European Commission

25⁺ Years of JRC Ocean Color Cal/Val Activities: A Synopsis

Giuseppe Zibordi

CEOS WGCV IVOS 34, USGS, Reston, August 29 – September 02, 2022

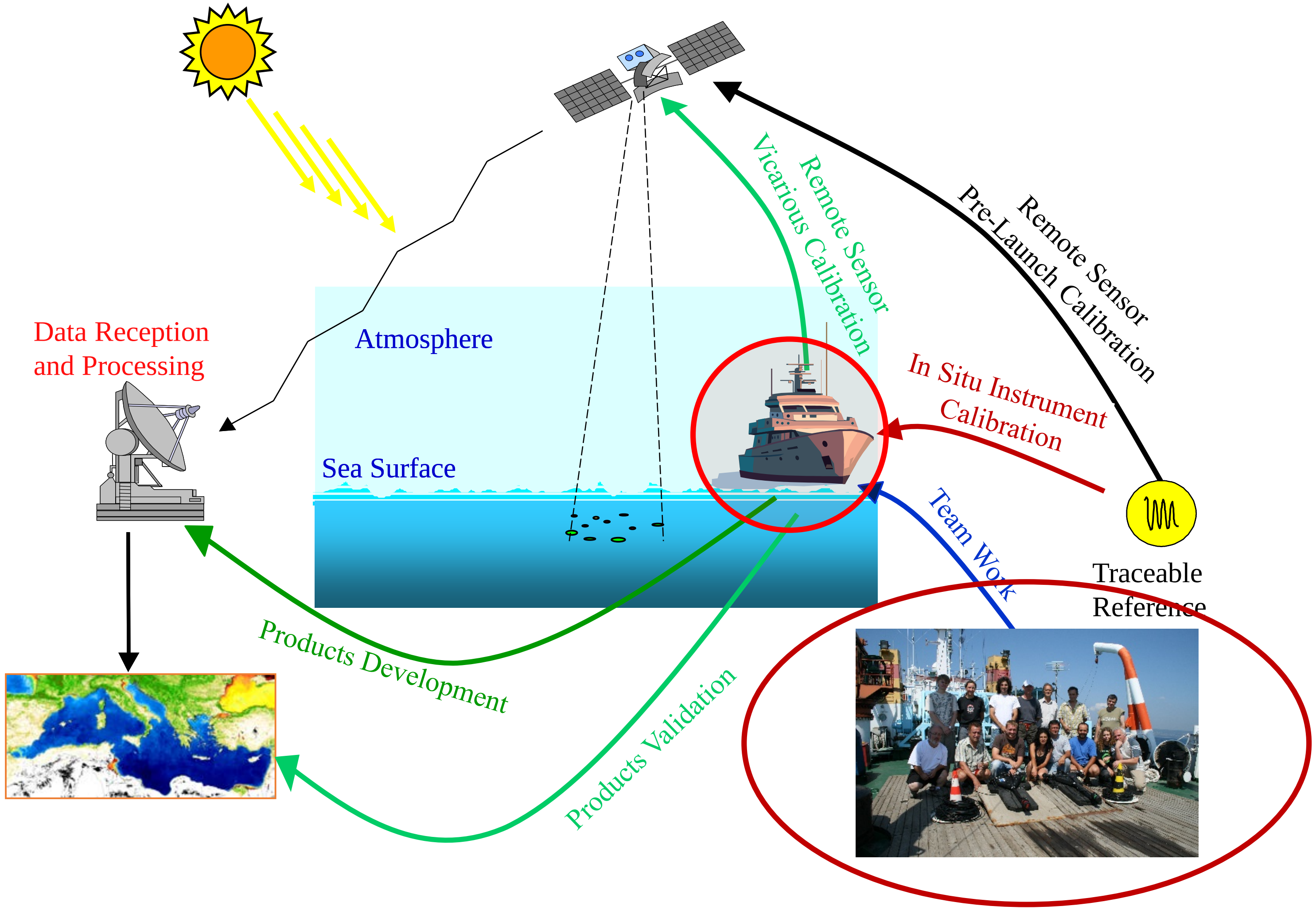
Joint Research Centre

CEOS WGCV IVOS workshop: To identify, quantify and verify the post-launch performance and relative biases of Earth Observation sensors

Joint Research Centre (JRC), Ispra, Italy
October 18 – 20, 2010

The Ocean Color Paradigm

In situ reference measurements are central to system vicarious calibration, data products development and validation



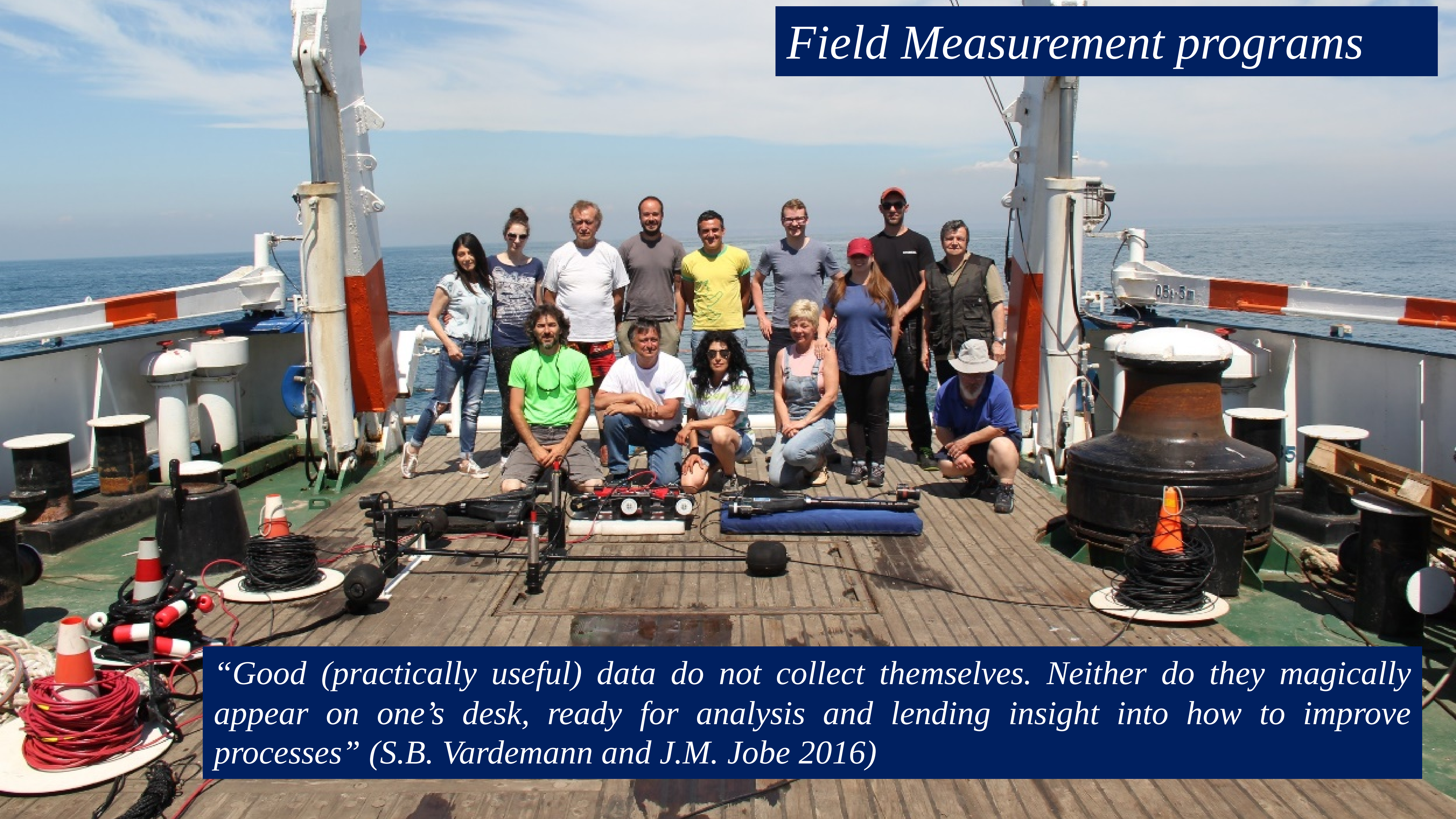
Outline

- ❑ *Field Measurement Programs*
- ❑ *Protocols*
- ❑ *Best practices*
- ❑ *Quality assurance and control*
- ❑ *Uncertainties*
- ❑ *System Vicarious Calibration*

Not a lecture. Just the synopsis of the JRC activities (personally) considered relevant for ocean color Cal/Val.

In the early 90's the question was: What could the we do relevant for the forthcoming ocean color missions (SeaWiFS, OCTS, MERIS, MODIS, …)?

Field Measurement programs

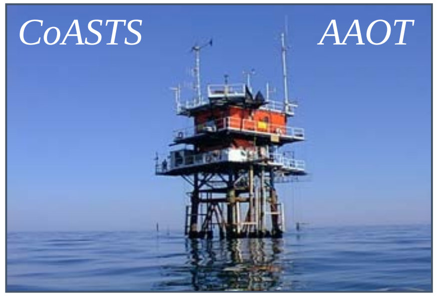


"Good (practically useful) data do not collect themselves. Neither do they magically appear on one's desk, ready for analysis and lending insight into how to improve processes" (S.B. Vardemann and J.M. Jobe 2016)

Coastal Atmosphere and Sea Time-Series (CoASTS) & Bio-Optical Mapping of marine Properties (BiOMaP)

One single objective

Produce comprehensive reference measurements applying identical and consolidated: technology, measurement and calibration protocols, processing codes and quality assurance / control criteria.

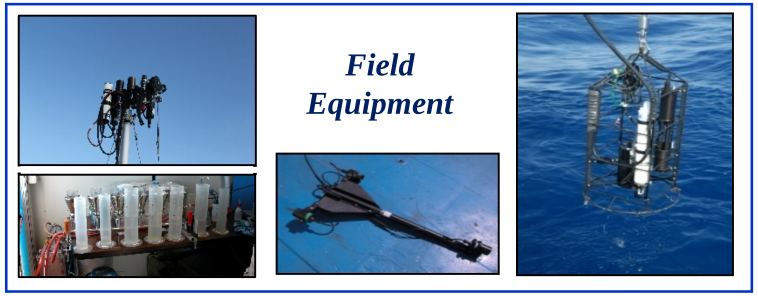


Field measurements

Radiometry: $L_u(z,\lambda)$, $E_d(z,\lambda)$, $E_u(z,\lambda)$, $E_d(0^+,\lambda)$, $E_i(0^+,\lambda)$, $E_s(\lambda)$

IOPs: $a(z,\lambda)$, $c(z,\lambda)$, $b_b(z,\lambda)$ by AC-9 and Hyd-6

Ancillary: $T_w(z)$, $C_w(z)$, T_a, P_a, RH, WS, CC, SS



Laboratory measurements on water samples

AOP: $a_{ys}(\lambda)$, $a_{ph}(\lambda)$, $a_{dp}(\lambda)$ by spectrophotometry

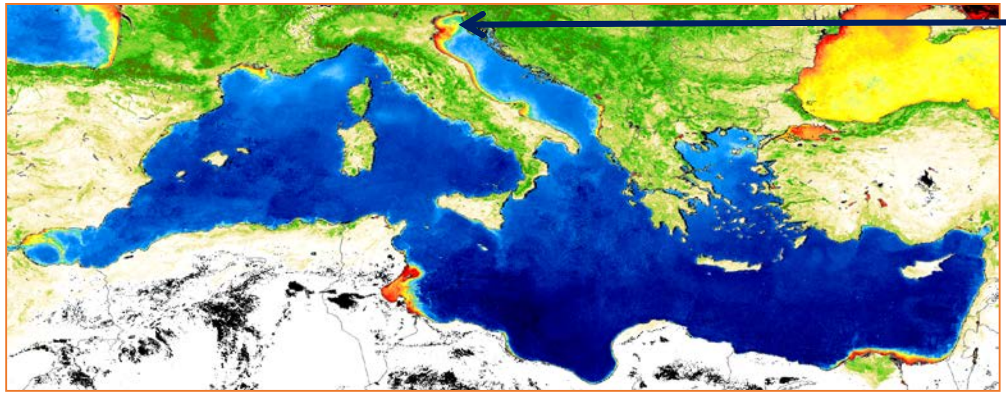
Concentrations: pigments by HPLC, TSM by gravimetry

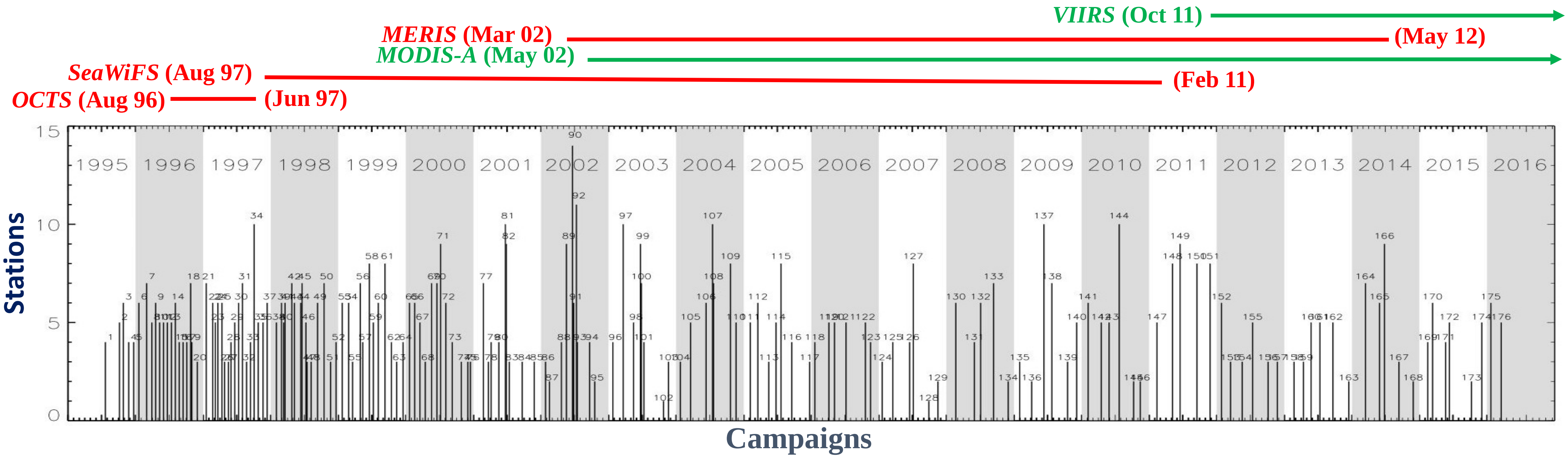
Joint Research Centre

Coastal Atmosphere and Sea Time Series (CoASTS):
a regional measurement program

1995-2016 *176 Campaigns* *2712 Bio-Optical Stations*

Time-series of monthly (bi-monthly) AOP and IOP measurements performed at a single costal site





G.Zibordi, J.-F. Berthon, J.P. Doyle, S. Grossi, C. Targa, D. van der Linde … ,Coastal Atmosphere and Sea Time Series (CoASTS), NASA Tech. Memo. 2002-206892.

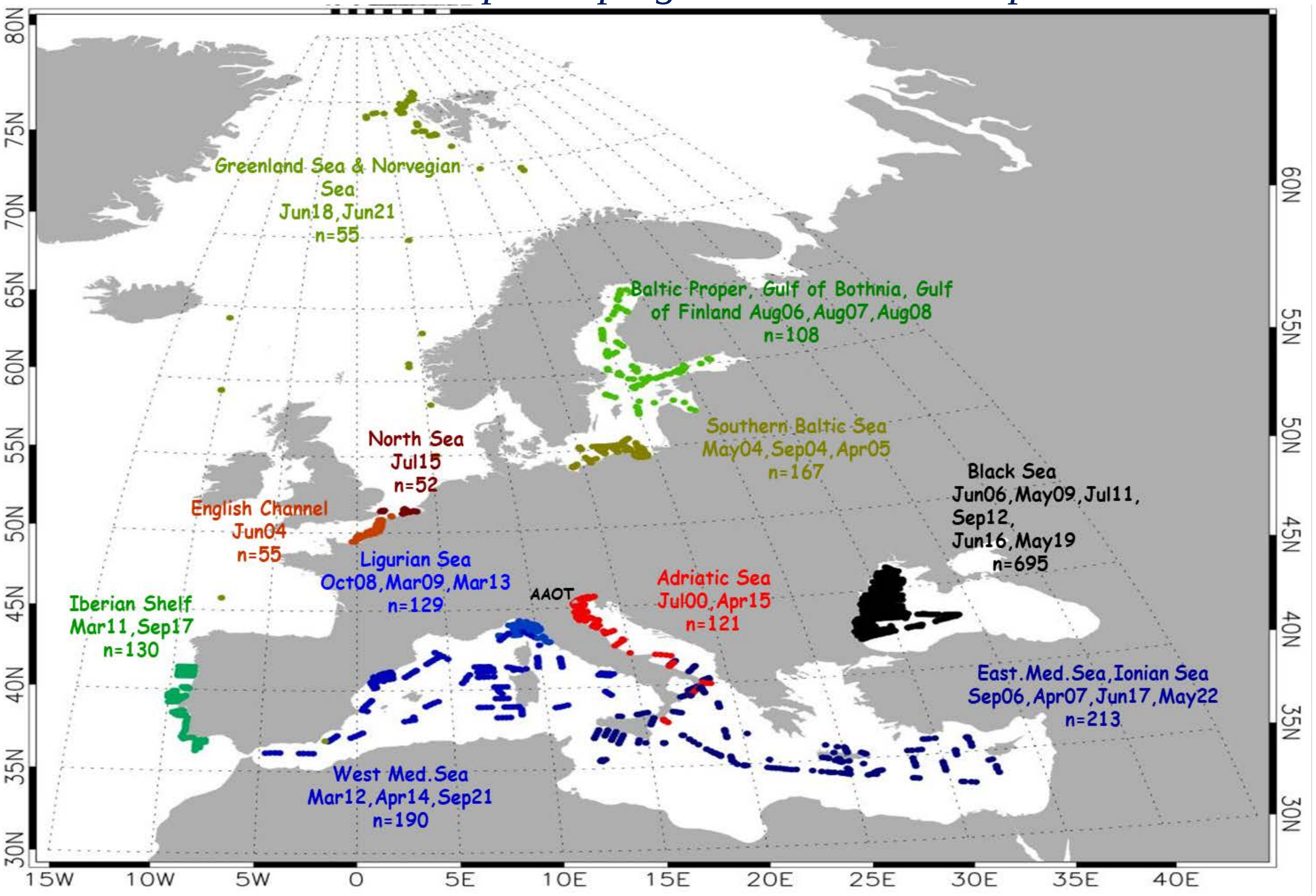
Bio-Optical mapping of Marine Properties (BiOMaP):
a pan-European measurement program

Joint Research Centre

2000-2022 *34 Ship Campaigns* *1915 Bio-Optical stations*

Geographically distributed AOP and IOP measurements performed in European seas.

