Copernicus FRM4SOC FICE 2025

Training on
In Situ Ocean Colour Radiometry

AERONET-OC

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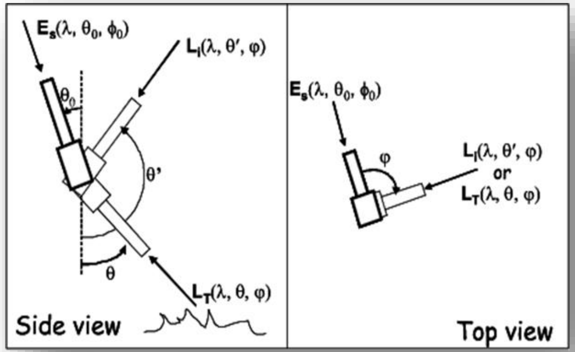
PROGRAMME OF THE EUROPEAN UNION
Copernicus Europe's eyes on Earth
IMPLEMENTED BY EUMETSAT
FRM4SOC Phase-2
fiducial reference measurements for satellite ocean colour
CNR ISMAR
ISTITUTO DI SCIENZE MARINE

7-19 July 2025
Venice, Italy

AERONET-OC

The outcome of an excellent NASA-JRC collaboration.

The Ocean Color component of AERONET (AERONET-OC), established in April 2002, is an asset for the major Space Agencies managing ocean color missions (e.g., EUMETSAT, KARI, NOAA, JAXA, ESA, CNSA, NASA, …) and by the ocean colour community at large.

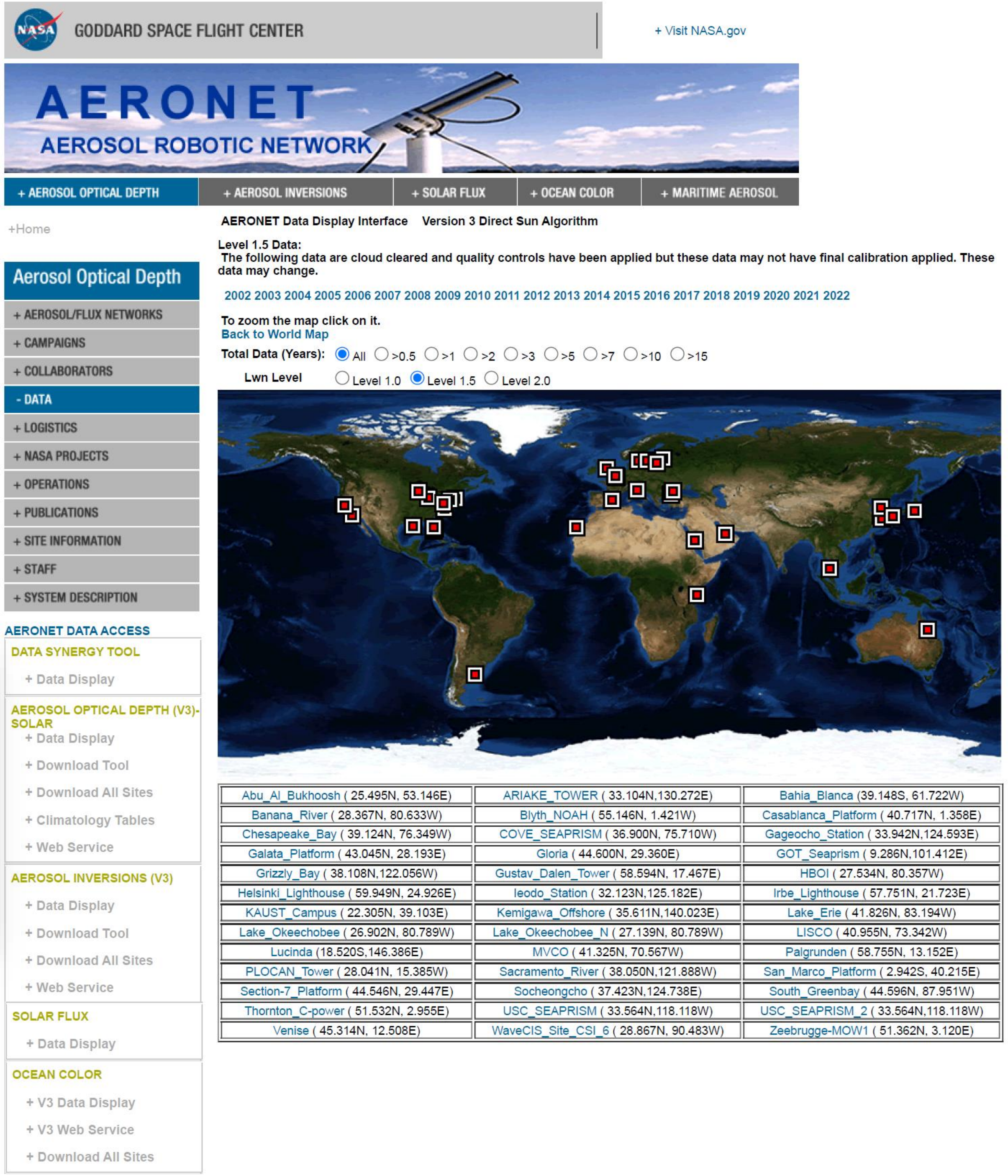


$(\varphi = \varphi_0 + 90^0; \theta = 40^0; \theta' = 140^0)$

Sky-radiance: L_i

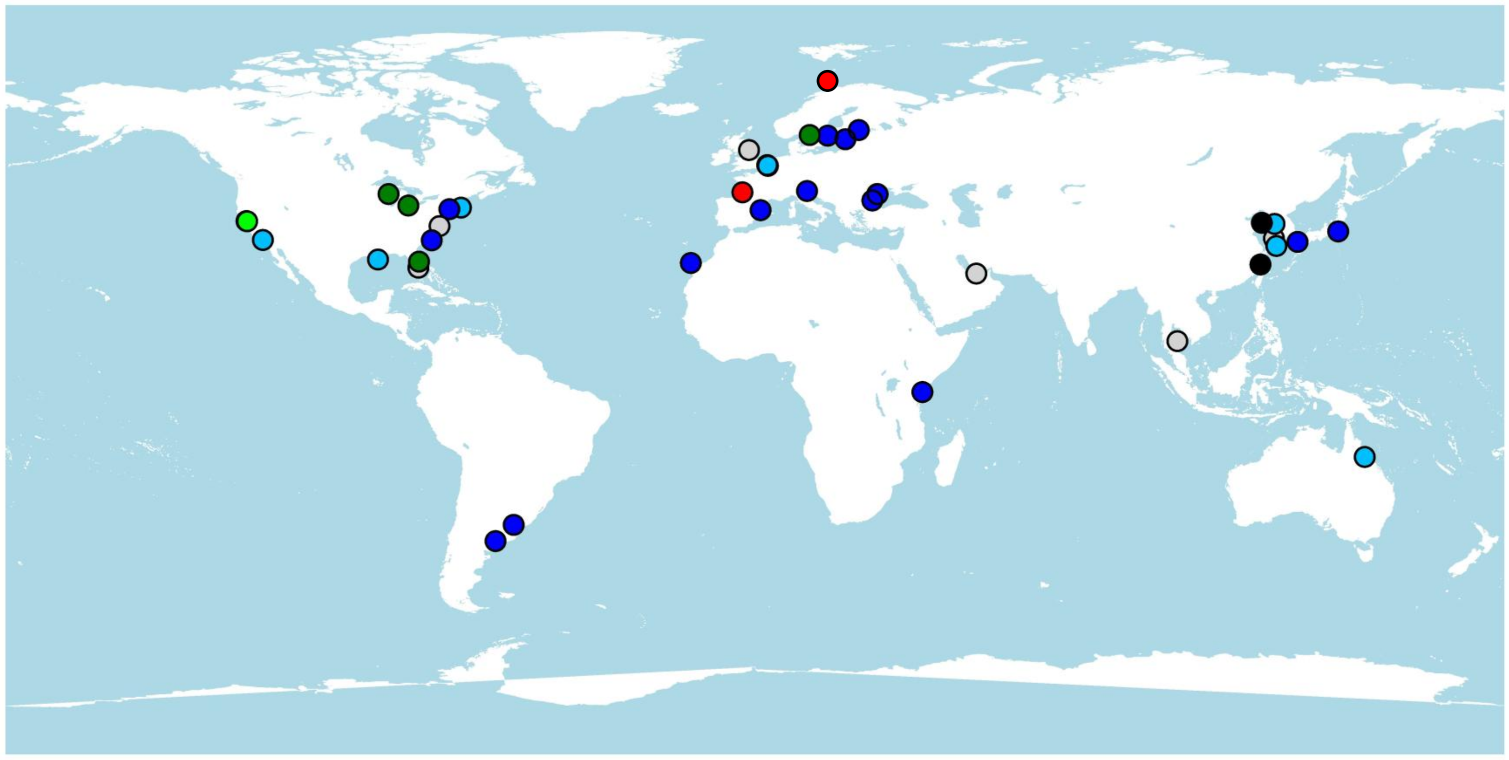
Sea-radiance: L_T

[redacted]



AERONET-OC: sites

The Ocean Color component of the Aerosol Robotic Network generating globally distributed time-series of standardized $L_{WN}(\lambda)$ and $\tau_a(\lambda)$ measurements targeting the validation of satellite ocean color data products



CE-318 (9-channel)

CE-318T (12-channel)

Active marine Active inland Potential Dismissed

- ***Active Marine sites (26,** 3 are on hold; plus 2 AERONET-OC equivalent sites managed by China whose data are not yet accessible)*

AAOT (replacing Venice); *Ariake_Tower; Bahia_Blanca*; *Casablanca_Platform; Chesapeake_Bay; Frying_Pan_Platform; Galata_Platform*; *Gustaf_Dalen_Tower*; *Helsinki_LightHouse* (on hold); *Irbe_Lighthouse*; *Kemigawa_Offshore*; *LISCO*; *Lucinda*; *MVCO*;*_PLOCAN_Tower*; *RdP-EsNM*; *San_Marco_Platform*; *Section-7_Platform* (replacing Gloria); *Ieodo Station* (on hold); *Socheongcho*; *Thornton_C-power* (on hold); *USC_SEAPRISM*; *WaveCIS_Site_CSI_6*; *Zeebrugge-MOW1*; Muping; Dongou.

