Hyperspectral algorithms for PACE OCI atmospheric correction and UV penetration using Ozone Monitoring Instrument (OMI) and TROPOspheric Monitoring Instrument (TROPOMI)

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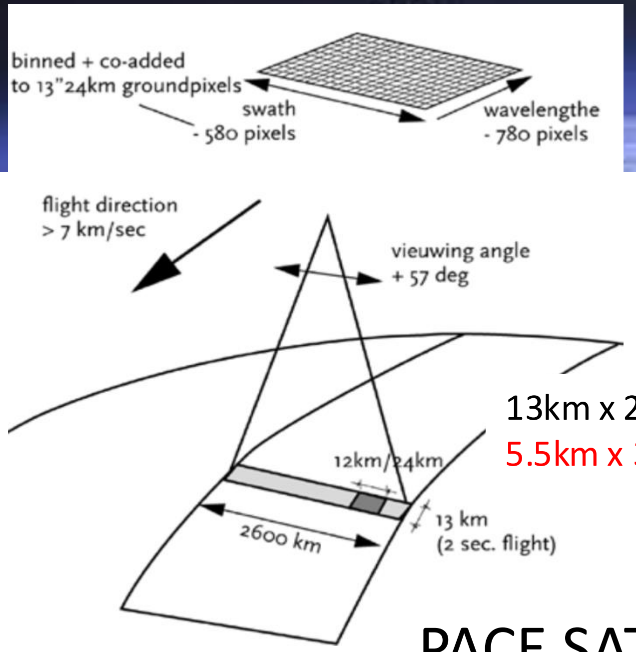
NASA EOS Aura
2004 – current
https://aura.gsfc.nasa.gov/

ESA/ EU Copernicus
Sentinel-5 Precursor
(TROPOMI)
2017 - current
http://www.tropomi.eu/



13km x 24km OMI
5.5km x 3.5km TROPOMI

PACE SAT 2023

We use OMI and TROPOMI measurements to

- calculate hyperspectral **underwater UV irradiance** and **UV penetration depths**;
- demonstrate **OCI atmospheric correction in UV** and fast **C_{hl} retrievals using machine learning**.
- Demonstrate OCI NO_2 retrievals.

Progress in Y3 (2022-2023)

✓Demonstrated OMI hyperspectral retrievals remote sensing reflectance (R_{rs}) for Case 1 waters and compared with Marine Optical BuoY (MOBY) R_{rs} measurements off the coast of Hawaii [Haffner et al., in prep.].

✓Demonstrated ML approach to atmospheric correction to fill in gaps resulting from cloud, aerosol, and sun glint [Fasnacht et al., 2022].

✓Demonstrated ML approach for NO_2 retrievals from high spatially resolved low spectral resolution OCI-like spectra [Joiner et al., 2023].

✓Calculated DNA damaging UV light penetration depths into global oceans by combining satellite measurements of extraterrestrial solar irradiance (TSIS) with
+ OMI measurements of total ozone,
+ OMI measurements of cloud/surface UV reflectivity,
+ MODIS chlorophyll concentrations [Vasilkov et al., 2022].

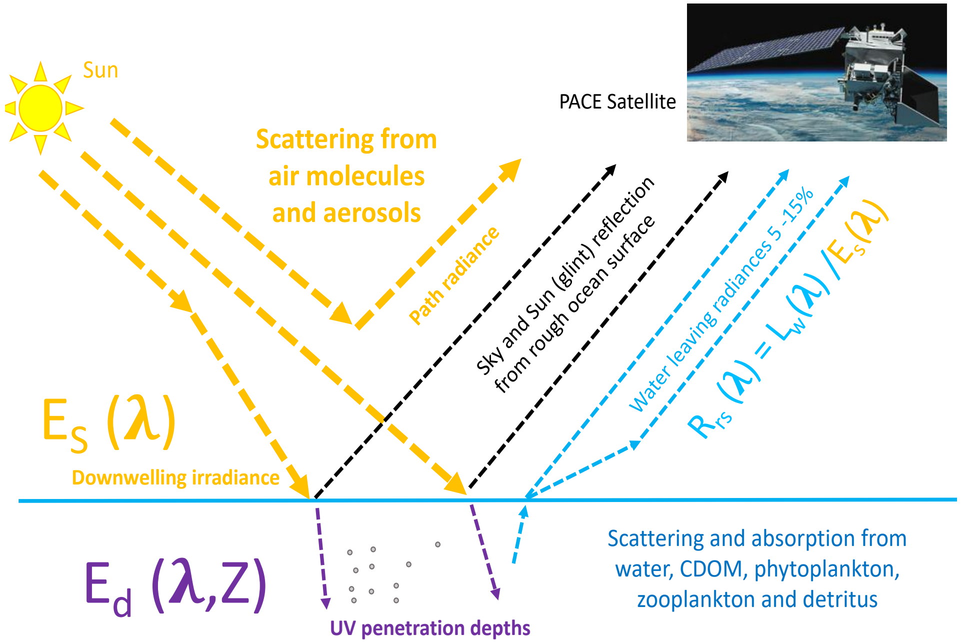
Hyperspectral UV-blue retrievals of water leaving radiance, $\mathbf{L_W}(\boldsymbol{\lambda})$, surface $\mathbf{E_s}(\boldsymbol{\lambda})$ and in-water $\mathbf{E_d}(\boldsymbol{\lambda},z)$ downwelling irradiances.

Downwelling Irradiance for all sky conditions

- *We calculate $E_s(\lambda)$ from 290nm to 399nm every 1nm*
- *We use OMI ozone and cloud/surface UV reflectivity.*
- *We calculate in-water diffuse attenuation coefficients $K_d(\lambda)$ using Hydrolight radiative transfer (RT) code and MODIS Chl.*

Water leaving radiance $L_W(\lambda)$ for cloud-free conditions

- *OMI 5nm-smoothed reflectances*
- *On-line VLIDORT RT code (v2.8.5) with Cox-Munk surface and water contributions.*
- *OMI retrievals of surface $GLER_{388}$ and AOD_{388}*
- *Modified MERRA-2 3D profiles of aerosol spectral optical properties*



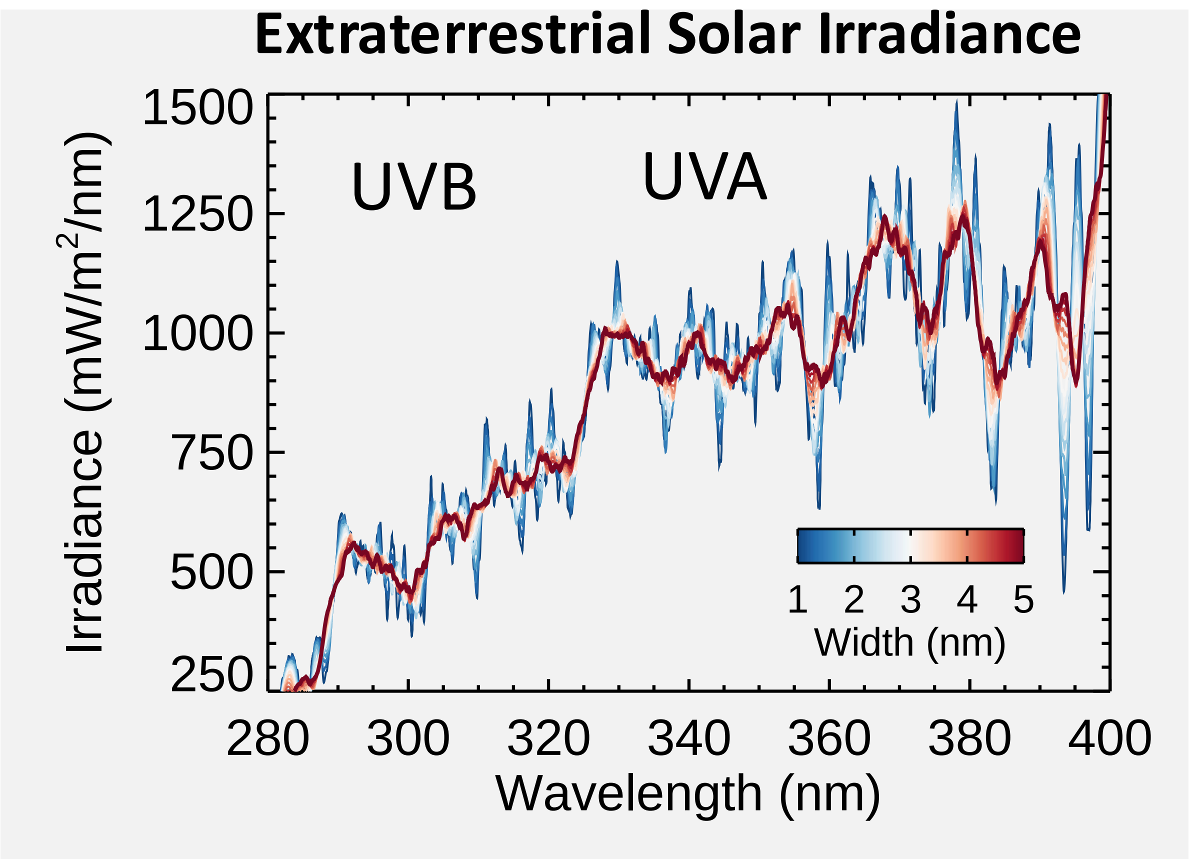
Vasilkov A. P., et al., Estimates of hyperspectral surface and underwater UV planar and scalar irradiances from OMI measurements and radiative transfer calculations, *Remote Sensing*, 14, 2278. https://doi.org/10.3390/rs14092278 , 2022