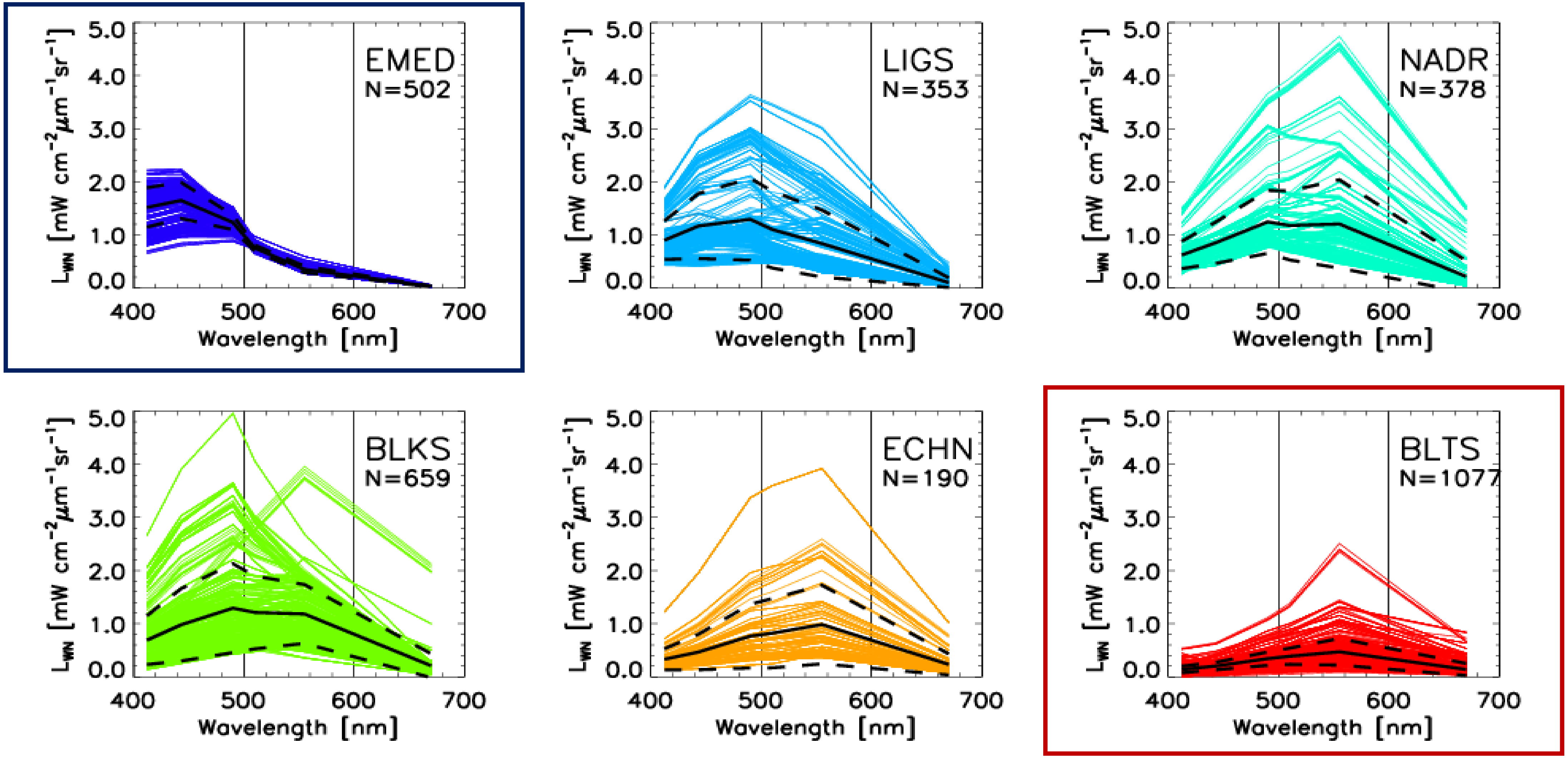
BiOMaP Ships



Zibordi, G., Berthon, J. F., Mélin, F., & D'Alimonte, D. (2011). Cross-site consistent in situ measurements for satellite ocean color applications: the BiOMaP radiometric dataset. Remote Sensing of Environment, 115, 2104–2115, 2011.

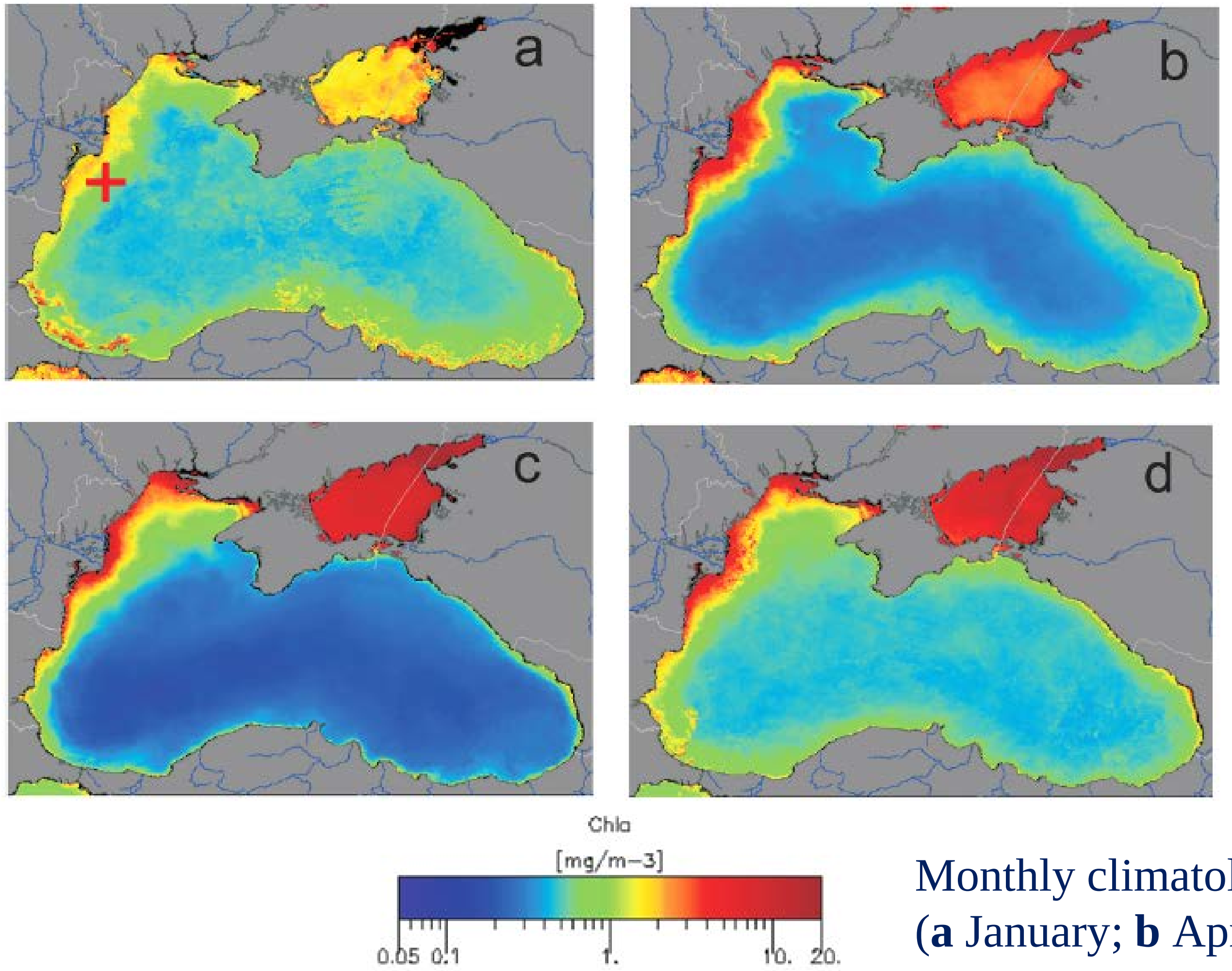
Joint Research Centre

L_{WN} *spectra from the various European Seas (BioMaP)*



G. Zibordi, J.-F. Berthon, F. Mélin and D. D'Alimonte. Cross-site consistent in situ measurements for satellite ocean color applications: the BiOMaP radiometric dataset. Remote Sensing of Environment,115, 2104–2115, 2011.

Regional application of BioMaP data



Chlorophyll-a (Chl-a) concentration in the Black Sea from: i. a Band-Ratio algorithm relying on a polynomial regression capturing the overall data trend; and ii. Multilayer Perceptron neural net fitting data non-linearity.

Now a Copernicus data product.

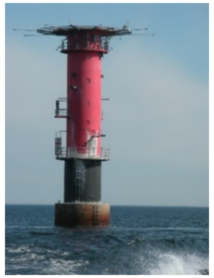
Monthly climatology maps of *Chl a* for the Black Sea (**a** January; **b** April; **c** July; **d** October).

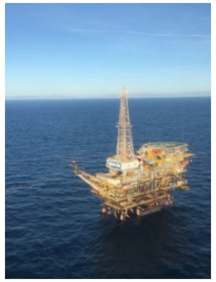
G. Zibordi, F. Mélin, J.-F. Berthon, and M. Talone. In Situ Autonomous Optical Radiometry Measurements for Satellite Ocean Color Validation in the Western Black Sea. *Ocean Science* 11, 275–286, 2015.

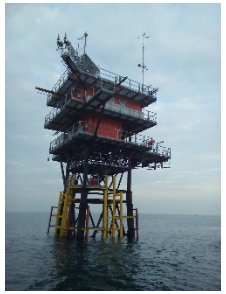
T. Kajiyama, D.D'Alimonte and G. Zibordi. Algorithms merging for the determination of Chlorophyll-a concentration in the Black Sea. *Geoscience and Remote Sensing Letters*, doi: 10.1109/LGRS.2018.2883539, 2018.

AERONET-OC:
an international automated measurement program

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



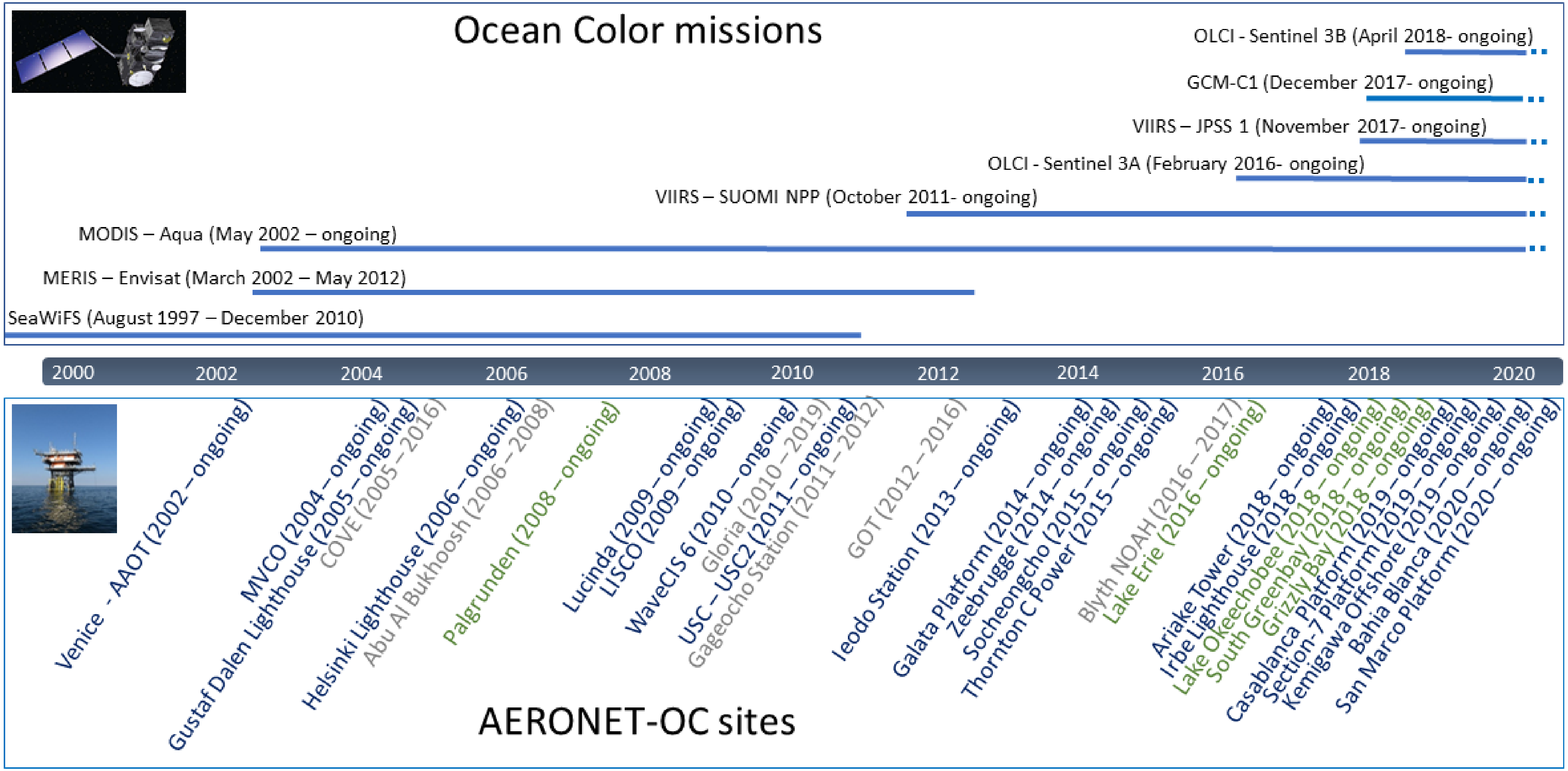




- *NASA manages the network by handling the instruments calibration and, data collection, processing and distribution within AERONET.*
- *JRC has (had) the responsibility of the processing algorithms, performs (performed) the final quality control of data and runs a number of European sites often in collaboration with national institutes.*

Zibordi, G., Holben, B., Hooker, S. B., Mélin, F., Berthon, J. F., Slutsker, I., ... & Al Mandoos, A. (2006). A Network for Standardized Ocean Color Validation Measurements. Eos Transactions, 87: 293, 297.

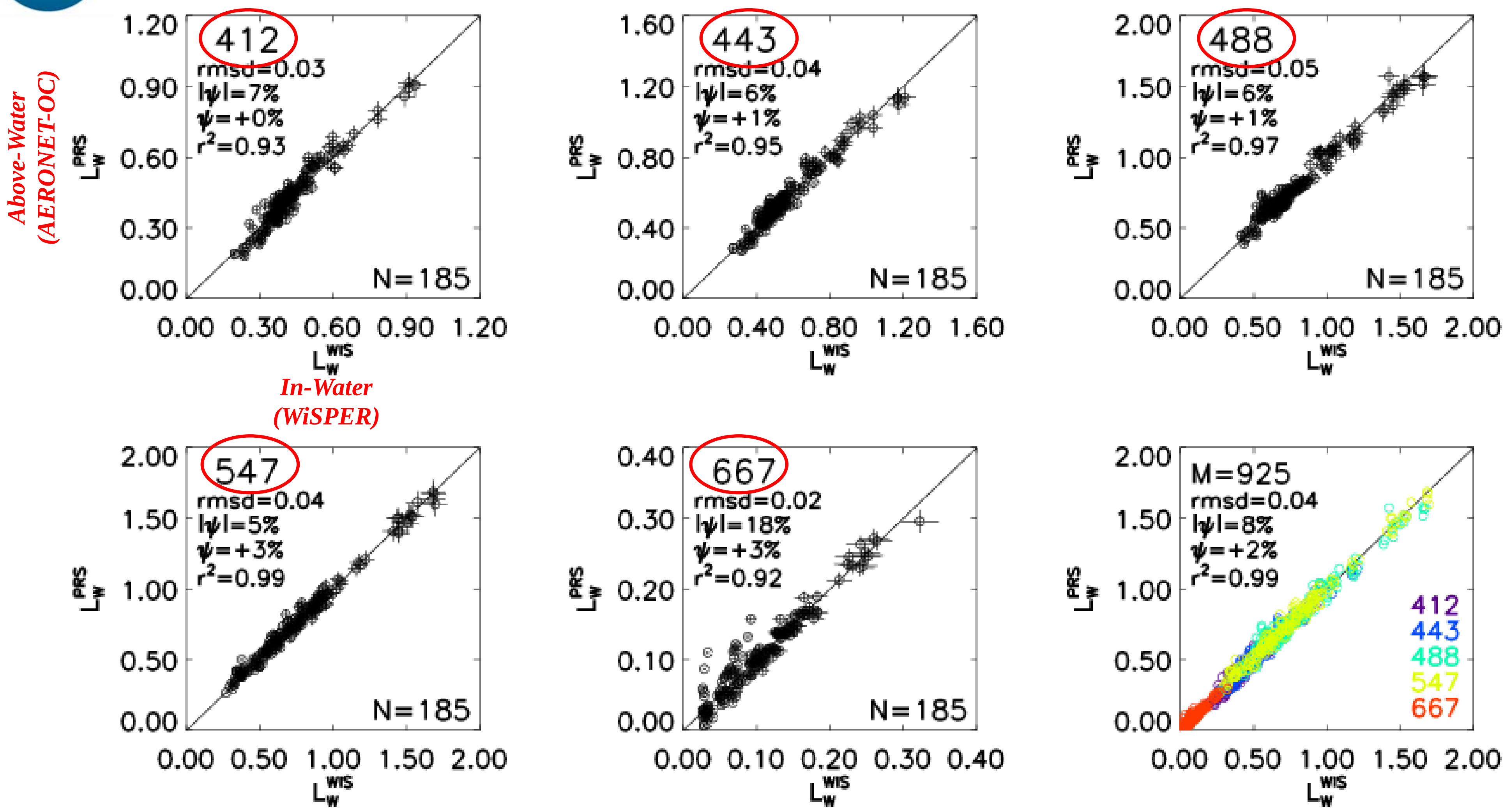
AERONET-OC: sites



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.

Assessment AERONET-OC L_W

How do compare Above-Water AERONET-OC with In-Water L_W data products?

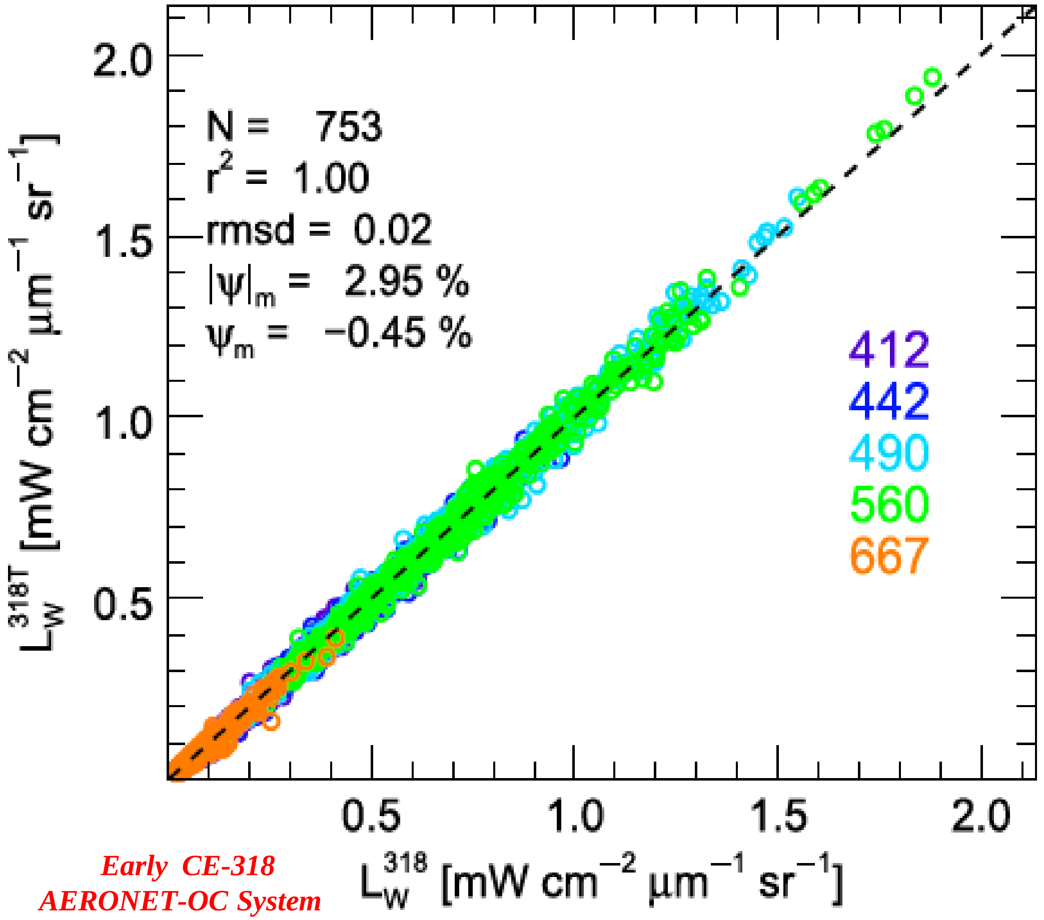


G. Zibordi 2016. Experimental evaluation of theoretical sea surface reflectance factors relevant to above-water radiometry. Optics Express, 24(6), A446-A459.

