Evaluation of Satellite Retrievals of UV Aerosol Optical Depth and Single Scattering Albedo using AERONET Observations

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AERONET Science and Application Exchange 2024
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Poster Presentations

Sept. 17, Changwoo Ahn et al., *Evaluation of Near UV Aerosol Products from EP-TOMS, Aura-OMI, S5p-TROPOMI, and DSCOVR/EPIC sensors using AERONET Measurements*

Sept. 17, Nickolay Krotkov et al., *Ground-based UV-VIS retrievals of Saharan dust absorption at Izaña Observatory*

Sept. 18, Vinay Kayetha at al., *Spectral Aerosol Absorption Models derived from AERONET-OMI-MODIS Synergy and its applications*

A bit of History: The TOMS Legacy

Nimbus 7 TOMS (Total Ozone Mapping Spectrometer), deployed in 1978, included 6 wavelengths:
312.5 and 317.5 nm (ozone absorbing) and 331.2, 340.0, 360.0, 380.0 nm (lower boundary reflectivity)

Testing the TOMS algorithm LER λ-dependence assumption:

In the mid 90's, R_{380} and R_{340} were independently retrieved and the residual quantity $\Delta R = R_{380} - R_{340}$ was calculated.

Resulting ΔR values were closely related to specific geophysical atmospheric and surface properties.

Over both, land and ocean surfaces, large positive ΔR values were associated with the presence of smoke and desert dust aerosol layers.

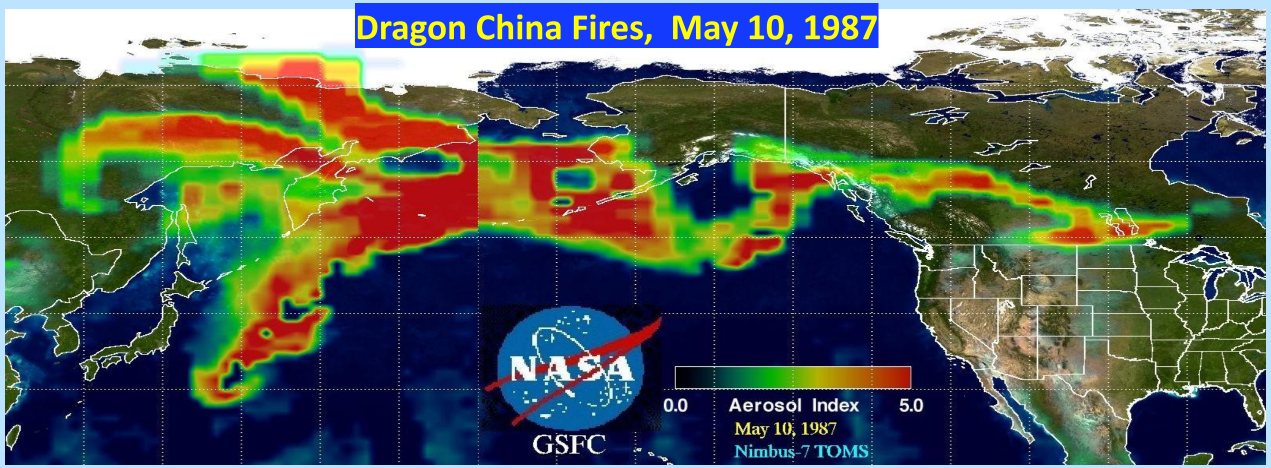
The residual ΔR quantity was later reformulated in terms of radiances as:

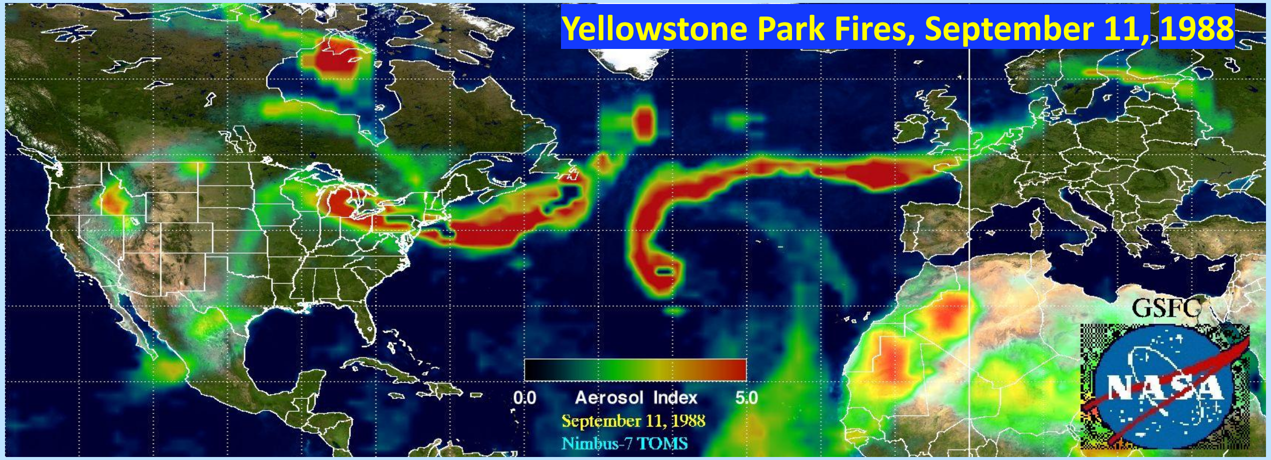
$$UVAI = -100\left[log\left(\frac{I_{340}}{I_{380}}\right)_{meas} - log\left(\frac{I_{340}}{I_{380}}\right)_{calc}\right]$$

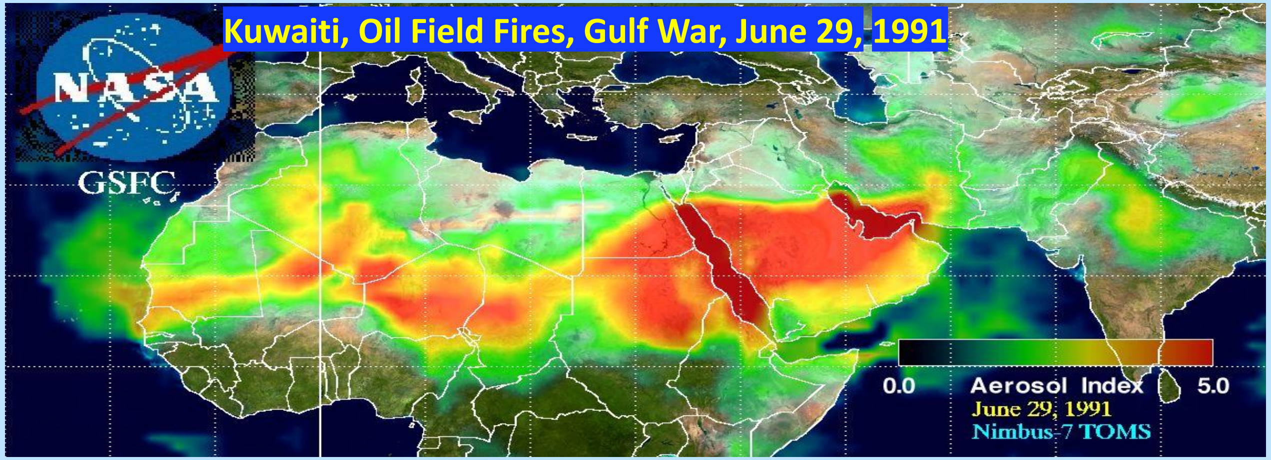
and has since been known as the UV Aerosol Index (UVAI).

The TOMS Legacy (2) : The UVAI is born

The UVAI detects absorbing aerosols over all terrestrial surfaces, including snow/ice, and above clouds.







