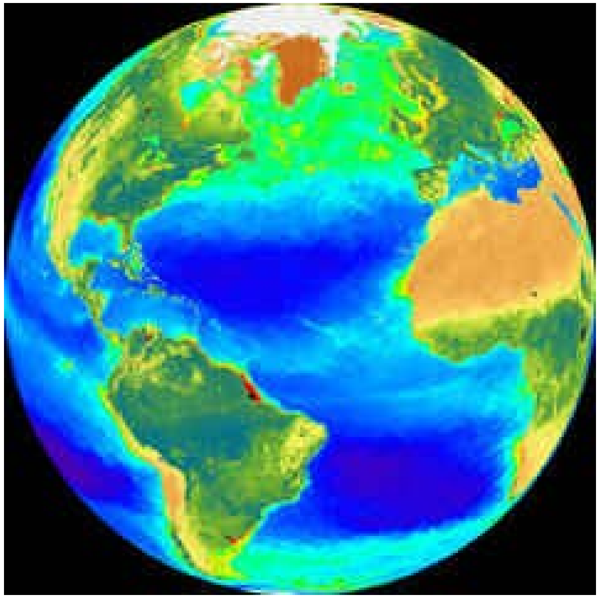
JRC Activities in Support of Satellite Ocean Color Cal/Val



Ocean Color Team

of the

Water Resources Unit

Institute for Environment and Sustainability

Prepared by *Giuseppe Zibordi* (May 2015)

Preface

… adequately sampled, carefully calibrated, quality controlled, and archived data for key elements of the climate system will be useful indefinitely.

C. Wunsch, R. W. Schmitt, and D. J. Baker (2013). ***Climate change as an intergenerational problem. Proceedings of the National Academy of Sciences of the United States of America****, 110, 4435-4436.*

Field Measurement Programs

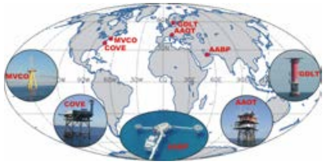
Joint Research Centre

Ongoing JRC Ocean Color Field Programs

CoASTS: Coastal Atmosphere and Sea Time Series (1995-present)
(time-series data for regional OC applications)

BiOMaP: Bio-Optical Marine Properties (2000-present)
(spatially distributed data for continental OC applications)

AERONET-OC: AERONET- Ocean Color (2002-present)
(spatially distributed time-series data for global OC applications)