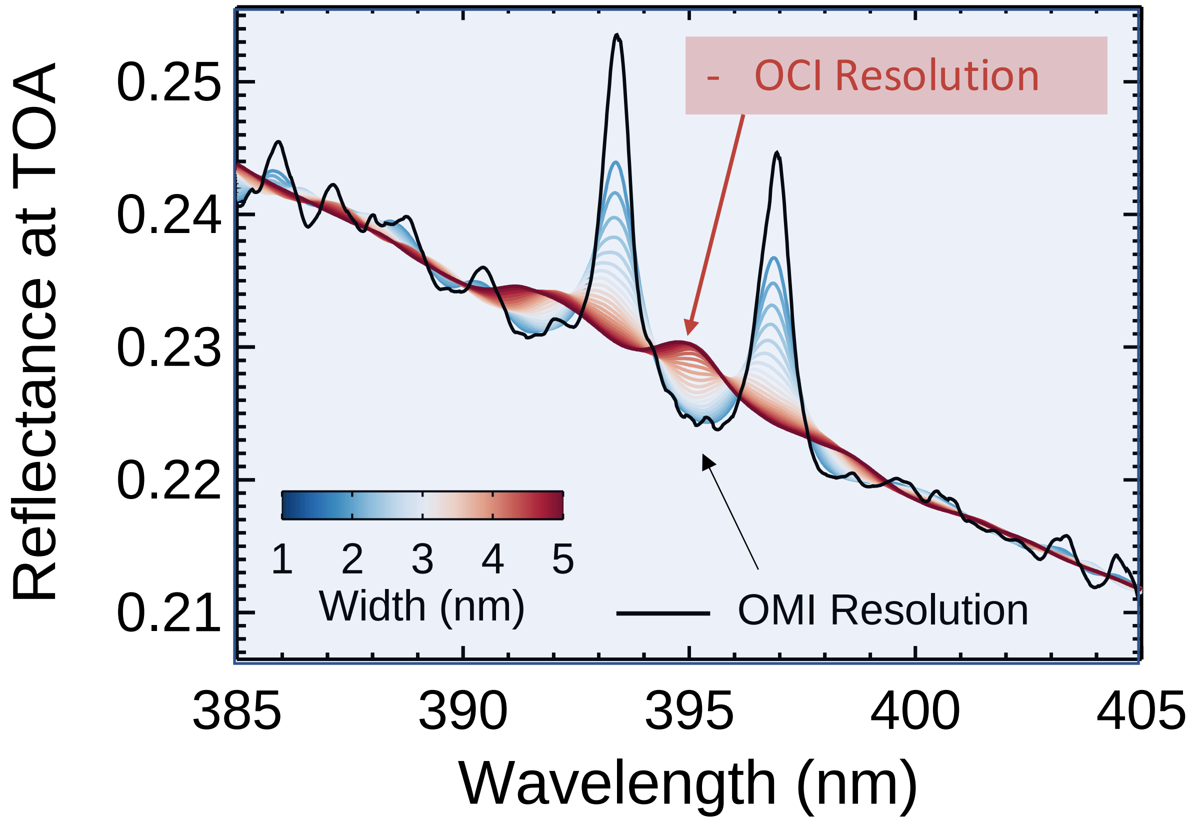
Korkin, S., et al., Numerical results for polarized light scattering in a spherical atmosphere, Journal of Quantitative Spectroscopy and Radiative Transfer, 287, 108194, https://doi.org/10.1016/j.jqsrt.2022.108194, 2022

Spurr, R. and Christi, M.: The LIDORT and VLIDORT Linearized Scalar and Vector Discrete Ordinate Radiative Transfer Models: Updates in the Last 10 Years, Springer, Cham, https://link.springer.com/chapter/10.1007/978-3-030-03445-0_1 , 2019.

Fasnacht, **Z.,** et al., A geometry-dependent surface Lambertian-equivalent reflectivity (GLER) product for UV/Vis retrievals - Part 2: Evaluation over open ocean, *Atmos. Meas. Tech*., 12, 6749–6769, https://doi.org/10.5194/amt-12-6749-2019 , 2019

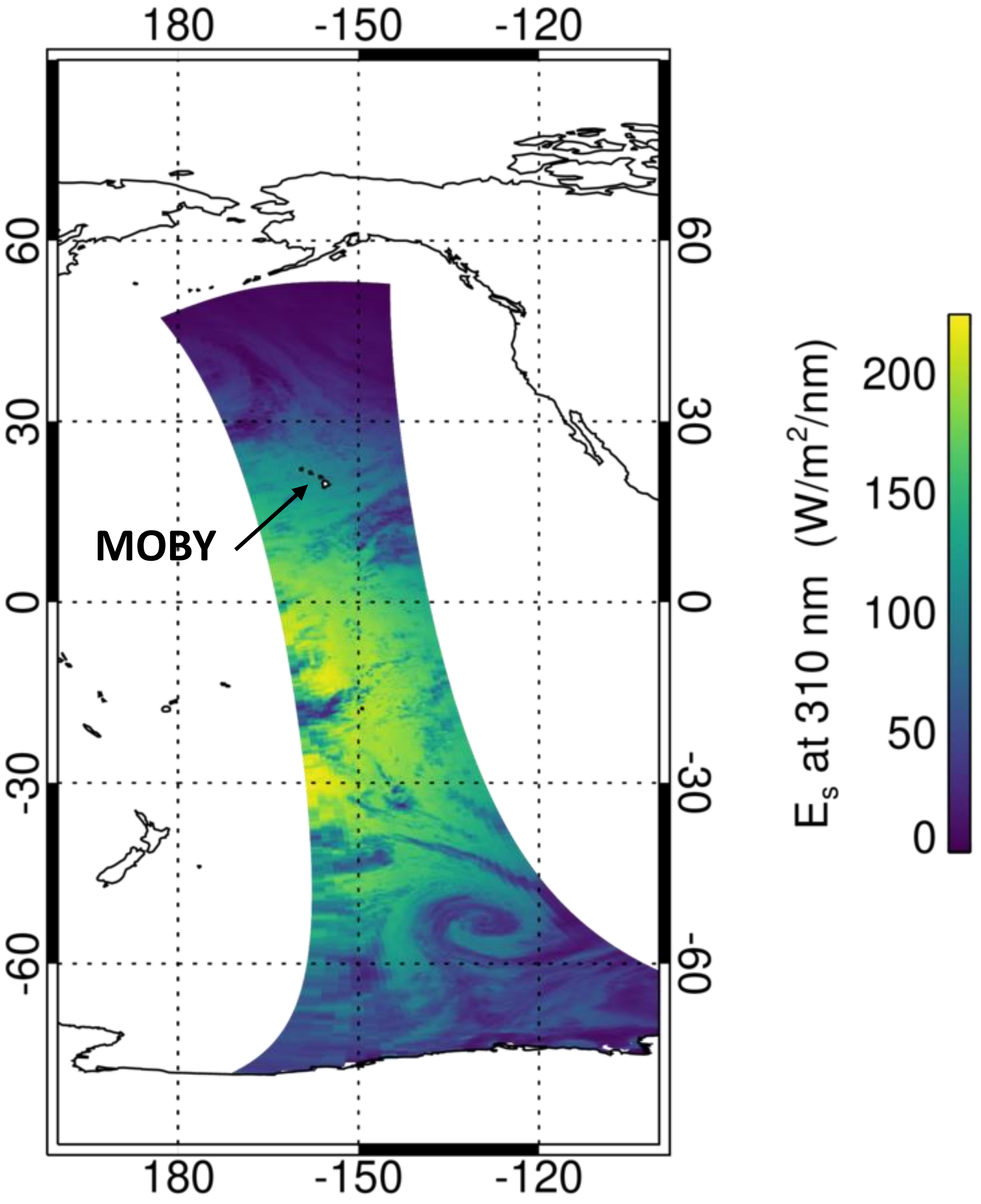
Smoothing OCI-like spectra using OMI reflectance measurements