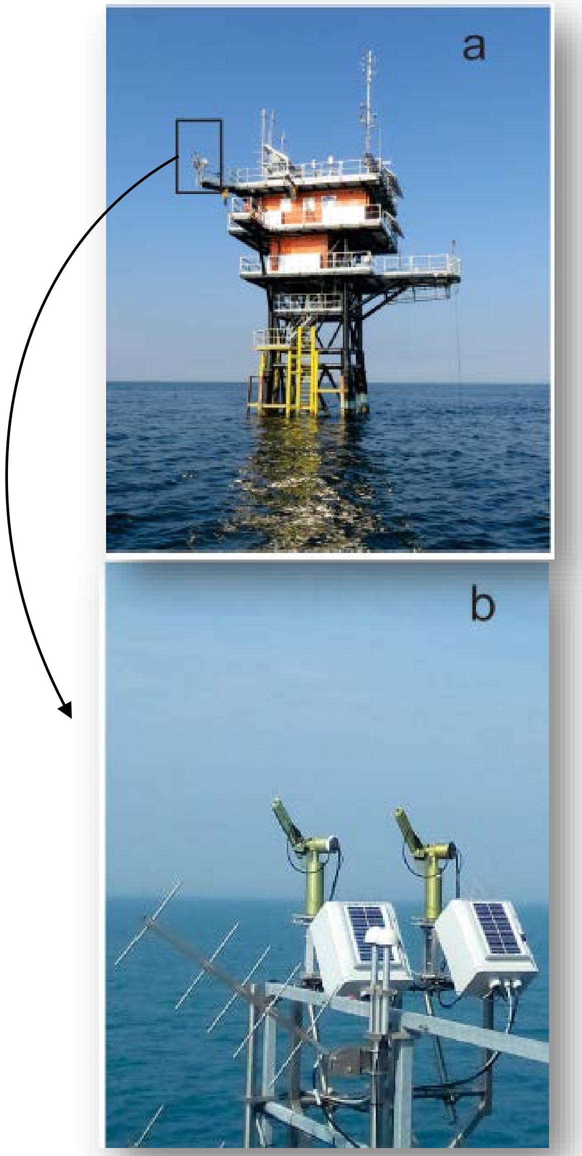
Assessment of CE-318T L_W data

How do compare L_W data from diverse AERONET-OC instrument versions?

New CE-318T AERONET-OC System (from late 2017)

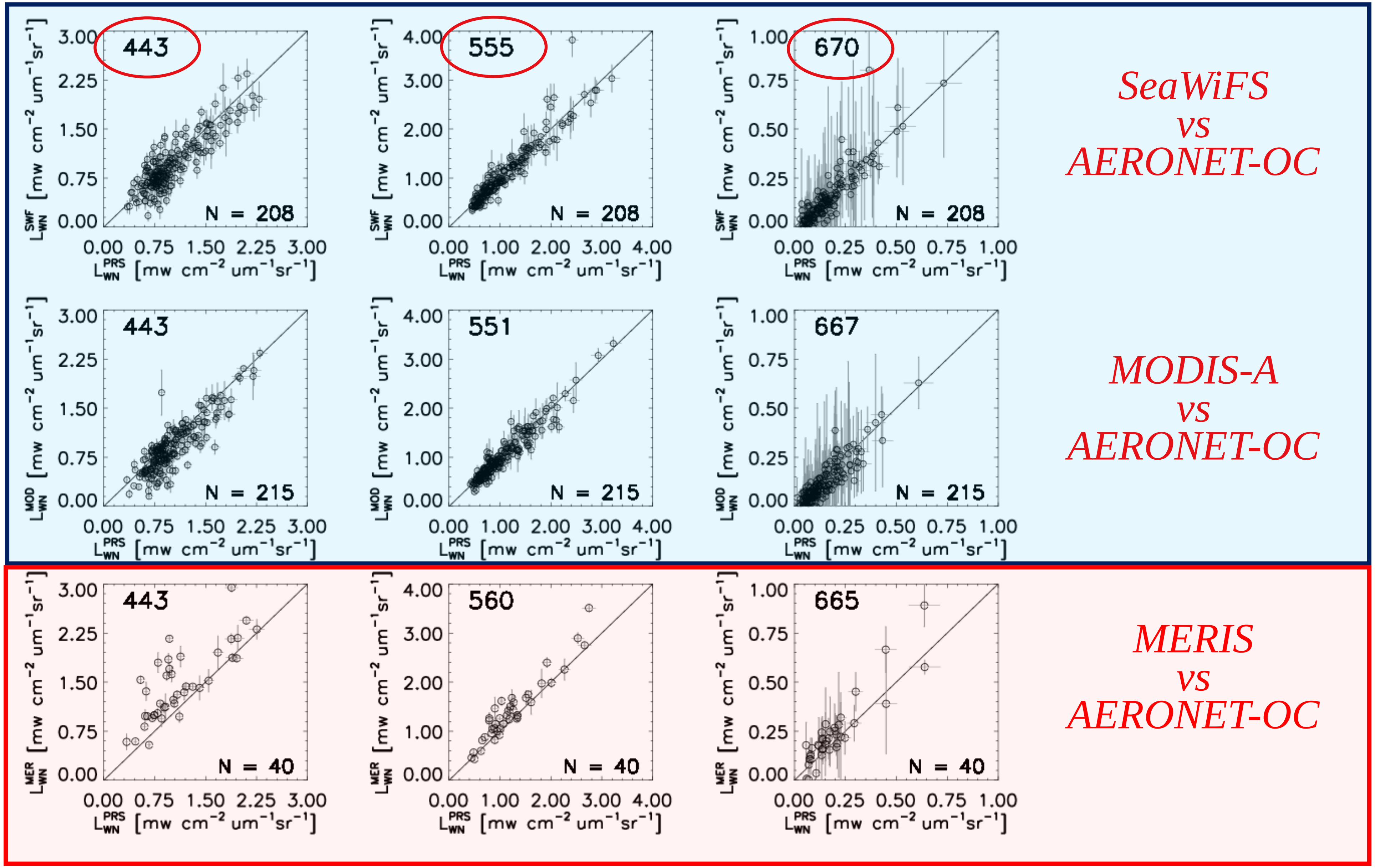


Early CE-318 AERONET-OC System



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.

Early AERONET-OC data application



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).

AERONET-OC data applications

Remote Sensing of Environment 272 (2022) 112911

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

ELSEVIER

Assessment of OLCI-A and OLCI-B radiometric data products across European seas

Giuseppe Zibordi[a,*], Ewa Kwiatkowska[b], Frédéric Mélin[a], Marco Talone[c], Ilaria Cazzaniga[a], David Dessailly[b], Juan Ignacio Gossn[b]

[a] Joint Research Centre of the European Commission, Ispra, Italy
[b] EUMETSAT, Remote Sensing and Products Division, Darmstadt, Germany
[c] Barcelona Expert Centre and Institute of Marine Sciences (ICM-CSIC), Barcelona, Spain

Remote Sensing of Environment 190 (2017) 289–301

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

ELSEVIER

Landsat 8 remote sensing reflectance (R_{rs}) products: Evaluations, intercomparisons, and enhancements

CrossMark

Nima Pahlevan[a,b,*], John R. Schott[c], Bryan A. Franz[a], Giuseppe Zibordi[d], Brian Markham[a], Sean Bailey[a], Crystal B. Schaaf[e], Michael Ondrusek[f], Steven Greb[g], Christopher M. Strait[h]

[a] NASA Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt, MD 20771, USA
[b] Science Systems and Applications, Inc., 10210 Greenbelt Road, Lanham, MD 20706, USA
[c] Rochester Institute of Technology, 54 Lomb Memorial Dr, Rochester, NY 14623, USA
[d] Institute for Environment and Sustainability, Joint Research Center, 21027 Ispra, VA, Italy
[e] University of Massachusetts Boston, 100 Morrissey Blvd., Boston, MA 02125, USA
[f] NOAA, NESDIS, STAR, SOCD, College Park, MD 20740, USA
[g] Wisconsin Department of Natural Resources, 2801 Progress Rd., Madison, WI 53716, USA
[h] Upstate Freshwater Institute, 224 Midler Park Dr, Syracuse, NY 13206, USA

Remote Sensing of Environment 115 (2011) 1955–1965

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

ELSEVIER

Comparison of three SeaWiFS atmospheric correction algorithms for turbid waters using AERONET-OC measurements

Cédric Jamet[a,b,*], Hubert Loisel[a,b], Christopher P. Kuchinke[c], Kevin Ruddick[d], Giuseppe Zibordi[e], Hui Feng[f]

[a] Univ Lille Nord de France, ULCO, LOG, F-62930 Wimereux, France
[b] CNRS, UMR 8187, F-62930 Wimereux, France
[c] Department of Physics, University of Miami, PO Box 248046, Coral Gables, FL 33124, USA
[d] Management Unit of the North Sea Mathematical Models (MUMM), Royal Belgian Institute for Natural Sciences (RBINS), 100 Gulledelle, B-1200 Brussels, Belgium
[e] Joint Research Centre, Institute for Environment and Sustainability, Global Environment Monitoring Unit, Ispra, 21020, Italy
[f] Ocean Process Analysis Laboratory, Institute for the Study of Earth, Oceans and Space, University of New Hampshire, Durham, NH 03824, USA

Remote Sensing of Environment 199 (2017) 218–240

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

ELSEVIER

Atmospheric correction over coastal waters using multilayer neural networks

CrossMark

Yongzhen Fan[a,*], Wei Li[a], Charles K. Gatebe[b], Cédric Jamet[c], Giuseppe Zibordi[d], Thomas Schroeder[e], Knut Stamnes[a]

[a] Light & Life Laboratory, Department of Physics and Engineering Physics, Stevens Institute of Technology, Hoboken, NJ 07307, USA
[b] NASA's Goddard Space Flight Center, Greenbelt, MD 20771, USA
[c] Univ. Lille, CNRS, Univ. Littoral Côte d'Opale, UMR 8187, LOG, Laboratoire d'Océanologie et de Géosciences, F 62930 Wimereux, France
[d] European Commission, Joint Research Centre, Institute for Environment and Sustainability, Ispra 21027, Italy
[e] Commonwealth Scientific and Industrial Research Organisation (CSIRO), Oceans and Atmosphere, Brisbane, QLD 4001, Australia

… more AERONET-OC data applications

798 APPLIED OPTICS / Vol. 49, No. 5 / 10 February 2010

Vicarious calibration of satellite ocean color sensors at two coastal sites

Frédéric Mélin* and Giuseppe Zibordi

European Commission—Joint Research Centre, Institute for Environment and Sustainability, Global Environment Monitoring Unit, TP272, Ispra 21027, Italy

*Corresponding author: frederic.melin@jrc.ec.europa.eu

Received 19 October 2009; revised 18 December 2009; accepted 9 January 2010; posted 13 January 2010 (Doc. ID 118689); published 2 February 2010

Remote Sensing of Environment 264 (2021) 112607

ELSEVIER

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Check for updates

Spectral variations of the remote sensing reflectance during coccolithophore blooms in the Western Black Sea

Ilaria Cazzaniga*, Giuseppe Zibordi, Frédéric Mélin

European Commission, Joint Research Centre (JRC), Ispra, Italy

EEE GEOSCIENCE AND REMOTE SENSING LETTERS, VOL. 19, 2022

Uncertainty Estimate of Satellite-Derived Normalized Water-Leaving Radiance

Giuseppe Zibordi, Marco Talone, *Senior Member, IEEE*, and Frédéric Mélin

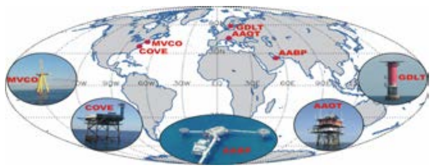
IEEE GEOSCIENCE AND REMOTE SENSING LETTERS, VOL. 9, NO. 6, NOVEMBER 2012

Trends in the Bias of Primary Satellite Ocean-Color Products at a Coastal Site

G. Zibordi, F. Mélin, and J. F. Berthon

Joint Research Centre

Match-up Performance Matrix:
what's best for ocean color validation?



Ranking (0-10) (0=lowest and 10 =highest)	*AERONET-OC (AAOT)*	*CoASTS (AAOT)*	*BiOMaP (ships)*
Measured Quantities	2	10	10
Matchups versus Deployment-Time	10	10	10
Accuracy	8	8	8
Temporal Representativity	10	2	1
Bio-optical Representativity	5	4	10
Matchups versus Funding	10	0.5	0.2
Overall mean	**7.7**	**5.9**	**6.5**

The cost per matchup:

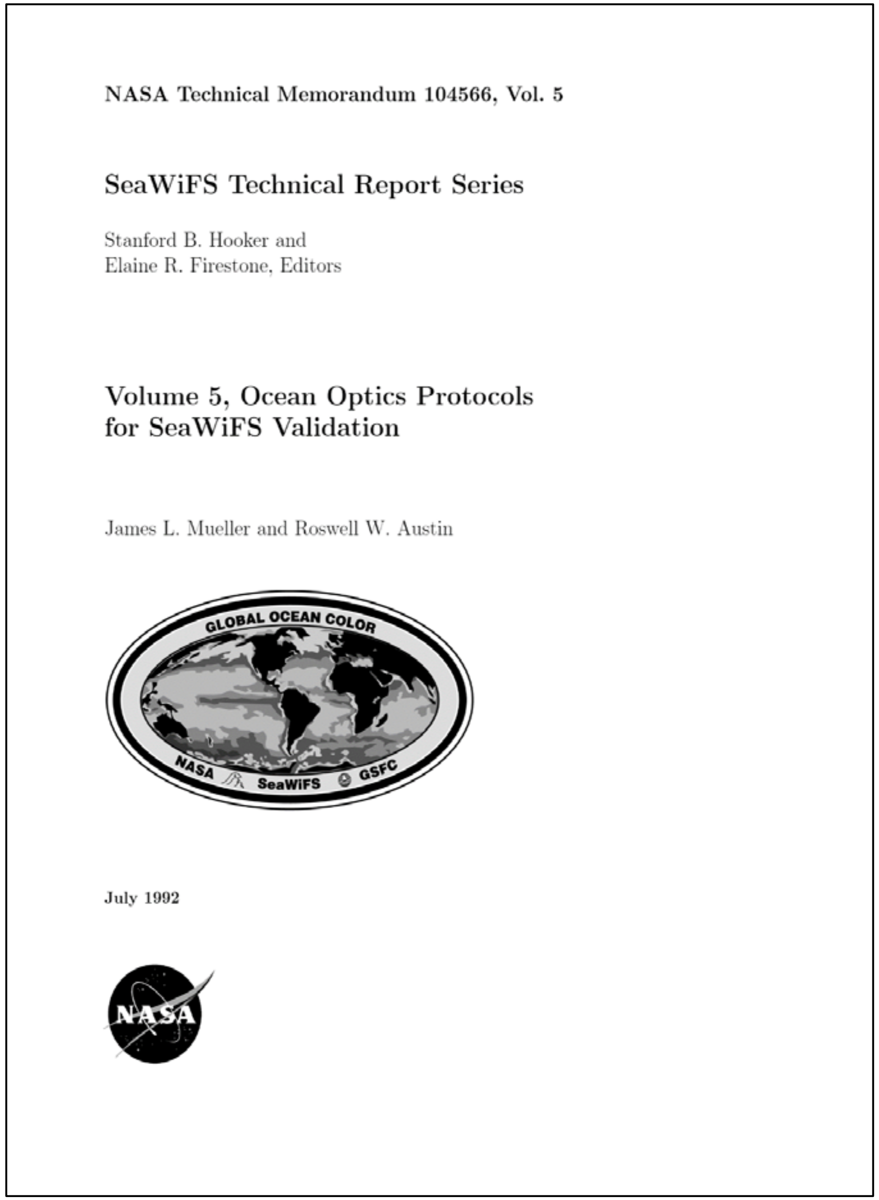
less than 0.5 US K$

more than 10 US K$

more than 25 US K$

Protocols and methods ensure standardization of measurements and the quantification uncertainties. Are they comprehensive ?