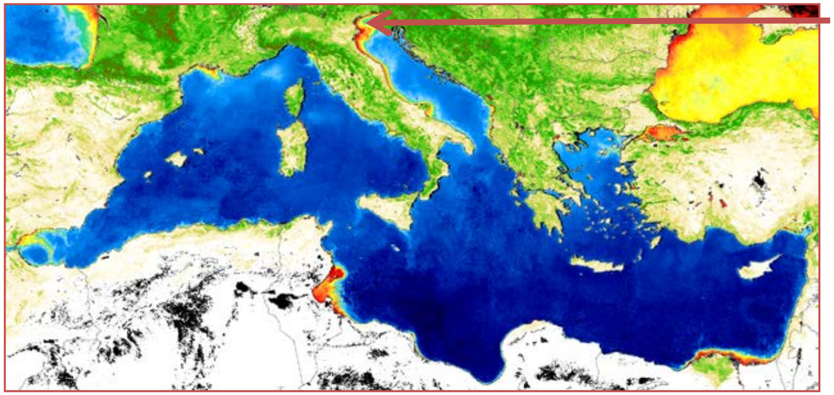
AERONET-OC

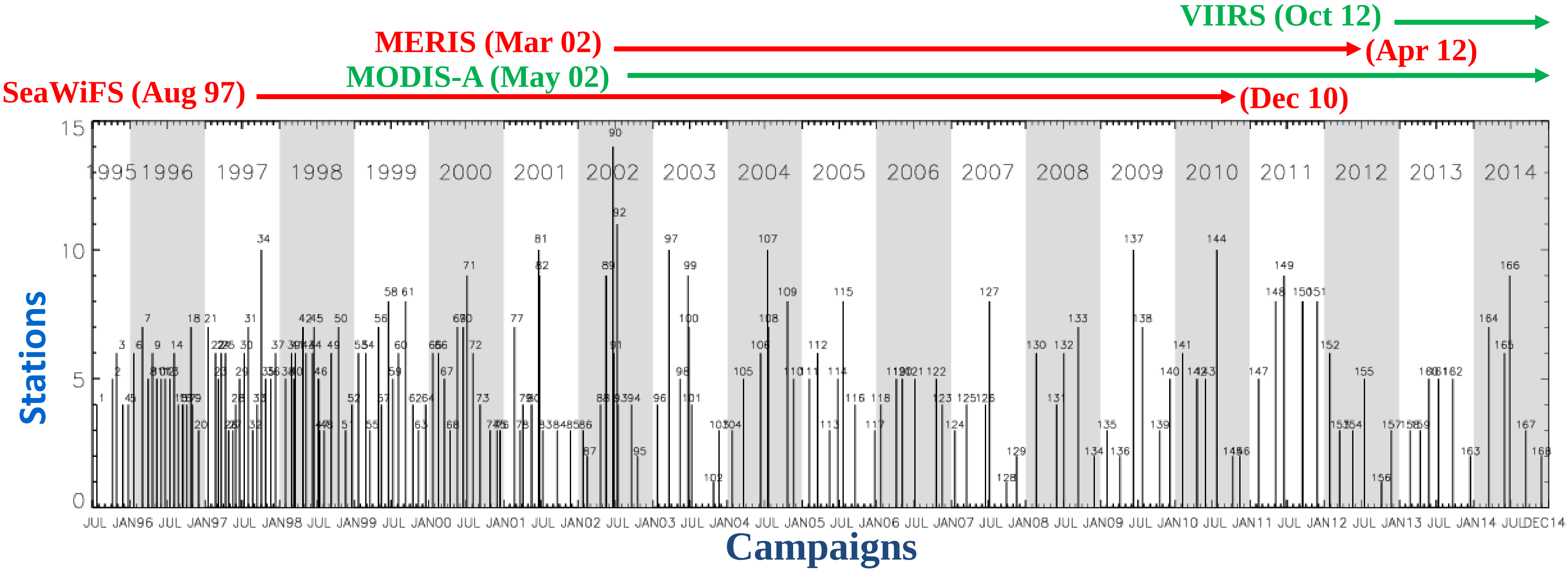
Primary objective of these JRC field programs is to support ocean color standardization and validation activities in view of the generation of **highly accurate satellite ocean color data products** for **Climate Data Records** applicable at regional, continental and global scale.

Joint Research Centre

CoASTS

Time-series of AOPs and IOPs measurements performed applying identical and consolidated: technology, measurement and calibration protocols, processing codes and quality assurance criteria.