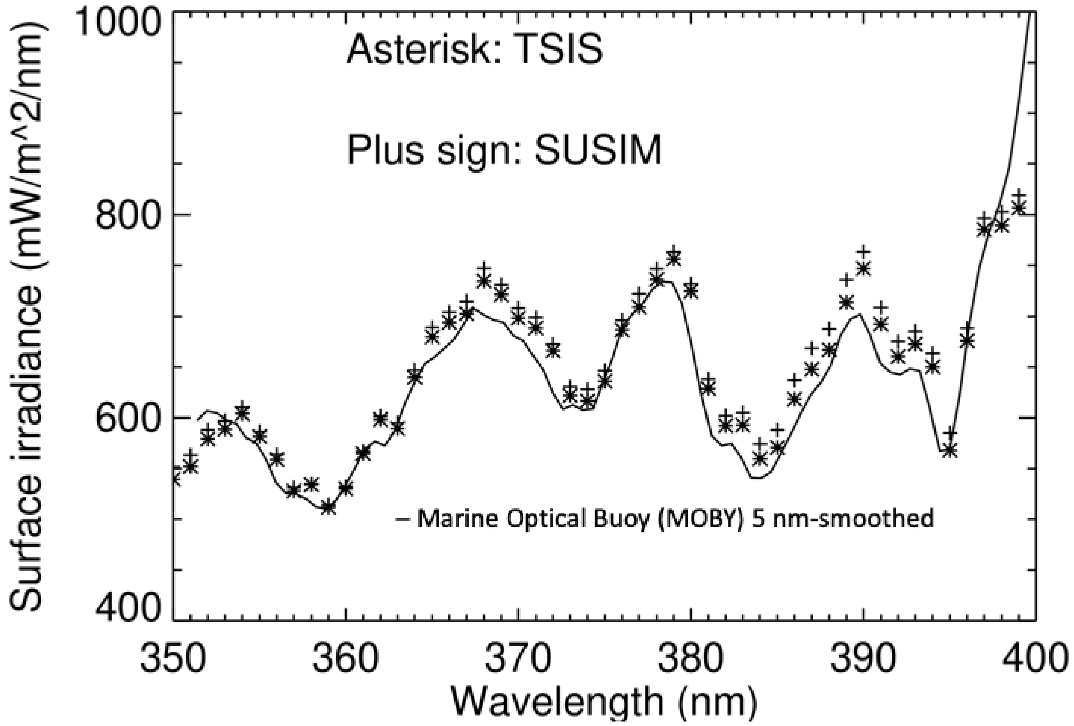




- Smoothing OMI measured Solar Irradiance (**Left**) and Earthshine radiance => => OCI-like smoothed Reflectance at TOA (**Right: red spectrum**)
- Accounting for OMI degradation in Collection 4
- OMI smoothed TOA reflectance spectra are available for testing OCI algorithms.

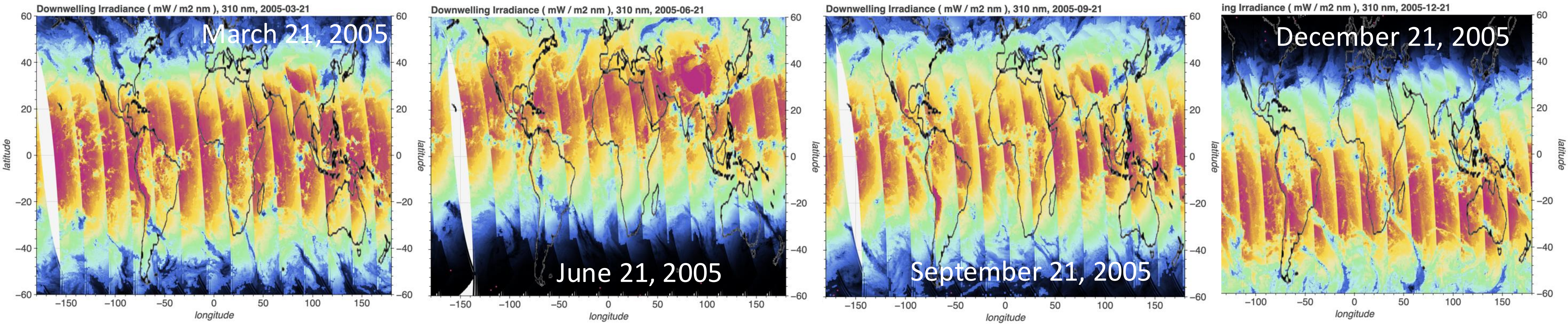
Spectral surface irradiance E_s compared with MOBY measurements



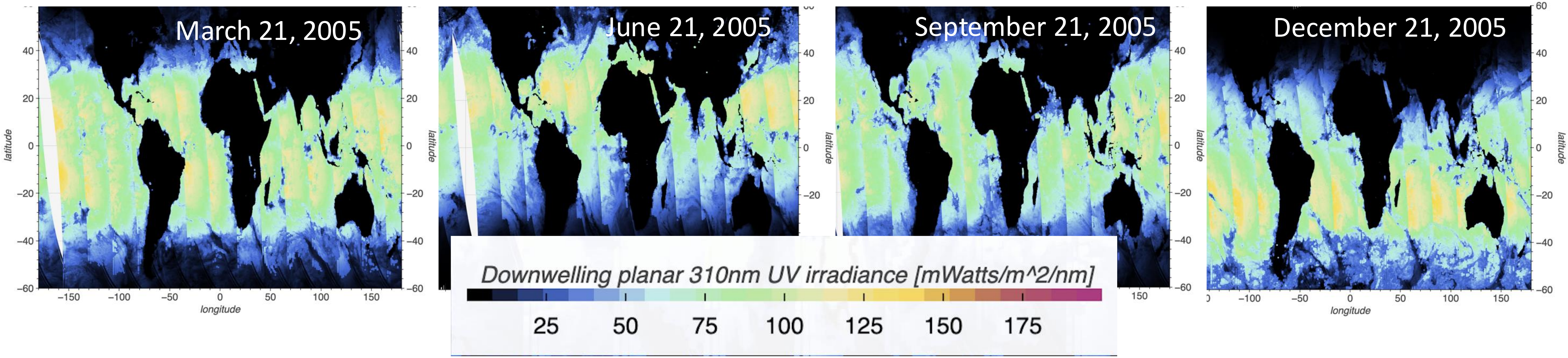


- ✓ Modified OMI/TROPOMI surface UV irradiance (E_S) algorithm to calculate hyperspectral E_s every 1nm at OCI spectral resolution 5nm.
- ✓ Validated with MOBY hyperspectral clear-sky E_S measurements within 5%.
- ✓ Using TSIS-1 solar irradiance reduces OMI Es retrieval bias with MOBY.

