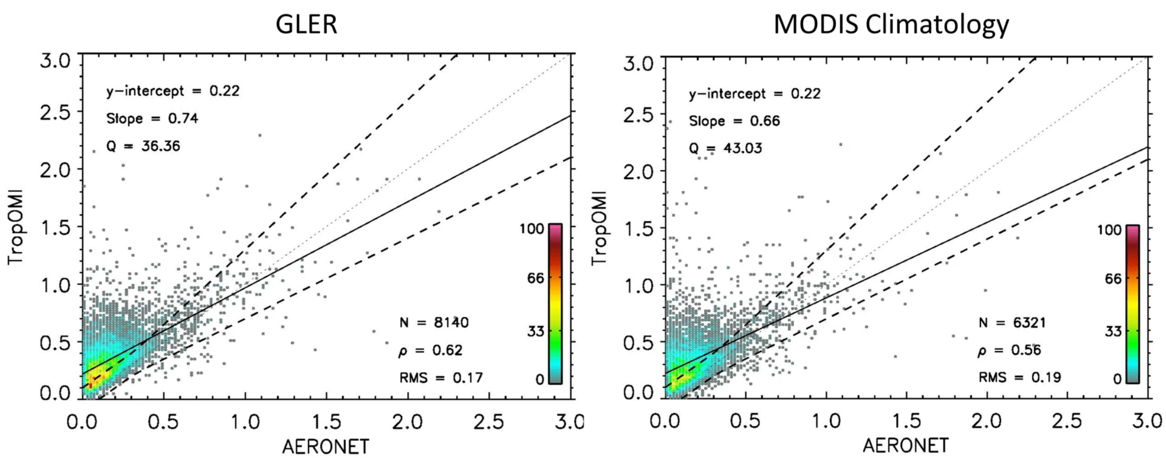


Figure 15. Monthly averages of AOD, SSA, and UVAI (Latitude vs. Time) for the entire TROPOMI mssion

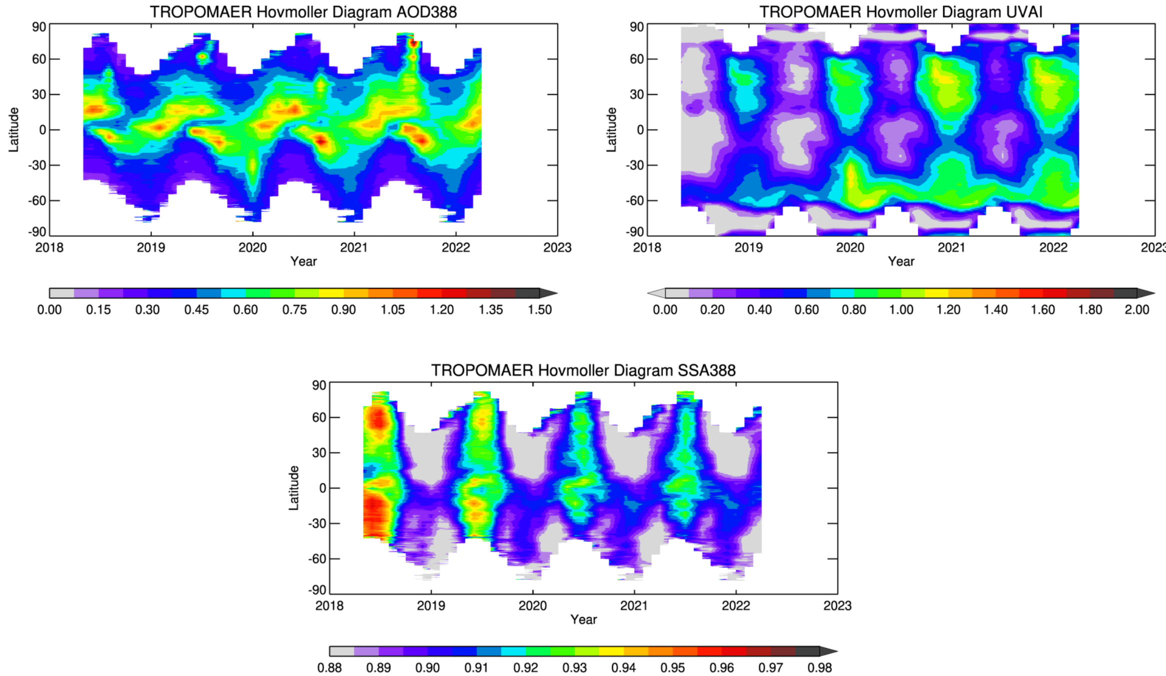
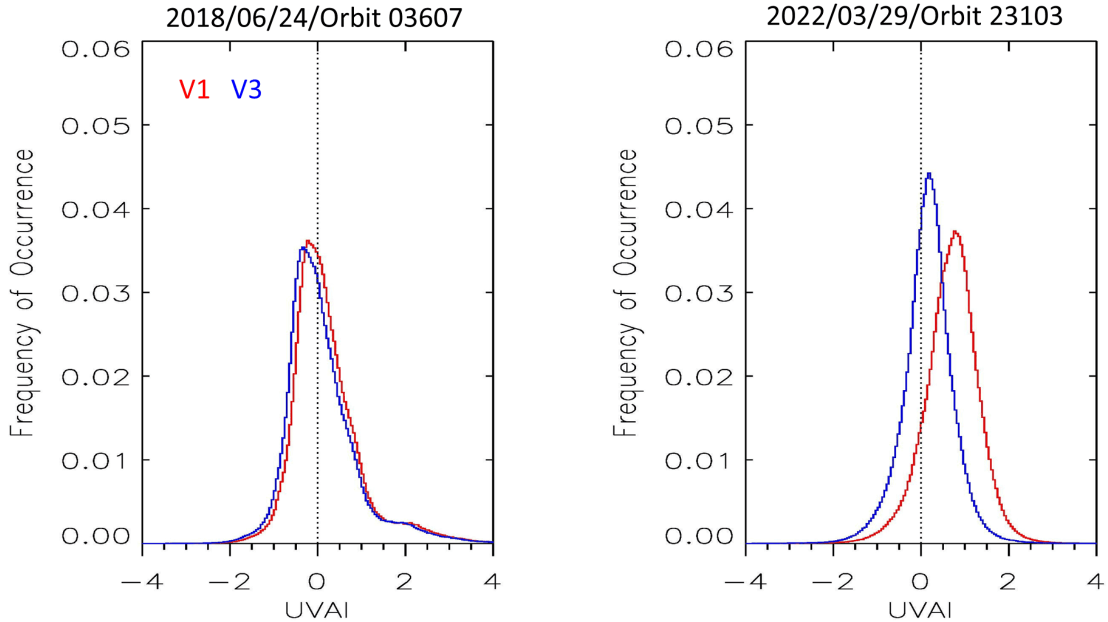