-Near zero for clouds and large particle size non- absorbing aerosols

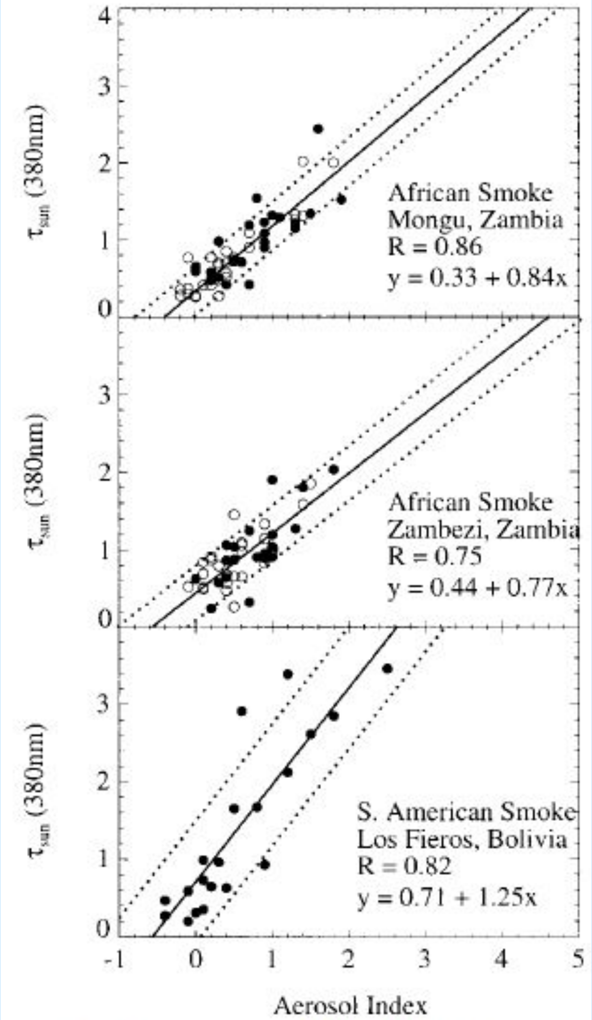
-Negative for non-absorbing aerosols

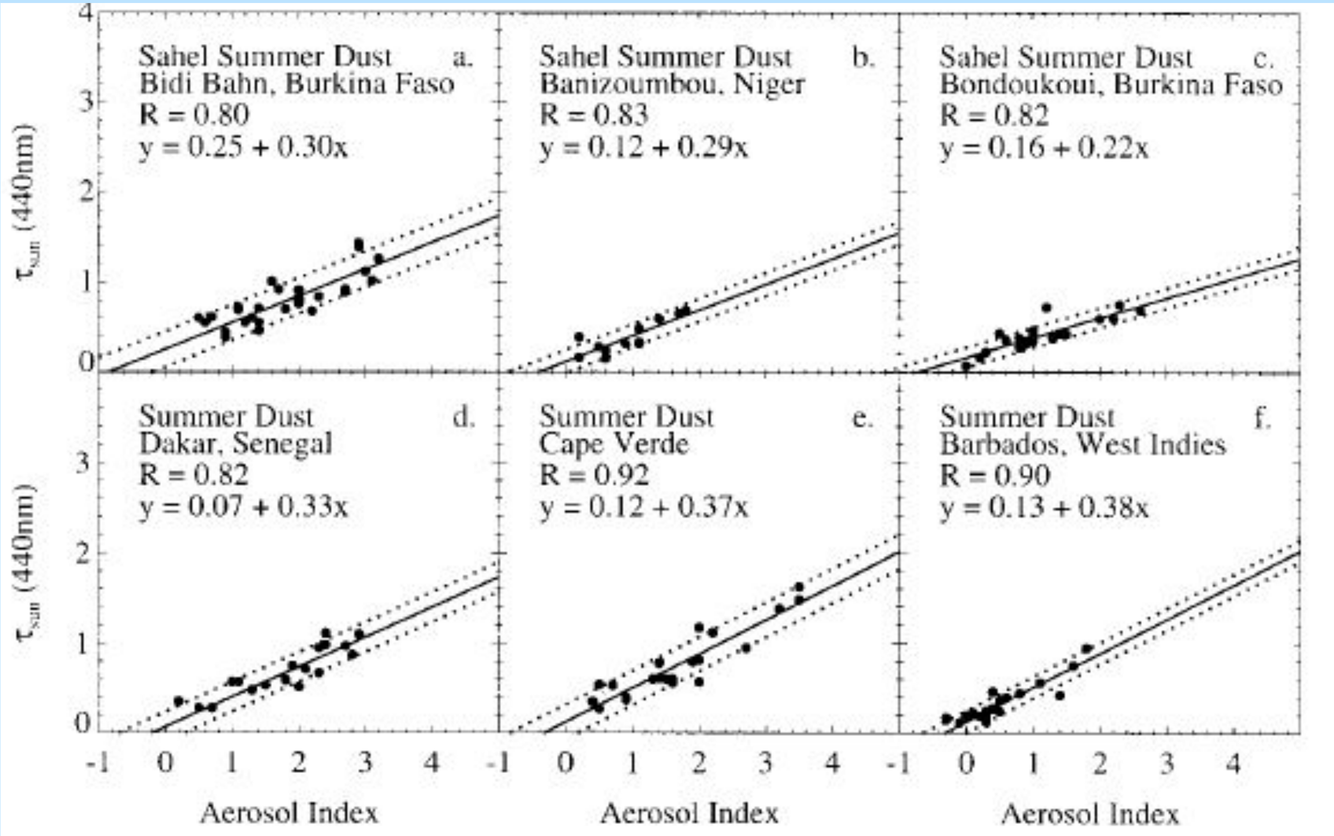
-Positive for uv-absorbing aerosols: mineral dust, smoke, volcanic ash.

The UVAI magnitude depends on Aerosol Optical Depth, Single Scattering Albedo, Aerosol Layer height (abs. aerosols)

Torres, O., and L. Remer, 2013, History of passive remote sensing of aerosol from space, ch.7 in Aerosol Remote Sensing, J. Lenoble, L. Remer, and D. Tanre, editors, Springer-Praxis, ISBN 978-3-642-17724-8, doi:10.1007/978-3-642-17725-5

Qualitative Evaluation of TOMS UVAI using AERONET AOD



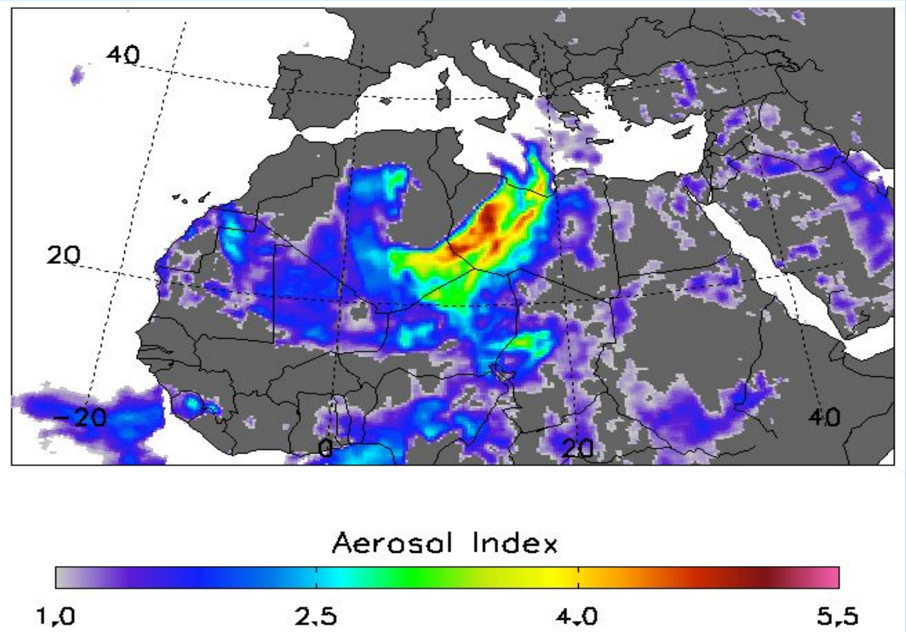


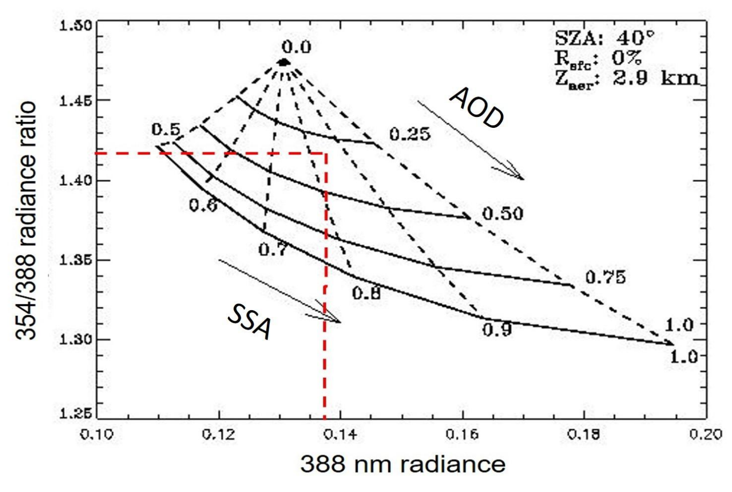
A clear non-unique relationship between UVAI and smoke/dust AOD was observed

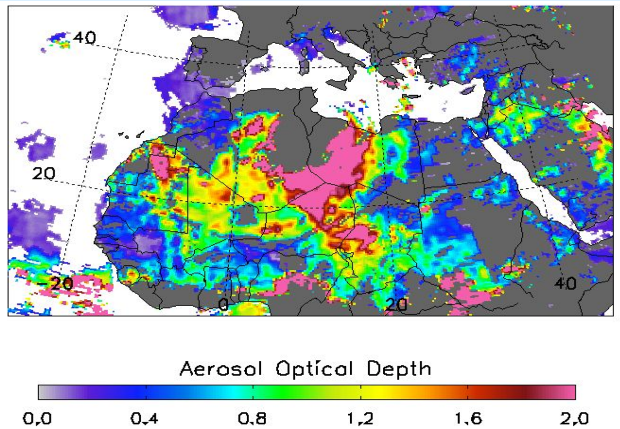
Hsu et al, 1999, Comparisons of the TOMS aerosol index with Sun-photometer aerosol optical thickness: Results and applications, JGR, 1999

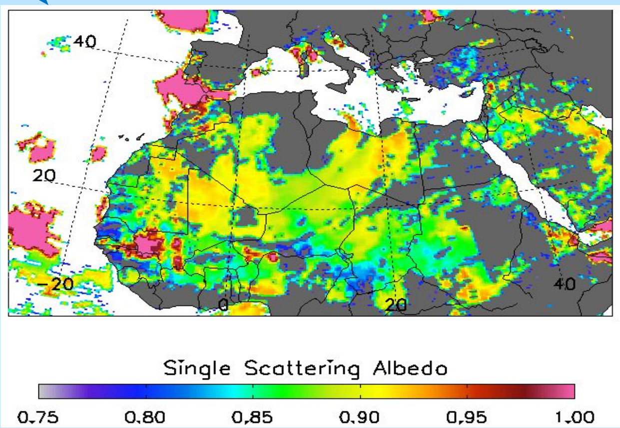
Extracting the information content of satellite UV measurements

The UVAI magnitude depends on aerosol optical depth (AOD), single scattering albedo (SSA), and aerosol layer height (ALH).
Assuming ALH, AOD and SSA can be retrieved.