Daily maps of surface irradianceE_s (310nm) at OMI overpass mean local time ~1:45pm

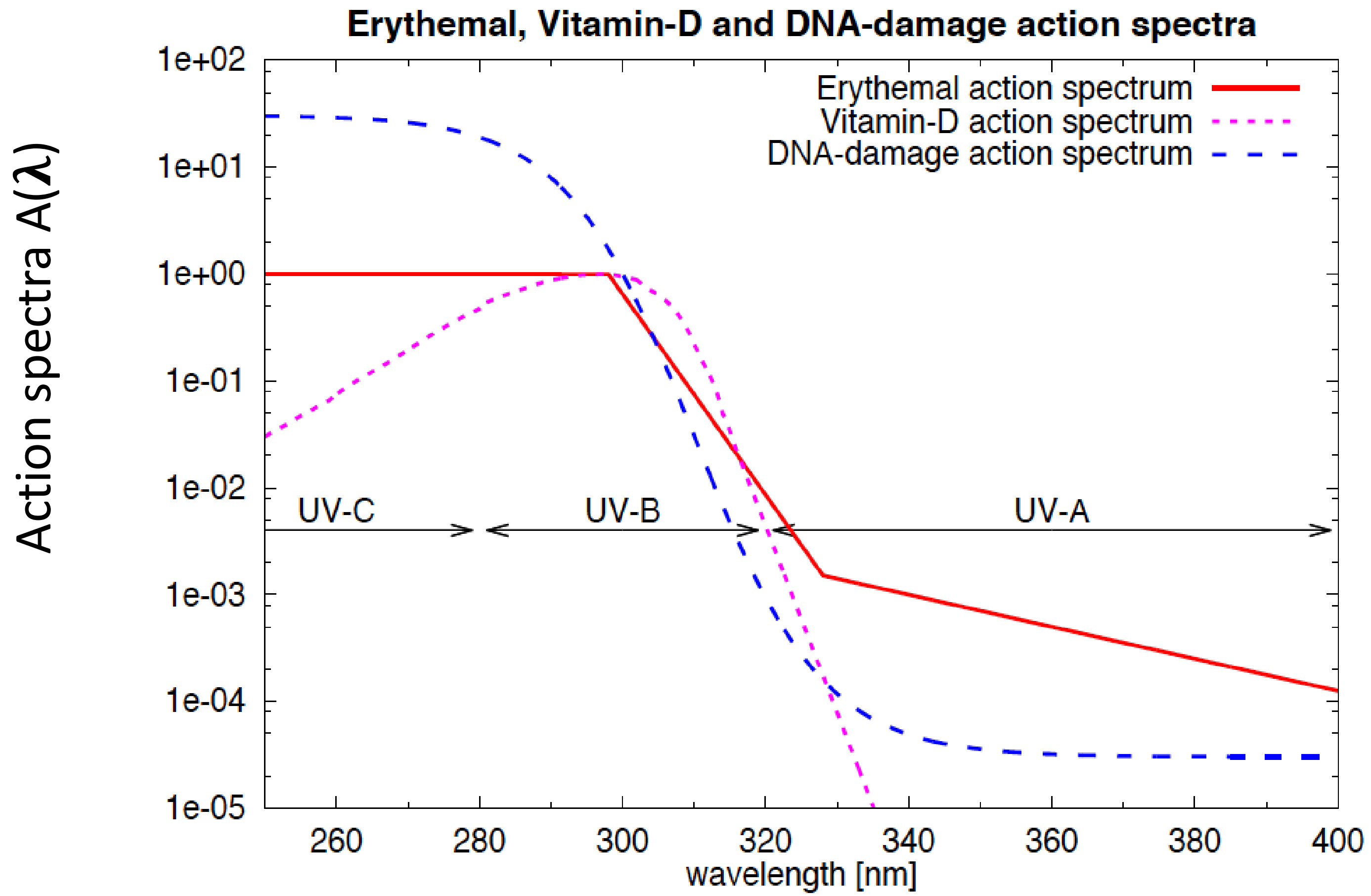


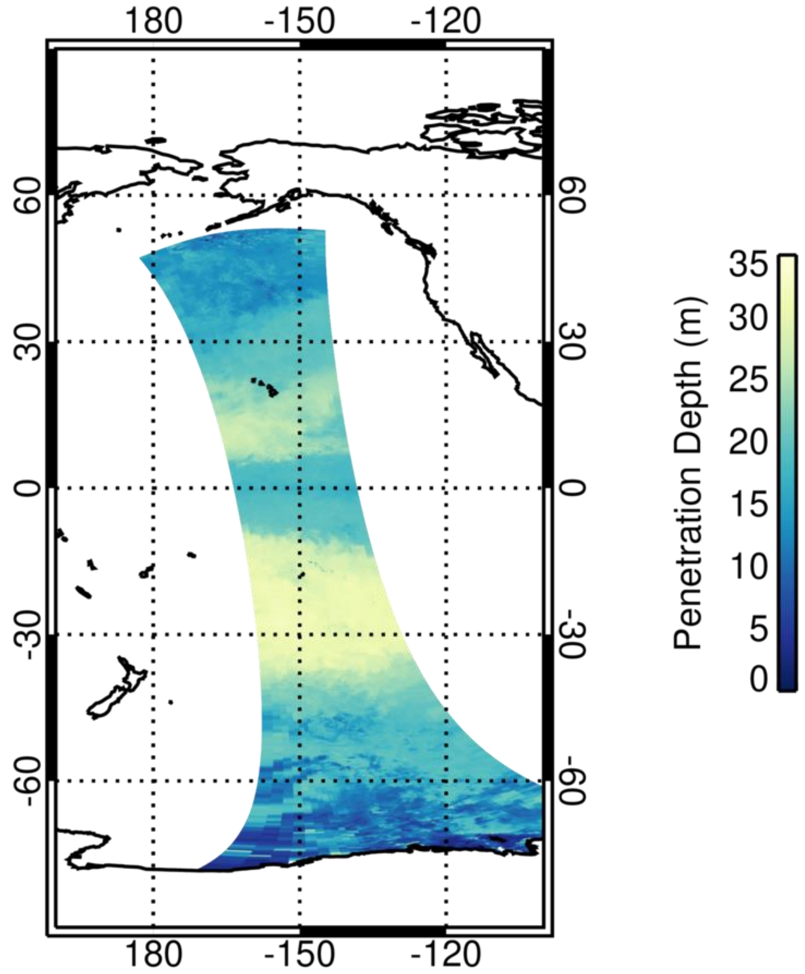
Underwater downwelling irradiance E_d (310nm) at 5m depth



More details in poster by Matthew Bandel et al.

