MAIAC Aerosol Retrieval and Hyperspectral Atmospheric Correction of TROPOMI Data

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Goals and Accomplishments:

Goals:

- Develop MAIAC-based algorithm for the atmospheric correction of OCI (1km) measurements over land
- Provide advanced aerosol products, including height and spectral absorption, from OCI
- Prototype and test developed algorithm using TropOMI

Progress in Y3 (2022-2023)

- ✓ Developed Multi-Angle Implementation of Atmospheric Correction (MAIAC) aerosol and atmospheric correction algorithm for OCI (testing with simulator data and getting ready to submit)

- ✓ Prototyped MAIAC aerosol retrieval and hyperspectral atmospheric correction algorithm over land on a limited number of subsets of TropOMI data.

- ✓ Validated retrieved 1-yr of aerosol optical depth (AOD) from TropOMI against AERONET over United States

- ✓ Demonstrated 1-yr of **hyperspectral atmospheric corrected surface reflectance spectra over land** from TropOMI over vegetation sites.

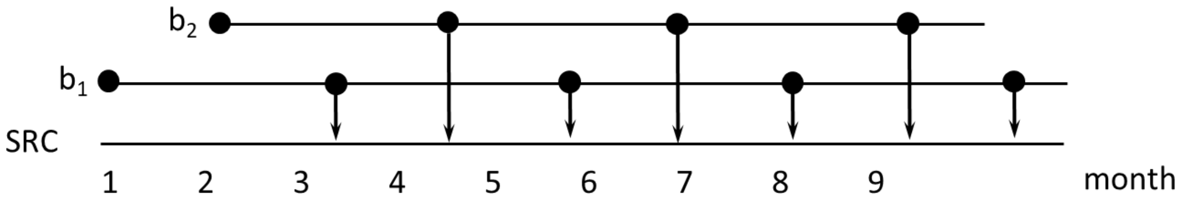
- ✓ Demonstrated 4D aerosol retrieval algorithm (AOD-k_0-SAE-**ALH**), followed by **aerosol speciation algorithm** for biomass burning smoke and mineral dust, prototyped with DSCOVR EPIC data. The speciation algorithm provides black carbon and brown carbon for biomass burning smoke, hematite and goethite for dust.

Spectral aggregation to emulate MAIAC MODIS-like vis-NIR and SWIR bands

MAIAC Features

- Grid TOA L1B data to 7km (TropOMI) or 1km (OCI) – work with polar-orbit data as "geostationary-like";
- Sliding window algorithm – store 4-16 last days of measurements in memory;
- RT with fully coupled BRDF model;
- Accumulate surface-related information for each grid cell (spectral BRDF, spatial variability, spectral ratios etc.) - improved cloud/snow detection and global aerosol retrievals over dark and bright surfaces
- **(Right table) OCI 10-15nm-aggregated reflectances**
- **Hyperspectral atmospheric correction uses swath data at native spectral resolution.**