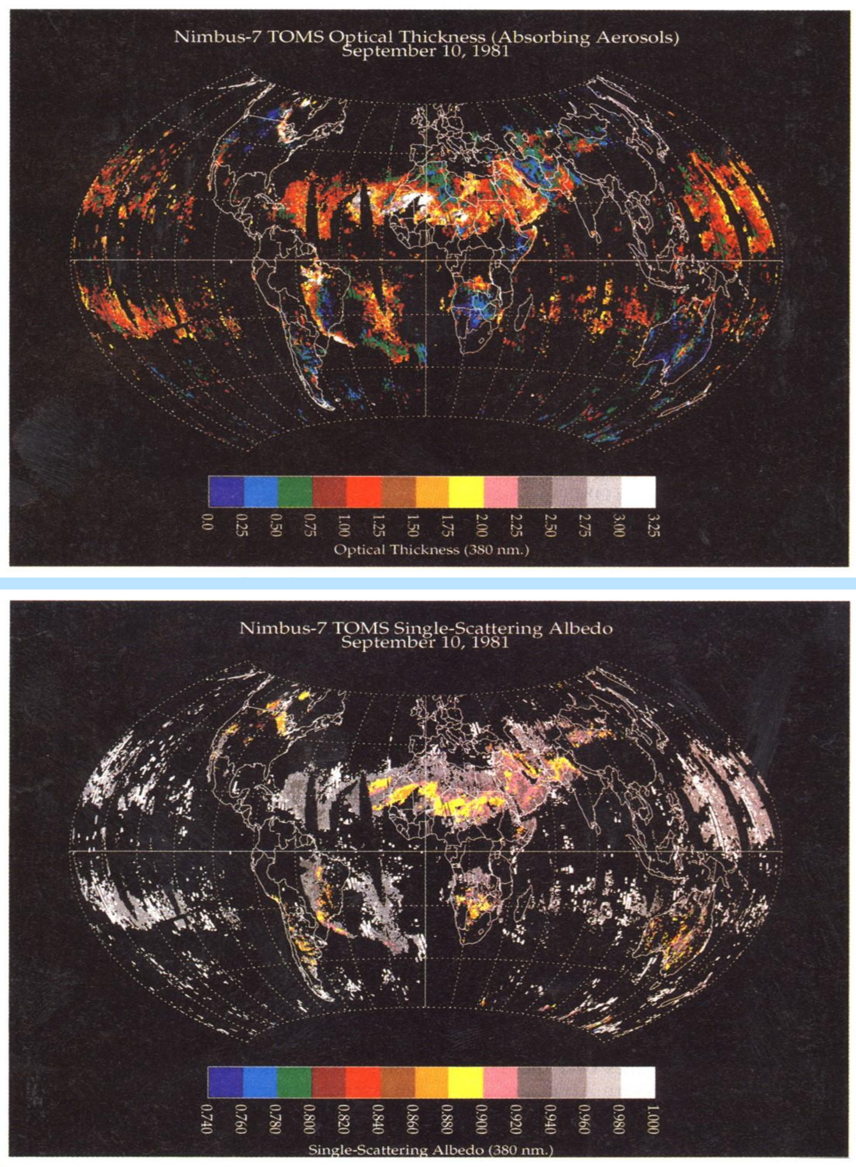


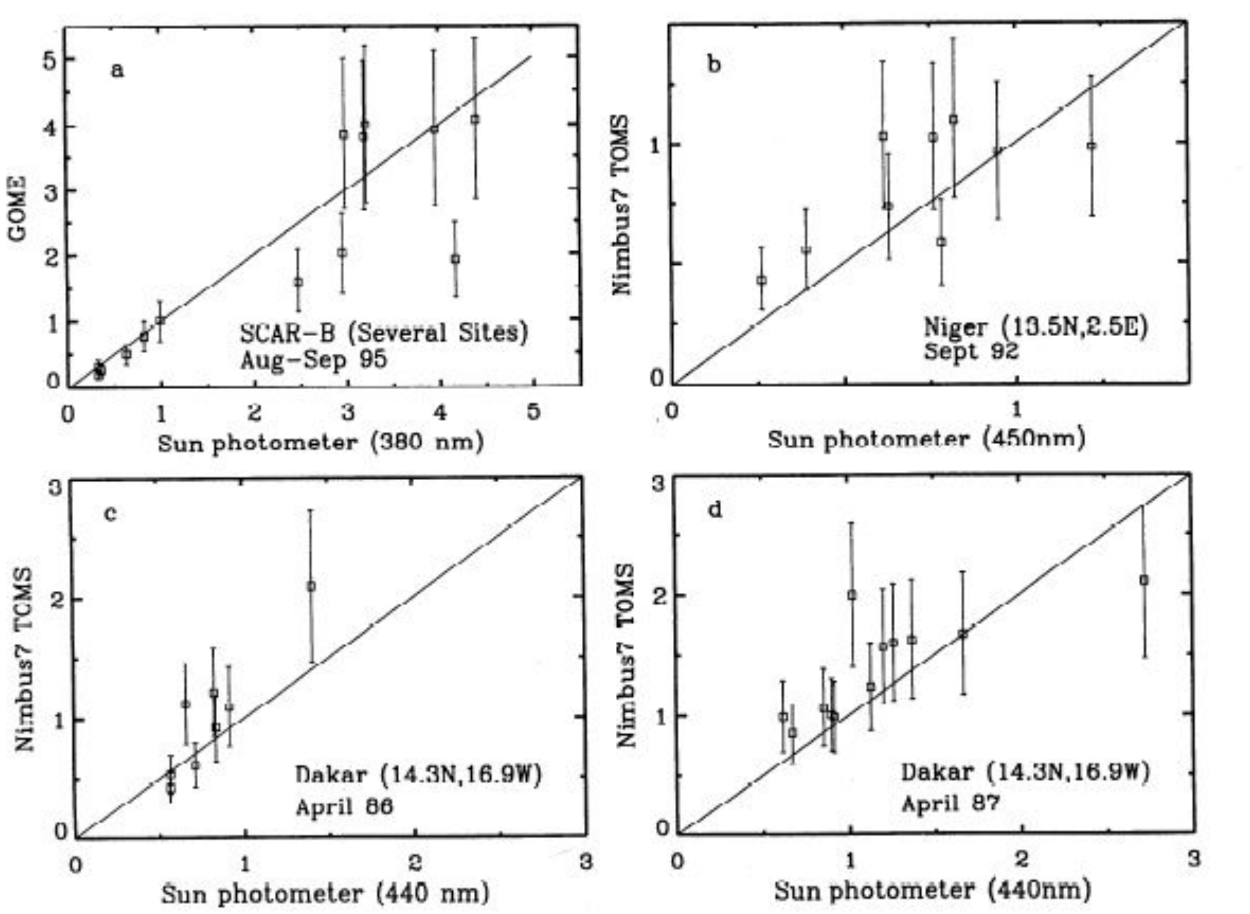




Torres, O., et al., Derivation of Aerosol Properties from Satellite Measurements of Backscattered Radiation: Theoretical Basis, JGR, 1998

Extracting the information content of satellite UV measurements (2)





AOD Validation using pre-AERONET sun-photometer sites

First Global maps of Aerosol Optical Depth and Single Scattering Albedo, September 10, 1981

Torres, O., et al., Derivation of Aerosol Properties from Satellite Measurements of Backscattered Radiation: Theoretical Basis, JGR, 1998

Global TOMS Aerosol Optical Depth Climatology

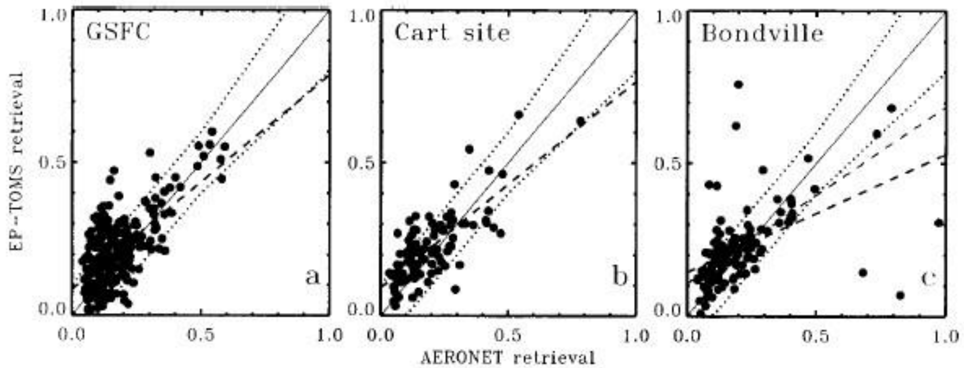


FIG. 1. Comparison of *EP*-TOMS retrieved optical depth for nonabsorbing aerosols to AERONET measurements at (a) Goddard Space Flight Center, (b) CART site, and (c) Bondville. The one-to-one agreement is indicated by the solid line. Dashed lines represent the predicted uncertainty of the satellite retrieval for nonabsorbing aerosols (larger of 0.1 and 20%). The thick dashed line is the resulting linear fit.