UV penetration depths (z_{10}) using action spectra $A(\lambda)$



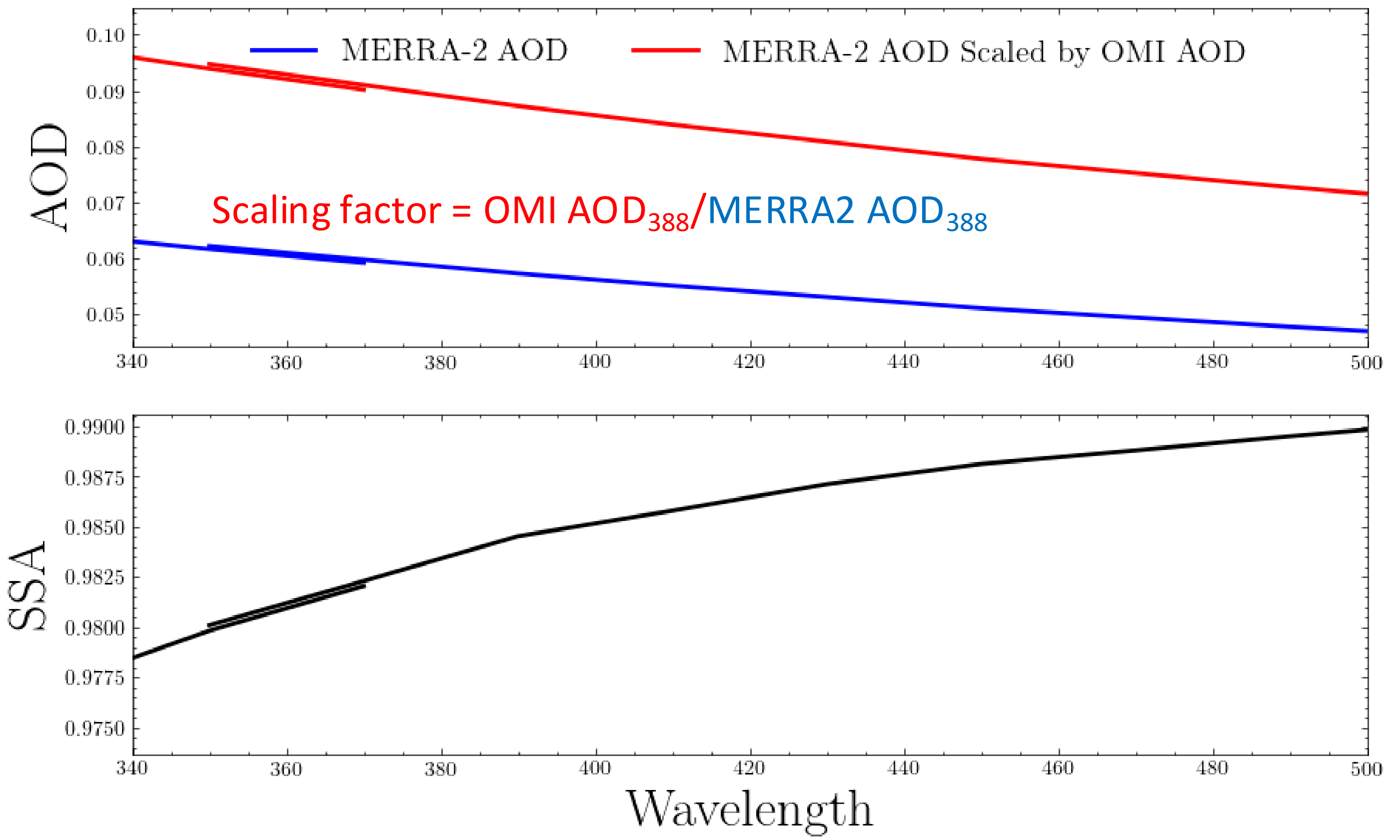


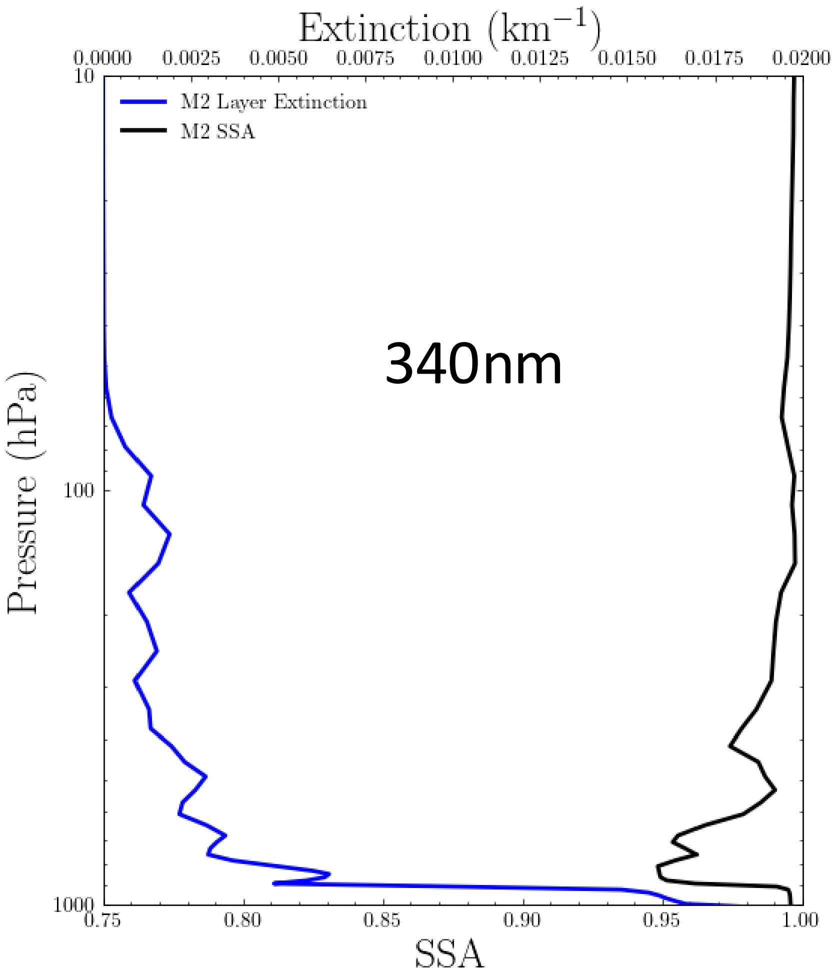
Users can convolve spectra $E_d(z)$ with an action spectrum $A(\lambda)$ to calculate UV dose rate D(z) and penetration depth, e.g., at 10% surface level (Z_{10}), for different biological processes, *e.g.*, DNA damage, Phytoplankton photoinhibition, etc.

10% penetration depth (Z_{10}) for DNA damage.

Vasilkov A. P., et al., Estimates of hyperspectral surface and underwater UV planar and scalar irradiances from OMI measurements and radiative transfer calculations, Remote Sensing, 14, 2278. https://doi.org/10.3390/rs14092278, 2022.