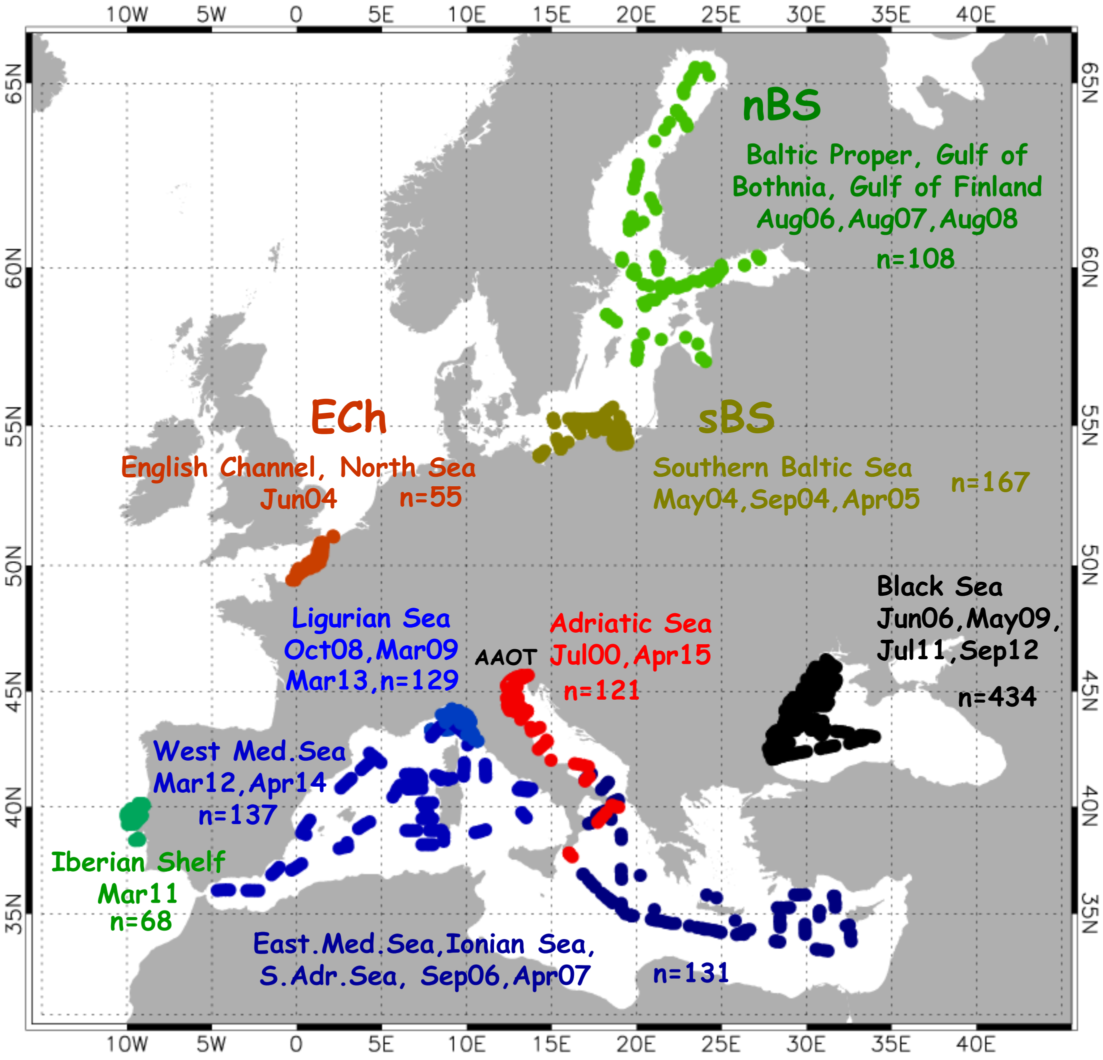


G.Zibordi, J.F.Berthon, J.P.Doyle, S.Grossi, D. van der Linde, C.Targa, L.Alberotanza. Coastal Atmosphere and Sea Time Series (CoASTS), Part 1: A long-term measurement program. NASA Tech. Memo. 2002-206892, v. 19, S.B.Hooker and E.R.Firestone, Eds., NASA Goddard Space Flight Center, Greenbelt, Maryland, 2002, 29 pp.

Joint Research Centre

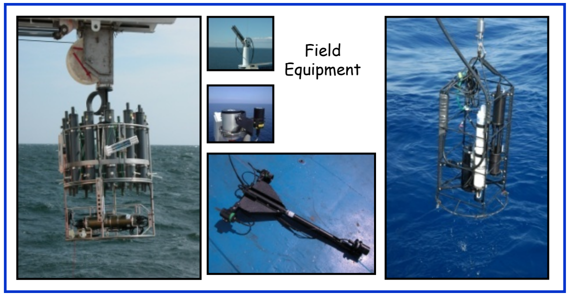
BiOMaP

Geographically distributed measurements of AOP and IOP produced applying cross-site identical and consolidated: technology, measurement and calibration protocols, processing codes and quality assurance criteria.



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.

CoASTS and BiOMaP measurements



Field measurements

- Profiles of $L_u(z, \lambda)$, $E_u(z, \lambda)$, and $E_d(z, \lambda)$
- Profiles of $c(z, \lambda)$ and $a(z, \lambda)$ *(from 01/97)*
- Profiles of $b_b(z, \lambda)$ *(from 04/00)*

Profiles
(manned)

- $E_d(0^+,\lambda)$ and $E_i(0^+,\lambda)$
- $E_s(0^+,\lambda)$
- Ancillary $(T_w(z), S_W(z), P_a, RH, T_a, W_s, W_d, C, M)$