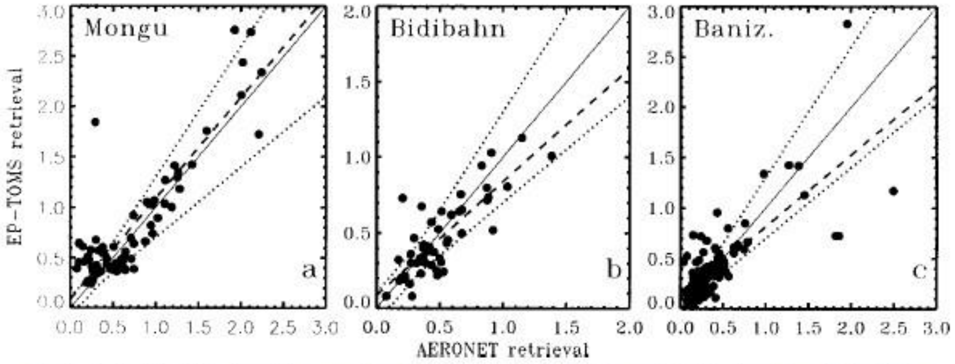
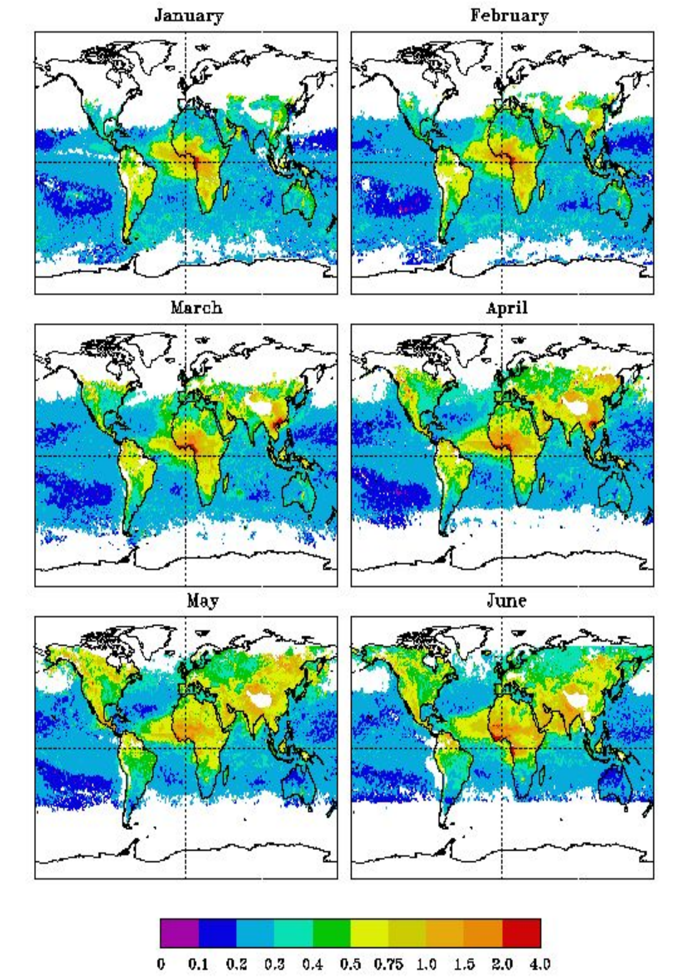
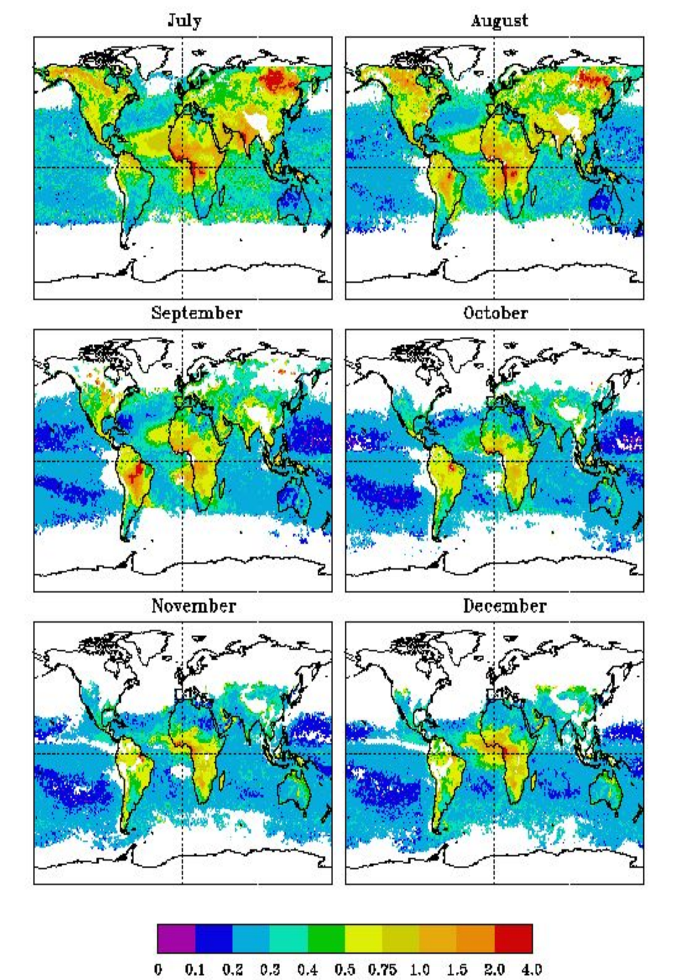


FIG. 2. As in Fig. 1 for absorbing aerosols at (a) Mongu, (b) Bidi-Bahn, and (c) Banizoumbou. Dashed lines represent the predicted uncertainty of the satellite retrieval for absorbing aerosols (larger of 0.1 and 30%).



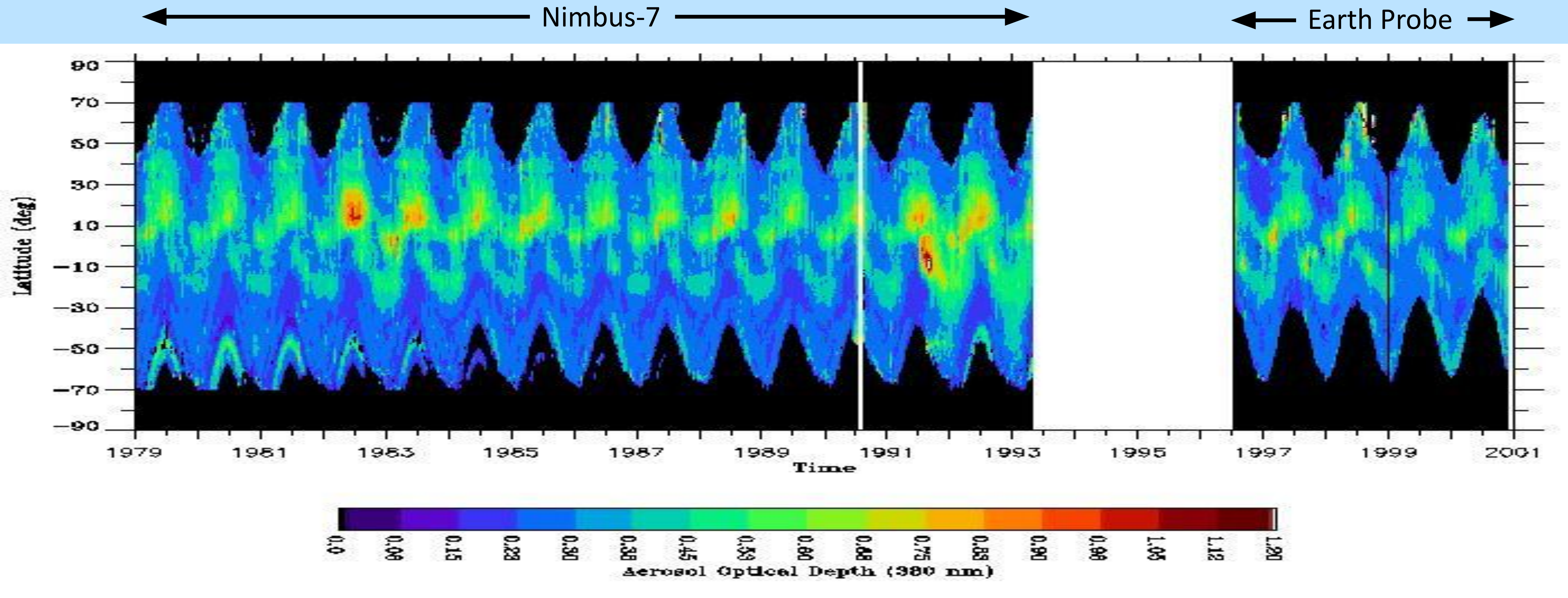


First use of AERONET data for AOD validation

First satellite-derived global AOD climatology over land and water

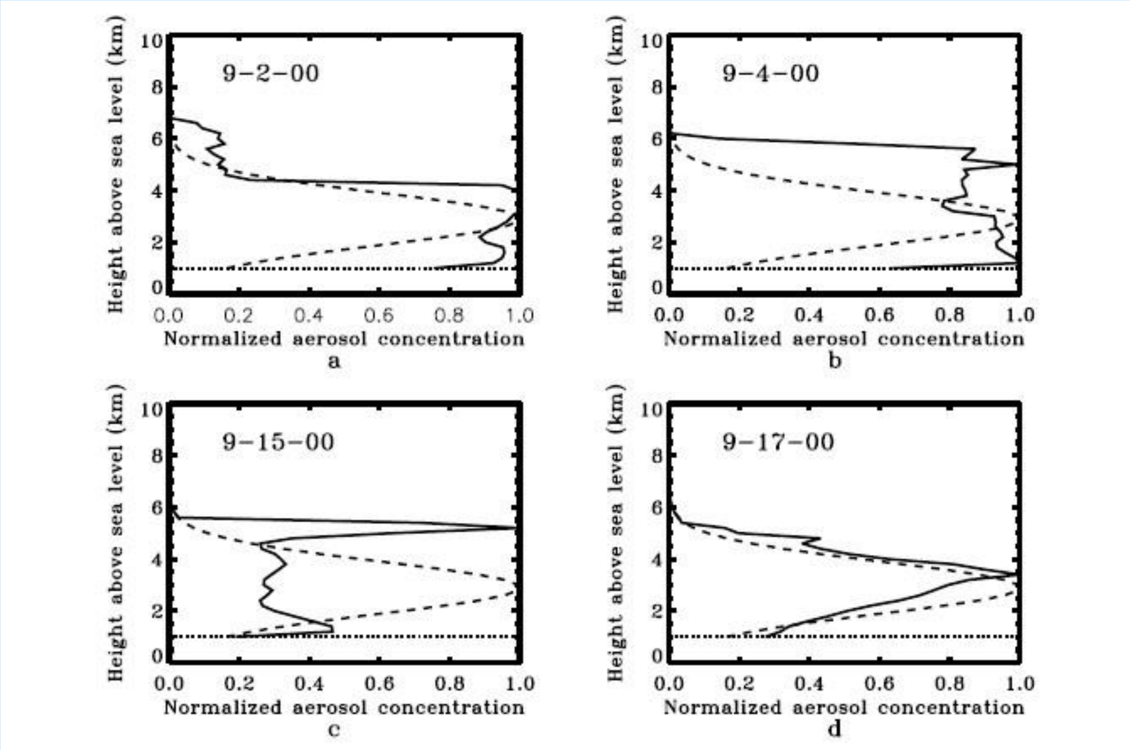
Torres, O., et al, A Long-Term Record of Aerosol Optical Depth from TOMS Observations and Comparison to AERONET Measurements, JAS, 2002