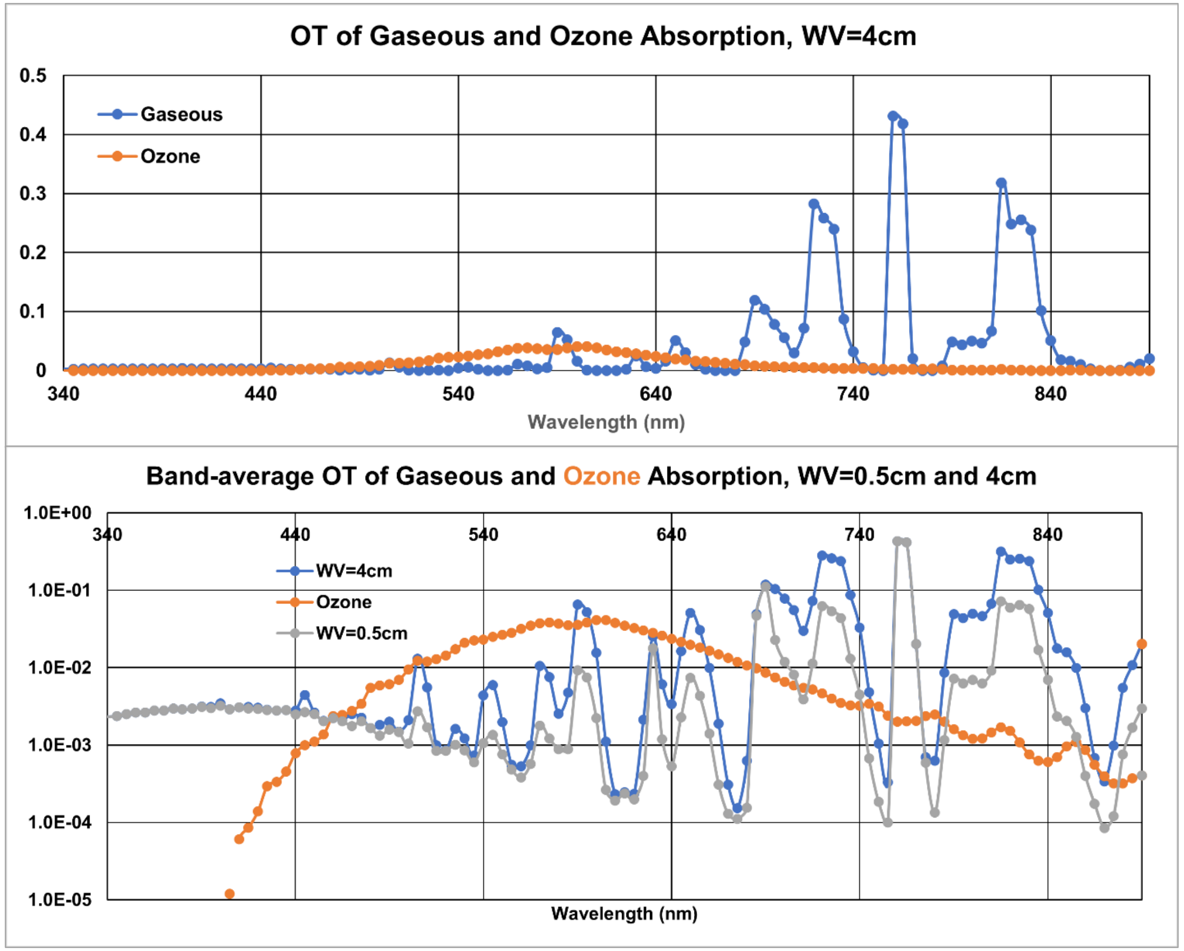
Use Dynamic Minimum Reflectance Method to Characterize Surface Spectral Ratios, SRC = $R_{0.47}/R_{2.13}$



Gridded MAIAC OCI Bands				
Band #	**MODIS Band #**	**Wavelength, nm**	**Heritage**	**Usage**
1	LY_BAND1	645	MODIS	As, Ad, C, Anc
2	LY_BAND2	855	MODIS	As, Aa, CWV, S, Anc
3	LY_BAND3	465	MODIS	As, Aa, Ad, C, S, Anc
4	LY_BAND4	552.5	MODIS	As, Ad, Anc
5	LY_BAND5	1250	MODIS/VIIRS	As, Aa,
6	LY_BAND6	1615	MODIS/VIIRS	As, Aa,
7	LY_BAND7	2130	MODIS aerosol	As, Aa, Ad, C, S, Anc
8	LY_BAND8	412.5	MODIS/VIIRS	Ad, S, Anc
9	LY_BAND9	340	EPIC	Aa, Ad,
10	LY_BAND10	387.5	EPIC (388)	Aa, Ad,
11	LY_BAND11	442.5	VIIRS	As, Aa, Ad,
12	LY_BAND12	2260	VIIRS	As, Aa, Ad, C,
13-14	LY_BAND13-LY_BAND14	**682.5**, 687.5	EPIC O2-B	Aa, C,
15-18	LY_BAND15-LY_BAND18	**755**, 760, 762.5, **772.5**	EPIC O2-A	Aa, C,
19	LY_BAND19	940	MODIS	CWV,
20	LY_BAND20	1038	MERIS	CWV,
21	LY_BAND26	1378	MODIS	C,