Figure 16. Comparison of Probability Distributions of the UVAI of current L1B version (V1) with those of new L1B (V3)

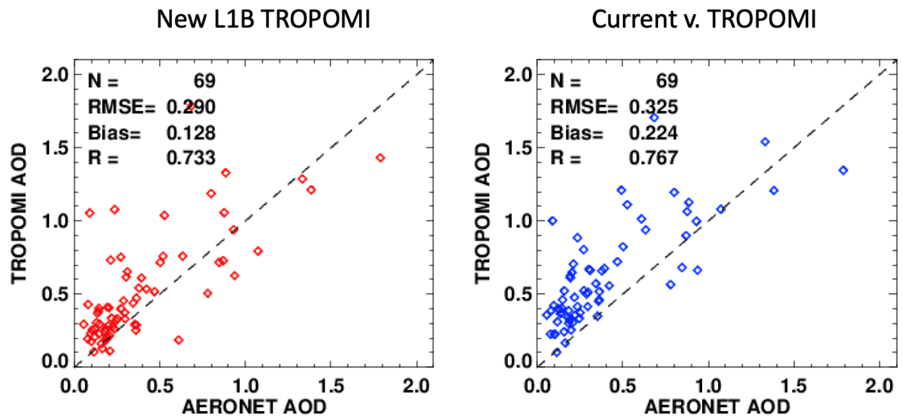


Orbit 3607	V1	V3
Mean	0.21	0.09
StDev.	0.81	0.82
Mode	-0.25	-0.36

Orbit 23103	V1	V3
Mean	0.69	0.16
StDev.	0.63	0.59
Mode	0.74	0.16

Figure 17. Comparison of TROPOMAER AOD from new and current L1B versions with AERONET AOD over selected 7 sites

Beijing
GSFC
Ilorin
Kanpur
Mezaira
Mongu_Inn
Tamanrasset_INM



SUMMARY & FUTURE WORK

1. Global aerosol products (i.e., AOD, SSA, AAOD, ACAOD, and UVAI) processed with the NASA's TROPOMI (version 1.0) aerosol algorithm (N-TROPOMAER) for the entire S-5 P/TROPOMI mission (April 2018 – Present) are available from the Earthdata Search site (https://search.earthdata.nasa.gov/search (https://search.earthdata.nasa.gov/search), DOI: 10.5067/MEASURES/AER/DATA204).