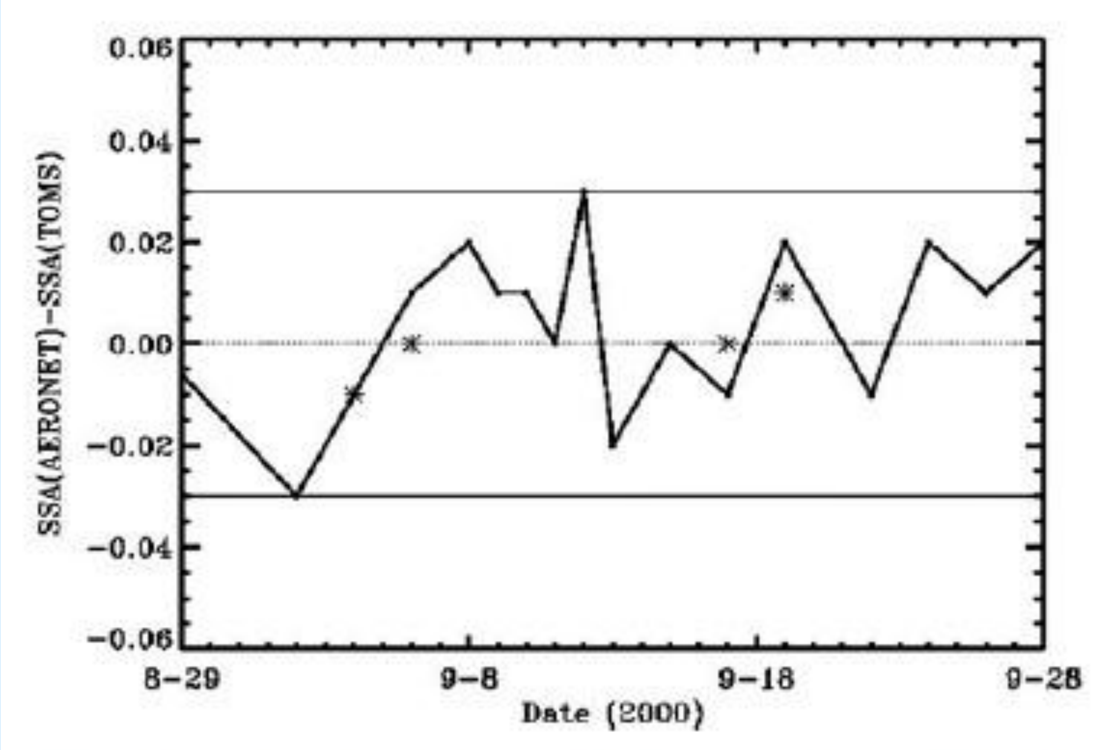
Global TOMS Aerosol Optical Depth Climatology (2)



Time-series of zonally averaged global AOD record from Nimbus-7 (1979-1993) and EP-TOMS (1996-2000) observations

Evaluation of EP-TOMS Single Scattering Albedo Retrievals during SAFARI 2000





Solid line: MPLNET measured aerosol profiles
Dashed line: Assumed Aerosol Profiles

AERONET-TOMS SSA difference as a function of time.
Asterisks indicate retrievals when MPLNET profile was used.

Torres, O., et al., Total Ozone Mapping Spectrometer measurements of aerosol absorption from space: Comparison to SAFARI 2000 ground-based observations, JGR, 2005

The post-TOMS fleet of spaceborne UV-capable sensors

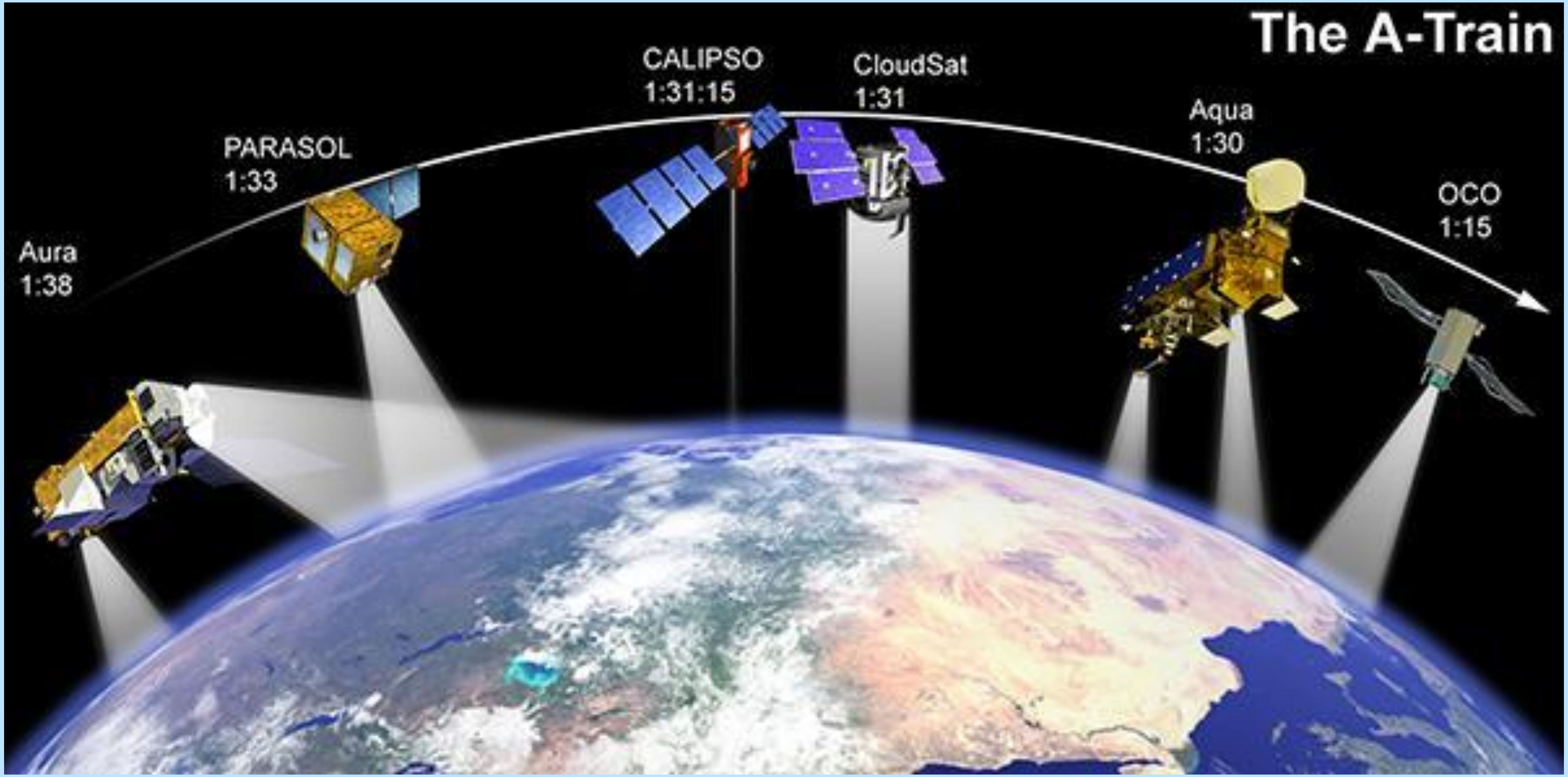
Agency	Sensor	Satellite	Spectral range of observations (nm)	Resolution	Period	Orbit
ESA	SCIAMACHY	Envisat	**240-2400 nm** (Hyp.)	32X215 km	2002-2012	LEO
ESA	GOME-2	MetopA	240-790 nm (Hyp.)	80X40 km	2006-Present	LEO
JAXA	CAI	GOSAT-TANSO	**380**,674,870,1600 nm	0.5 km	2009 - ?	LEO
KNMI	OMI	Aura	**270-500 nm** (Hyp.)	13x24 km	2004-Present	LEO
NOAA	OMPS	S-NPP	270 -400 nm (Hyp.)	50 km	2012-Present	LEO
ESA	GOME2	MetopB	240-790 nm (Hyp.)	80X40 km	2012-Present	LEO
NASA	EPIC	DSCOVR	318,**340**, **388**, 443,551,680,688,764,780 nm	~ 18 km	2015-Present	L1
JAXA	SGLI	GCOM-C	**380**-2210 nm (19 channels)	0.25 km	2017-Present	LEO
EU (CAMS/ESA)	TROPOMI	Sentinel 5 Precursor	**270-500**; 675-775 & 2305-2385 (Hyp.)	3.5X5.5 km	2018-Present	LEO
JAXA	TANSO-CAI/2	GOSAT-2	fw: **343**,443,674,1630 and bw: **380**,550,869	0.5 km	2019 - Present	LEO
NIER (Korea)	GEMS	GK-2B	**300-500** nm (Hyp.)	3.5X8 Km	2020-Present	GEO
NOAA	OMPS	JPSS-2	270-400 nm (Hyp.)	50 km	2022-Present	LEO
NASA-SAO	TEMPO	Intelsat-40	**290-490** & 540-740 (Hyp.)	2.1x4.7	2023-Present	GEO
NASA	OCI	PACE	**340-890** nm (2.5nm steps)	1.2 km	2024-Present	LEO

Sensors with combined UV-VIS observing capabilities

Fourteen sensors with UV-VIS spectral capability (most at moderate spatial resolution) have been deployed over the last 20 years. EPIC, TROPOMI, TEMPO, and OCI include O2A/B bands, that enable aerosol layer height retrieval capability.