Modifying MERRA-2 oceanic aerosol UV optical properties: profiles and spectra



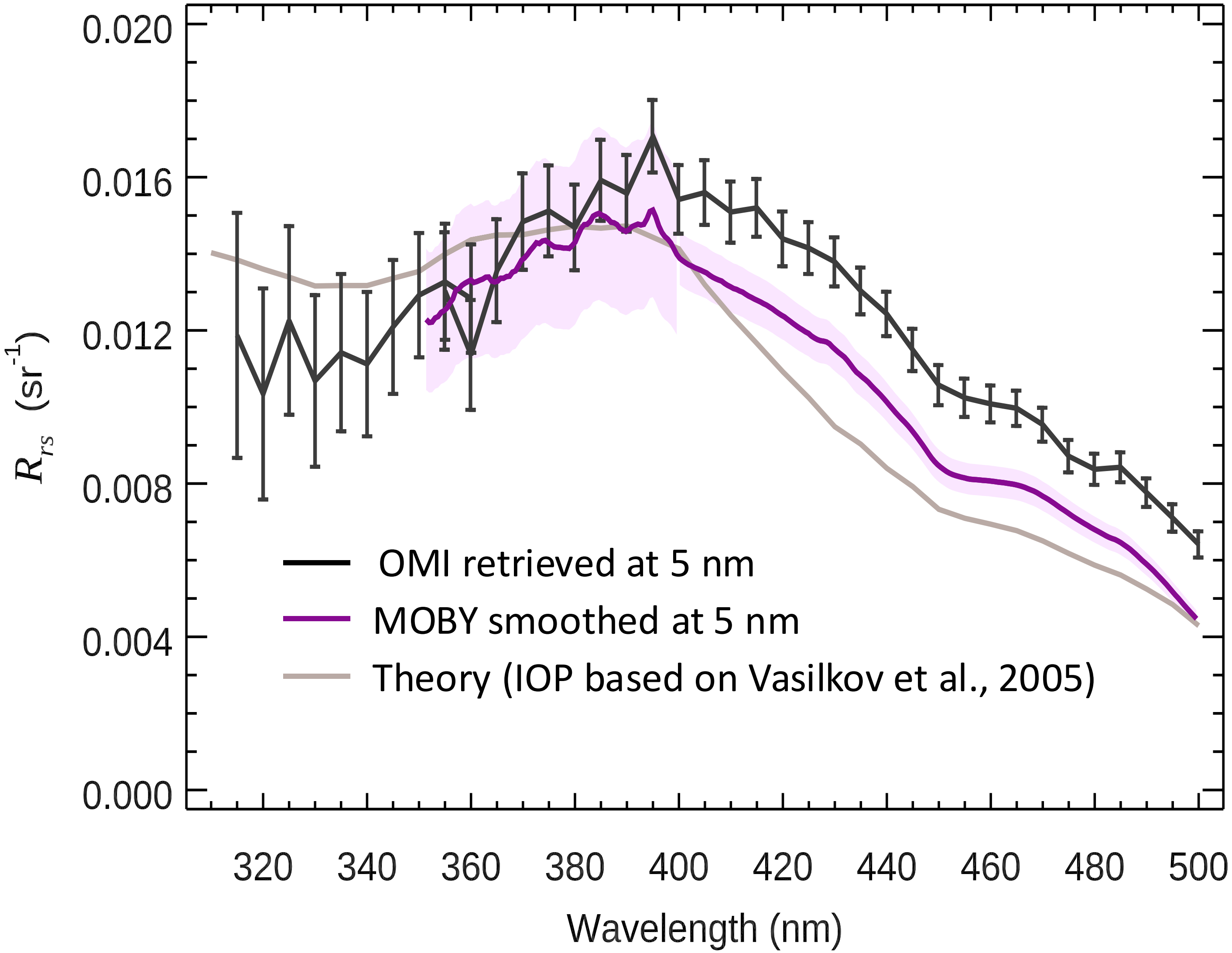


Top: MERRA-2 spectral AOD (blue) normalized with OMI retrieved AOD at 388nm (red).
Bottom: New MERRA-2 extinction weighted spectral single scattering albedo (SSA)

MERRA-2 (M2) vertical profiles of aerosol extinction (blue) and single scattering albedo (SSA, black) at 340nm for MOBY location.

Hyperspectral R_{rs} retrievals compared with MOBY measurements

OMI R_{rs} on Feb 10, 2005 over MOBY



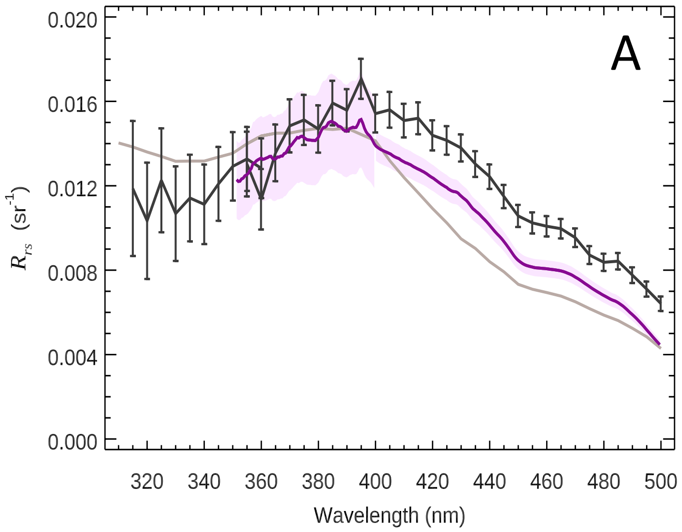
- We retrieve R_{rs} from 315-500 nm using OMI data at OCI spectral resolution.
- Atmospheric correction is on-line using VLIDORT coupled ocean-atmosphere RT with aerosol & O_3 data from MERRA-2 & OMI.
- Ocean water IOP based on *Vasilkov et al. (Applied Optics,* 2005) semi-empirical parameterization for pure water, Chl and CDOM.

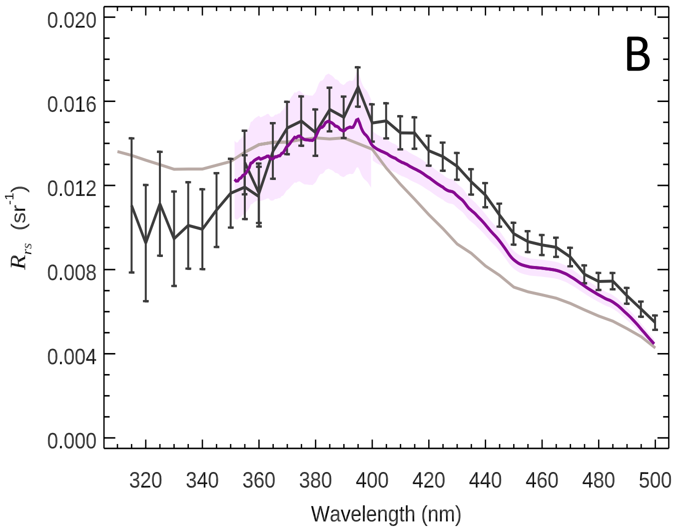
- Validated TOA radiance calculations for molecular atmospheres with rough ocean surface using *Chowdhary et al.* (2019) tables.

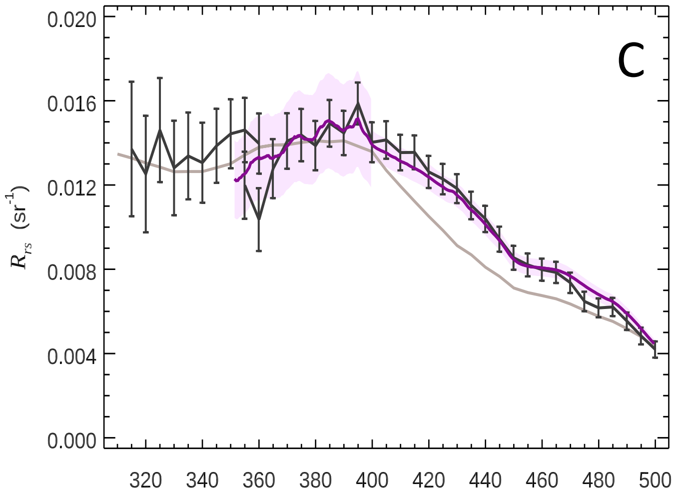
More details in poster by Haffner et al.