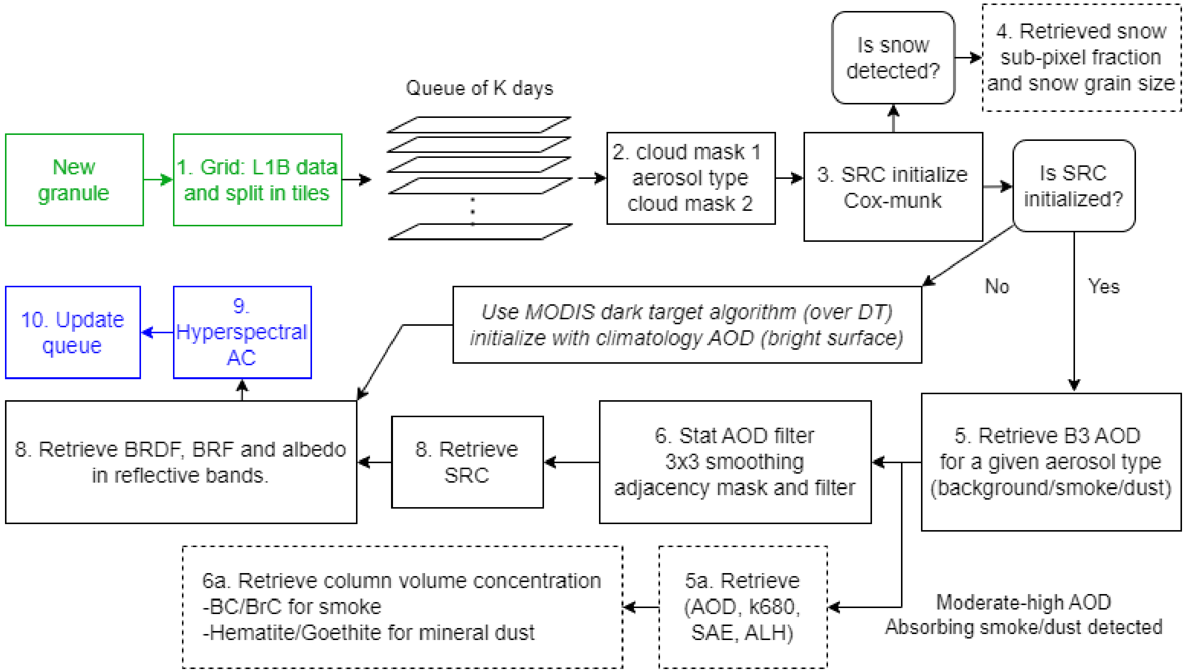
* As : Aerosol Standard (AOD & AOD-FMF), Ad : Aerosol (Advanced), Ad : Aerosol Detection (Smoke/Dust), CWV : Column Water Vapor, C : Cloud Detection, S : Shadow Detection, Anc : Ancillary MODIS use

Look-Up Tables for Hyperspectral Atmospheric Correction



- The figure shows LBL-integrated tauAbs at 5nm res. at 2 WV levels. The LBL are based on HITRAN-2020 with latest MT_CKD continuum model for atmospheric H_2O, NO_2, CO_2, and O_2.
- In AC algorithm, we are correcting for WV-variation based on LUTs generated at WV=0.5, 1.5, 3.5, and 5cm.
- Look-Up Tables for Hyperspectral Atmospheric Correction are computed with SHARM-IPC code which has an accuracy of LBL computations (Lyapustin, 2003), with vector correction for path radiance in the range 340-600nm.

Processing Diagram



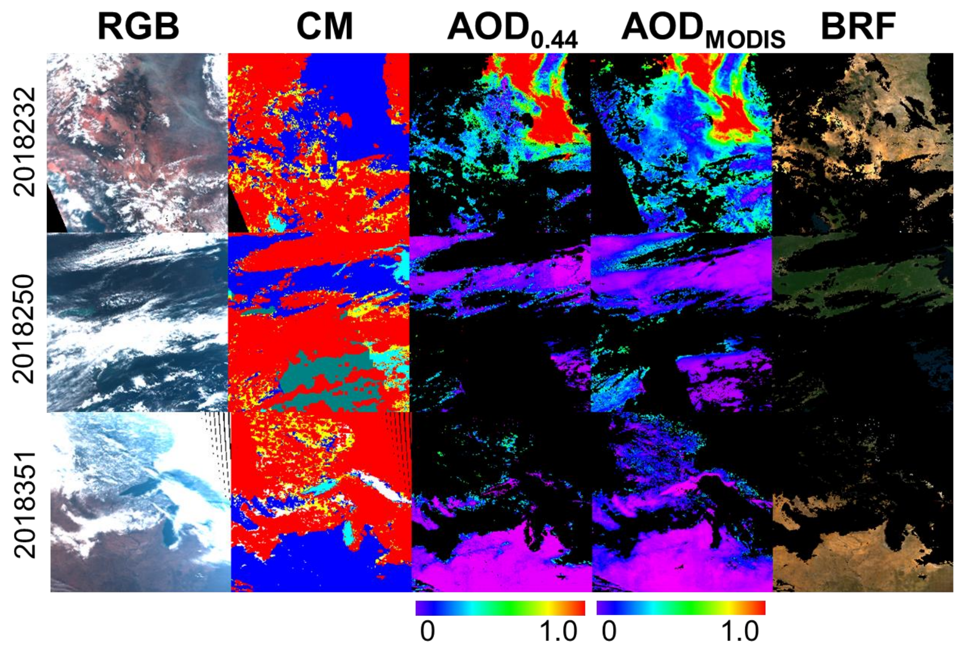
Step 1) Gridding
- 340 - 890 nm (14 wavelengths)
- 940 to 2260 nm (7 wavelengths)
- Rotated-sinusoidal projection (Lyapustin et al., 2021)

Step 2) Standard MAIAC Processing (Lyapustin et al., 2018)
- 4) MODIS ancillary monthly BRDF as prior for AC
- 5a, 6a) prototyped with DSCOVR EPIC (Go et al., 2022)