Multi-year UV aerosol records

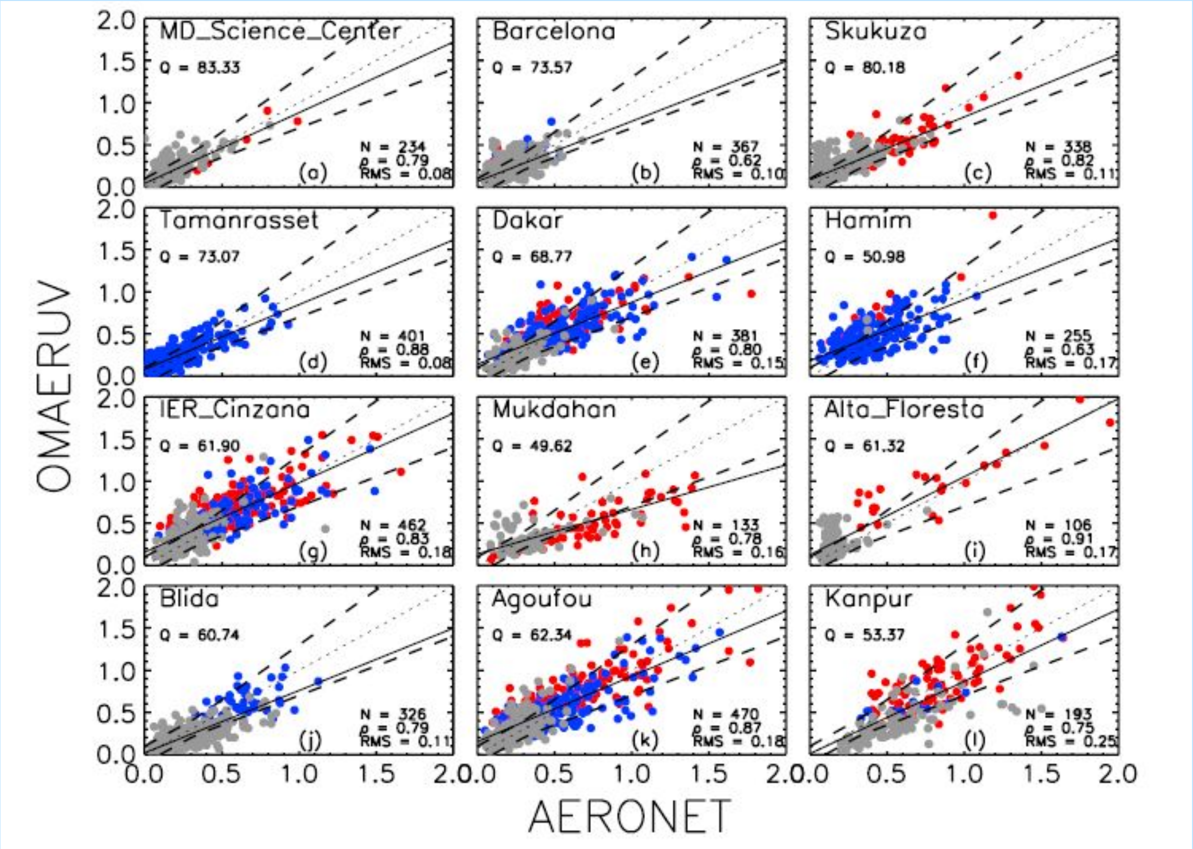
The Aura Ozone Monitoring Instrument (OMI): TOMS successor



AURA spacecraft launched on July 15, 2004
Initial payload: MLS, HRDLS, TES, OMI (MLS and OMI still operational)
OMI: hyper-spectral sensor (270-500 nm), 13x24 km nadir resolution (developed by KNMI)
Near UV aerosol algorithm (OMAERUV) uses observations at 354 and 388 nm

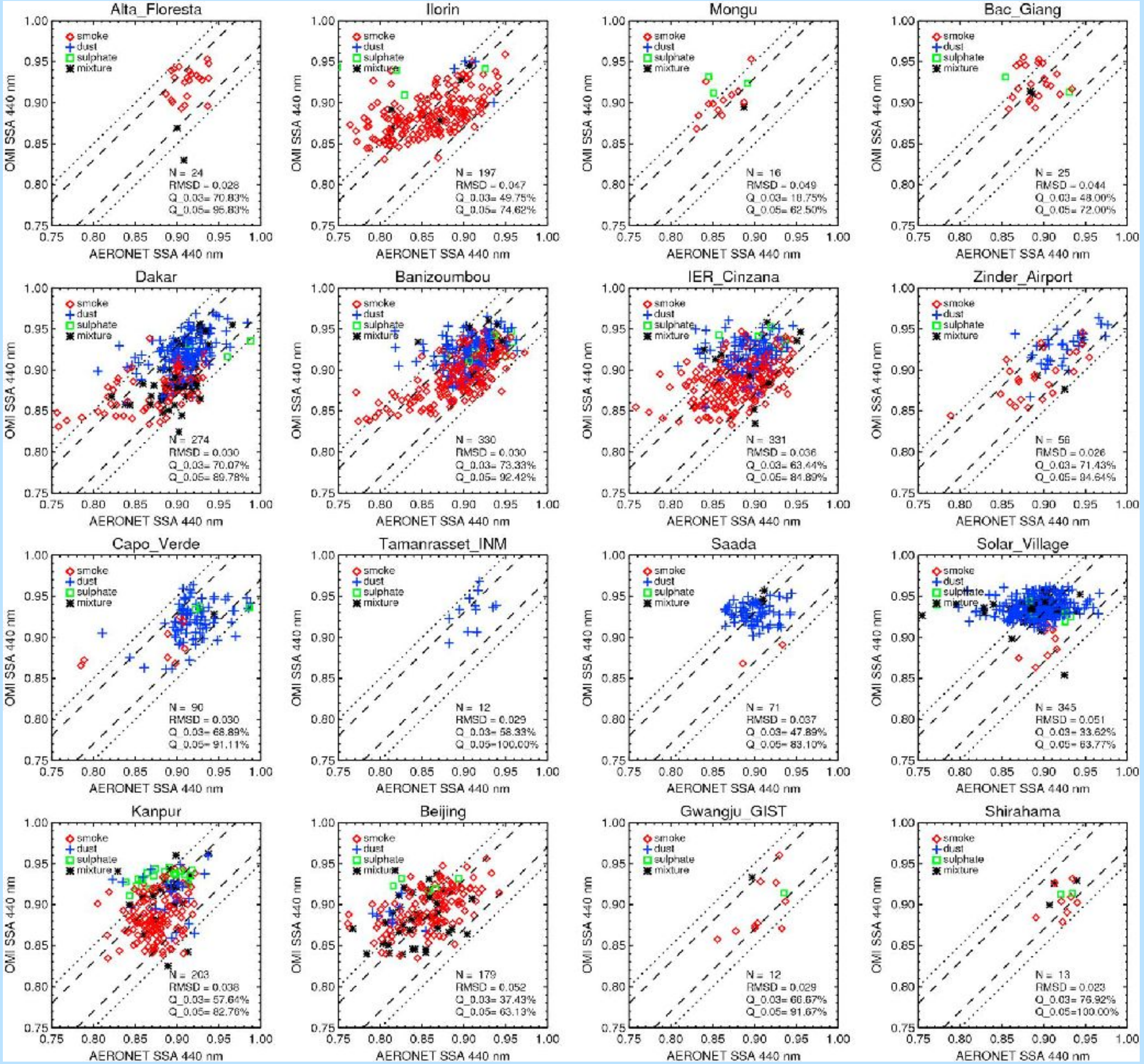
OMI Aerosol Products Validation / Evaluation

Aerosol Optical Depth



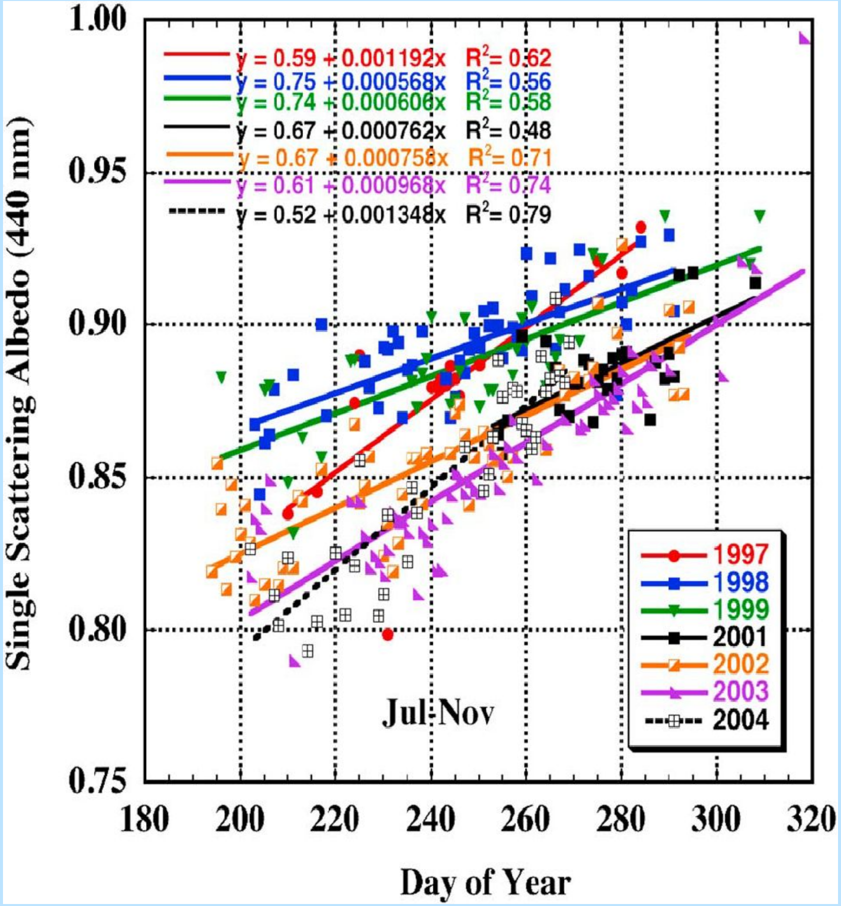
Ahn, C., et al., (2014), Assessment of OMI near-UV aerosol optical depth over land, J. Geophys. Res. Atmos., 119, 2457–2473, doi:10.1002/2013JD020188.