Hyperspectral R_{rs} retrievals compared with MOBY measurements

Aura/OMI Feb 10, 2005



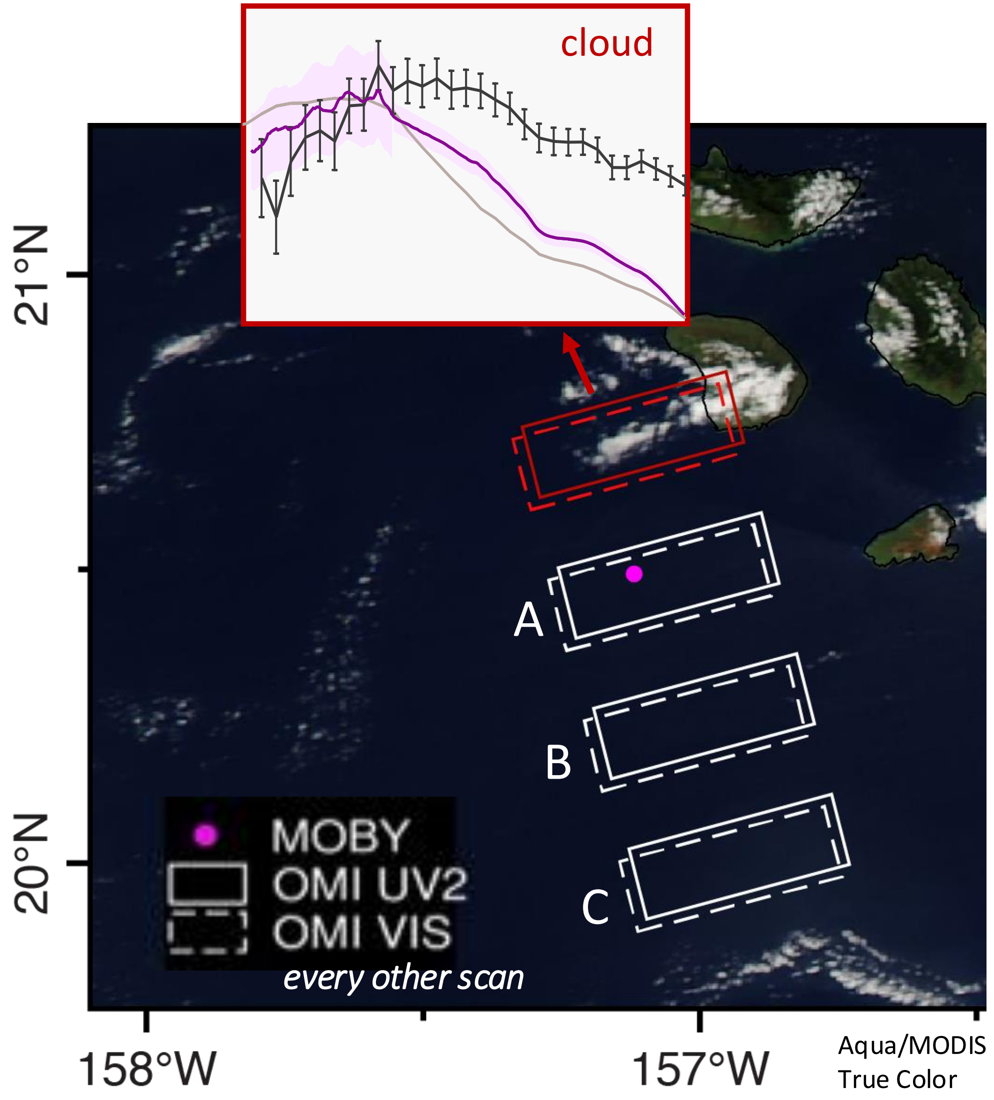




OMI at 5 nm

MOBY at 5 nm

Theory (Vasilkov et al., 2005)



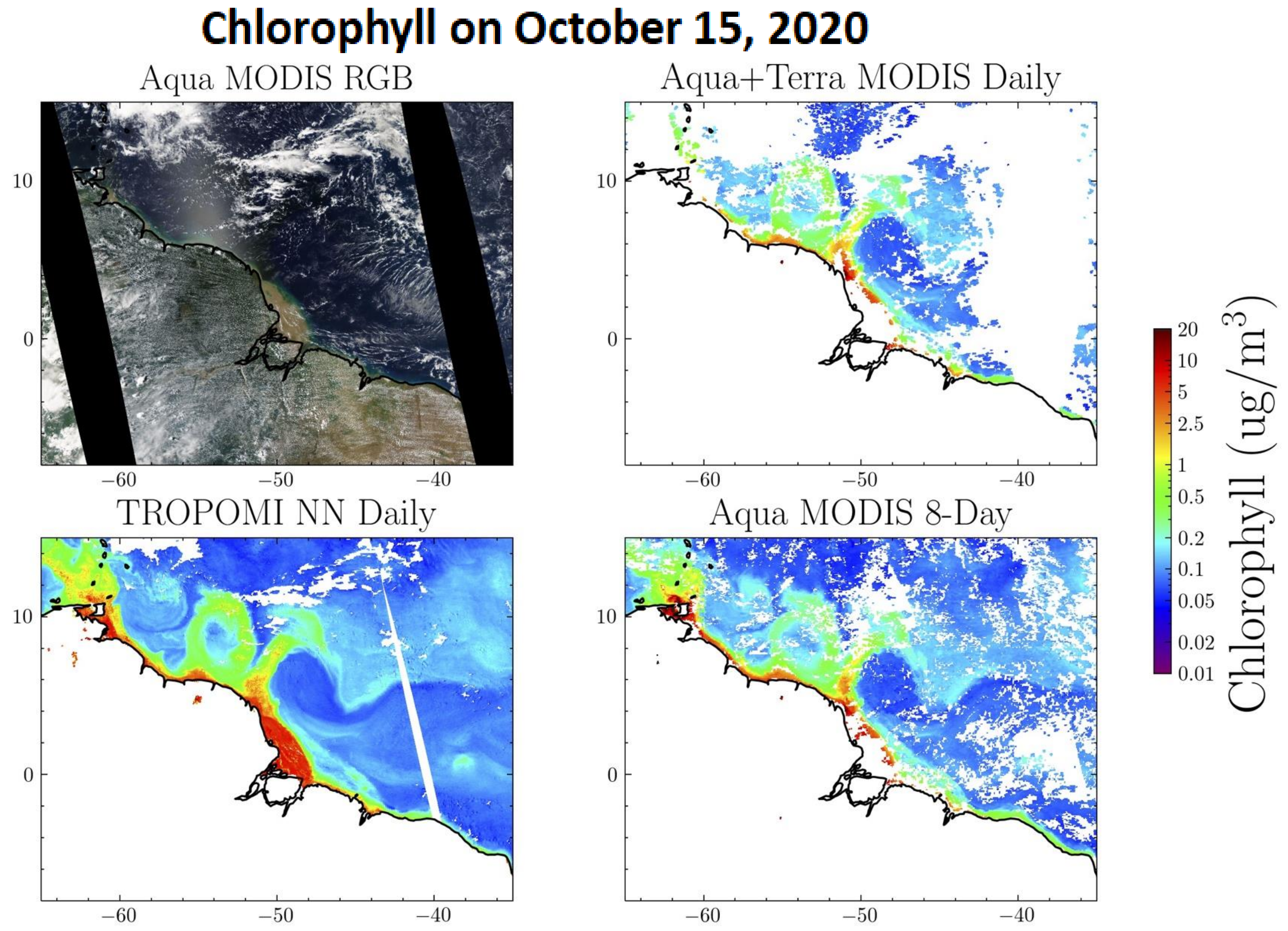
See poster by Haffner et al.

- Spectral features in OMI R_{rs} and MOBY are highly consistent.
- Bias in R_{rs} has little spectral dependence in clear sky scenes.

Applying machine learning (ML) approach to estimate chlorophyll in cloud-, aerosol-, and glint-contaminated conditions

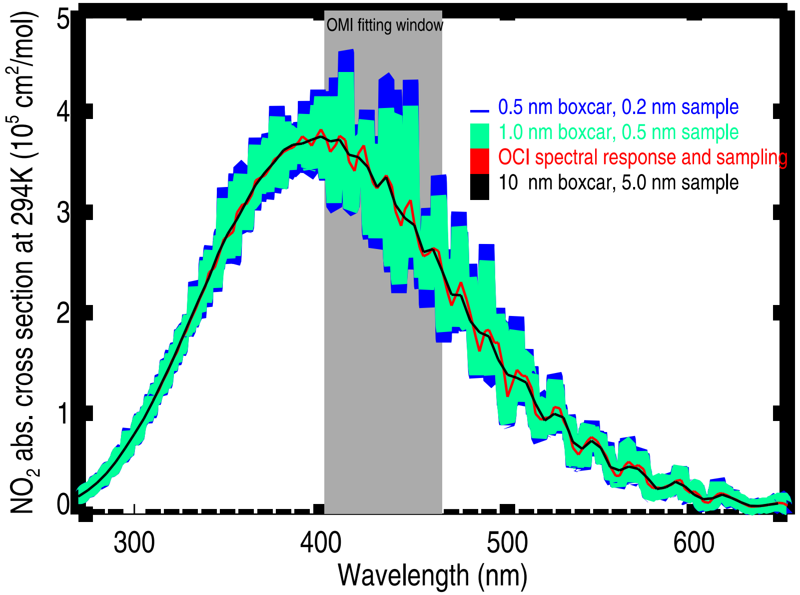
- ML approach used to separate the spectral signatures of clouds, aerosol, glint, and trace-gases from those of water leaving radiance (in light to moderate amounts of cloud)

- **Right**: approach applied to NE coast of South America
  - TROPOMI (UV and blue spectra) provides enhanced spatial coverage compared with MODIS in cloud and sun glint conditions
  - Some features not captured in 8-day MODIS composite but are captured with our TROPOMI data.