Protocols


NASA Technical Memorandum 104566, Vol. 5

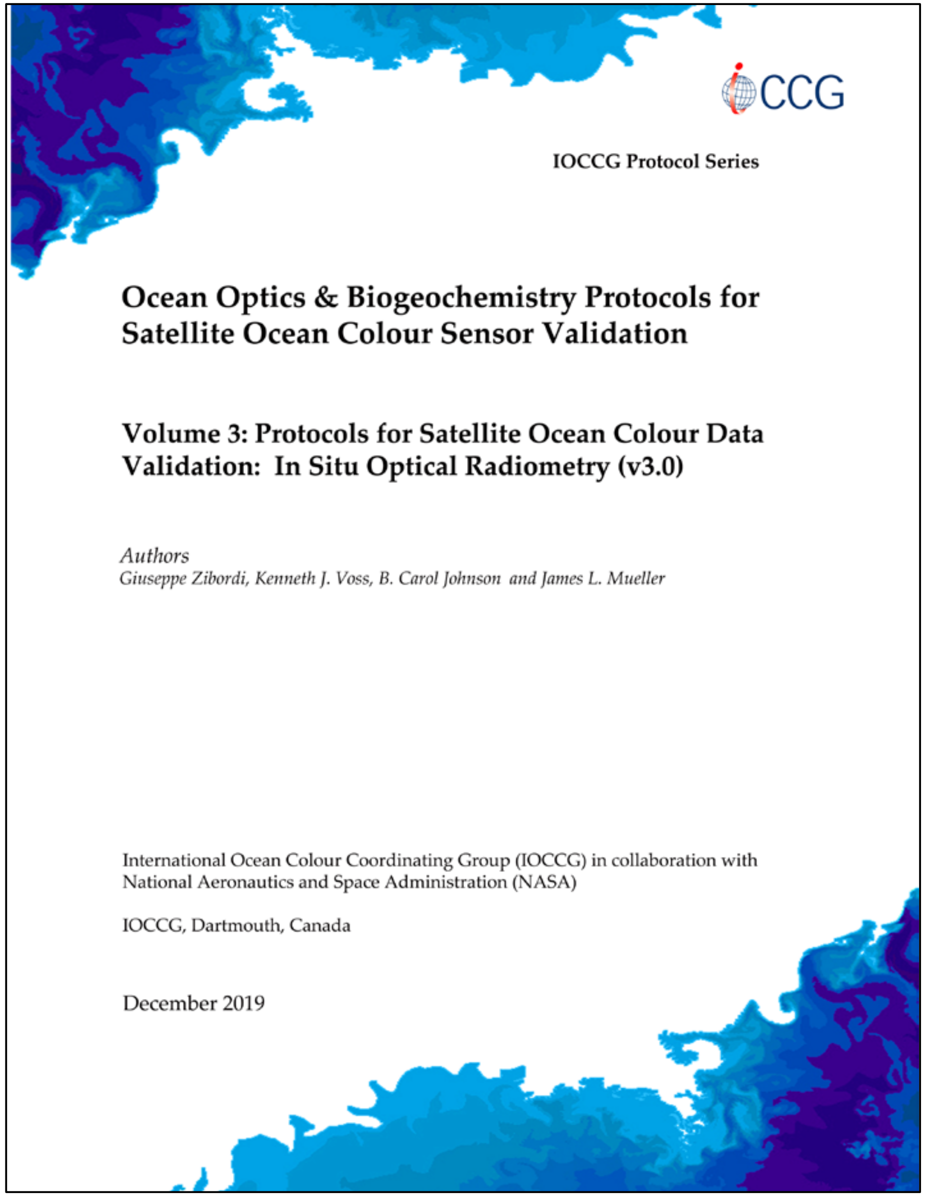
SeaWiFS Technical Report Series

Stanford B. Hooker and
Elaine R. Firestone, Editors

Volume 5, Ocean Optics Protocols
for SeaWiFS Validation

James L. Mueller and Roswell W. Austin

July 1992



IOCCG Protocol Series

Ocean Optics & Biogeochemistry Protocols for
Satellite Ocean Colour Sensor Validation

Volume 3: Protocols for Satellite Ocean Colour Data
Validation: In Situ Optical Radiometry (v3.0)

Authors
Giuseppe Zibordi, Kenneth J. Voss, B. Carol Johnson and James L. Mueller

International Ocean Colour Coordinating Group (IOCCG) in collaboration with
National Aeronautics and Space Administration (NASA)

IOCCG, Dartmouth, Canada

December 2019

"… adequately sampled, carefully calibrated, quality controlled, and archived data for key elements of the climate system will be useful indefinitely" (Wunsch, R.W. Schmitt, and D.J. Baker 2013)

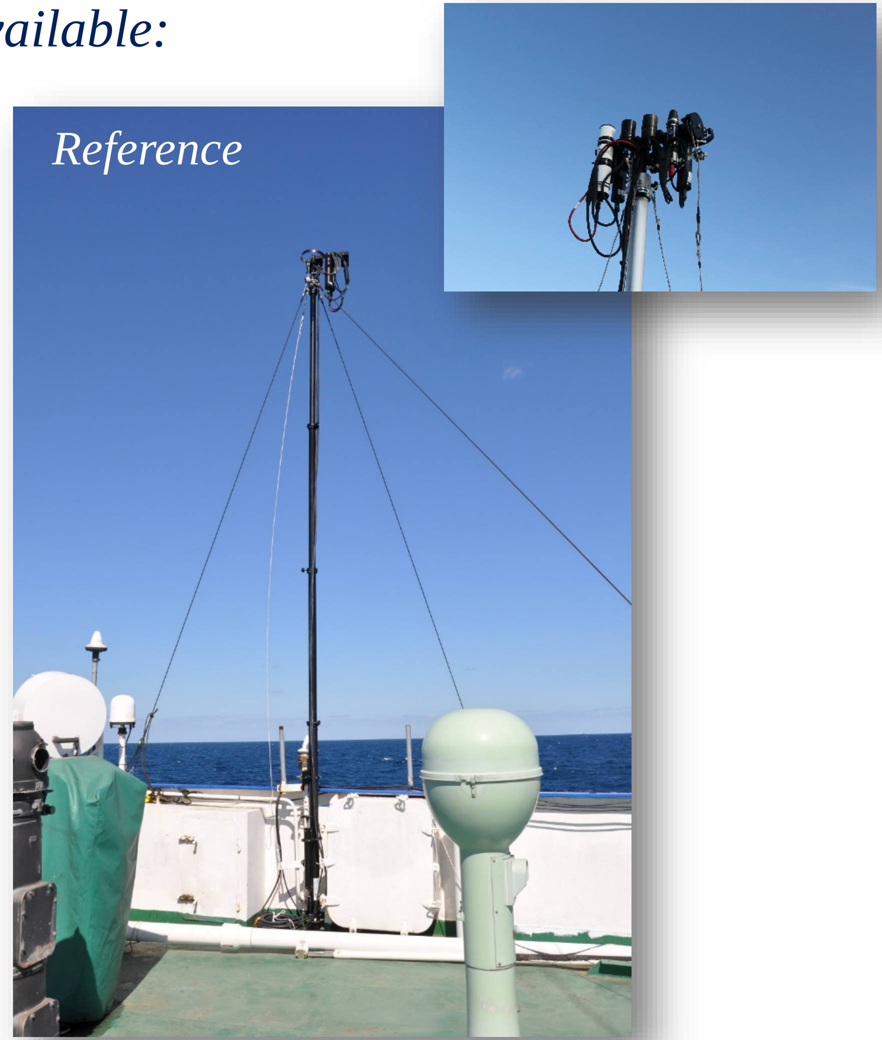
Joint Research Centre

Measurement Protocols

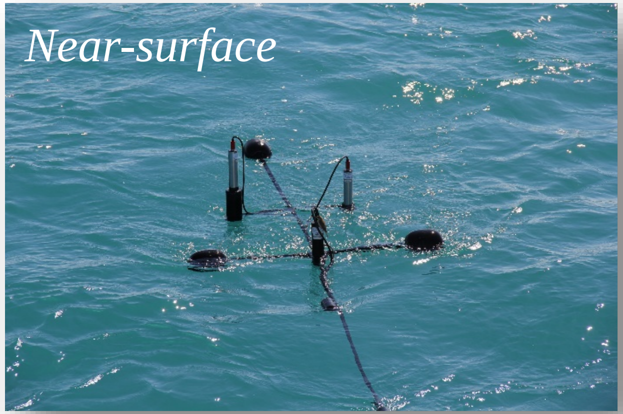
While keeping $L_{WN}(\lambda)$ or $R_{RS}(\lambda)$ as target quantities for ocean color Cal/Val, various in-water, above-water and near-surface protocols are available:

In-water free-fall

Above-water



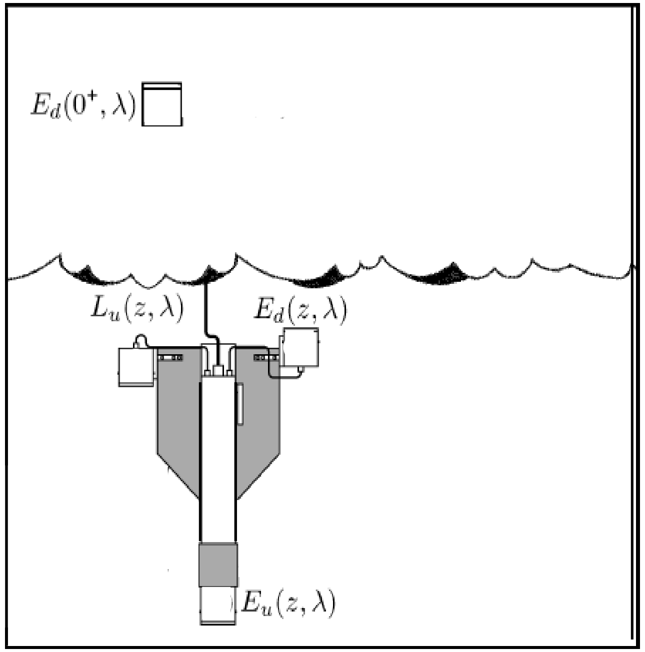
Reference

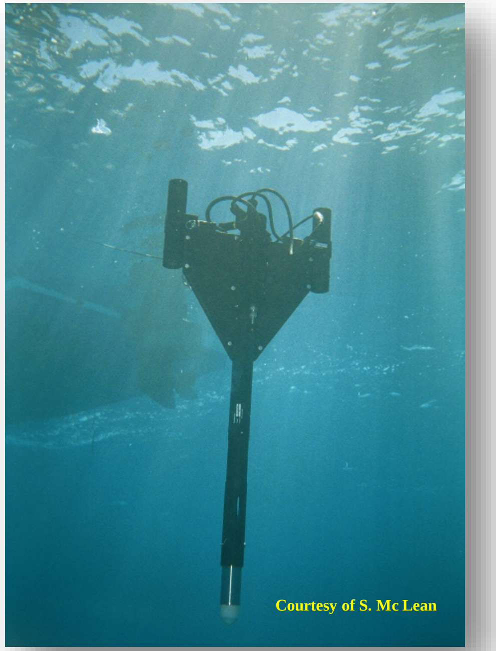


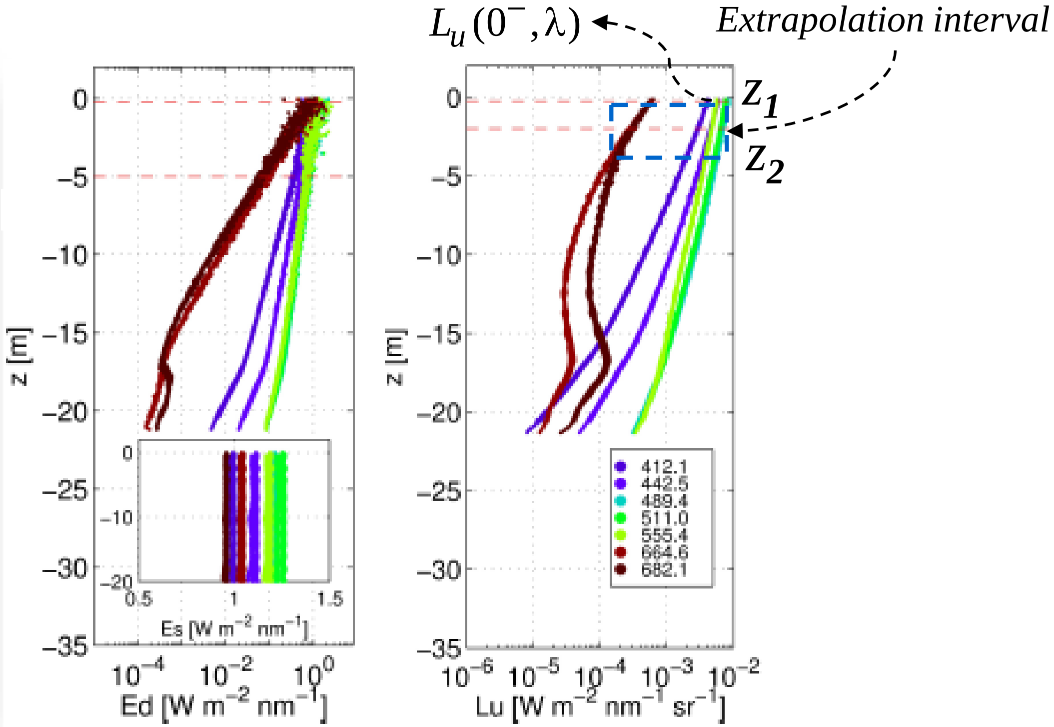
Near-surface

Above-water (automated)

In-Water Radiometry







$$L_u(z,\lambda) = L_u(0^-,\lambda)\cdot e^{-K_L(\lambda)\cdot z}$$

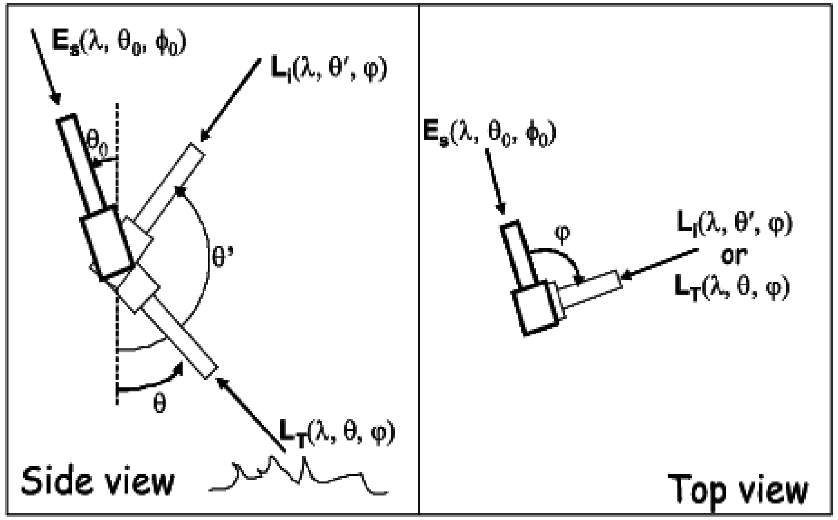
How many measurements per unit depth are required to ensure minimization of wave perturbations?

Findings from moderately optically complex waters indicated the need for 20 samples per meter to ensure extrapolation of $L_u(0^-,\lambda)$ with an uncertainty lower than 1% across the visible spectrum.

Zibordi, G., D'Alimonte, D., & Berthon, J. F. (2004). An evaluation of depth resolution requirements for optical profiling in coastal waters. Journal of Atmosph. and Oceanic Tech., 21, 1059-1073.

D'Alimonte, D., Zibordi, G., & Kajiyama, T. (2018). Effects of integration time on in-water radiometric profiles. Optics express, 26, 5908-5939

Above-Water Radiometry



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

Sea-radiance: L_T

Sky-radiance: L_i

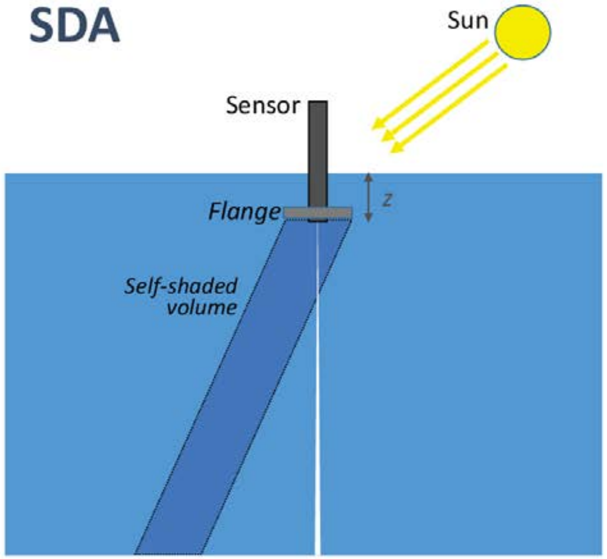
$$L_W(\varphi,\theta,\lambda) = L_T(\varphi,\theta,\lambda) - \rho(\varphi,\theta,\theta_0,W)L_i(\varphi,\theta',\lambda) \quad \& \quad L_W(\lambda) = L_W(\varphi,\theta,\lambda)C_{\Im Q}(\lambda,\theta,\varphi,\theta_0,\tau_a,IOP,W)$$

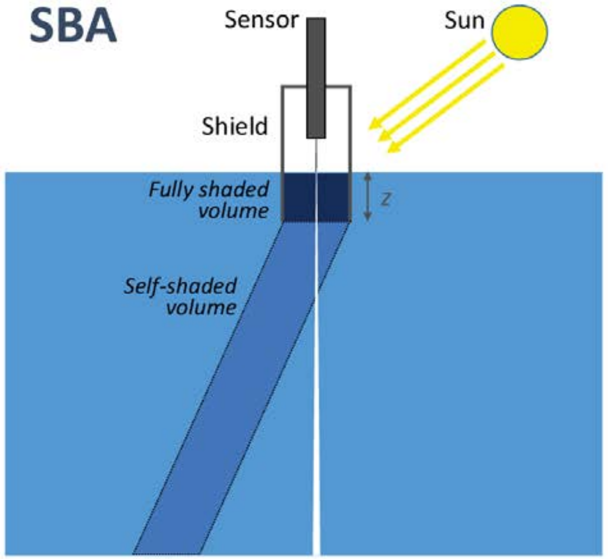
The accuracy of sea-surface reflectance ρ is challenged by modelling accuracy and the actual knowledge of sky radiance and wave slope distributions.
How can we ensure accuracy to data by minimizing the impact of uncertainties in ρ ?

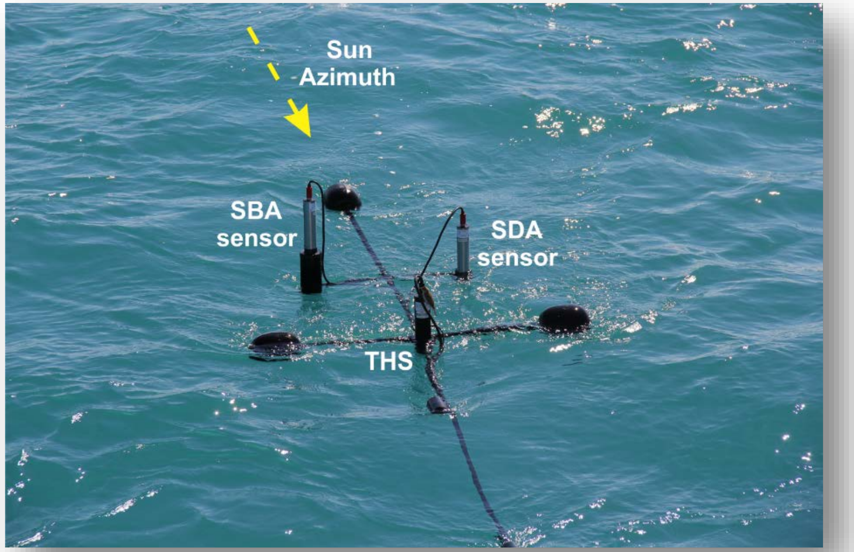
Applying strict viewing geometries and restricting the generation of data products to those measurement conditions minimizing high-glint contributions (i.e., avoiding relatively high wind speeds and low sun zeniths, both identifiable through the measurements themselves).

Zibordi G., Mélin F., Berthon J. F., Holben B., Slutsker I., Giles D., ... & Seppälä J. (2009). AERONET-OC: a network for the validation of ocean color primary products. Journal of Atmospheric and Oceanic Technology, 26(8), 1634-1651.

Single Depth (SDA) & Sky-Blocked Approach (SBA)







Are the SBA and SDA approaches leading to a different accuracy in data products?