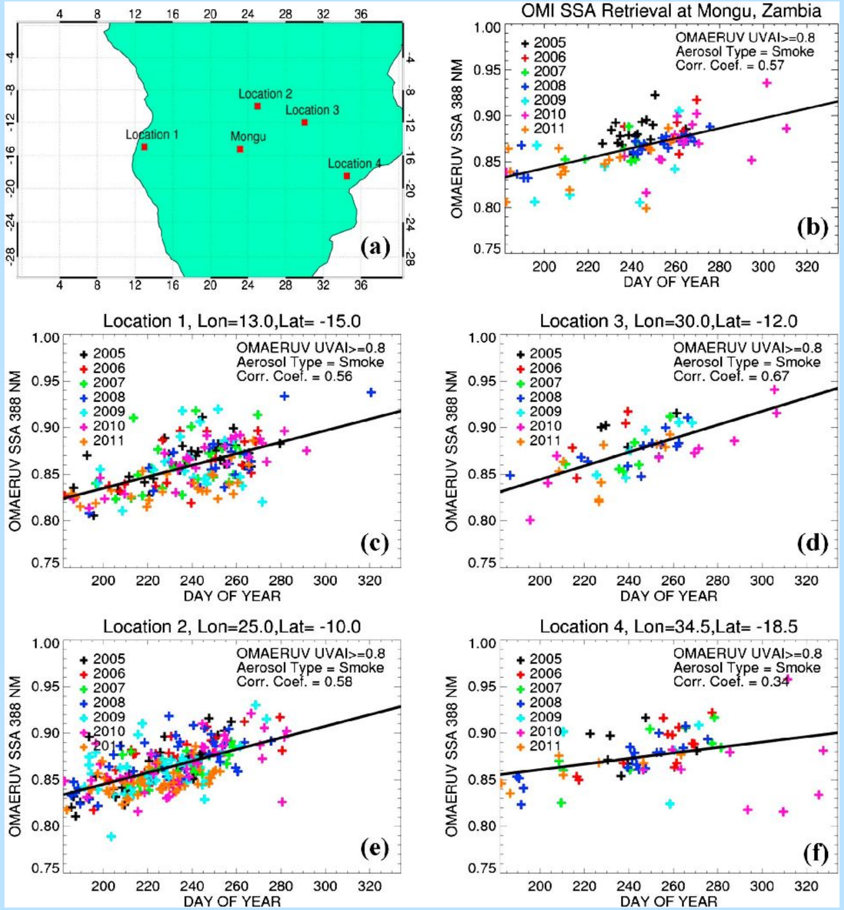
Single Scattering Albedo

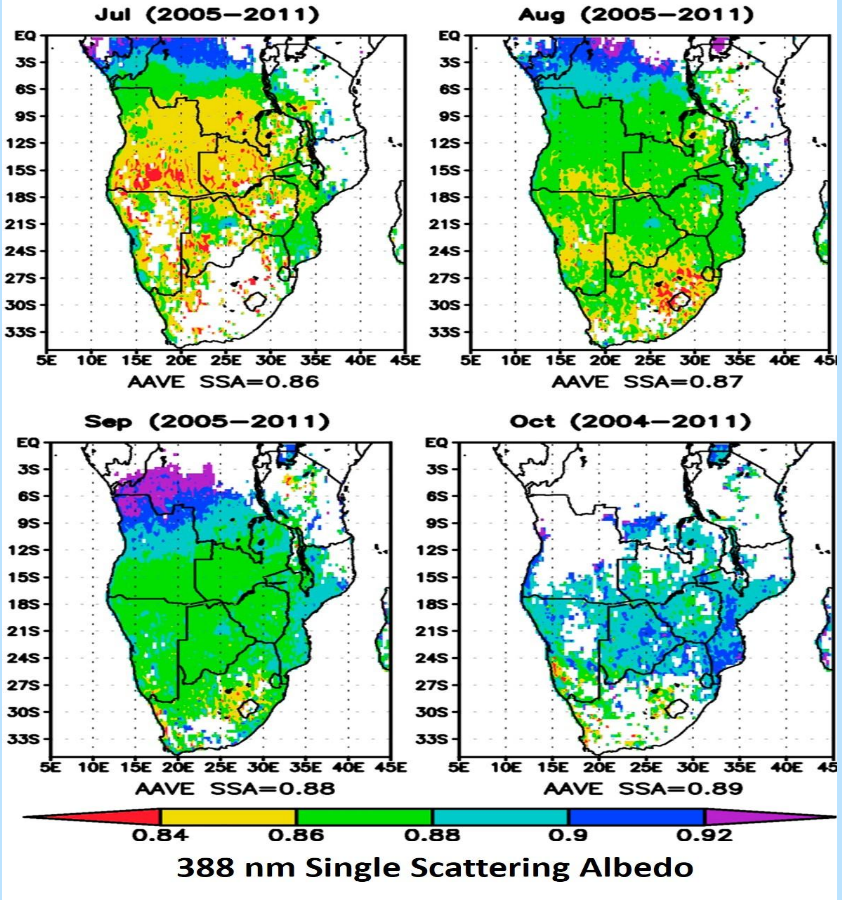


Jethva, H., et al, (2014), Global assessment of OMI aerosol single-scattering albedo using ground-based AERONET inversion, J. Geophys. Res. Atmos., 119, doi:10.1002/2014JD021672.

Seasonal Trends in Single Scattering Albedo from AERONET and OMAERUV Observations



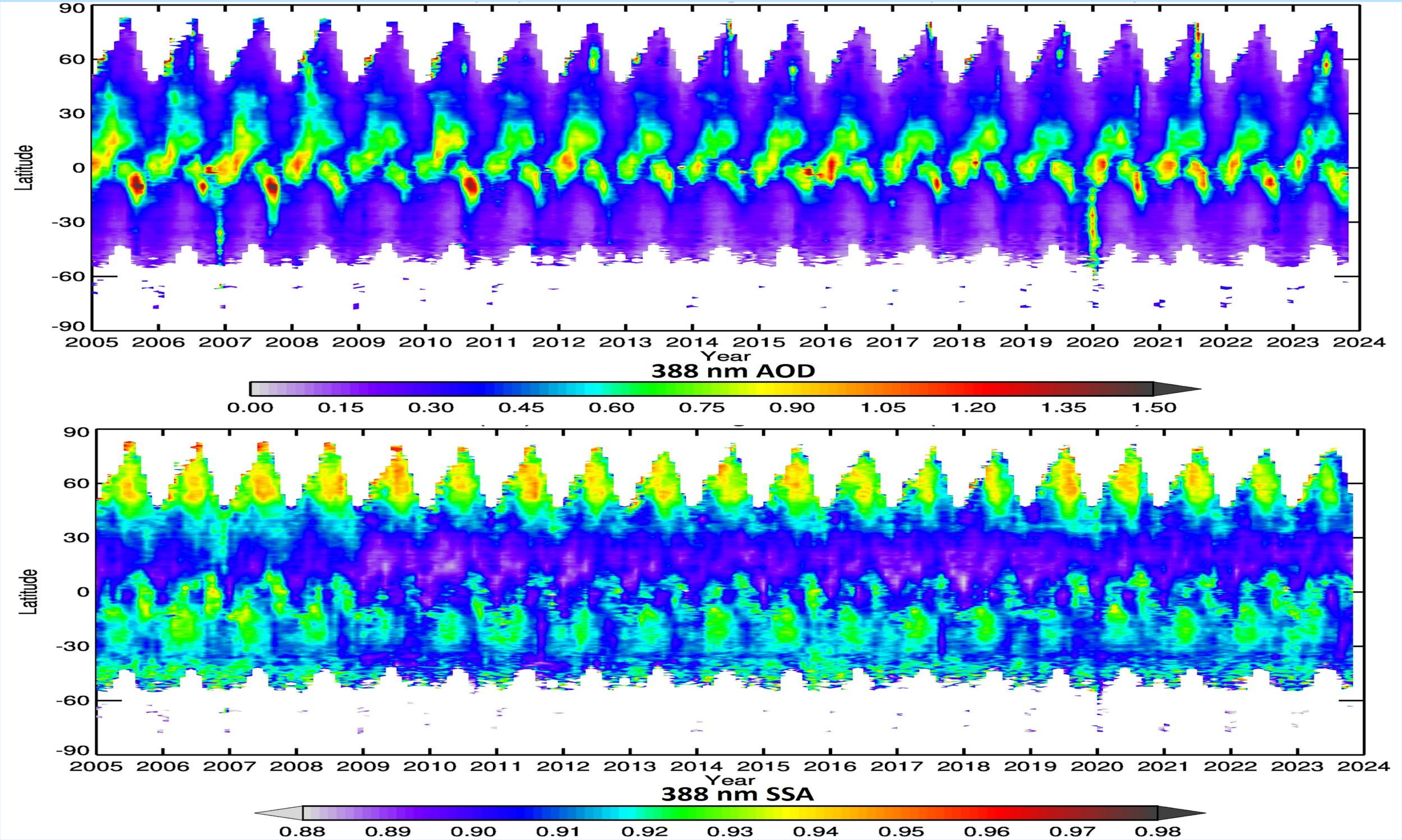




OMAERUV derived SSA annual cycle is consistent with AERONET retrievals. The SSA seasonality is observed throughout much of southern Africa. These findings lead to improvements in MODIS retrieval algorithms.

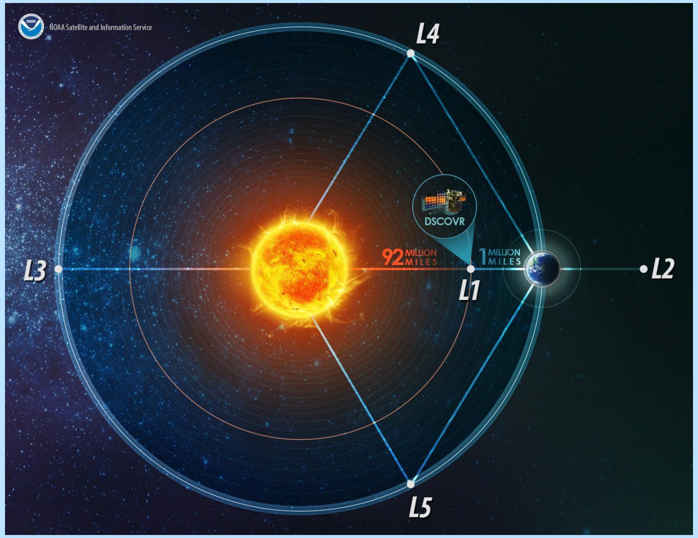
Eck, T.F. et al., A seasonal trend of single scattering albedo in southern African biomass-burning particles: Implications for Satellite products and estimates of emissions for the world's largest biomass burning source, JGR, 2013