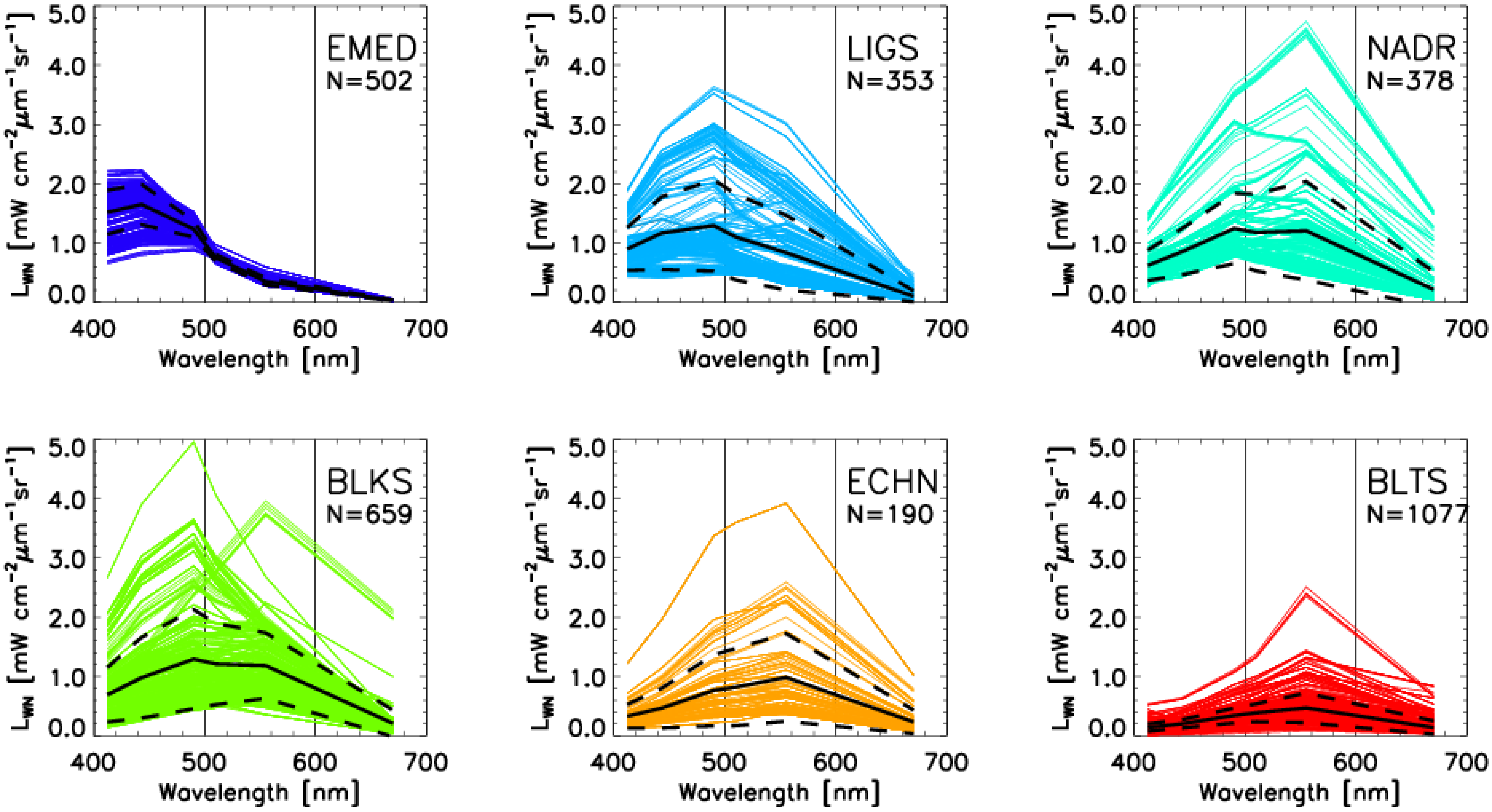
Related laboratory analysis from field water samples

- *Pigments (HPLC)*
- $a_{ph}(\lambda)$ and $a_{dp}(\lambda)$
- $a_{ys}(\lambda)$
- *TSM*

Samples
(conditioned)