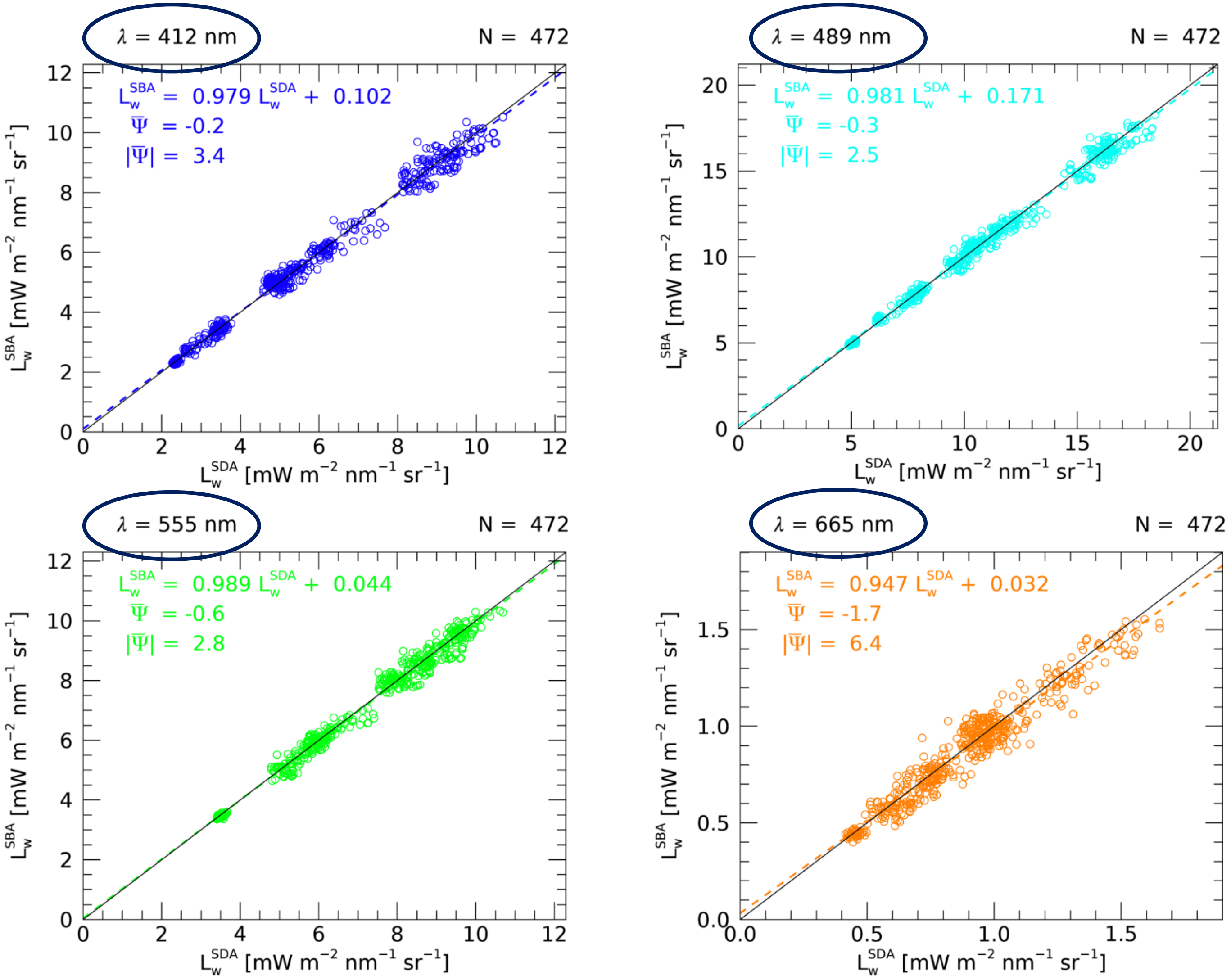
SDA ⟶ $$L_W^{SDA}(\lambda) = L_u(z,\lambda)\cdot C_{ss}^{SDA}(\lambda, a, I_r, \theta_0, R_d, f^{SDA})\cdot C_{K_L}(\lambda, K_L, z)\cdot \frac{t_{wa}(\lambda)}{n_w^2(\lambda)}$$

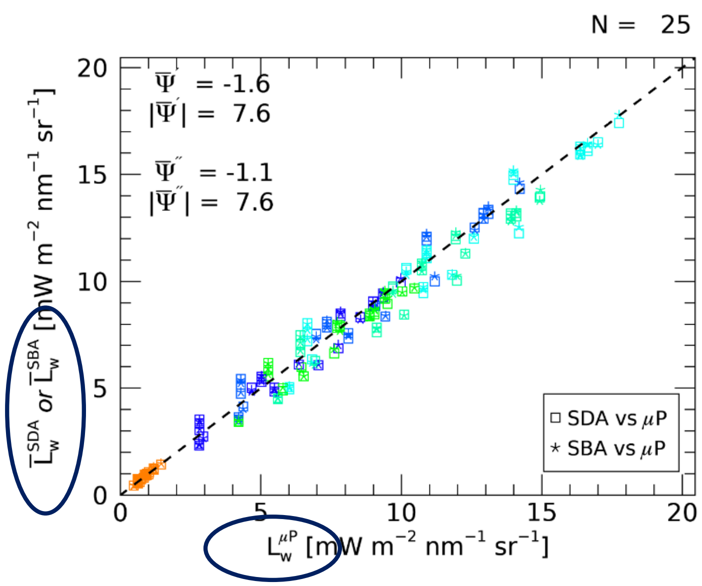
SBA ⟶ $$L_W^{SBA}(\lambda) = L_W(z,\lambda)\cdot C_{ss}^{SBA}(\lambda, a, I_r, R_d, f^{SBA})\cdot C_{is}(\lambda, a, b_b, z)\cdot C_{K_L}(\lambda, K_L, z)\cdot C_{ww}(\lambda)$$

Zibordi, G., & Talone, M. (2020). On the equivalence of near-surface methods to determine the water-leaving radiance. Optics Express, 28(3), 3200-3214.

Joint Research Centre

SBA v.s. SDA derived L_W





Inter-comparisons, supported by the comprehensive parameterization of optical processes demonstrated the equivalence of the two near-surface methods, without any major advantage of one with respect to the other.

Zibordi, G., & Talone, M. (2020). On the equivalence of near-surface methods to determine the water-leaving radiance. Optics Express, 28(3), 3200-3214.

Joint Research Centre

Calibrations and Characterizations

Which are the basic requirements for field instruments calibration and characterization ?

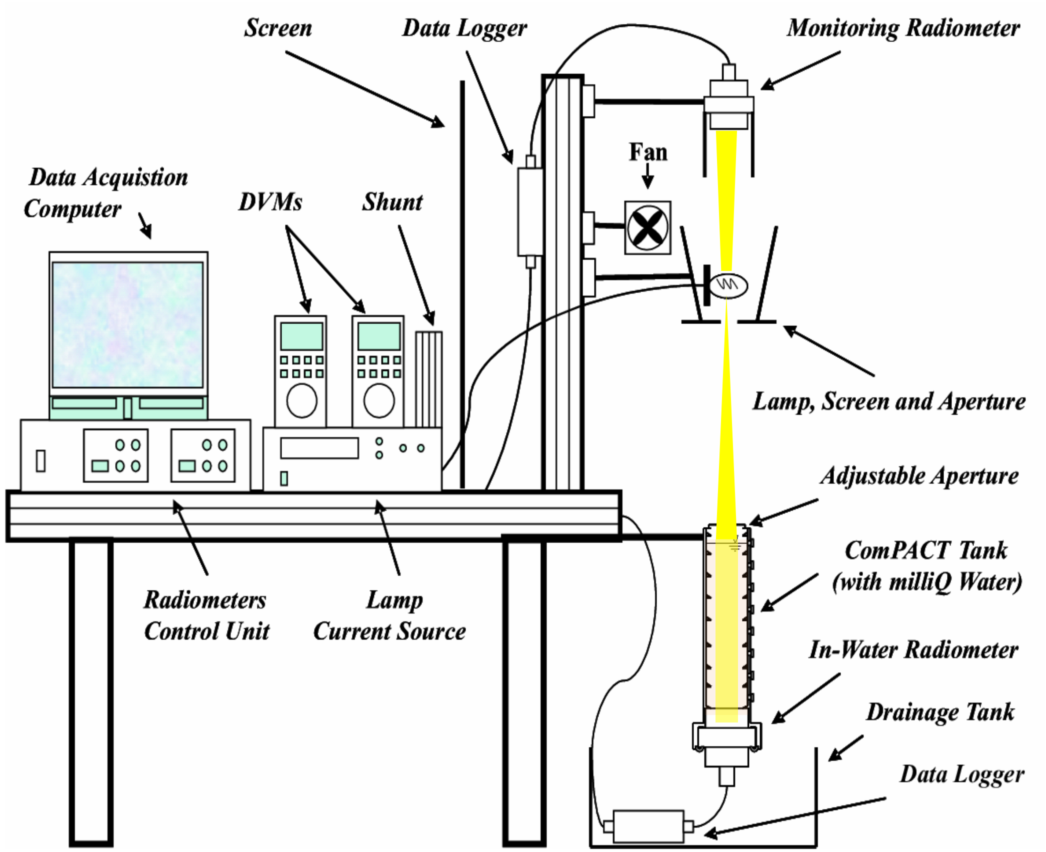
	Regular	Occasional	Initial	Class-based
Radiometric responsivity	X			
Spectral response		X		
Out-of-band & stray-light		X		
Immersion factor (irradiance)			X	
Immersion factor (radiance)				X
Angular response			X	
Linearity				X
Integration time				X
Temperature response				X
Polarization sensitivity				X
Dark signal	X			
Temporal response				X
Pressure effects				X

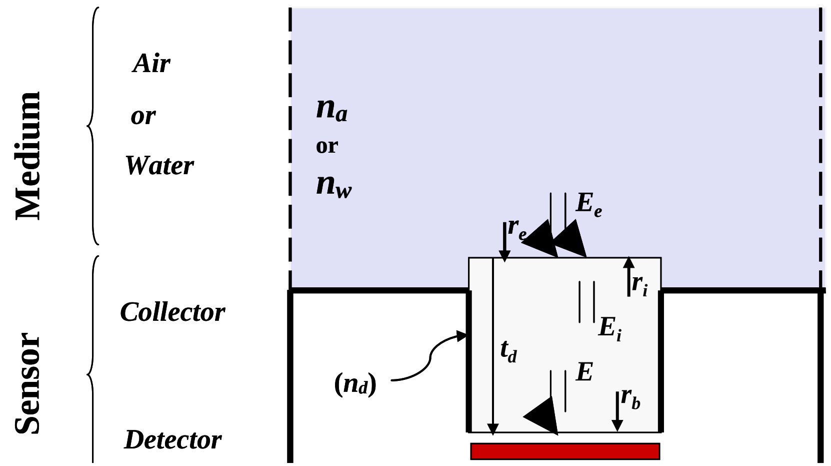
Very unlikely individual research teams can ensure comprehensive characterizations. Occasional, initial and class-based characterizations should be taken over by major measurement programs in agreement with manufacturers and reference laboratories. This implies a standardization of instrument models.

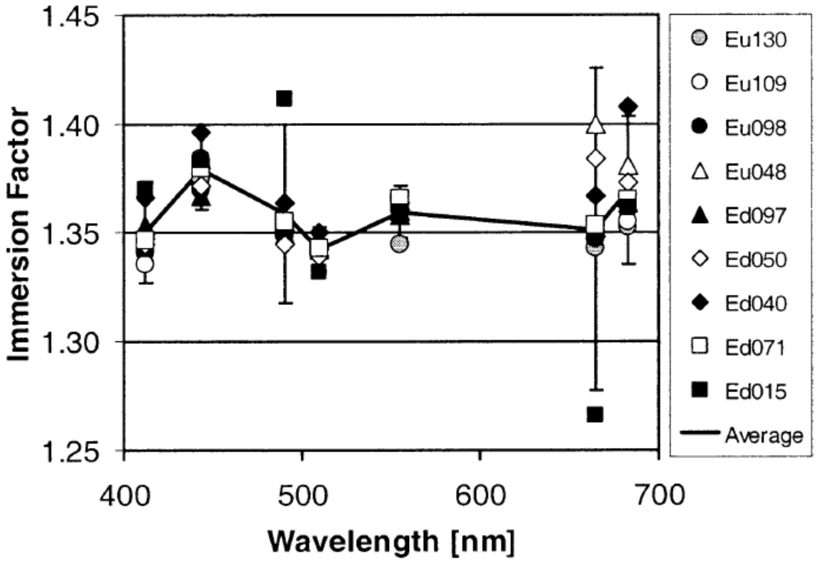
IOCCG Protocol Series (2019). Protocols for Satellite Ocean Colour Data Validation: In Situ Optical Radiometry. Zibordi, G., Voss, K. J., Johnson, B. C. and Mueller, J. L. IOCCG Ocean Optics and Biogeochemistry Protocols for Satellite Ocean Colour Sensor Validation, Volume 3.0, IOCCG, Dartmouth, NS, Canada.

Immersion Factor I_f (irradiance)

Immersion factor (irradiance): regular, initial, occasional or class-based?





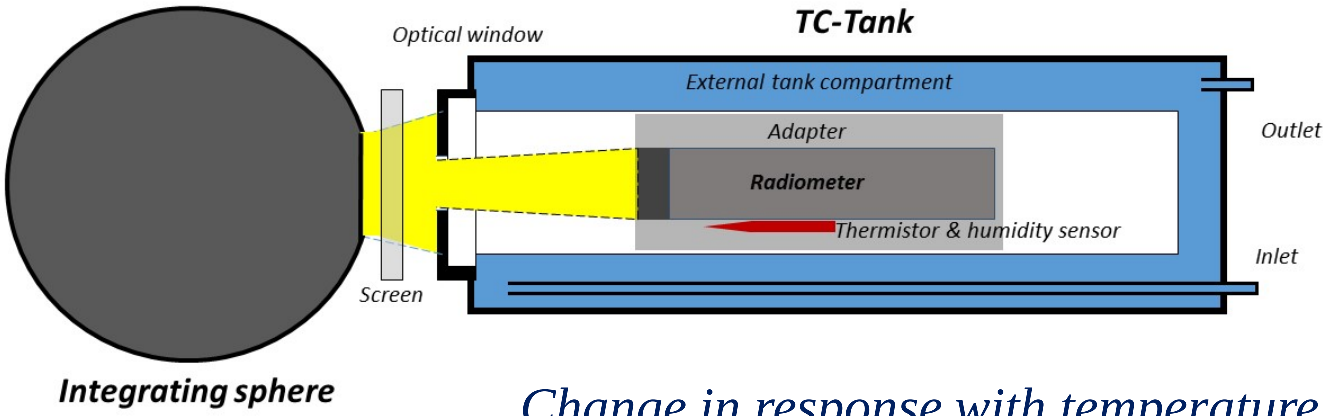


It must be (at least) initial and performed for each unit because of the mechanical / optical differences affecting collectors.

Zibordi G., Hooker S. B., Mueller J., & Lazin G. (2004). Characterization of the immersion factor for a series of in-water optical radiometers. Journal of Atmospheric and Oceanic Technology, 21(3), 501-514.

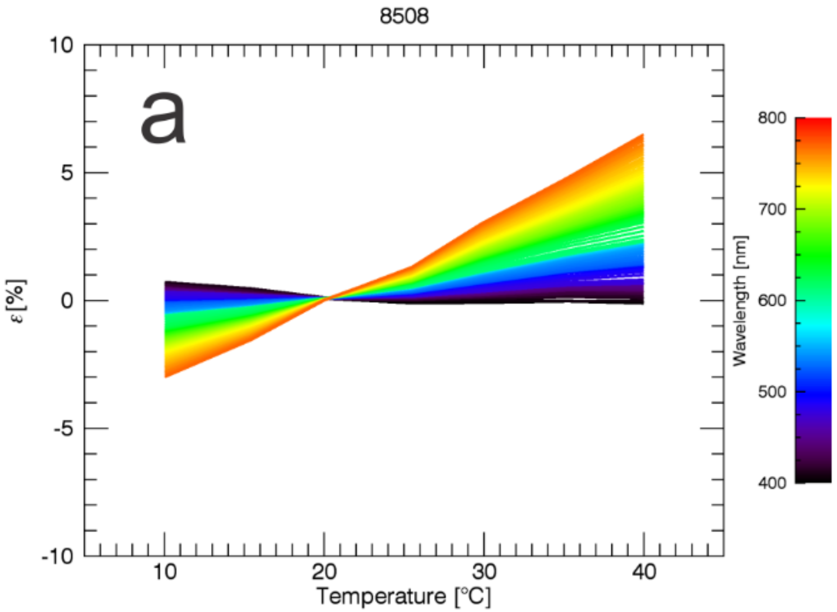
Temperature response

Temperature response: regular, initial, occasional or class-based?

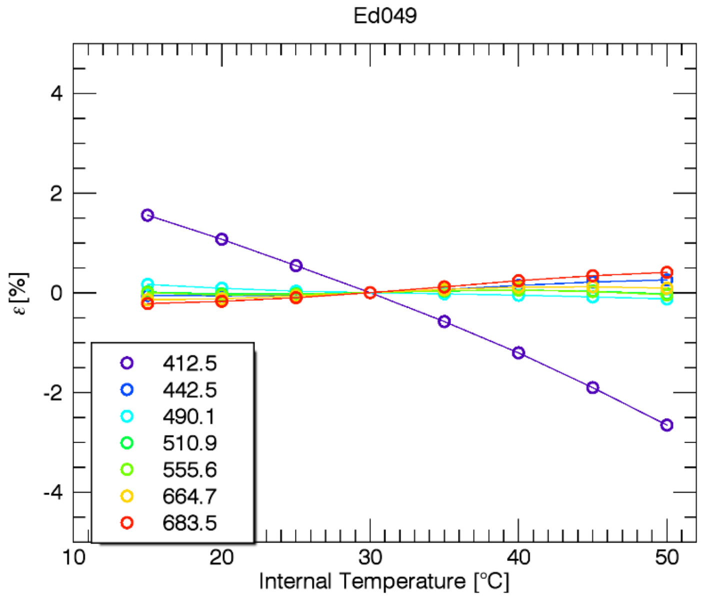


Depending on the allowed uncertainties, it can be class-based for some instrument models.

Change in response with temperature



RAMSES



OCR-507

Zibordi, G., Talone, M., & Jankowski, L. (2017). Response to temperature of a class of in situ hyperspectral radiometers. Journal of Atmospheric and Oceanic Technology, 34(8), 1795-1805.