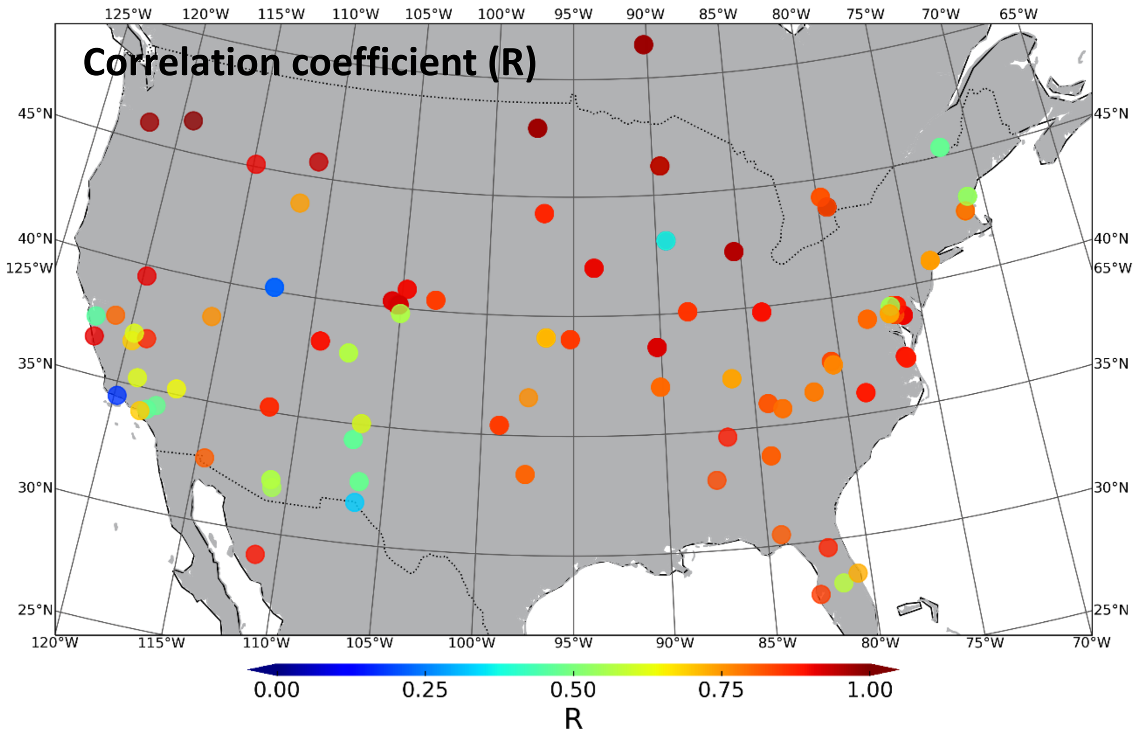
Step 3) Swath Atmospheric Correction
- Hyperspectral surface reflectance (BRF) will be provided in original swath-based pixel

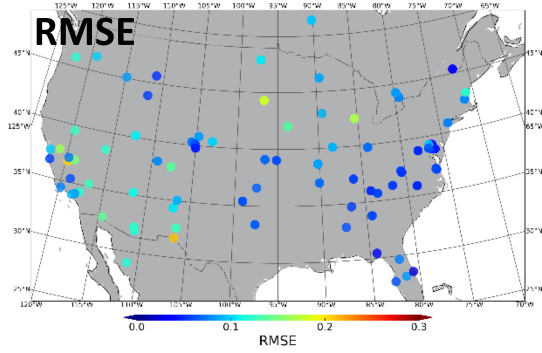
Level-2 Products:
- Atmosphere:
  - CM; WV; AOD; spectral imaginary refractive index (k_0, b) for smoke and dust; single scattering albedo (SSA); aerosol layer height (ALH)
- Land Surface:
  - Kiso, Kvol, Kgeo – coefficients of RTLS BRDF model (0.47, 0.55, 0.66, 0.87, 1.24, 2.13µm).
  - Hyperspectral SR (BRF): ~220 (may consider 80-100) values per pixels for 350-890nm range with 2.5nm step in atmospheric windows

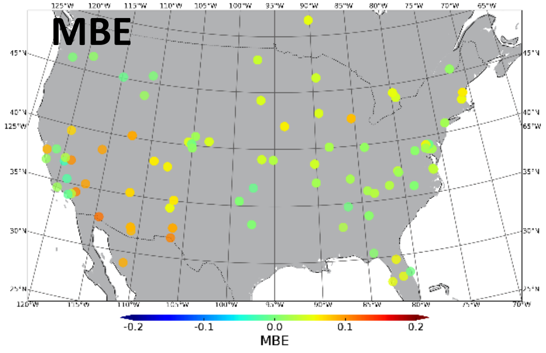
Retrieval results: Example of MAIAC-TROPOMI retrievals over United States