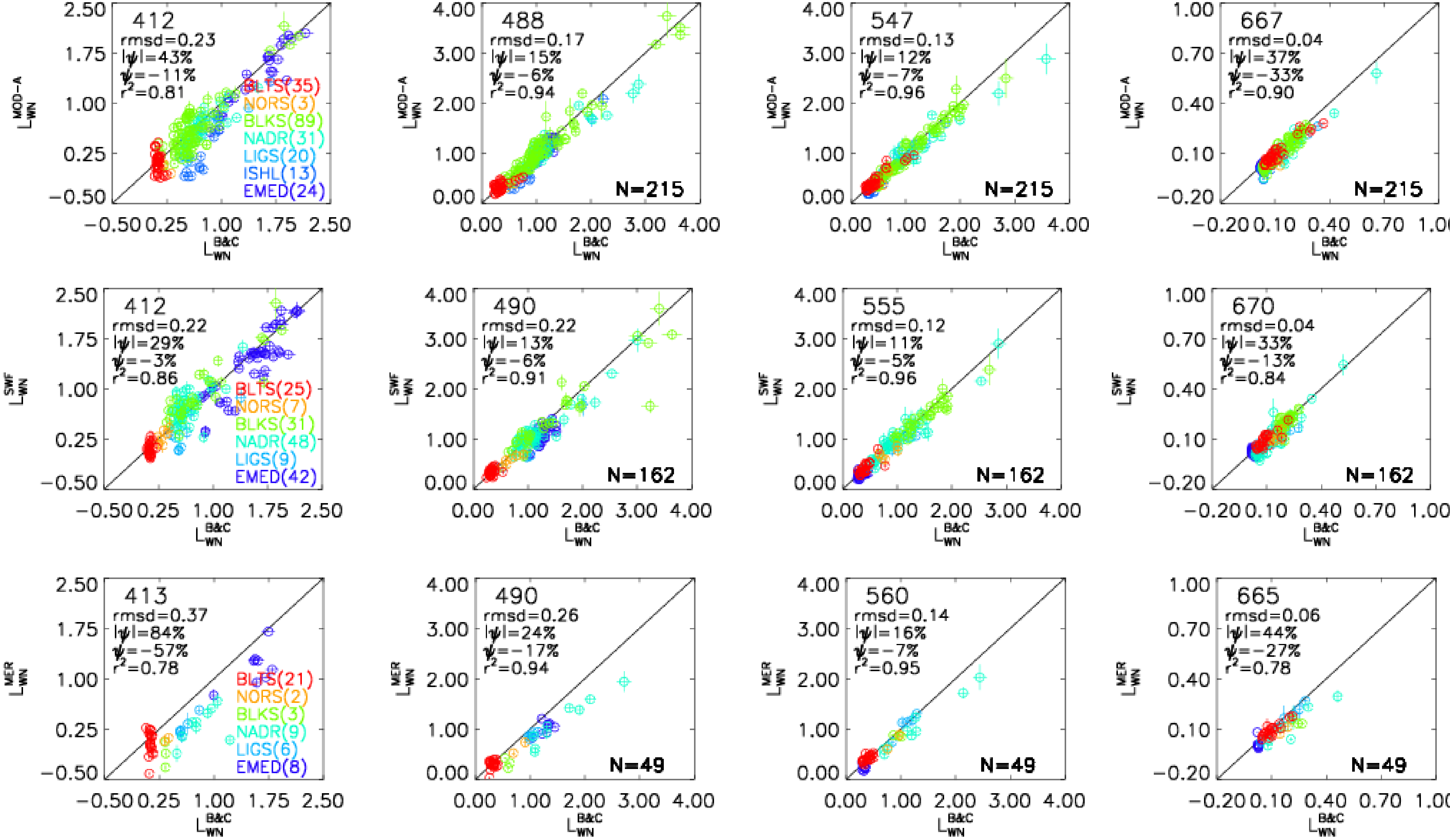
Joint Research Centre

BiOMaP (Bio-Optical Marine Properties): L_{WN} spectra from the various European Seas



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.

Cross-mission assessment of L_{WN}



G.Zibordi et al. An Assessment of MERIS Ocean Color Products for European Seas. Ocean Science Discussion, 2012.

AERONET-OC sites

AERONET-OC generates globally distributed highly consistent time-series of standardized $L_{WN}(\lambda)$ and τ_a measurements.