Additional characterizations

Joint Research Centre

National Physical Laboratory

TARTU OBSERVATORY space research centre

3966 Vol. 55, No. 15 / May 20 2016 / Applied Optics Research Article

applied optics

Stray light effects in above-water remote-sensing reflectance from hyperspectral radiometers

Marco Talone,[1,*] Giuseppe Zibordi,[1] Ilmar Ansko,[2] Andrew Clive Banks,[3] and Joel Kuusk[2]

[1]European Commission, Joint Research Centre, Institute for Environment and Sustainability, 21027 Ispra, Italy
[2]Department of Remote Sensing, Tartu Observatory, 61602 Tõravere, Tartumaa, Estonia
[3]Environment Division, National Physical Laboratory (NPL), Teddington, Middlesex TW11 0LW, UK
*Corresponding author: marco.talone@jrc.ec.europa.eu

10092 Vol. 55, No. 35 / December 10 2016 / Applied Optics Research Article

applied optics

Polarimetric characteristics of a class of hyperspectral radiometers

Marco Talone* and Giuseppe Zibordi

Joint Research Center, Directorate for Sustainable Resources, 21027 Ispra, Italy

OPEN ACCESS
IOP Publishing | Bureau International des Poids et Mesures Metrologia
Metrologia 55 (2018) 747–758 https://doi.org/10.1088/1681-7575/aadd7f

Non-linear response of a class of hyper-spectral radiometers

Marco Talone and Giuseppe Zibordi

Directorate for Sustainable Resources, Joint Research Centre, European Commission, Ispra, Italy

OPEN ACCESS
IOP Publishing Metrologia
Metrologia 57 (2020) 025008 (7pp) https://doi.org/10.1088/1681-7575/ab6277

Reduction of non-linearity effects for a class of hyper-spectral radiometers

Marco Talone[1], Giuseppe Zibordi[1] and Agnieska Białek[2]

[1] Joint Research Centre, European Commission, Ispra, Italy
[2] National Physical Laboratory, Teddington, United Kingdom

… and more characterizations

1 August 2007 / Vol. 46, No. 22 / APPLIED OPTICS 5529

Effects of cosine error in irradiance measurements from field ocean color radiometers

Giuseppe Zibordi[1,*] and Barbara Bulgarelli[2]

[1]Global Environment Monitoring Unit, Institute for Environment and Sustainability, Joint Research Centre, 21020 Ispra, Italy
[2]Sensors, Radartechnologies and Cybersecurity Unit, Institute for the Protection and Security of Citizens, Joint Research Centre, 21020 Ispra, Italy

IOP Publishing Metrologia
Metrologia **50** (2013) 187–199 doi:10.1088/0026-1394/50/3/187

Cosine error for a class of hyperspectral irradiance sensors

S Mekaoui and G Zibordi

European Commission–Joint Research Centre, Institute for Environment and Sustainability, Ispra, Italy

E-mail: Sabri.Mekaoui@jrc.ec.europa.eu and Giuseppe.Zibordi@jrc.ec.europa.eu

302 Journal of Atmospheric and Oceanic Technology Volume 23

Immersion Factor of In-Water Radiance Sensors: Assessment for a Class of Radiometers

Giuseppe Zibordi

Inland and Marine Waters Unit, Joint Research Centre of the European Union, Ispra, Italy

Institute of Physics Publishing Journal of Optics A: Pure and Applied Optics
J. Opt. A: Pure Appl. Opt. 8 (2006) 252–258 doi:10.1088/1464-4258/8/3/005

Immersion factors for the RAMSES series of hyper-spectral underwater radiometers

Giuseppe Zibordi[1] and Miroslaw Darecki[2]

[1] Inland and Marine Waters Unit, Joint Research Centre, Ispra, Italy
[2] Institute of Oceanology, Polish Academy of Sciences, Sopot, Poland

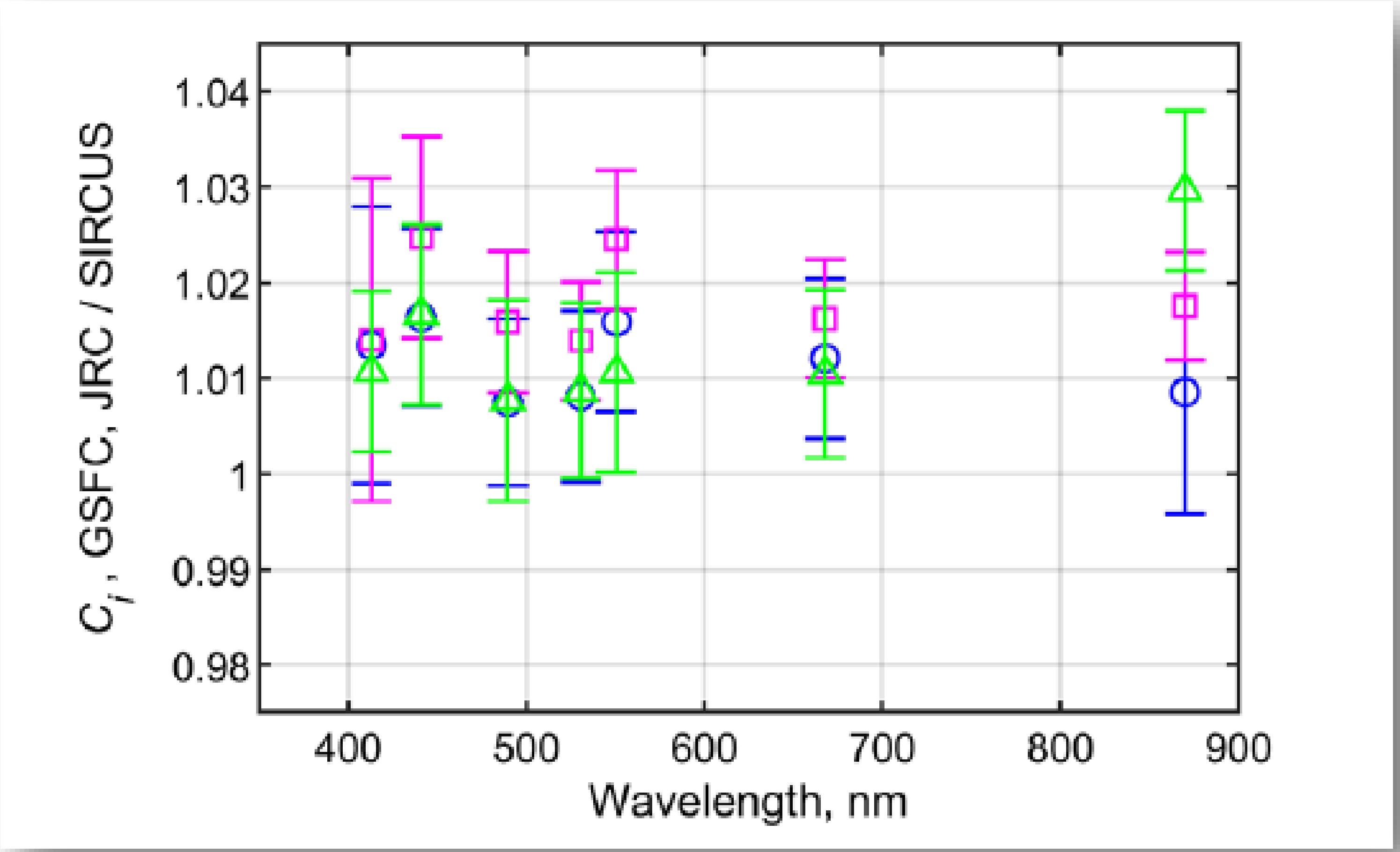
Which are the recommended best-practices?

Best Practices

"We should do the radiometry correctly, or not do it at all" (Richard Beck, 2022)

Inter-Calibrations

How consistent are fully independent absolute radiometric calibrations?



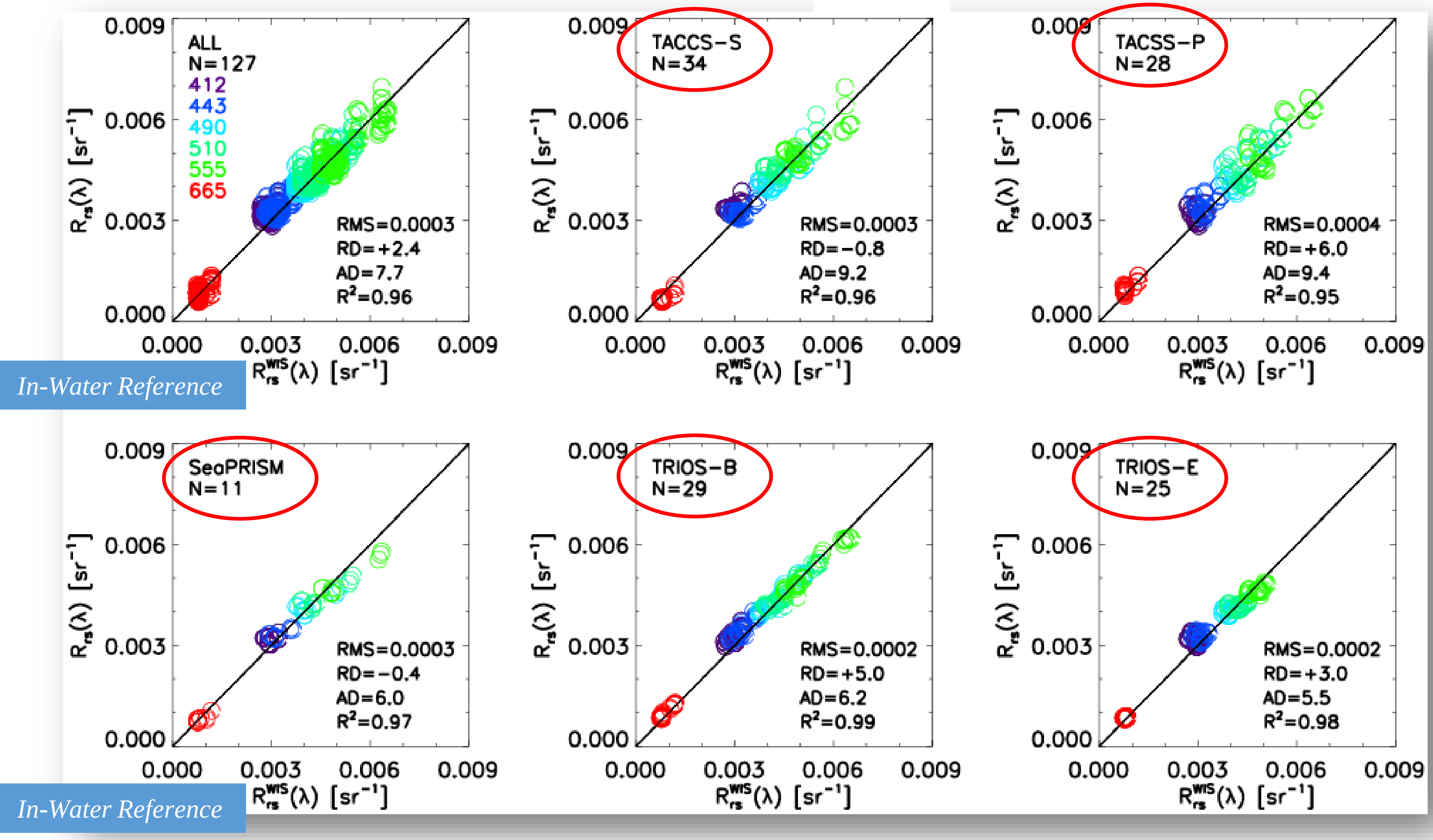
Inter-calibrations among laboratories are essential to identify issues in calibration set-ups, sources, or even protocol implementations.

Ratio of NASA-GSFC ○ ,□ and JRC △ to NIST SIRCUS radiance calibrations (note the use of error-bars and the adoption of absolute reference values).

Johnson, B. C., Zibordi, G., Brown, S. W., Feinholz, M. E., Sorokin, M. G., Slutsker, I., ... & Yoon, H. W. (2021). Characterization and absolute calibration of an AERONET-OC radiometer. Applied Optics, 60(12), 3380-3392.

Field inter-comparisons

How consistent are fully independent field measurements?



Field inter-comparisons, duly supported by laboratory calibrations and characterizations, offer a unique solution for the verification of protocol implementations and instrument performance.

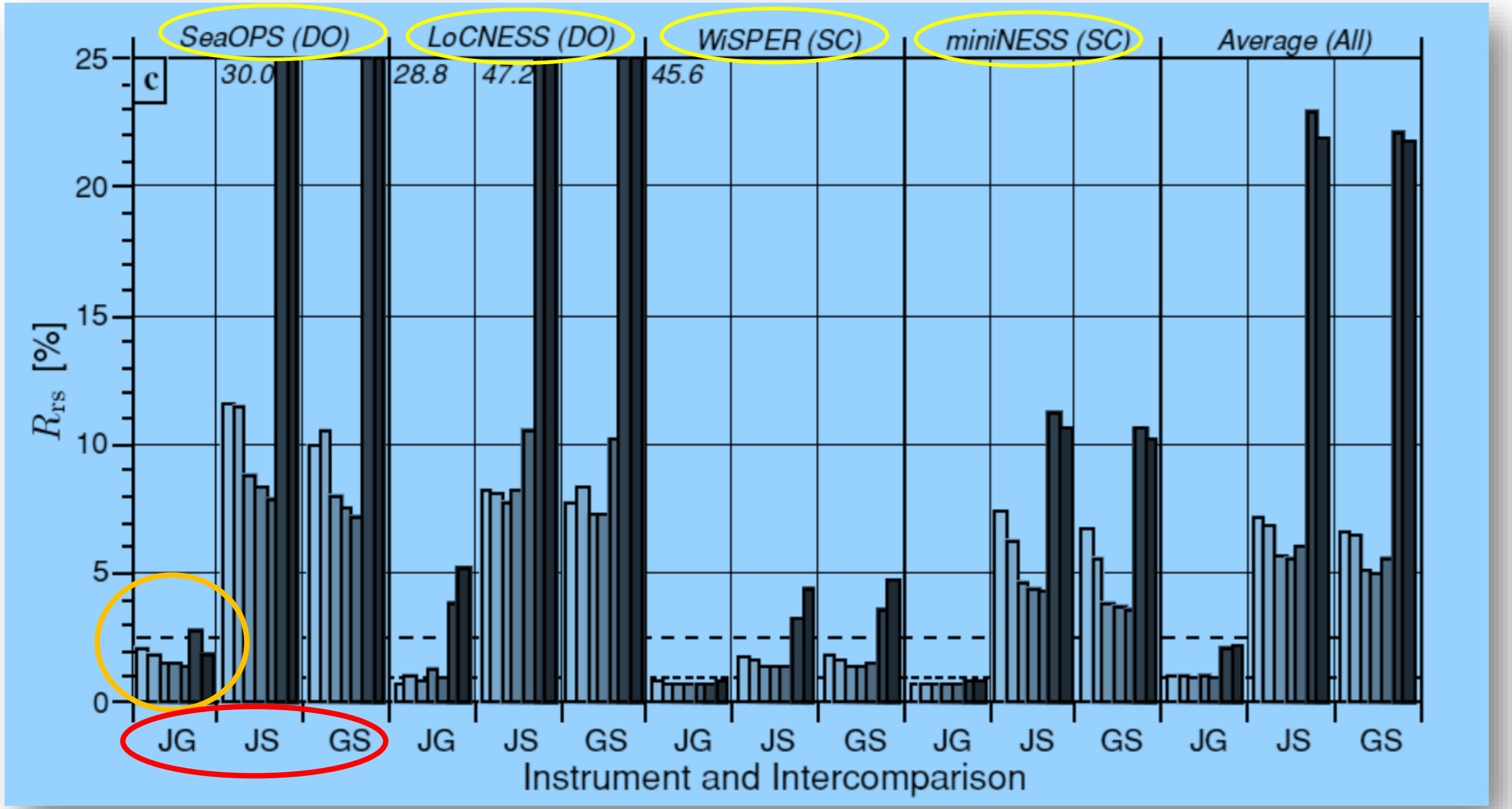
They also offer an excellent way for know-how transfer.

R_{RS} from a variety of above-water and in-water radiometer systems/methods with respect to the reference values determined with an in-water system/method

Zibordi, G., Ruddick, K., Ansko, I., Moore, G., Kratzer, S., Icely, J., & Reinart, A. (2012). In situ determination of the remote sensing reflectance: an inter-comparison. Ocean Science, 8(4), 567-586.

Processors inter-comparison

How consistent are data products from fully independent processors?



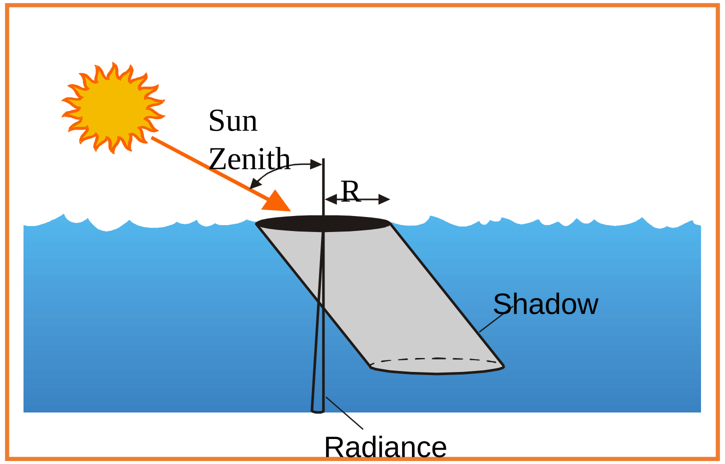
The impact of diverse processing implementations is a major overlooked issue.

Standardization is essential for operational activities.

Percent differences in spectral R_{RS} from a variety of in-water systems processed with 3 fully independent codes (but inspired by the same protocols).

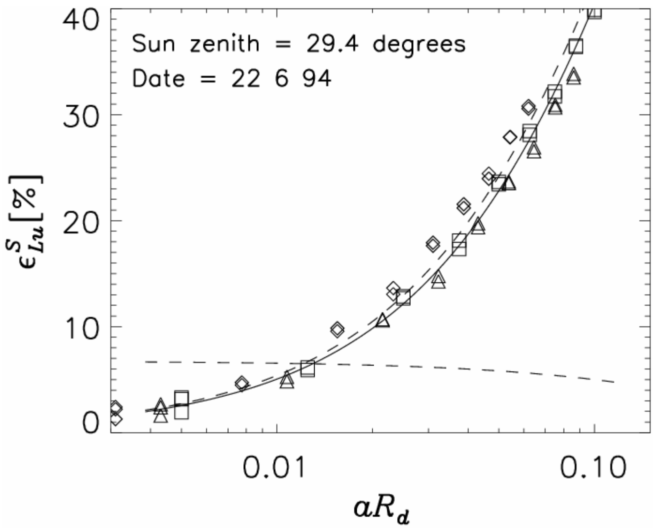
Hooker, S.B., G. Zibordi, J-F. Berthon, D. D'Alimonte, S. Maritorena, S. McLean, and J. Sildam, 2001: Results of the Second SeaWiFS Data Analysis Round Robin, March 2000 (DARR-00). NASA Tech. Memo. 2001–206892, Vol. 15, S.B. Hooker and E.R. Firestone, Eds., NASA Goddard Space Flight Center, Greenbelt, Maryland, 71 pp.

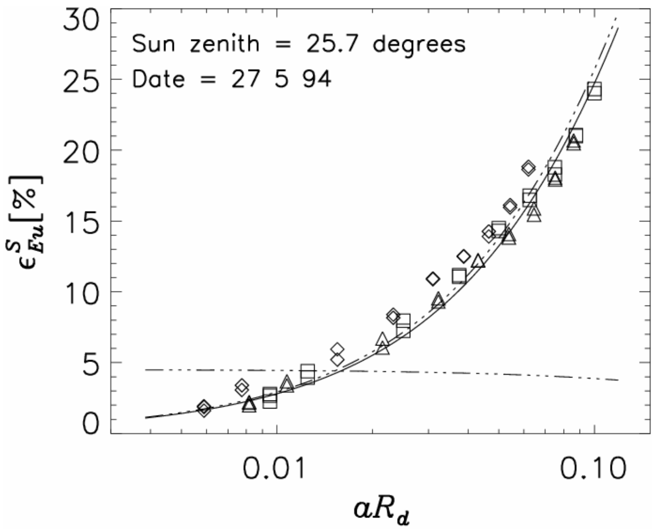
Not neglecting (self-)shading effects



Self-shading perturbations can be estimated as a function of the radiometer geometry and the water optical properties (conveniently expressed by the instrument radius and the water absorption coefficient, respectively).

Can self-shading be confidently computed?