2. TROPOMAER has been further upgraded with following improvements :

- Geometry-dependent surface Lambertian-Equivalent Reflectivity (GLER) product for retrieving AOD at 466 nm.
- Time-averaged GEOS-CF total column density of carbon monoxide data for aerosol type identification.
- ALH and 680 nm AOD derived from observations at 680 nm and at the Oxygen-B band (688 nm).
- Climatological data set of UV–visible aerosol absorption using AERONET and OMI–MODIS synergy for estimating SSA values in the visible.

3. The performance of these new algorithmic upgrades is now under evaluation with AERONET and CALIOP observations.

4. We plan to reprocess the entire mission with an upgraded version TROPOMAER of a newly calibrated Level 1B data in the next year (2023).

5. This enhanced UV-VIS algorithm will also be applied to observations by the currently operational EPIC (Earth Polychromatic Imaging Camera) on DSCOVR at L1 point and the upcoming TEMPO (Tropospheric Emissions: Monitoring of Pollution) on the Intelsat 40e geostationary satellite.

Acknowledgments:

We thank PIs for maintaining and processing AERONET aerosol data (https://aeronet.gsfc.nasa.gov/index. html) used in the TROPOMAER validation study.

ABSTRACT

This poster presentation describes an expanded NASA TROPOMI (Tropospheric Monitoring Instrument) aerosol algorithm (N-TROPOMAER) that takes advantage of TROPOMI observations in the ultraviolet and visible spectral regions. The availability of the Oxygen B-band observations, and the unprecedentedly high spatial resolution (3.5 km X 5.5 km) for a hyper-spectral sensor are significant improvements for aerosol properties retrieval. The heritage N-TROPOMAER aerosol algorithm uses near-ultraviolet radiances at 354 nm and 388 nm from Sentinel 5 Precursor-TROPOMI for simultaneously retrieving aerosol optical depth (AOD), single-scattering albedo (SSA), and above-cloud aerosol optical depth (ACAOD) at 388 nm, along with the qualitative UV aerosol index (UVAI). We have expanded the inversion capability beyond the UV, to retrieve AOD at 466 nm and 680 nm. Surface reflectance effects at 466 nm are accounted for using a recently developed geometry-dependent surface Lambertian-equivalent reflectivity (GLER) product, which is derived from the top-of-atmosphere radiance computed with Rayleigh scattering and surface bidirectional reflectance distribution function (BRDF) for the exact viewing geometry at the sensor's spatial resolution. Aerosol layer height (ALH) and 680 nm AOD are simultaneously derived from observations at 680 nm and at the Oxygen-B band (688 nm). Another important upgrade is the use of time averaged total column carbon monoxide from the NASA GEOS-CF (Global Earth Observing System Composition Forecast) as a tracer of carbonaceous aerosols. This enhanced UV-VIS algorithm will also be applied to observations by the currently operational EPIC (Earth Polychromatic Imaging Camera) on DSCOVR at L1 point and the upcoming TEMPO (Tropospheric Emissions: Monitoring of Pollution) on the Intelsat 40e geostationary satellite.

REFERENCES

- Kayetha , V., Torres O., and Jethva, H., Retrieval of UV-Visible aerosol absorption using AERONET and OMI-MODIS synergy: Spatial and temporal variability across major aerosol environments, Atmos. Meas. Tech., 15, 845–877, 2022 https://doi.org/10.5194/amt-15-845-2022.

- Keller, C. A., Knowland, K. E., Duncan, B. N., Liu, J., Anderson, D. C., Das, S., Lucchesi, R. A., Lundgren, E. W., Nicely, J. M., Nielsen, E., Ott, L. E., Saunders, E., Strode, S. A., Wales, P. A., Jacob. D. J., and Pawson, S. (2021). Description of the NASA GEOS composition forecast modeling system GEOS-CF v1.0. Journal of Advances in Modeling Earth Systems, 13, e2020MS002413. https://doi.org/10.1029/2020MS002413

- Qin W., Fasnacht Z., et al., A geometry-dependent surface Lambertian-equivalent reflectivity product for UV–Vis retrievals – Part 1: Evaluation over land surfaces using measurements from OMI at 466 nm, Atmos. Meas. Tech., 12, 3997–4017, 2019 https://doi.org/10.5194/amt-12-3997-2019.

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