- ***Active inland sites (5)***

Palgrunden; Banana_River; Lake_Erie; South_Greenbay; Sacramento_River.

Potential sites (2)

Gulf_of_Biscay, Norwegian Sea

AERONET-OC: band settings

Multi-spectral radiometry, but benefitting of multi-decadal advancement in (fore)optics design, measurement methods, instruments handling, data management and processing.

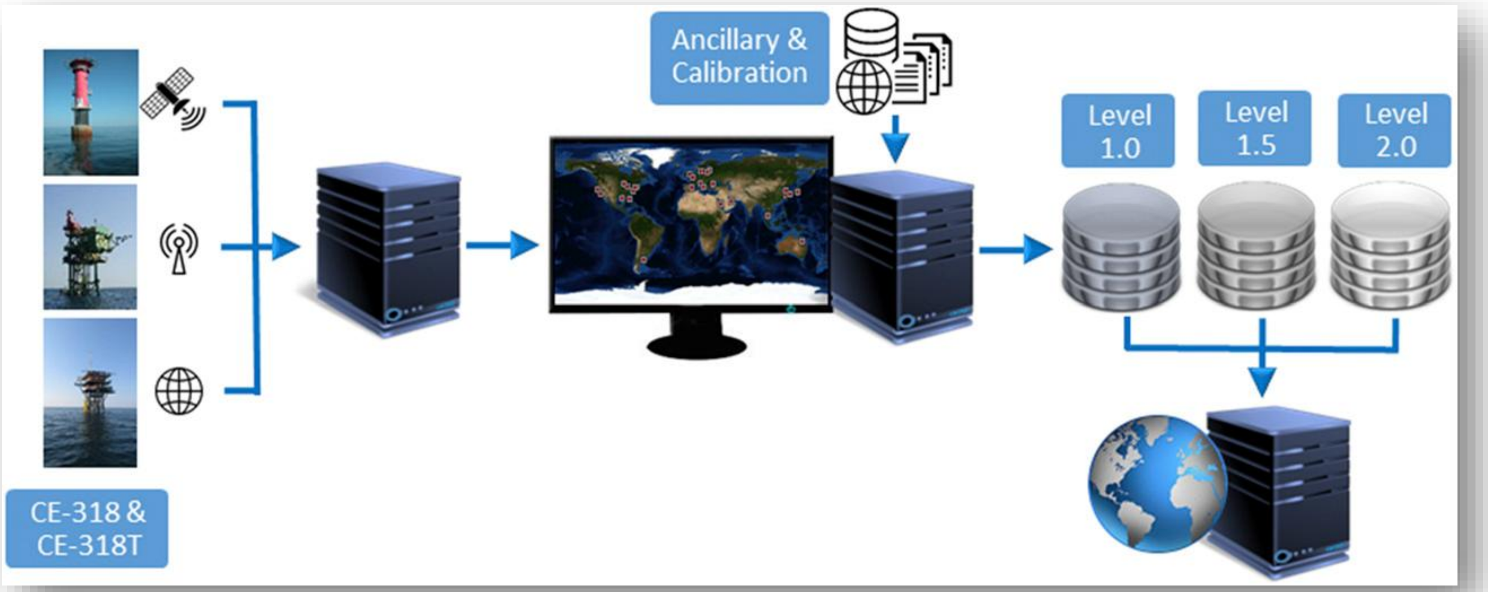
- *CE-318 9-channel for* ***marine*** *applications (considered obsolete).*
- *CE-318T 12-channel with two standard configurations for* ***marine and lake*** *applications.*

Band settings

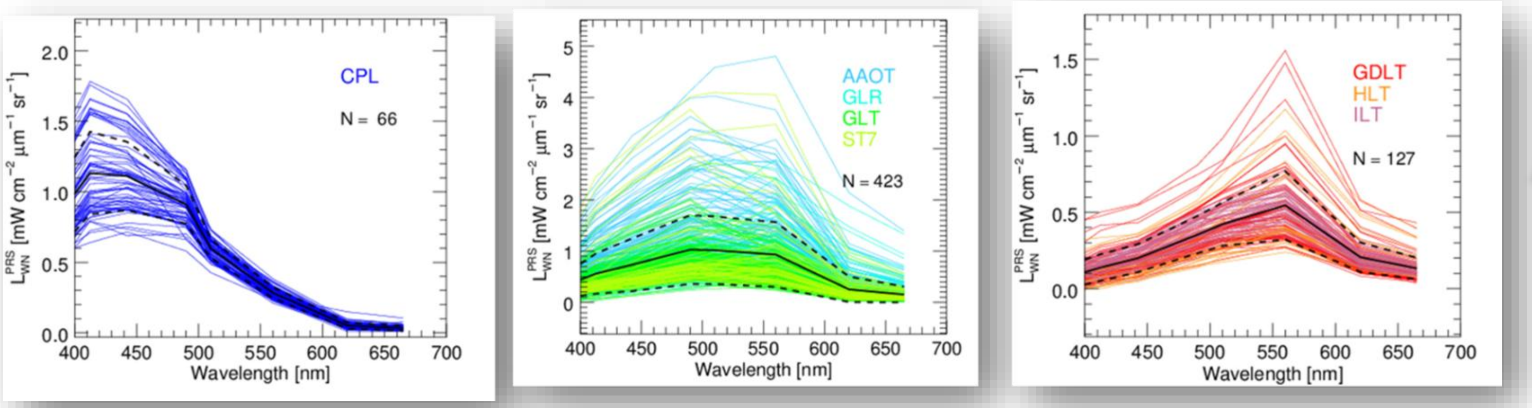
Satellite Sensors	Wavelengths [nm]																			
MODIS		412.5	443	488		531	551		667	678		748				870		905	940	
VIIRS (20 nm)		412	445	488			555		672			746			865					
OLCI (10 nm)	400	412.5	442.5	490	510		560	620	665	681	709	754	...	779	865		885	900	940	1020

AERONET-OC	Wavelengths [nm]																			
PRS-09		412	443	488		531	551		667							870			940	1020
PRS-12 (sea)	400	412.5	442.5	490	510		560	620	665					779	865				940	1020
PRS-12 (lake)		412.5	442.5	490	510		560	620	667	681	709				865				940	1020