Collection 4 OMAERUV Global Aerosol Record

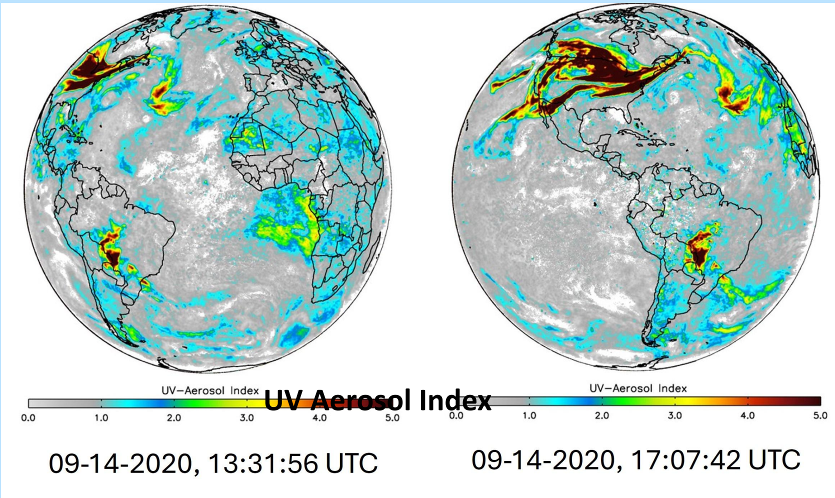


Earth Polychromatic Imaging Camera (EPIC)
Deep Space Climate Observatory (DSCOVR)

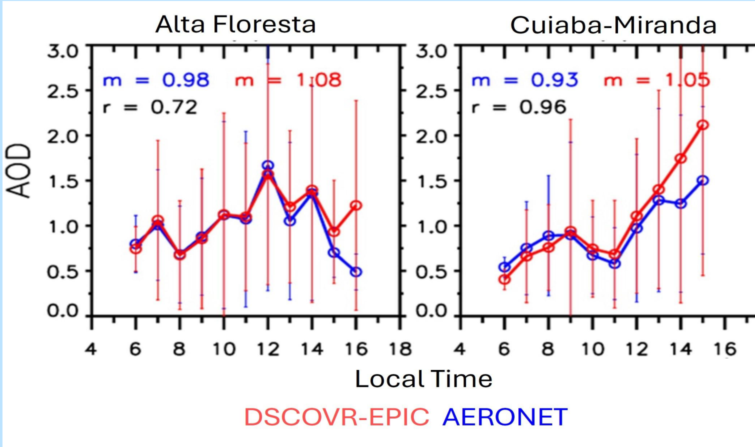
Lagrangian-1 (L1) Vantage Point

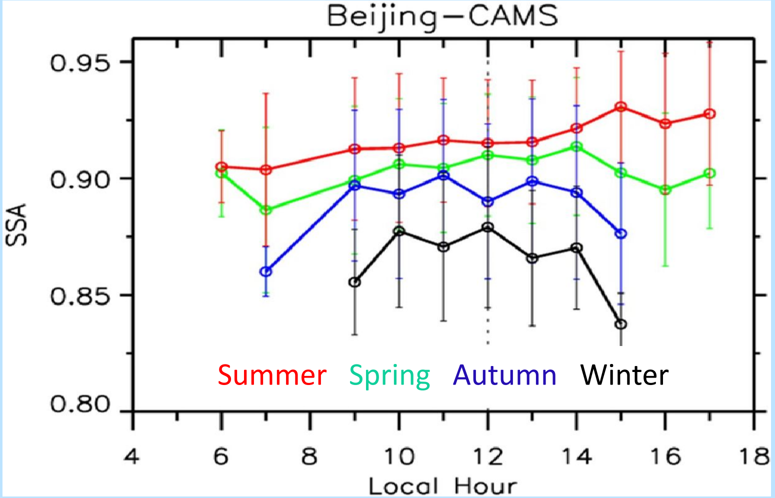


EPIC's view of multiple fires in the Western Hemisphere on September 14, 2020



EPIC-measured diurnal variability of aerosol AOD (Brazil) and SSA (China)





-EPIC at the L1 point, 1.6 million km away, observes the rotating sunlight Earth-disk on near-hourly basis.

-Channels (nm): 317, 325, 340, 388, 443, 551, 680, 688, 764, 780

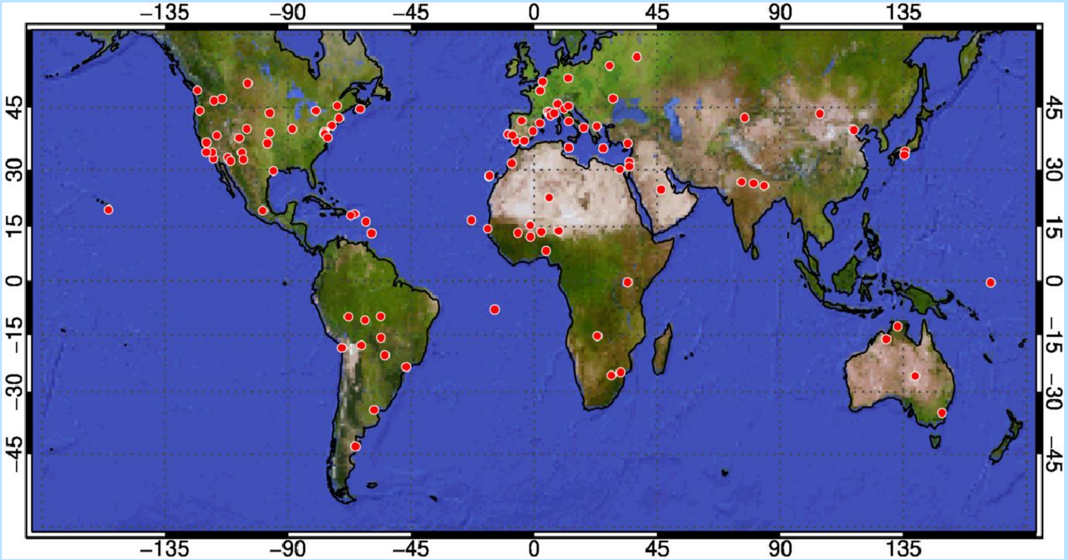
-EPIC is effectively a global GEO sensor.

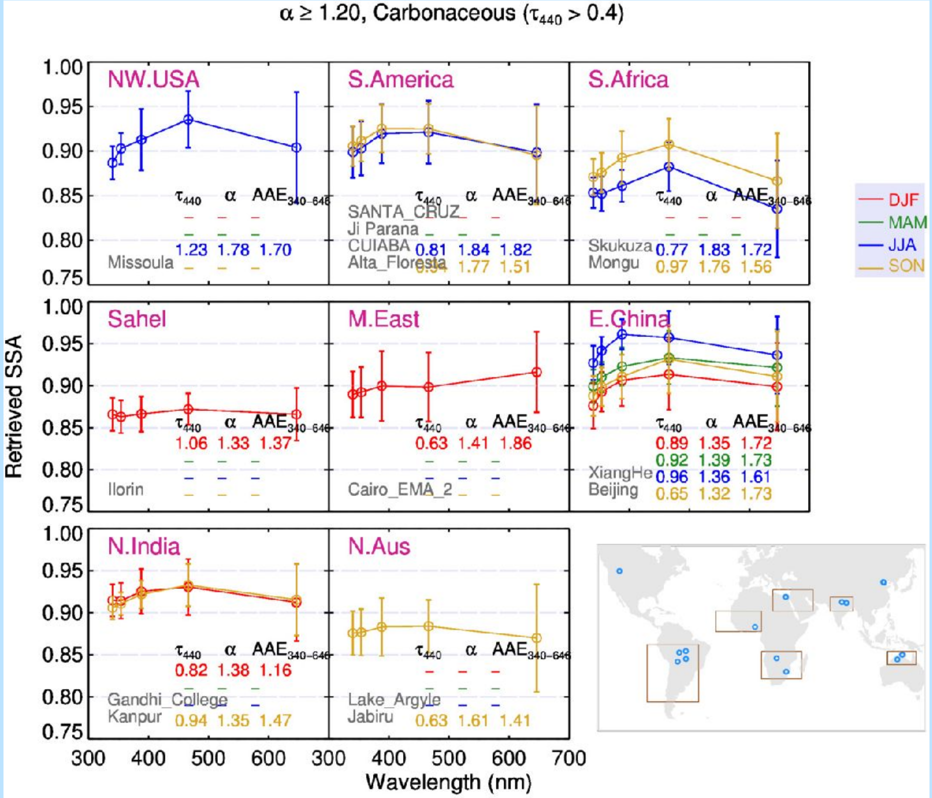
-It captures the diurnal variability of observed parameters.

Torres, O., & Ahn, C. (2024). Local and regional diurnal variability of aerosol properties retrieved by DSCOVR/EPIC UV algorithm, Journal of Geophysical Research: Atmospheres, 129

Synergistic use AERONET and satellite observations for UV-VIS for aerosol absorption characterization

Explaining satellite-measured near-UV radiances (340, 354, 388 nm) by OMI and visible radiances (466, 646 nm) by Aqua-MODIS with collocated (AERONET) measurements of total column extinction aerosol optical depth, in terms of retrieved total column wavelength-dependent SSA using radiative transfer calculations.





Kayetha et al., *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

Closing Remarks

-The 40-yr long TOMS-OMI UVAI/AOD/SSA record is the longest available satellite dataset over land and water surfaces.

-The earliest part of the AERONET AOD record in the 1990's was fundamentally important in providing a data set that confirmed the scientific validity of an emerging long-term UV AOD satellite record.

-As the first global aerosol record ever produced, TOMS data provided previously unknown information on specific smoke and dust aerosol sources and transport paths.

-AERONET aerosol absorption products also contributed to the evaluation of UV single scattering albedo derived from observations by the TOMS, OMI, TROPOMI, and EPIC observations.

-These satellite-based datasets on UV-absorbing aerosols have contributed to modelling improvements, allowing a more reliable interpretation of the long-term aerosol record.

-For more information on the important AERONET role on the validation & evaluation of the multi-sensor and multi-decadal satellite UV AOD and SSA records, see posters by Ahn et al (today), Krotkov et al (today) and Kayetha et al (tomorrow).