[1-yr AOD dataset validation against AERONET]







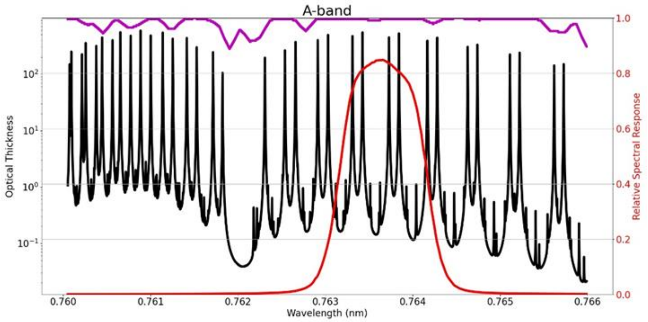
- **(Left)** MAIAC aerosol optical depth (AOD) from TROPOMI agrees well with MAIAC MODIS Aqua AOD 443nm
- MAIAC MODIS AOD has a high 1km spatial resolution vs 7km for TROPOMI and resolves AOD between clouds.
- **(Right)** MAIAC AOD Validation results
- Validation periods: 2018.04.30 – 2019.04.30.
- Results will be updated when TROPOMI L1B V2 data are publicly released.

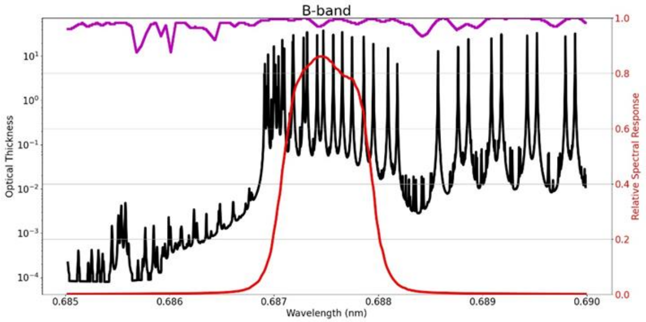
4D-retrievals : AOD - k_0 – SAE(b) - ALH

- Minimum Reflectance Method to characterize spectral SR ratio at 340, 388, 443 and 680nm in 4 SZA bins
- Absorbing smoke/dust aerosols detection using AI (340-388) and $AOD_{340}/AOD_{388}<0.8$, $AOD_{388}/AOD_{443}<0.8$
- Absorption model: $k_\lambda = k_0 (\lambda / \lambda_0)^{-b}$ where λ_0 = 680nm
  (*in the limit of small particles, AAE~b+1, where Absorption Ångström Exponent AAE is defined for the AAOD*).
- Real *refIM* and size distribution are fixed for smoke and dust models
- AOD-k_0-b-H retrieval using **Levenberg-Marquart optimal fit** of 340, 388, 443, **688/680nm** (and 780nm over ocean):

$$F^2 = 1/N \sum \left(\frac{L_\lambda^m - L_\lambda^t}{\sigma_\lambda L_\lambda^m}\right)^2 = \min\{AOD_{443}, k_0, b, H\}$$