Infrastructure and the data products



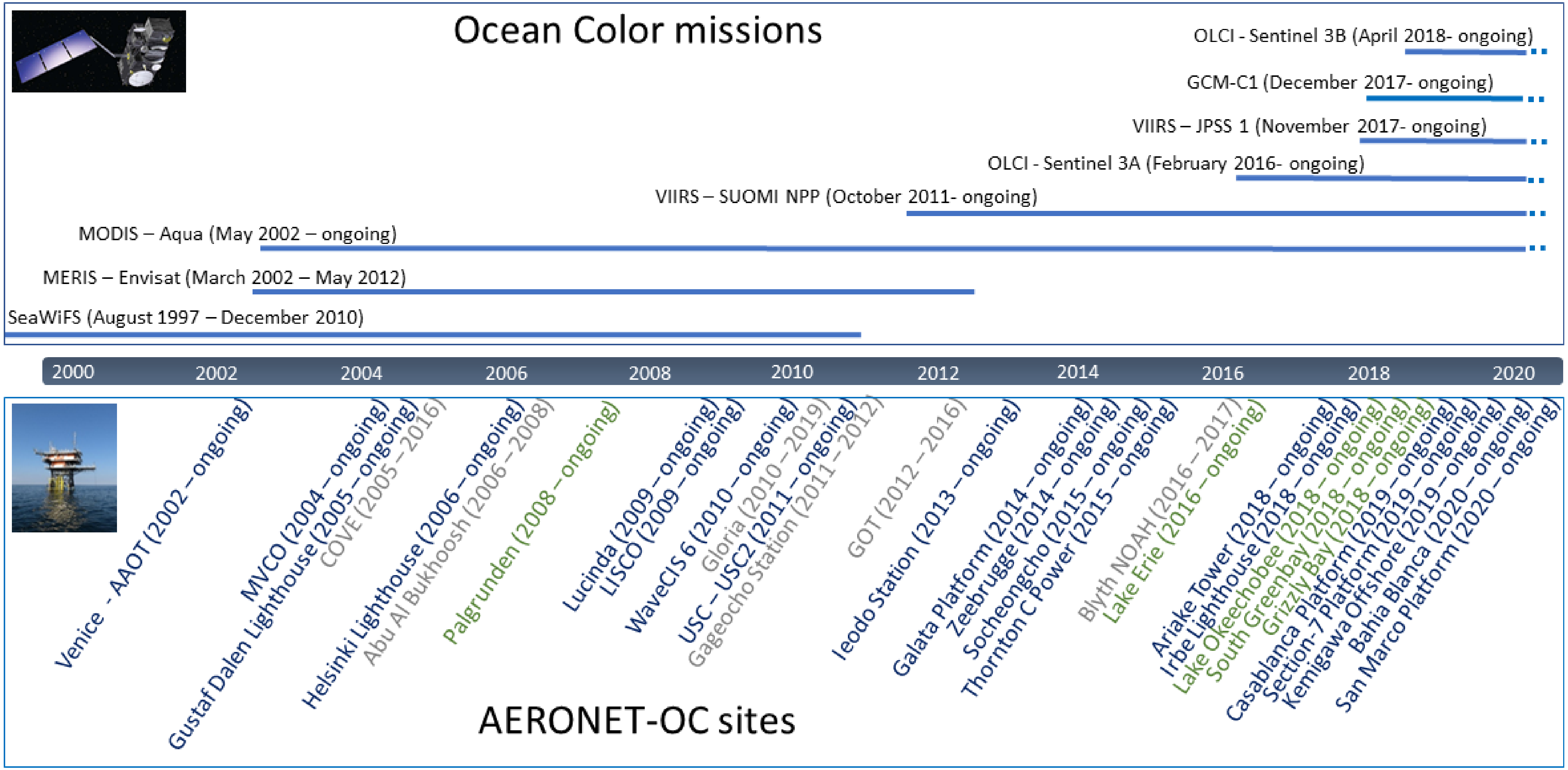
$L_{WN}(\lambda)$ *and* $\tau_a(\lambda)$



$$L_{WN} = (L_T - \rho L_i)\, C_A C_Q$$

Zibordi, G., Holben, B. N., Talone, M., D'Alimonte, D., Slutsker, I., Giles, D. M., & Sorokin, M. G. (2021). Advances in the Ocean Color component of the Aerosol Robotic Network (AERONET-OC). Journal of Atmospheric and Oceanic Technology, 38(4), 725-746.

AERONET-OC: sites (2002-2020)



Zibordi, G., Holben, B. N., Talone, M., D'Alimonte, D., Slutsker, I., Giles, D. M., & Sorokin, M. G. (2021). Advances in the Ocean Color component of the Aerosol Robotic Network (AERONET-OC). Journal of Atmospheric and Oceanic Technology, 38(4), 725-746.

AERONET-OC: Quality Levels

AERONET-OC products are classified at different QC levels:

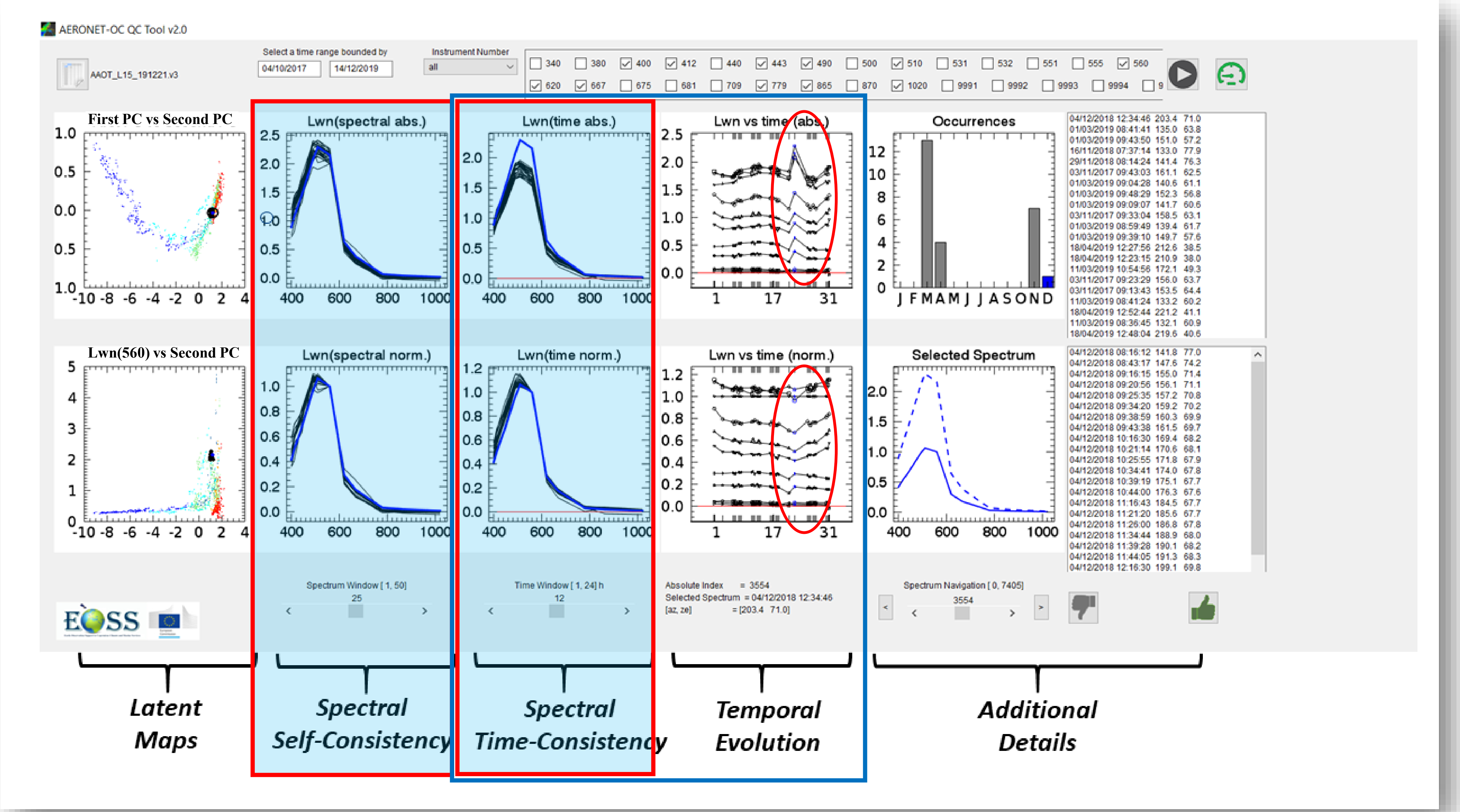
Level 1.0-> ▪ $L_{WN}(\lambda)$ *determined from complete measurement sequences.*

Level 1.5->
- *Cloud screened aerosol optical thickness data exist;*
- *Replicate sky and sea radiance measurements exhibit low variance;*
- *Empirical thresholds are satisfied (e.g., exceedingly negative or positive values).*

Level 2.0->
- *Pre- and post-deployment calibration coefficients exhibit justifiable differences within 5%;*
- *An automated screening is passed to determine the:*
  - i. *consistency of* $L_{WN}(\lambda)$ *spectral shapes within the data set itself (relative consistency),*
  - ii. *absence of short-term glitches or systematic daily trends (temporal consistency).*

Zibordi, G., Holben, B. N., Talone, M., D'Alimonte, D., Slutsker, I., Giles, D. M., & Sorokin, M. G. (2021). Advances in the Ocean Color component of the Aerosol Robotic Network (AERONET-OC). Journal of Atmospheric and Oceanic Technology, 38(4), 725-746.

Expert Based QC

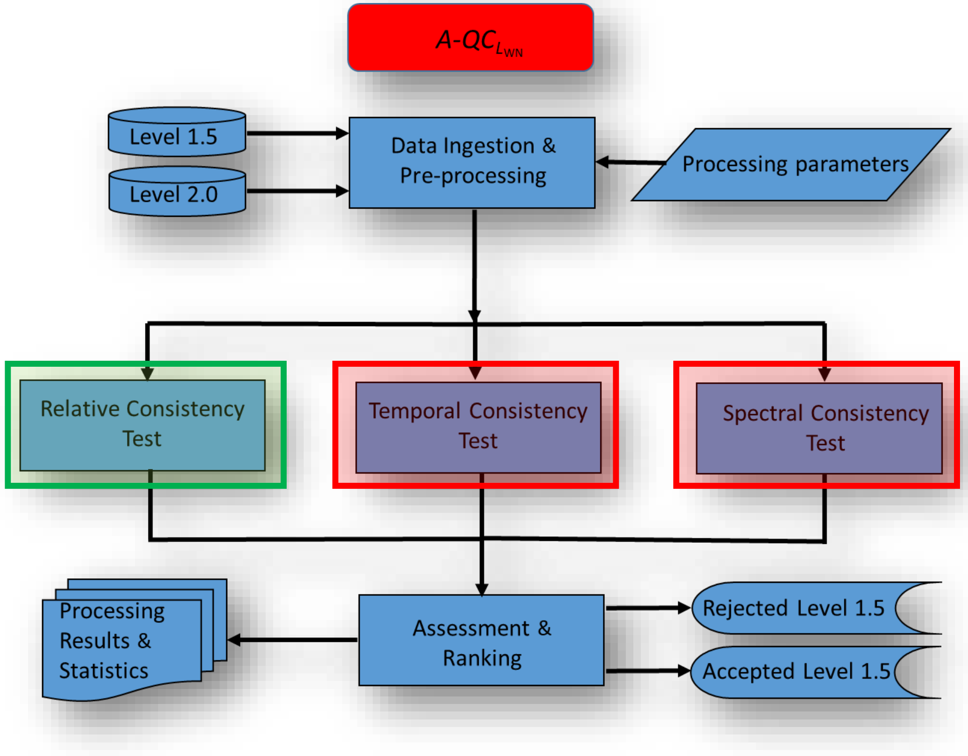


The same principles are now applied in a fully automated QC procedure

Zibordi, G., Holben, B. N., Talone, M., D'Alimonte, D., Slutsker, I., Giles, D. M., & Sorokin, M. G. (2021). Advances in the Ocean Clor component of the Aerosol Robotic Network (AERONET-OC). Journal of Atmospheric and Oceanic Technology, 38(4), 725-746.