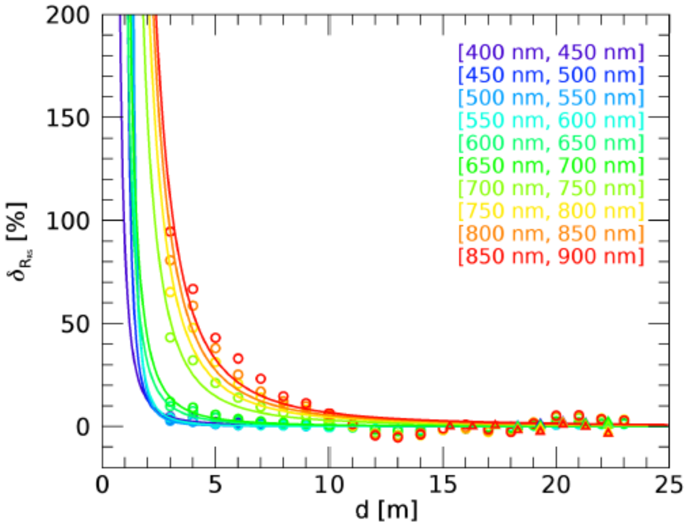


Zibordi, G., & Ferrari, G. M. (1995). Instrument self-shading in underwater optical measurements: experimental data. Applied Optics, 34(15), 2750-2754.

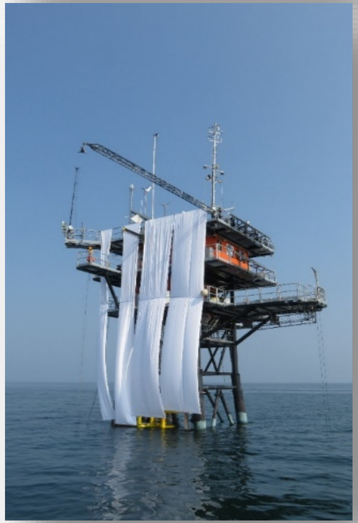
Minimizing superstructure perturbations

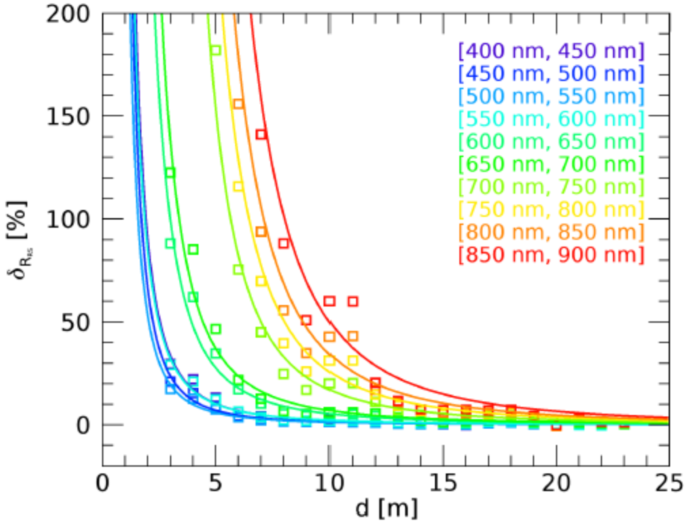
(the AAOT example)

Are superstructures leading to wavelength-dependent perturbations ?



Perturbations as a function of the distance for actual measurement conditions.





Perturbations as a function of the distance for measurement conditions worsened by the increased reflectance of the superstructure.

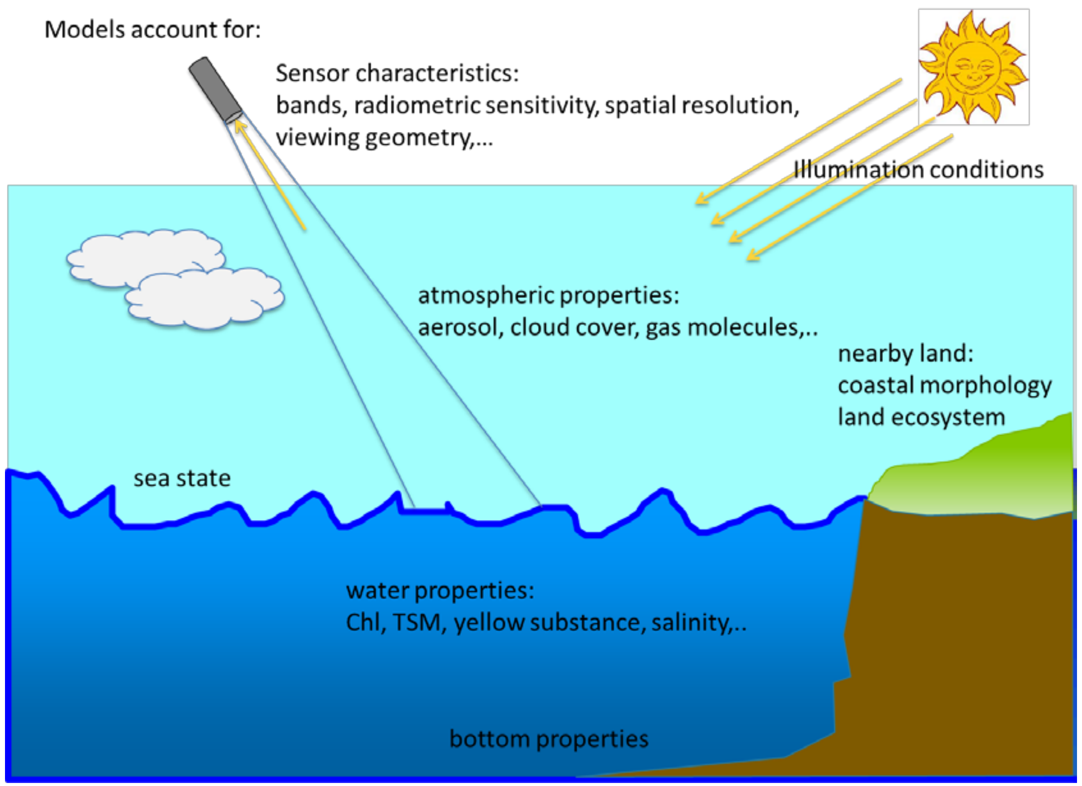
M. Talone and G. Zibordi, 2019. *Spectral assessment of deployment platform perturbations in above-water radiometry. Optics Express, 27*(12), A878-A889.

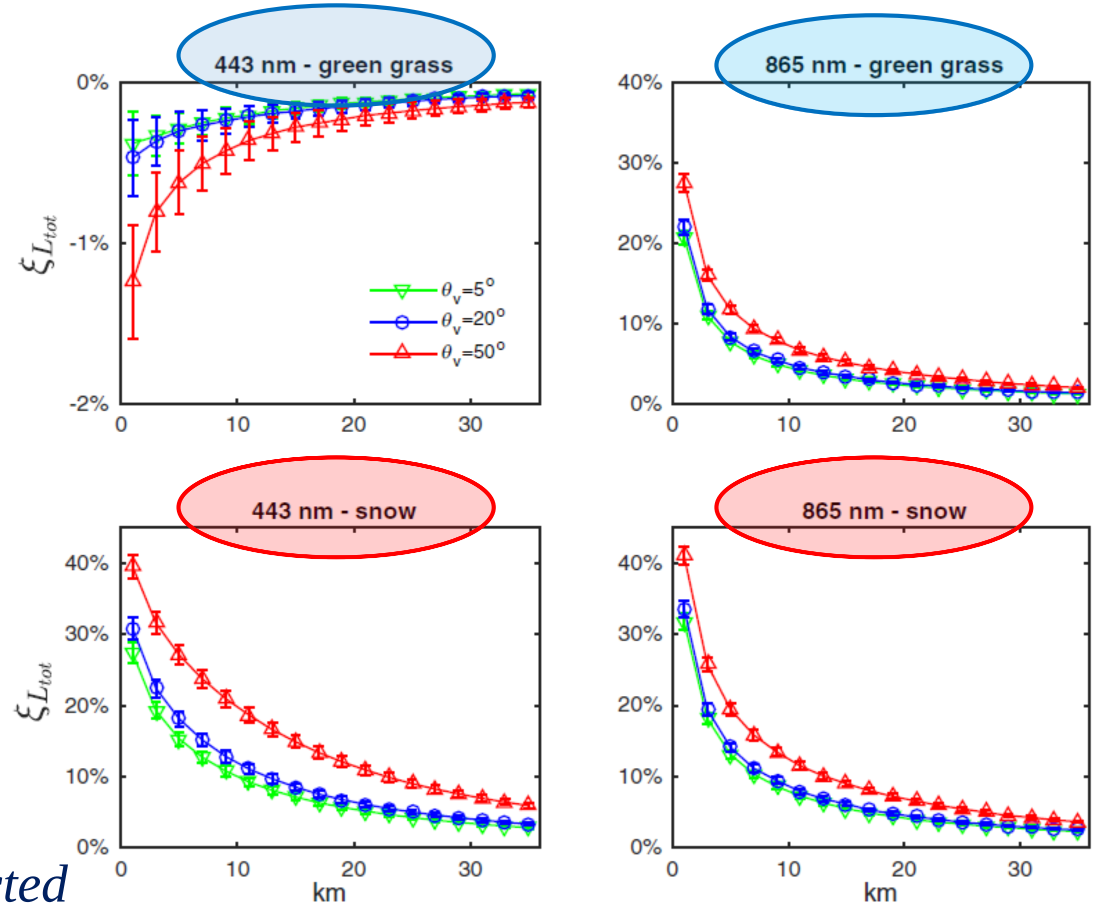
Joint Research Centre

Avoiding adjacency perturbations

(when possible)

How much distant from the coast should we collect data?





In situ reference measurements should be ideally collected at tens of nautical miles from the coast to ensure match-ups analysis not significantly affected by adjacency perturbations.

Adjacency perturbations at the satellite sensor as a function of the distance from the coast.

B. Bulgarelli, V. Kiselev, G.Zibordi (2017). Adjacency effects in satellite radiometric Products from coastal waters: a theoretical analysis for the northern Adriatic Sea. Applied Optics, 56 (4), 854–869.

B. Bulgarelli, G. Zibordi (2018). On the detectability of adjacency effects in ocean color remote sensing of mid-latitude coastal environments by SeaWiFS, MODIS-A, MERIS, OLCI, OLI and MSI. Remote sensing of Environment, 209, 423-438.

How can we ensure best confidence to in situ reference data?

Quality Assurance and Control

often, wisely and purposely collected data carry such clear message that they essentially "analyze themselves" (Vardemann and Jobe 2016)


NPL
… but it often requires the implementation of ad-hoc methods

AERONET-OC Quality Control:
an example

AERONET-OC products are classified at different QC levels:

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

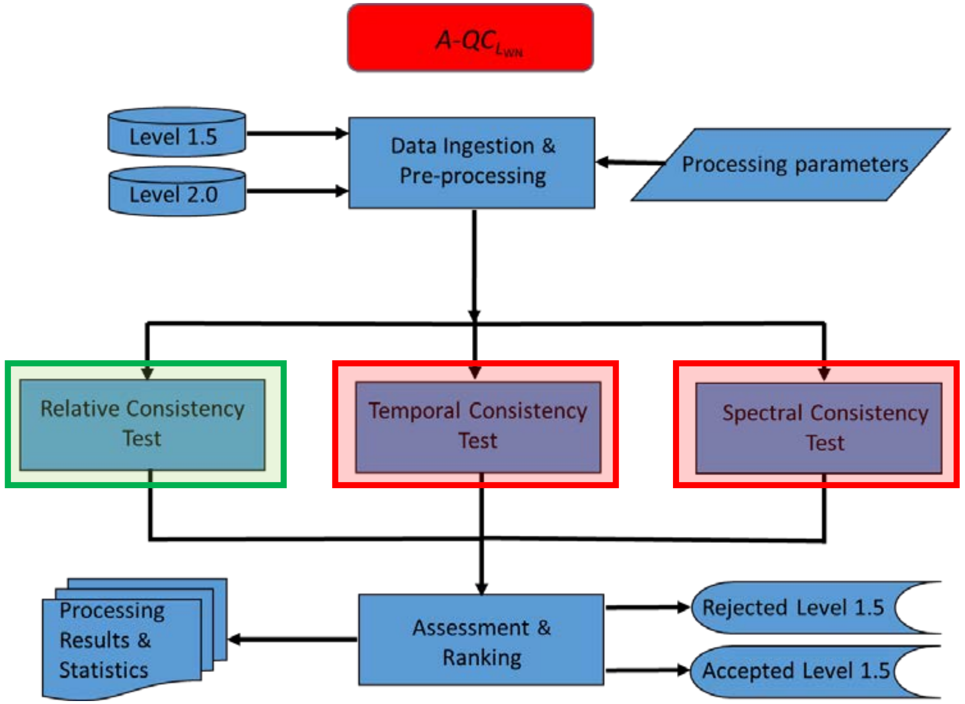
Level 1.5->
- Cloud screened aerosol optical thickness data exist;
- Replicate sky and sea radiance measurements exhibit low variance;
- Empirical thresholds are satisfied (e.g., exceedingly negative or positive values).

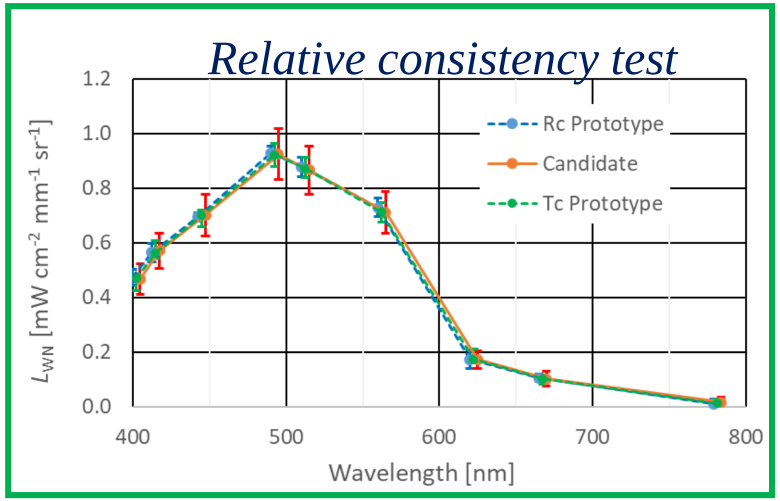
Level 2.0->
- Pre- and post-deployment calibration coefficients exhibit justifiable differences within 5%;
- A final expert-based spectrum-by-spectrum screening is (was) passed to determine the:
  - i. consistency of $L_{WN}(\lambda)$ spectral shapes within the data set itself (self-consistency),
  - ii. non-anomalous features with respect to reference data (relative- consistency),
  - iii. the absence of short-term glitches or systematic daily trends.

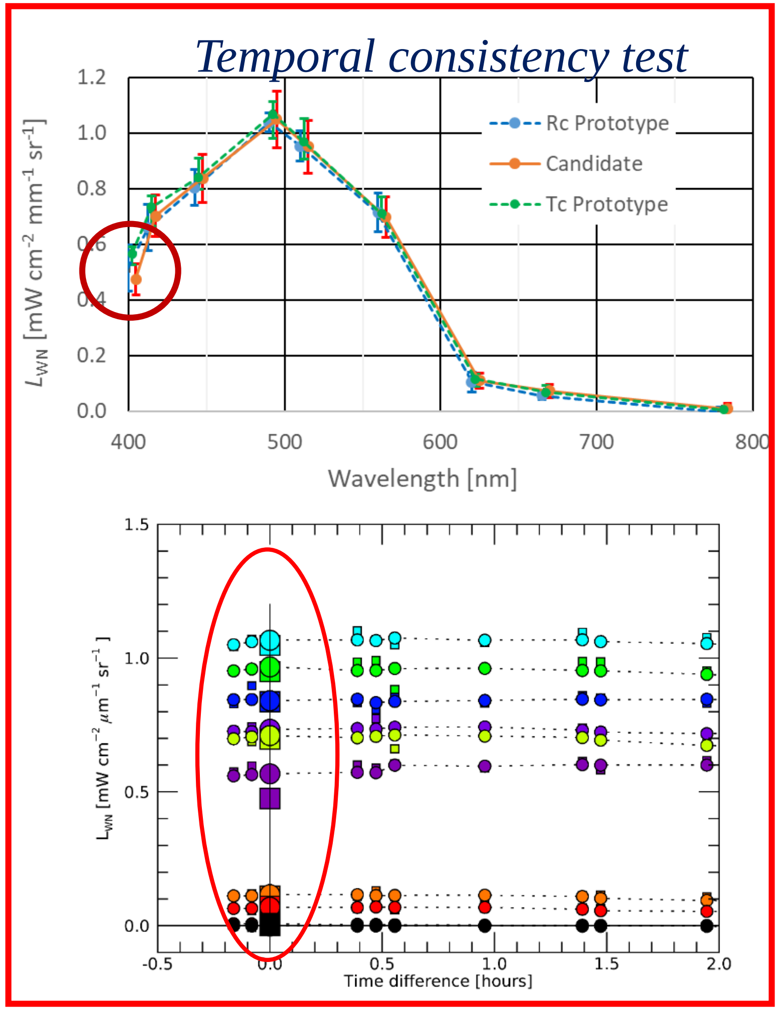
Moving from an expert-based to a fully automated QC?

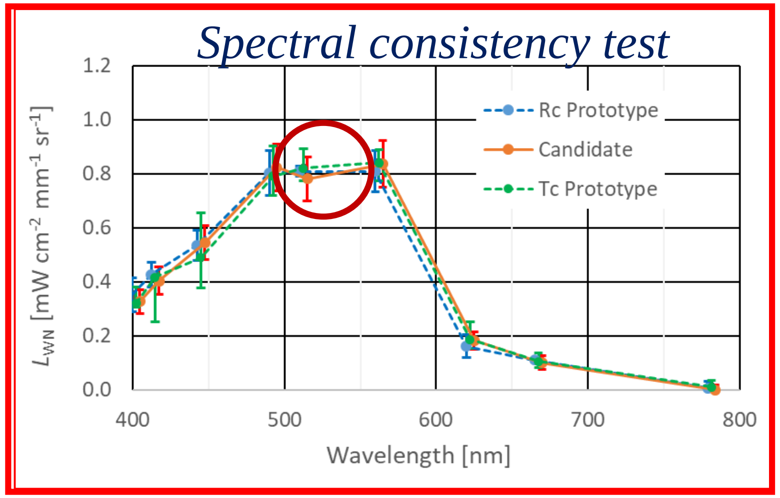
G.Zibordi, B.Holben, I.Slutsker, D.Giles, D.D'Alimonte, F.Mélin, J.-F. Berthon, D. Vandemark, H.Feng, G.Schuster, B.Fabbri, S.Kaitala, J.Seppälä. AERONET-OC: a network for the validation of Ocean Color primary radiometric products. Journal of Atmospheric and Oceanic Technology, 26, 1634-1651, 2009.