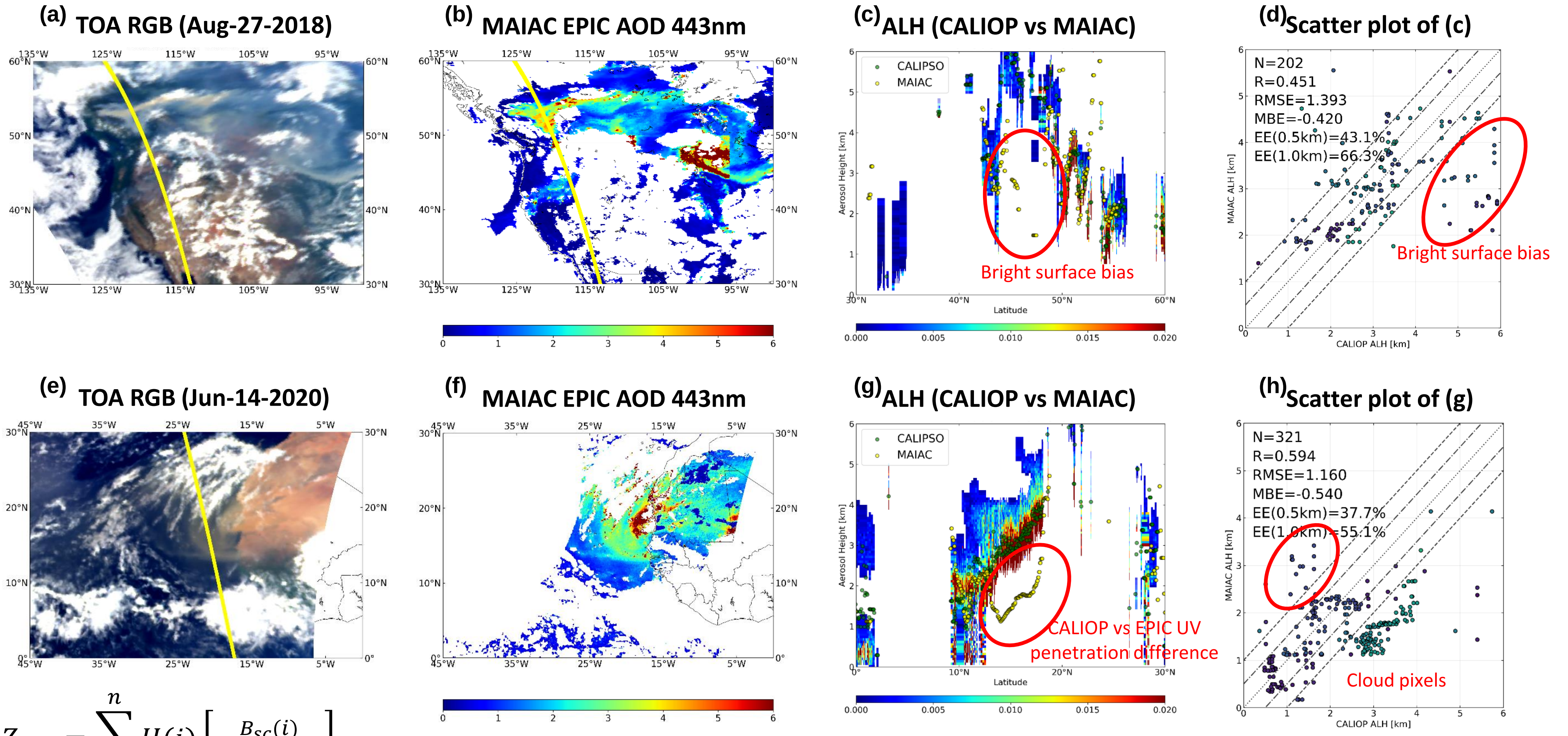
- LUT-based retrievals on a 4x4x4 tensor of b={0.1-4}, k_0 ={0.001-0.016}^{smoke} and {0.0006-0.003}^{dust}, H={0.5–7km}.
- LUT_{O2} are generated with SHARM-IPC [Lyapustin, 2003] code (accuracy ~0.1% vs LBL but ~100 times faster).
- The algorithm uses 8-dim linear interpolation in (geom, P, AOD, k_0, b, H) - fast.





Lyapustin, A., 2003: Interpolation and Profile Correction (IPC) method for shortwave radiative transfer in spectral intervals of gaseous absorption. J. Atmos. Sci., 60, 865-871

Example of MAIAC-EPIC 4D-retrievals : AOD - k_0 – SAE(b) - ALH



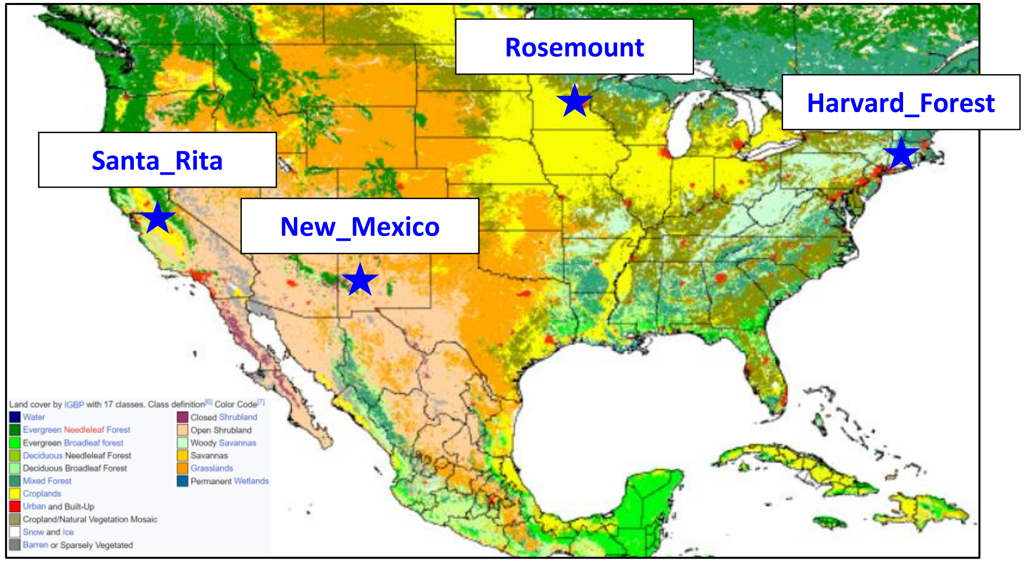
$$Z_{aer} = \sum_{i-1}^{n} H(i)\left[\frac{B_{sc}(i)}{\sum_{i=1}^{n} B_{sc}(i)}\right]$$