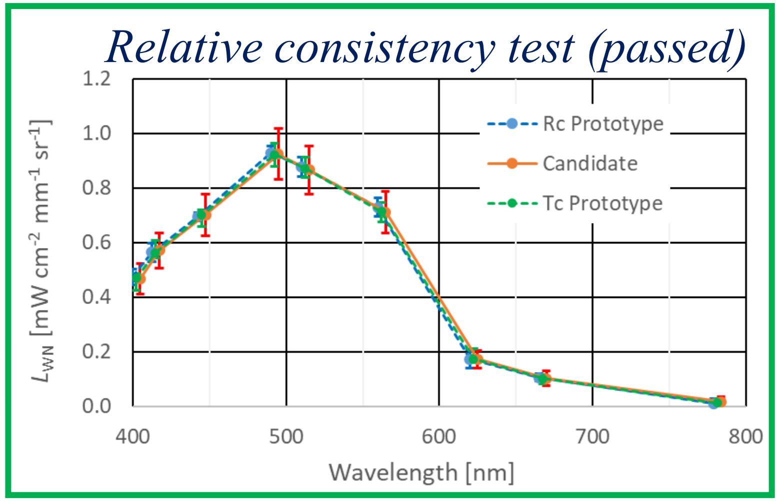
Automated QC procedure

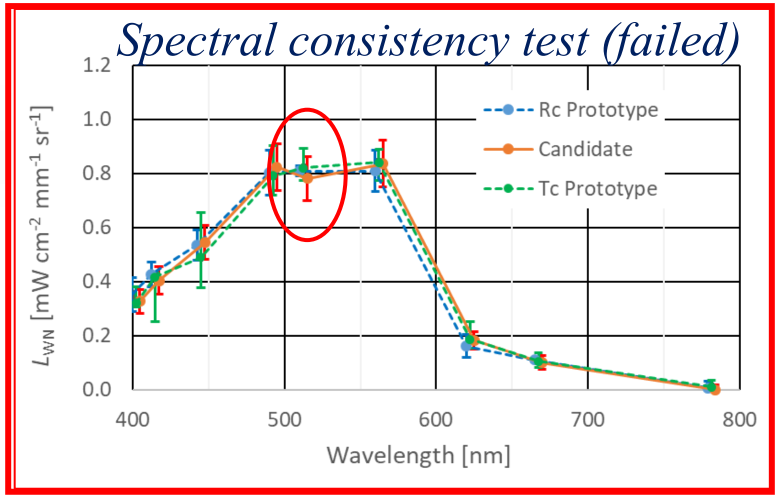
Automated QC: Checking "Candidate" (actual) versus "Prototype" (reference) L_{WN} spectra

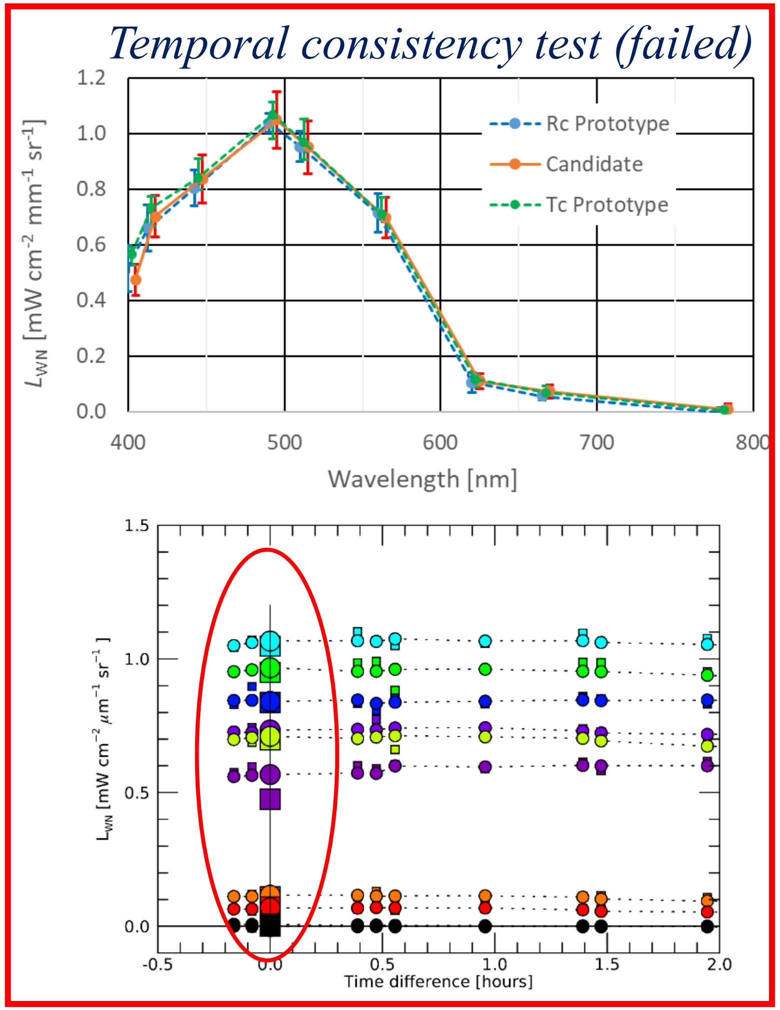


$$\left|\Delta\left[L_{WN}(\lambda)\right]\right| < 2\cdot\sqrt{\sigma_P^2(\lambda)+u_C^2(\lambda)}$$

(*coverage factor k=2*)







Error bars indicate:

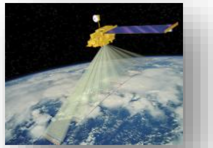
i. ±2σ determined for the spectra contributing to the "Prototype";

ii. ±2 u(Lwn) quantified for the "Candidate"

G. Zibordi, D. D'Alimonte, T. Kajiyama. Automated Quality Control of AERONET-OC L_{WN} data. Journal of Atmospheric and Oceanic Technology, 39, 1961-1972 (2022).