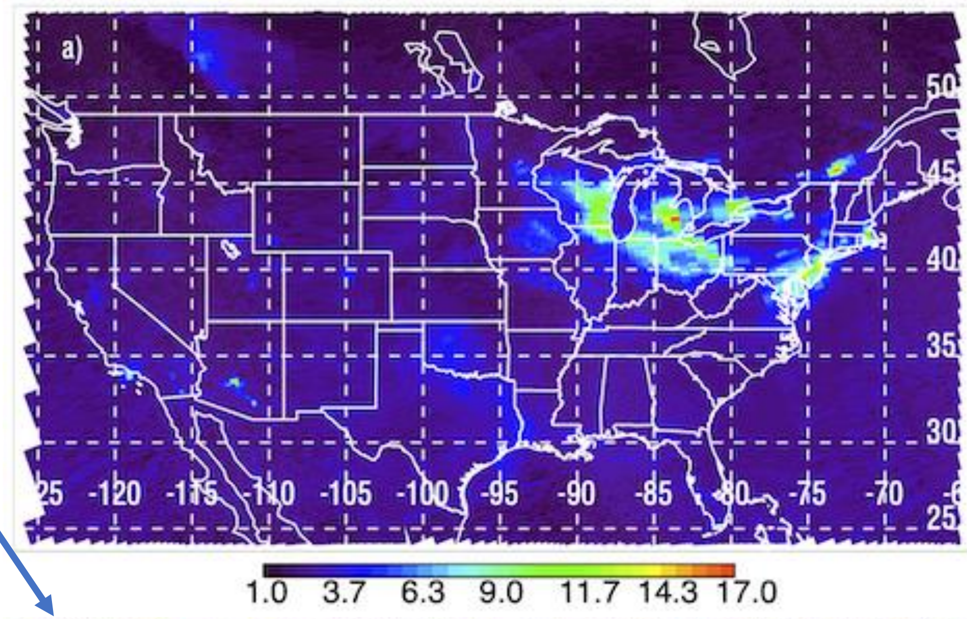
Fasnacht, Z., Joiner, J., Haffner, D., Qin, W., Vasilkov, A., Castellanos, P., and Krotkov, N., Using Machine Learning for Timely Estimates of Ocean Color Information From Hyperspectral Satellite Measurements in the Prescence of Clouds Aerosols, and Sun glint, *Frontiers in Remote Sensing, 2022*

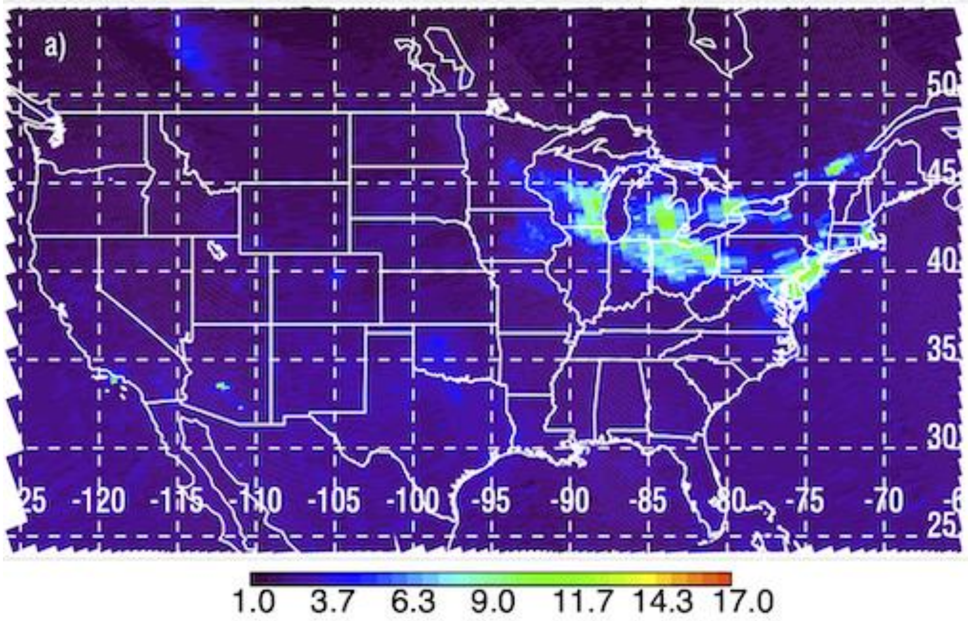
PACE OCI NO_2 retrievals



OMI NO_2 retrievals (the target)

Simulated OCI retrievals at OMI resolution (real OCI data will be at much higher spatial resolution!)





- Spectral structure in NO_2 cross sections is present at PACE OCI spectral resolution and can be leveraged to retrieve NO_2 given high enough signal-to-noise ratios.
- We simulated PACE data with OMI and OCI noise model.
- Averaging OCI data in time or space will produce NO_2 retrievals that can be used for atmospheric correction as well as science, e.g., potentially downscaling of TROPOMI to even higher spatial resolution (see Joiner et al., 2023).
- Can be trained using collocated TROPOMI data.

Joiner, J., et al., Use of machine learning and principal component analysis to retrieve nitrogen dioxide (NO_2) with hyperspectral imagers and reduce noise in spectral fitting, Atmospheric Measurement Techniques, 16, 481-500, 10.5194/amt-16-481-2023, 2023

Publications (2022-2023)

1. Joiner, J., Marchenko, S., Fasnacht, Z., Lamsal, L., Li, C., Vasilkov, A., and Krotkov, N., Use of machine learning and principal component analysis to retrieve nitrogen dioxide (NO_2) with hyperspectral imagers and reduce noise in spectral fitting, Atmospheric Measurement Techniques, 16, 481-500, 10.5194/amt-16-481-2023, 2023.
2. Korkin, S., E.-S. Yang, R. Spurr, C. Emde, P. Zhai, N. Krotkov, A. Vasilkov, A. Lyapustin, Numerical results for polarized light scattering in a spherical atmosphere, Journal of Quantitative Spectroscopy and Radiative Transfer, 287, 108194, https://doi.org/10.1016/j.jqsrt.2022.108194, 2022.
3. Fasnacht, Z., Joiner J, Haffner D, Qin W, Vasilkov A, Castellanos P and Krotkov N., Using Machine Learning for Timely Estimates of Ocean Color Information from Hyperspectral Satellite Measurements in the Presence of Clouds, Aerosols, and Sunglint, Frontiers in Remote Sensing, 3, 846174, https://doi.org/10.3389/frsen.2022.846174, 2022.
4. Vasilkov A. P., Krotkov, N. A., Haffner, D., Fasnacht, Z., Joiner, J., Estimates of hyperspectral surface and underwater UV planar and scalar irradiances from OMI measurements and radiative transfer calculations, Remote Sensing, 14, 2278. https://doi.org/10.3390/rs14092278, 2022.
5. Joiner, J., Z. Fasnacht, W. Qin, Y. Yoshida, A. P. Vasilkov, C. Li, L. Lamsal, and N. Krotkov, Use of Hyper-Spectral Visible and Near-Infrared Satellite Data for Timely Estimates of the Earth's Surface Reflectance in Cloudy and Aerosol Loaded Conditions: Part 1–Application to RGB Image Restoration Over Land With GOME-2, Frontiers in Remote Sensing, 2, https://doi.org/10.3389/frsen.2021.716430, 2022.
6. Jethva, H., Haffner, D. P., Bhartia, P. K., & Torres, O.. Estimating spectral effects of absorbing aerosols on backscattered UV radiation. Earth and Space Science, 9, e2022EA002354. https://doi.org/10.1029/2022EA002354, 2022.