- Z_{aer}: attenuated-backscatter-weighted height
- $B_{sc}(i)$: attenuated backscatter at height $H(i)$
- n: number of layers

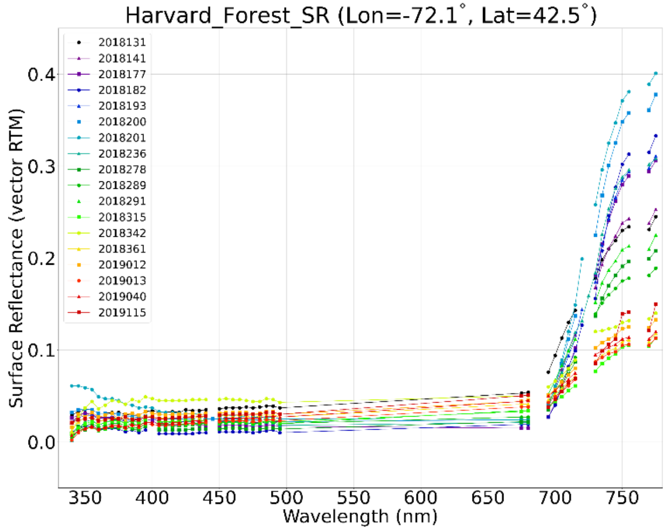
- CALIOP ALH is calculated as the attenuated-backscatter-weighted height according to the equation (1) [Torres et al., 2013].
- Underestimation points of MAIAC ALH (c), (d), (g) against CALIOP calculated ALH may be due to bright surface bias or limitation of CALIOP penetration measurements.
- Overestimation points of MAIAC ALH (h) against CALIOP calculated ALH may be due to mis-detected cloud pixels

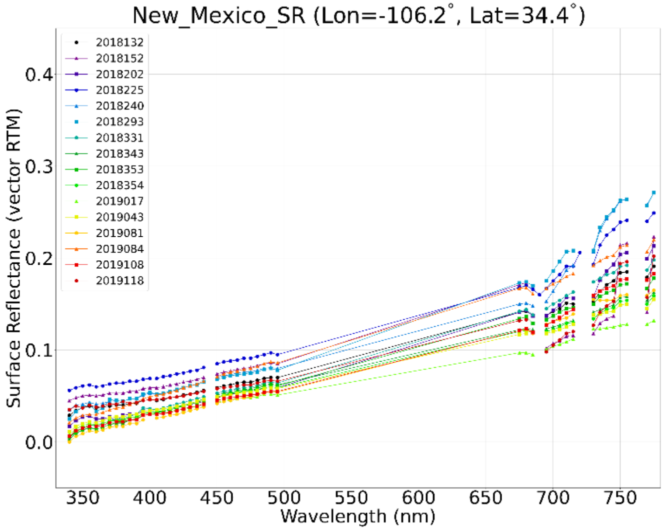
Hyperspectral surface reflectance from TropOMI: seasonal variation

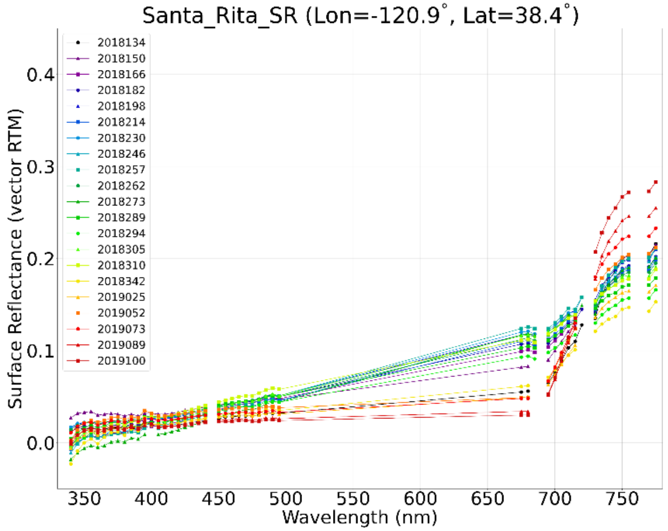
- Atmospherically corrected hyperspectral surface reflectance is shown over FluxNet sites.
- The hyperspectral surface reflectance over vegetated temperate regions shows smooth spectra from blue to NIR with highest NIR reflectance in mid-July, and shows expected seasonality of green-up, maturity and senescence.
- Negative surface reflectance in UV should be related to a known TROPOMI low calibration bias (about -5% at 340-400nm compared to OMPS).