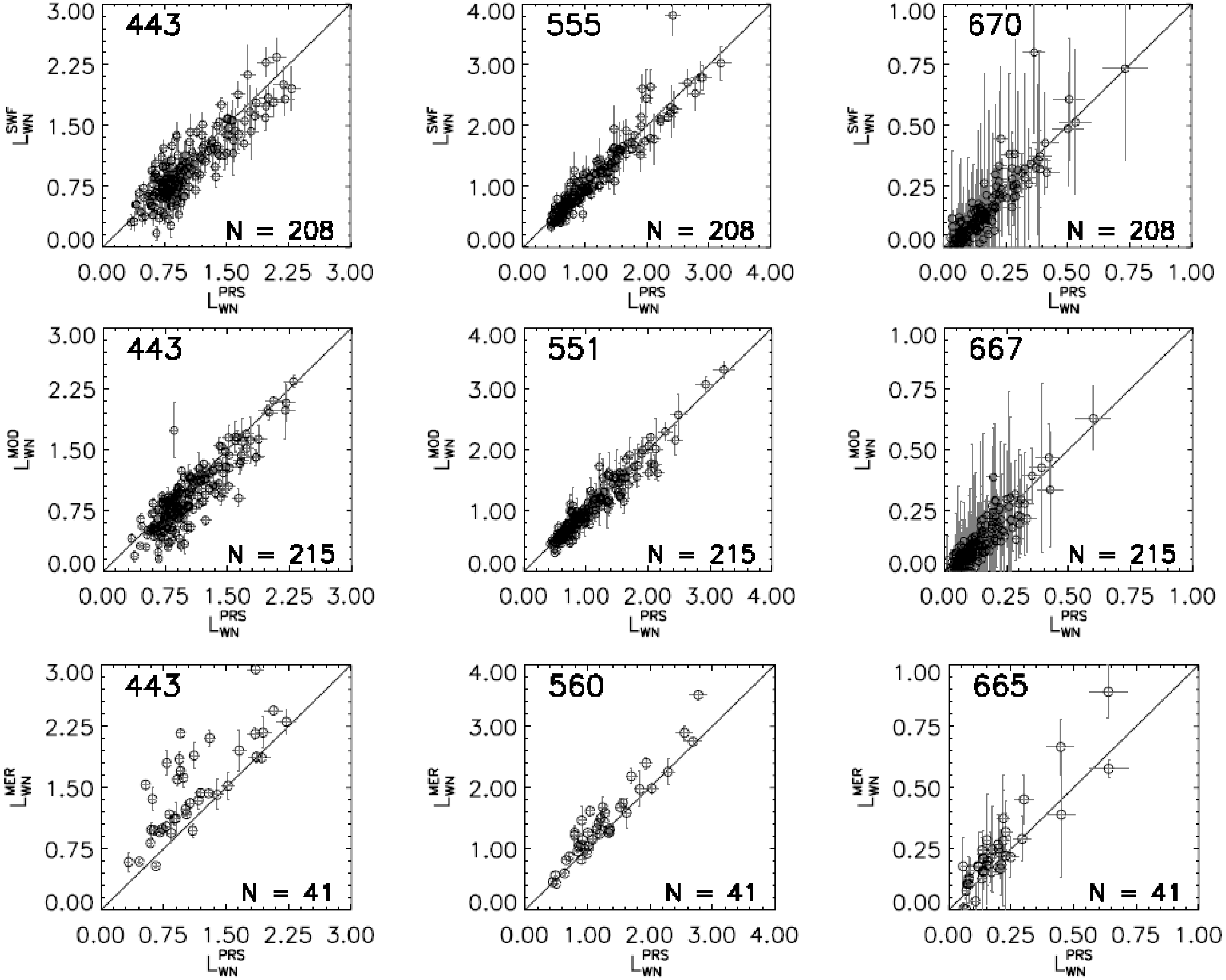
Early AERONET-OC data application

Sea-viewing Wide Field-of-view Sensor (SeaWiFS)



Moderate-resolution Imaging Spectro-radiometer (MODIS)

Medium Resolution Imaging Spectrometer (MERIS)

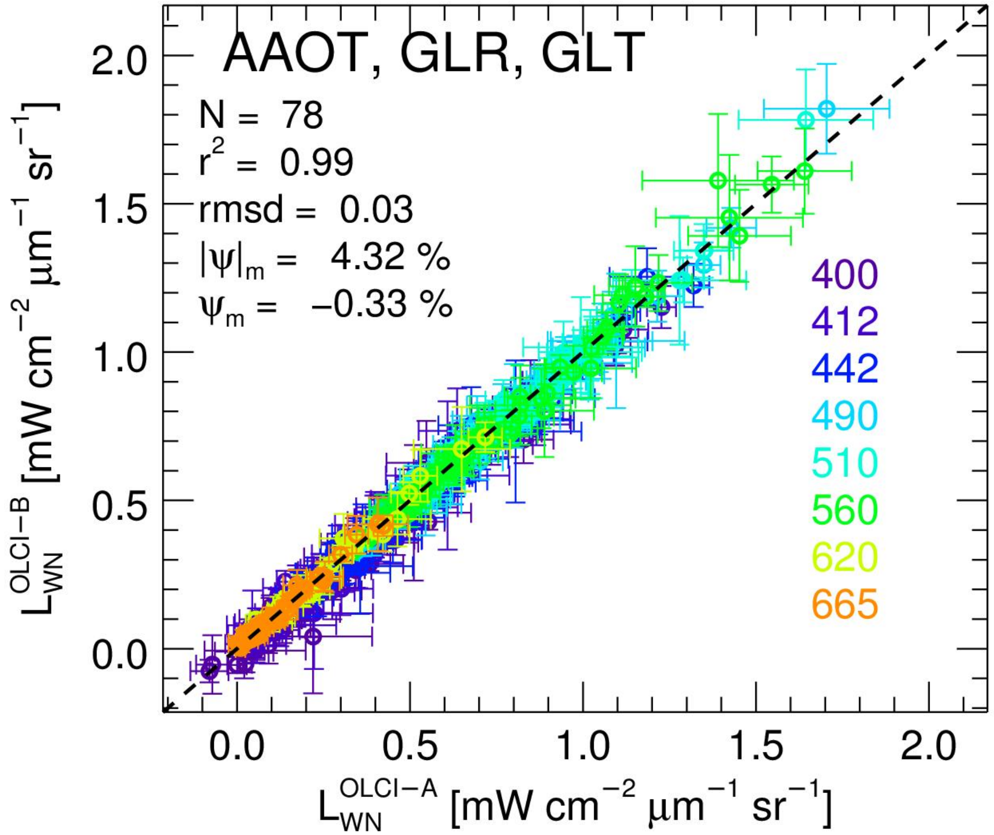


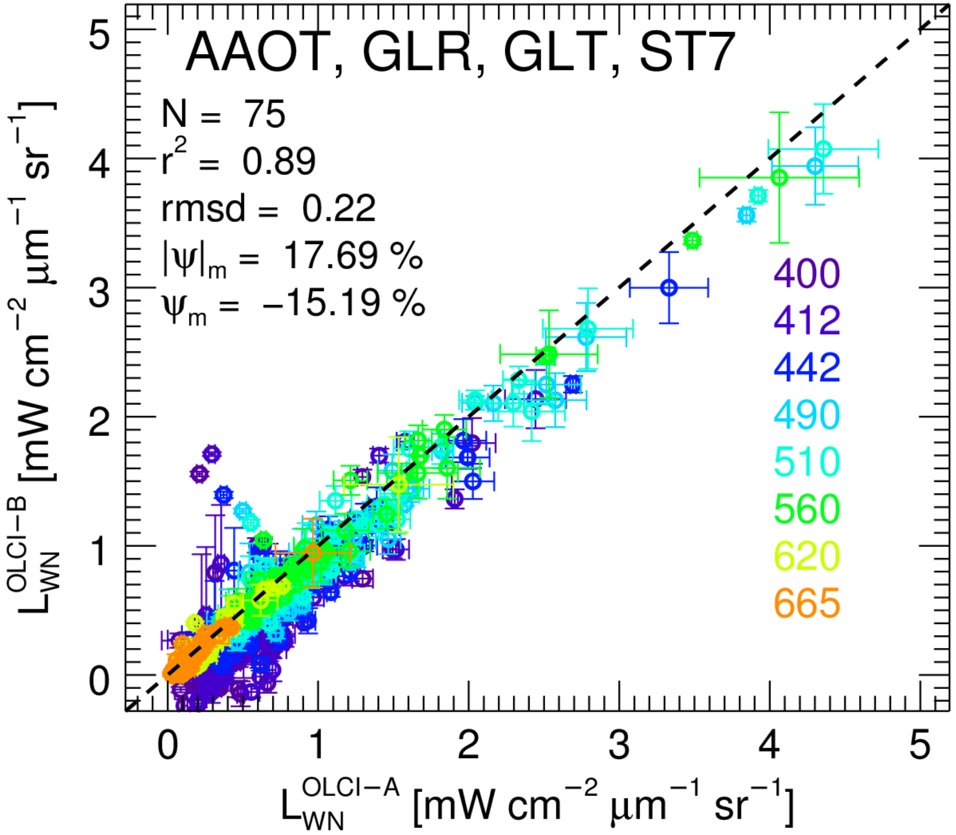
These scatter plots were included in the first publication that in 2006 showed the relevance of autonomous above-water radiometry in support of satellite ocean colour validation activities.

Almost two decades later someone wrote that AERONET-OC changed the way to perform validation activities.

Zibordi, G., Mélin, F., & Berthon, J. F. (2006). Comparison of SeaWiFS, MODIS and MERIS radiometric products at a coastal site. Geophysical Research Letters, 33(6).

Looking into L_{WN} data features





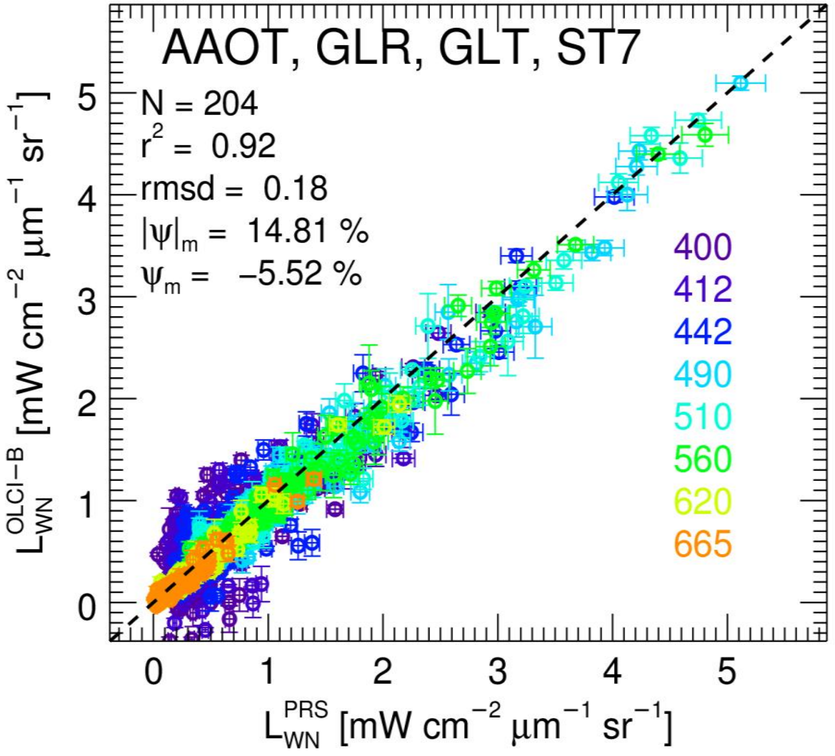
Tandem Phase (Sentinel-3B and Sentinel-3A flying 30 seconds apart on the same orbit: data are from corresponding cameras)