Automated QC of AERONET-OC L_{WN}







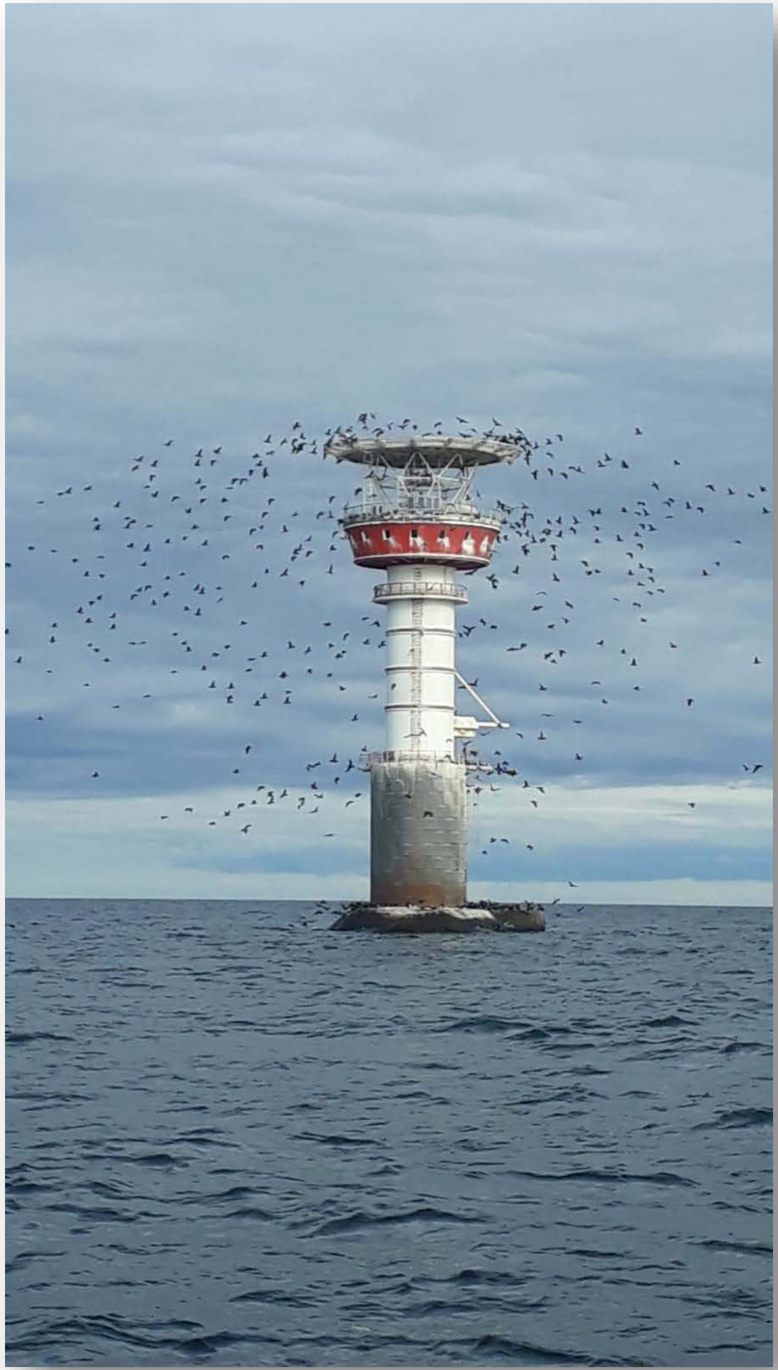


Automated QC checking "Candidate" (actual) versus "Prototype" (reference) L_{WN} spectra

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 (2022). Automated Quality Control of AERONET-OC L_{WN} data. Journal of Atmospheric and Oceanic Technology, (in press).

Are uncertainties always appreciated?



Uncertainties

"A measurement of any kind is incomplete unless accompanied with an estimate of the uncertainty associated with that measurement" (J.M. Palmer and B.G. Grant, 2009)

Uncertainties following GUM

Given the measurement equation

$$L_{\mathrm{WN}} = (L_{\mathrm{T}} - \rho\, L_{\mathrm{i}})\, C_A\, C_Q$$

where the term C_A removes the basic dependence on sun zenith, atmosphere and sun-earth distance, and the term C_Q removes the dependence from bidirectional effects (naturally including the viewing geometry).

Neglecting correlations among input quantities and non-linearity of the measurement model, the application of the Guide to the Expression of Uncertainty in Measurement (GUM) leads to

$$\tilde{u}_c^2(L_{\mathrm{WN}}) = (C_Q C_A)^2\, \tilde{u}_c^2(L_{\mathrm{W}}) + (L_{\mathrm{W}} C_A)^2\, u^2(C_Q) + (L_{\mathrm{W}} C_Q)^2\, u^2(C_A)$$

with

$$\tilde{u}_c^2(L_{\mathrm{W}}) = u^2(L_{\mathrm{T}}) + L_{\mathrm{i}}^2\, u^2(\rho) + \rho^2 u^2(L_{\mathrm{i}})\,.$$

What values to expect for $\tilde{u}_c\,(L_{\mathrm{WN}})$ and $\tilde{u}_c\,(L_{\mathrm{WN}})/L_{\mathrm{WN}}$?

M. Gergely and G. Zibordi, "Assessment of AERONET L_{WN} uncertainties," Metrologia ***51****, 40–47 (2014).*

I. Cazzaniga and G. Zibordi, "Assessment of AERONET L_{WN} uncertainties: Revisited," Journal of Atmospheric and Oceanic Technology (submitted and revised, 2022).

Joint Research Centre

Uncertainties in AERONET-OC L_{WN}

λ	412	551	667
AAOT	5.3 [0.038; 0.71]	4.9 [0.049; 1.00]	7.3 [0.010; 0.13]
GLR	8.6 [0.027; 0.31]	5.6 [0.038; 0.67]	9.6 [0.011; 0.11]
AABP	11.1 [0.050; 0.44]	6.8 [0.033; 0.47]	9.5 [0.009; 0.08]
GDLT	16.3 [0.018; 0.11]	5.7 [0.027; 0.47]	6.4 [0.007; 0.10]
HLT	27.4 [0.016; 0.06]	6.7 [0.026; 0.39]	6.9 [0.008; 0.12]

$\tilde{u}_c\,(L_{\mathrm{WN}})/L_{\mathrm{WN}}$ [%]

$\tilde{u}_c\,(L_{\mathrm{WN}})$ [mW ...]

L_{WN} [mW ...]

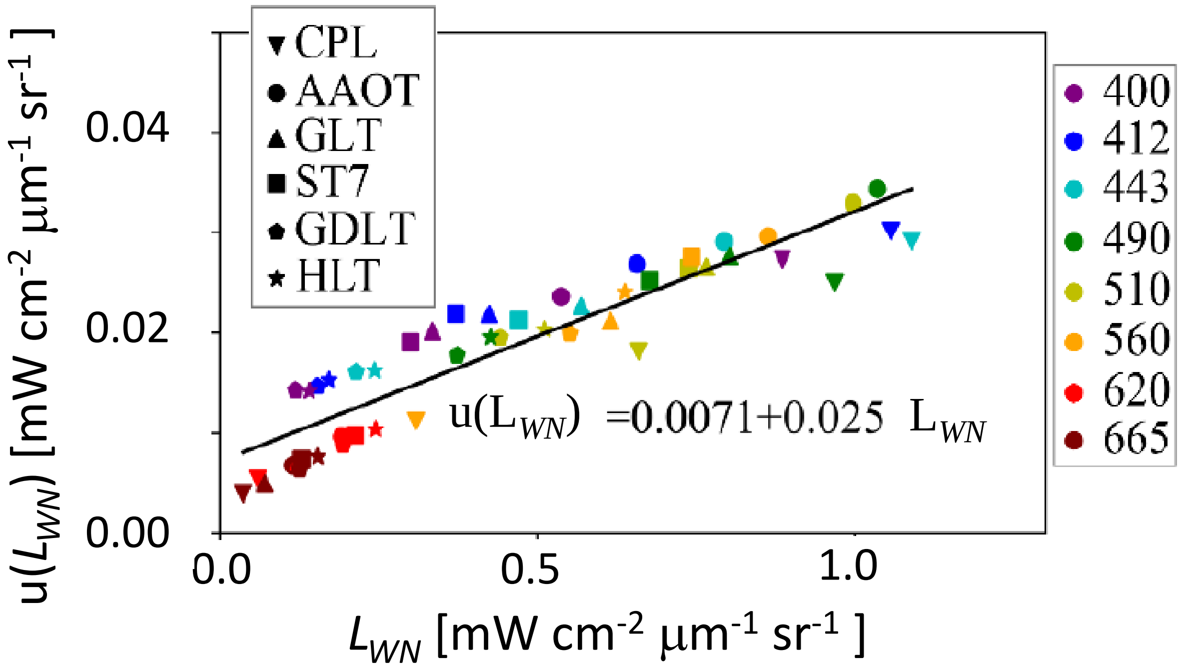
Relative spectral combined uncertainties $\tilde{u}_c$ (L_{WN})/L_{WN} (%) and, in brackets, combined standard uncertainties $\tilde{u}_c$ (L_{WN}) and median L_{WN} (mW cm^{-2} sr^{-1} µm^{-1}), respectively, for various AERONET-OC sites.

The generic 5% uncertainty requirement does not reflect actual requirements/capabilities when considering non-oceanic waters.

M. Gergely and G. Zibordi, "Assessment of AERONET L_{WN} uncertainties," Metrologia ***51****, 40–47 (2014).*

Parameterization of AERONET-OC L_{WN} uncertainties

While considering the need to compute uncertainties for individual measurements, is there any way to statistically estimate uncertainties for AERONET-OC L_{WN} ?



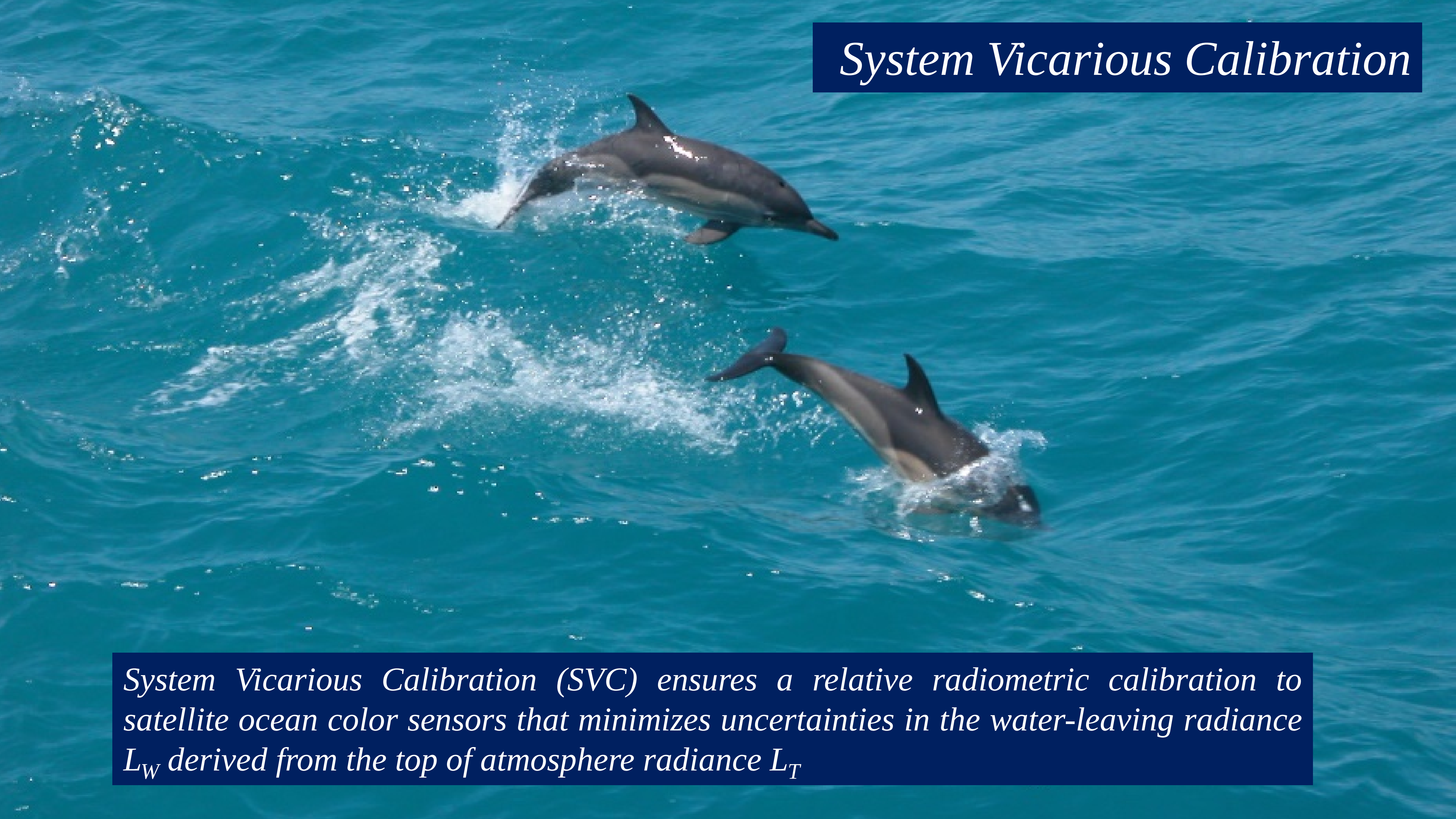
Scatterplots of median L_{WN} values versus corresponding absolute uncertainties $u(L_{WN})$ for data restricted to cases characterized by $W < 3\ ms^{-1}$.

I. Cazzaniga and G. Zibordi, "Assessment of AERONET L_{WN} uncertainties: Revisited," Journal of Atmospheric and Oceanic Technology (submitted and revised, 2022).

Are SVC requirements for the creation of ocean color CDR definitively shared by the community?

What about general requirements for in situ reference data, spectral resolution and sites location?

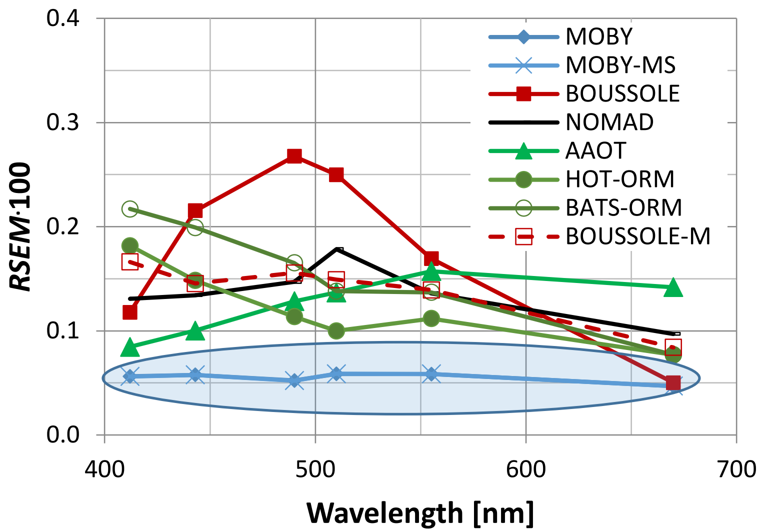
System Vicarious Calibration



System Vicarious Calibration (SVC) ensures a relative radiometric calibration to satellite ocean color sensors that minimizes uncertainties in the water-leaving radiance L_W derived from the top of atmosphere radiance L_T

Basic requirements

Is there any basic recommendation for in situ reference data supporting SVC?



Relative standard error of the mean (RSEM) of g-factors g determined from $RSEM = (\sigma_g/g)/\sqrt{N_y}$, with σ_g standard deviation of g assumed invariant with time and N_y the scaled number of match-ups per decade.

The higher RSEM values are likely explained by:

i. *measurement perturbations due environmental changes, and;*
ii. *temporal change of the in situ measurement system or by the adoption of different measurement methods.*

Overall, ***the creation of ocean colour CDRs should ideally*** *rely on:*

- ***One main long-term in situ calibration system (site and radiometry)*** *established and sustained with the objective to maximize accuracy and precision over time of g-factors and thus minimize biases among satellite data products from different missions;*

- *and* ***unique (i.e., standardized) atmospheric models and algorithms for the atmospheric correction*** *to maximize cross-mission consistency of data products at locations different from that supporting SVC.*

G.Zibordi, F. Mélin, K.J. Voss, B.C. Johnson, B.A. Franz, E. Kwiatkowska, J.P. Huot, M. Wang, D. Antoine. System Vicarious Calibration for Ocean Color Climate Change Applications: Requirements for In Situ Data. Remote Sensing of Environment, 159, 361–69, 2015.

Joint Research Centre | UNIVERSITY OF MIAMI | NIST National Institute of Standards and Technology

SVC spectral resolution & sites requirements

Remote Sensing of Environment 190 (2017) 122–136

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

An evaluation of marine regions relevant for ocean color system vicarious calibration

Giuseppe Zibordi *, Frédéric Mélin

European Commission, Joint Research Centre, Ispra, Italy

Research Article

Vol. 25, No. 16 | 7 Aug 2017 | OPTICS EXPRESS A798

Optics EXPRESS

Impact of spectral resolution of *in situ* ocean color radiometric data in satellite matchups analyses

GIUSEPPE ZIBORDI,[1,*] MARCO TALONE,[1] KENNETH J. VOSS,[2] AND B. CAROL JOHNSON[3]

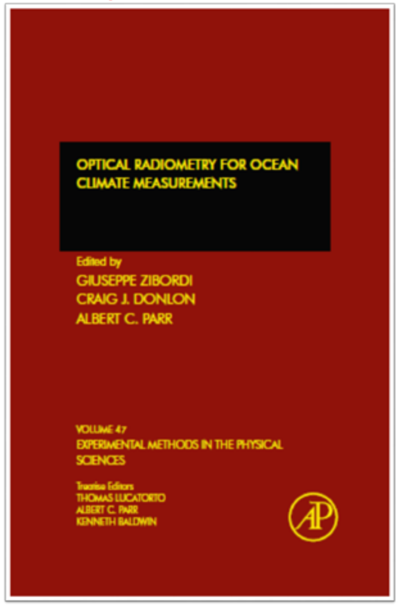
[1] *European Commission, Joint Research Centre, 21027 Ispra, Italy*

[2] *University of Miami, Coral Gables, Florida 33124, USA*

[3] *Sensor Science Division, National Institute of Standards and Technology, Gaithersburg, MD, USA*

[*] *giuseppe.zibordi@ec.europa.eu*

Concluding: The way forward for ocean color Cal/Val
(just restating what already indicated and definitively obvious)



- *Lessons learnt indicate **the need for at least one long-term reference site providing in situ optical radiometry data** of exceptional quality for system vicarious calibration across successive missions.*
- *The assessment of satellite data products and the development of bio-optical algorithms should be supported by **geographically distributed radiometric measurements from regions representative of the world seas**. In all cases, data quality should be assured through **the application of state of the art measurement protocols, fully characterized and well-calibrated field radiometers, and finally validated processing schemes** (ideally benefitting of measurement networks).*
- ***Data, complemented by uncertainty values,** should be **stored in dedicated and accessible repositories.***
- ***Inter-comparisons of extended field methods, instruments, and data reduction schemes** are the way to secure accuracy.*
- ***Standardization of measurements and data reduction**, is an invaluable component of the overall strategy to assure high consistency to field data regardless of source and region.*
- *The development of new methods and instruments need high consideration. However, **the use of newly developed methods or instruments in operational programs needs to be carefully done** to avoid introducing significant discontinuities or inconsistencies in time series or in globally distributed data.*
- *Finally, it is important to highlight that **international collaboration** on each element of the proposed strategies is essential both in benefiting from transnational experience and optimizing the use of resources.*

G. Zibordi and K.J.Voss, Requirements and Strategies for In Situ radiometry in Support of Satellite Ocean Color. In Optical Radiometry for Oceans Climate Measurements, Experimental Methods in the Physical Sciences volume 47, G. Zibordi, C.Donlon and A. Parr Ed.s, Elsevier - Academic Press, Amsterdam (December 2014).

It was an honor collaborating with many of you.

Thank you & Goodbye

giuseppe.zibordi@eoscience.eu


… are there any questions ?