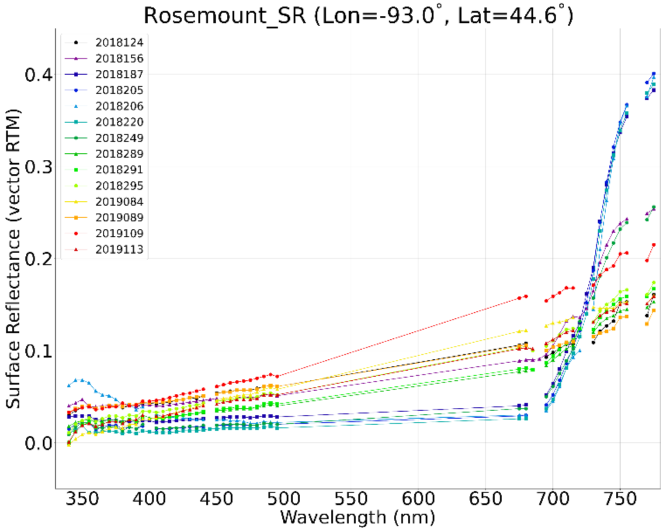


Land cover by IGBP with 17 classes (https://en.wikipedia.org/wiki/Land_cover)

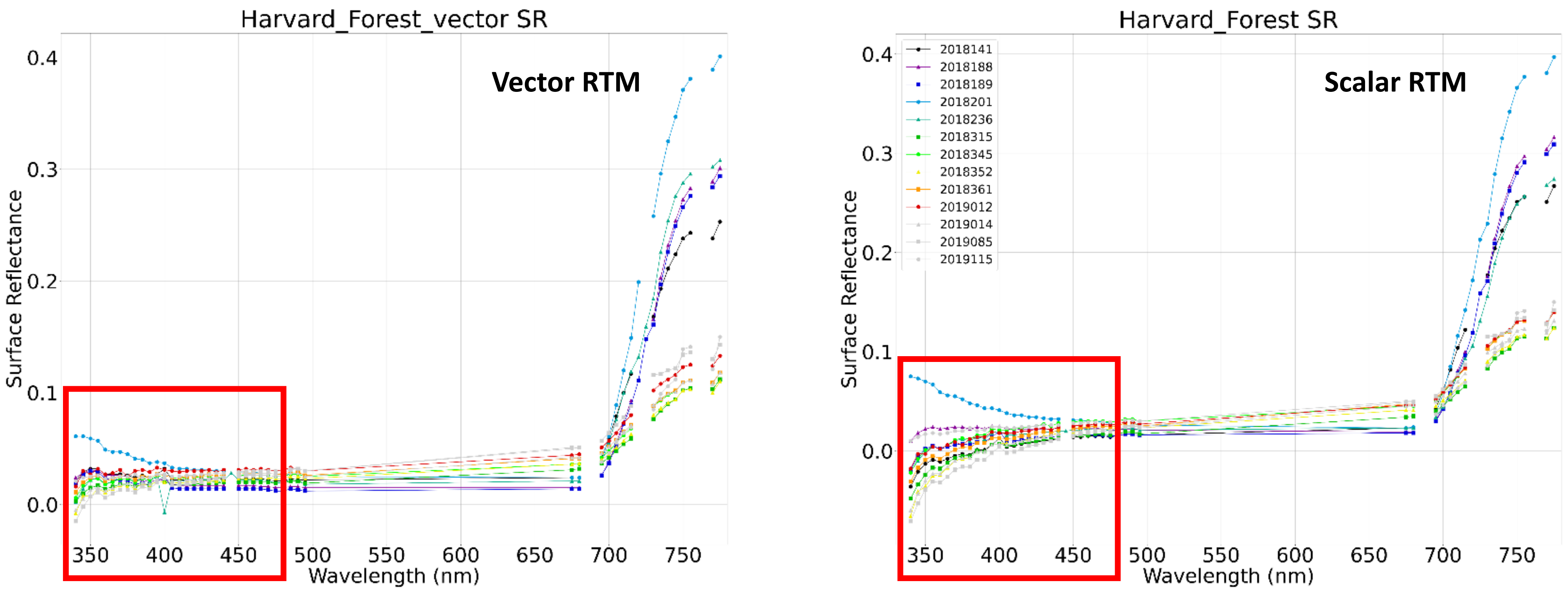








Vector RTM vs Scalar RTM in UV wavelengths



- The scalar approximation of radiative transfer model in UV region can overestimate the TOA normalized radiance by up to 3% at the scattering angle of Θ = 120° (so-lar zenith angle, viewing zenith angle, and relative azimuth angle are 30°, 30°, and 0°, respectively); and, by more than 8.4% at the scattering angle of Θ = 90° (solar zenith angle, viewing zenith angle, and relative azimuth angle are 60°, 30°, and 0°, respectively) [Ding and Wang, 2019].

References

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