Post Tandem Phase (Sentinel-3B and Sentinel-3A providing data one hours apart over the same site: data are from camera 3-4 for OLCI-A and from Camera 1 for OLCI-B)

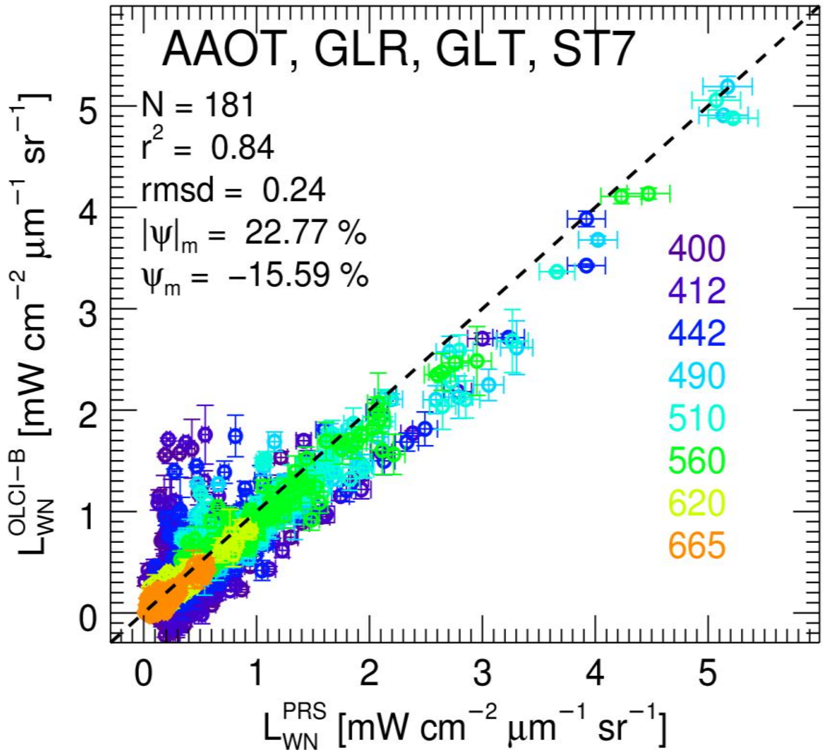
The same findings are confirmed for each water type

Zibordi, G., Kwiatkowska, E., Mélin, F., Talone, M., Cazzaniga, I., Dessailly, D., & Gossn, J. I. (2022). Assessment of OLCI-A and OLCI-B radiometric data products across European seas. Remote Sensing of Environment, 272, 112911.

Evidence of viewing angle dependence



OLCI-B matchup data with $\theta^{OLCI\text{-}B} < 30^0$

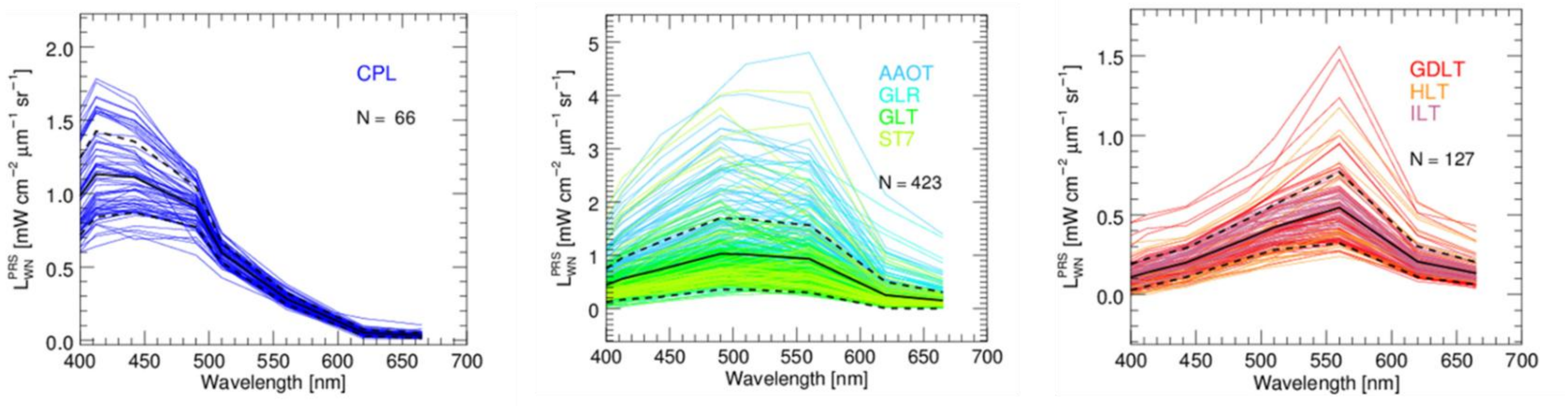


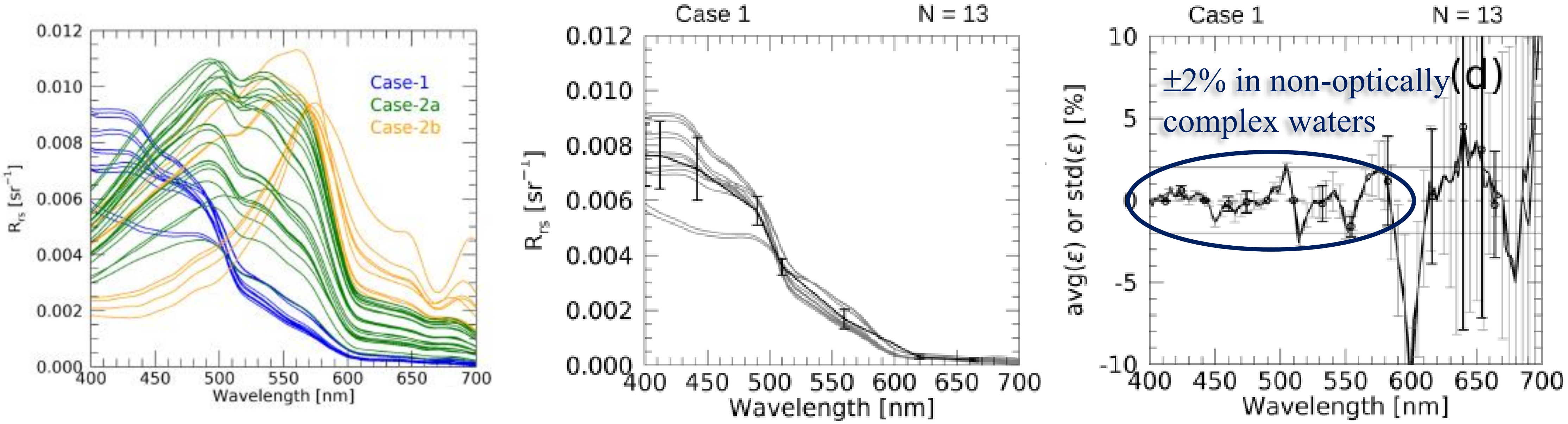
OLCI-B matchup data with $\theta^{OLCI\text{-}B} > 30^0$

Data show evidence of viewing angle dependence in OLCI data products!

Zibordi, G., Kwiatkowska, E., Mélin, F., Talone, M., Cazzaniga, I., Dessailly, D., & Gossn, J. I. (2022). Assessment of OLCI-A and OLCI-B radiometric data products across European seas. Remote Sensing of Environment, 272, 112911.

Applications: spectral matching





Talone, M., Zibordi, G., & Pitarch, J. On the Application of AERONET-OC Multispectral Data to Assess Satellite-Derived Hyperspectral Rrs. IEEE Geoscience and Remote Sensing Letters, 21, 1-5 (2024).

AERONET-OC Version 4

Version-3 (https://aeronet.gsfc.nasa.gov/cgi-bin/draw_map_display_seaprism_v3)

- *Rely on spectrally independent ρ-factors from Mobley (1999)*
- *Comprehensive and fully automated QC at Level 2.0.*
- *Data products (i.e., L_{WN}) corrected for brdf according to the Chla- and IOP-based methods.*

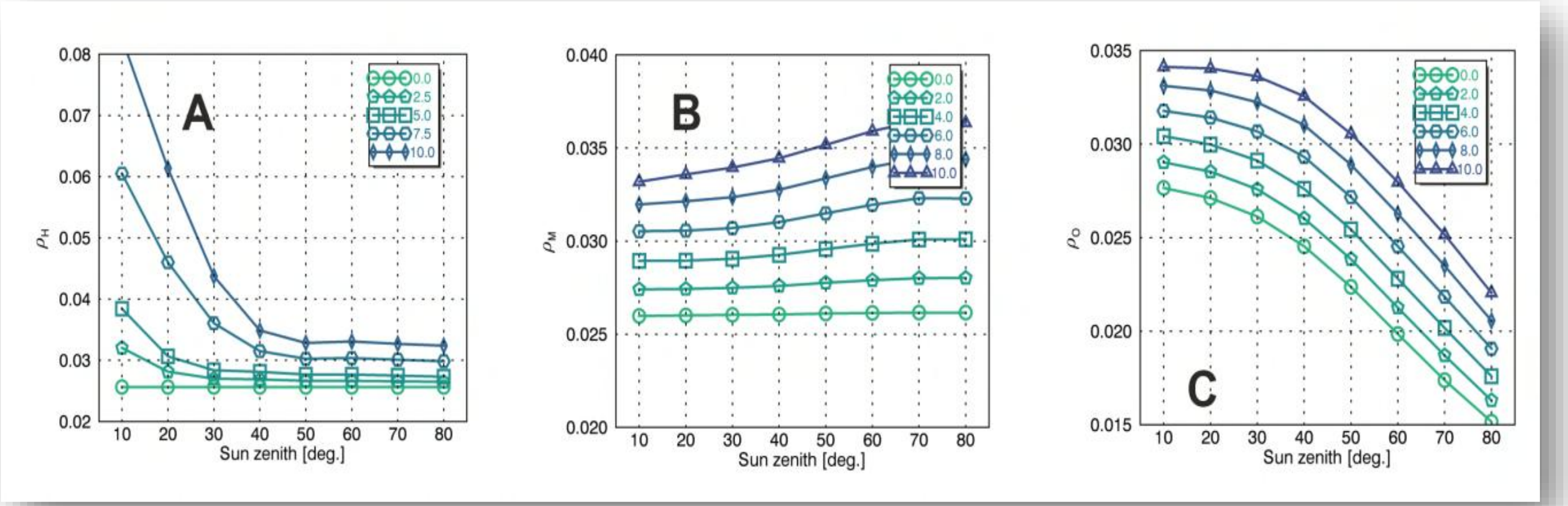
Toward ***Version-4***

- *Application of advanced sea surface reflectance factors accounting for the spectral dependence as a function of aerosol type and optical depth (polarization excluded).*
- *Comprehensive and fully automated QC also at Level 1.5 (i.e., incorporating most of the current quality checks applied for Level 2.0).*
- *Ranking of individual L_{WN} as a function of spectral and temporal consistency for a better assessment of satellite data products.*
- *Statistical determination of L_{WN} uncertainties for individual measurements.*
- *Increased number of quality checked L_{WN} and decreased intra-band uncertainties especially over inhomogeneous regions.*

Zibordi, G., Holben, B. N., Talone, M., D'Alimonte, D., Slutsker, I., Giles, D. M., & Sorokin, M. G. (2021). Advances in the Ocean Color component of the Aerosol Robotic Network (AERONET-OC). Journal of Atmospheric and Oceanic Technology, 38(4), 725-746.

Zibordi G., D'Alimonte D., Bulgarelli B., Kajiyama T., Slutsker I., (2025) . On the impact of alternative processing on AERONET-OC L_{WN} . Journal of Atmospheric and Oceanic Technology, submitted.

Standard and alternative ρ-factors

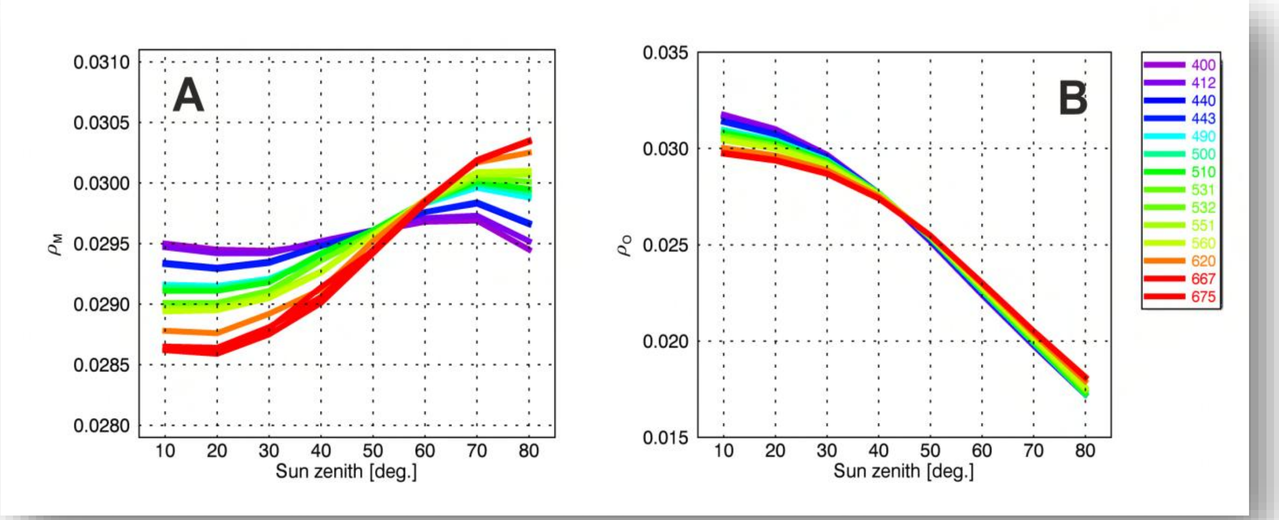


Panel A: ρ_H at 550 nm accounting for both direct sun and diffuse skylight for $\tau_a = 0.26$.

Panel B: ρ_M accounting for the sole diffuse skylight for $\tau_a = 0.2$.

Panel C: ρ_O accounting for the sole diffuse skylight for $\tau_a = 0.2$.

W in the 0 – 10 m s^{-1} range (the Y-scales are optimized).



Panel A: spectral dependence of ρ_M

Panel B: spectral dependence of ρ_O

$400 < \lambda < 675$ nm, W = 4 m s^{-1} $\tau_a = 0.2$ (the Y-scales are optimized).

Zibordi G., D'Alimonte D., Bulgarelli B., Kajiyama T., Slutsker I., (2025). On the impact of alternative processing on AERONET-OC L_{WN}. Journal of Atmos. and Ocean. Tech., submitted.

Standard and alternative processing

Standard processing (ST-P)

L_{WN} data from the basic AERONET-OC processing relying on:

i. the regular AERONET-OC quality control of field measurements aimed at removing sequences affected environmental perturbations such as clouds, foam and mostly sun-glint through the application of thresholds to each measurement sequence;
ii. the mean of a percentage of the lowest sea-radiance values obtained during each valid measurement sequence (*Lt_min_rel*).
iii. the ρ_H factors; and
iv. the *Chla-based* (Morel *et al.* 2002) correction approach for bidirectional effects.

Alternative processing (AM-P)

L_{WN} data from the alternative AERONET-OC processing relying on:

i. the regular AERONET-OC quality control of field measurements;
ii. the average of all the sea-radiance values collected during each valid measurement sequence (*Lt_mean*);
iii. the ρ_M factors for the sole sky-light component (Bulgarelli et al. *unpublished*) determined for an atmospheric model characterized by continental aerosol with 80% relative humidity representing the climatology of AERONET coastal sites; and
iv. the *IOP-based* correction approach.

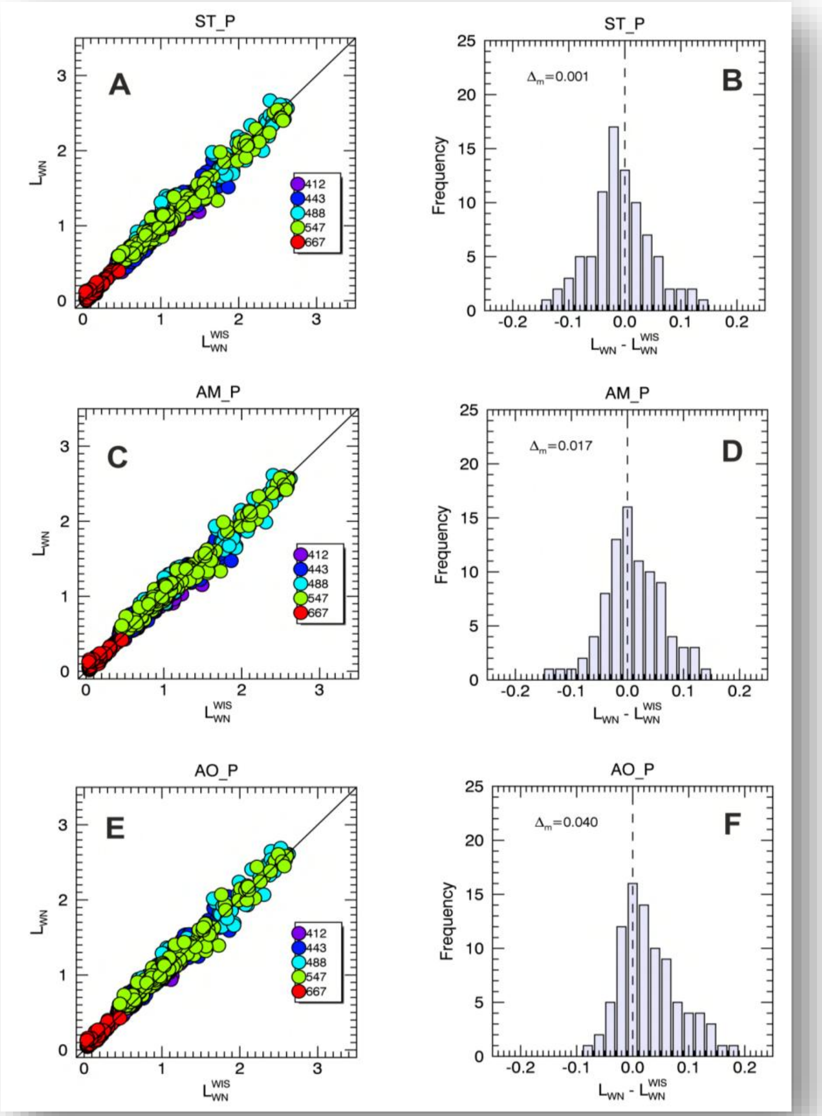
Alternative Processing (AO-P)

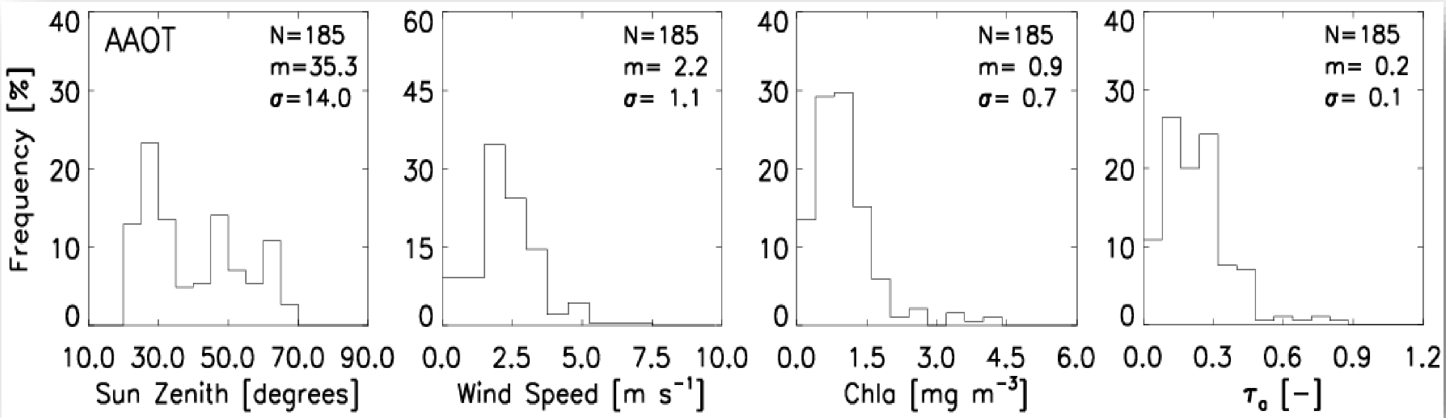
L_{WN} data from the alternative AERONET-OC processing relying on:

i. the regular AERONET-OC quality control of field measurements;
ii. the average of all the sea-radiance values collected during each valid measurement sequence (*Lt_mean*);
iii. the ρ_O factors for the sole sky-light component (Harmel 2023) determined with the atmospheric model characterized by a continental aerosol with 70% relative humidity and accounting for polarization effects; and
iv. the *IOP-based* correction approach.

Zibordi G., D'Alimonte D., Bulgarelli B., Kajiyama T., Slutsker I., (2025) . On the impact of alternative processing on AERONET-OC L_{WN}. Journal of Atmos. and Ocean. Tech., submitted.

Comparison with reference in-water L_{WN}

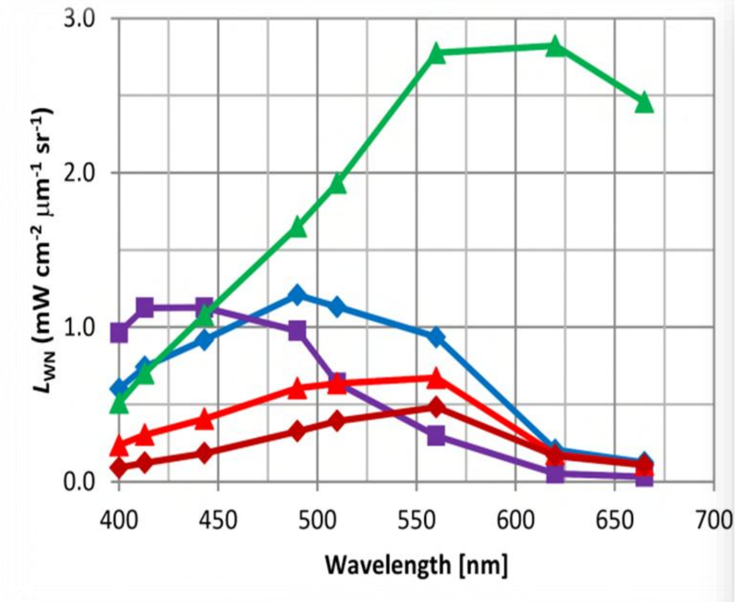




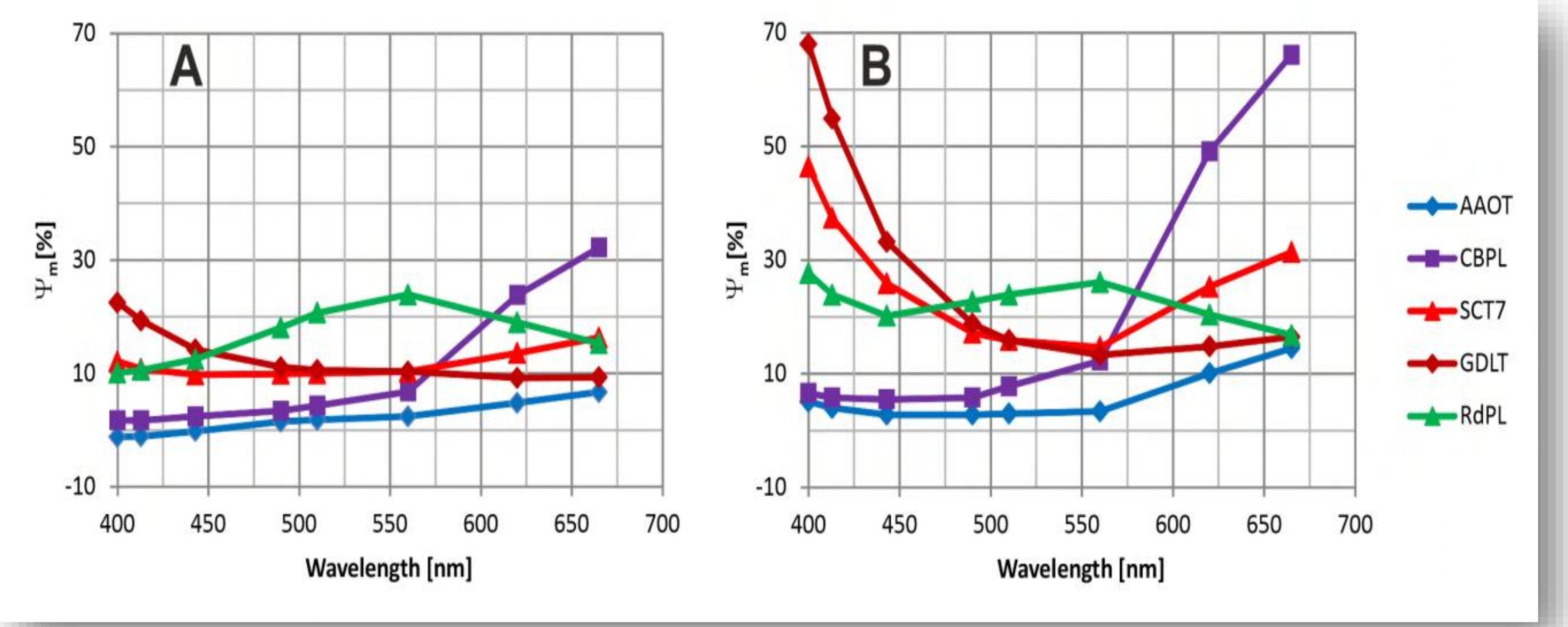
λ	ψ_m(ST-P)	ψ_m(AM-P)	ψ_m(AO-P)
412	1.3	3.2	6.2
443	−0.1	1.6	4.6
488	0.4	3.4	3.7
547	0.1	2.8	3.9
667	−4.9	2.9	6.8

Zibordi G., D'Alimonte D., Bulgarelli B., Kajiyama T., Slutsker I., (2025) . On the impact of alternative processing on AERONET-OC L_{WN}. Journal of Atmos. and Ocean. Tech., submitted.

Alternative vs. standard processing



Median L_{WN} spectra from the AERONET-OC sites



Median percent differences ψ_m from the comparison of AERONET-OC data products determined with the alternative AM-P (panel A) and the AO-P processing (panel B), with respect to the ST-P one.

Zibordi G., D'Alimonte D., Bulgarelli B., Kajiyama T., Slutsker I., (2025) . On the impact of alternative processing on AERONET-OC $L_{WN.}$ Journal of Atmos. and Ocean. Tech., submitted.

End