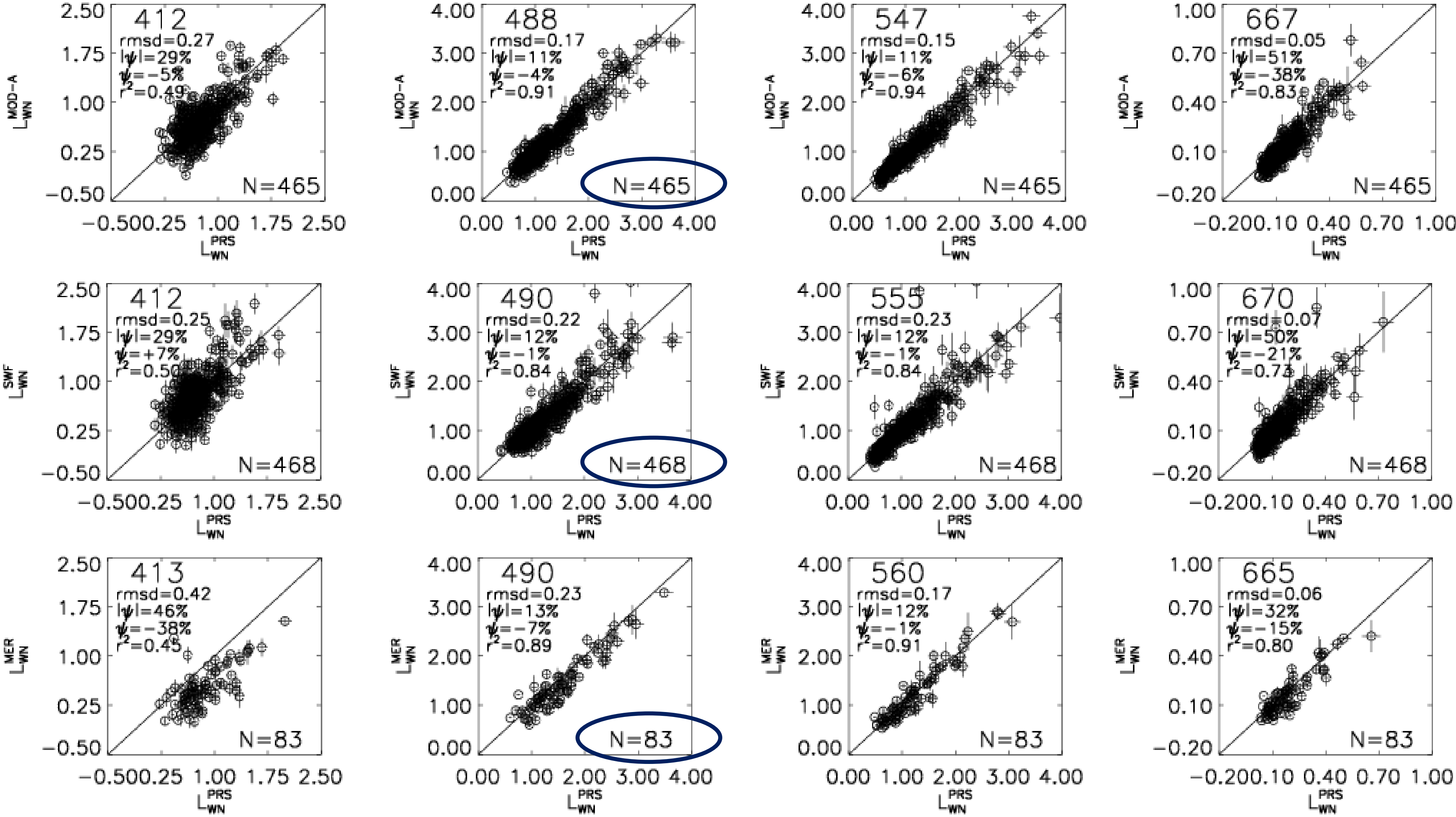
🟥 Current sites 🔴 Planned sites 🟡 Potential sites

- **NASA** manages the network infrastructure (i.e., handles the instruments calibration and, data collection, processing and distribution within AERONET).
- **JRC** has the scientific responsibility of the processing algorithms and performs the quality assurance of data products (in addition to the management of 5 out of 15 sites).
- **PIs** establish and maintain individual AERONET-OC sites.

G.Zibordi et al. A Network for Standardized Ocean Color Validation Measurements. Eos Transactions, 87: 293, 297, 2006.

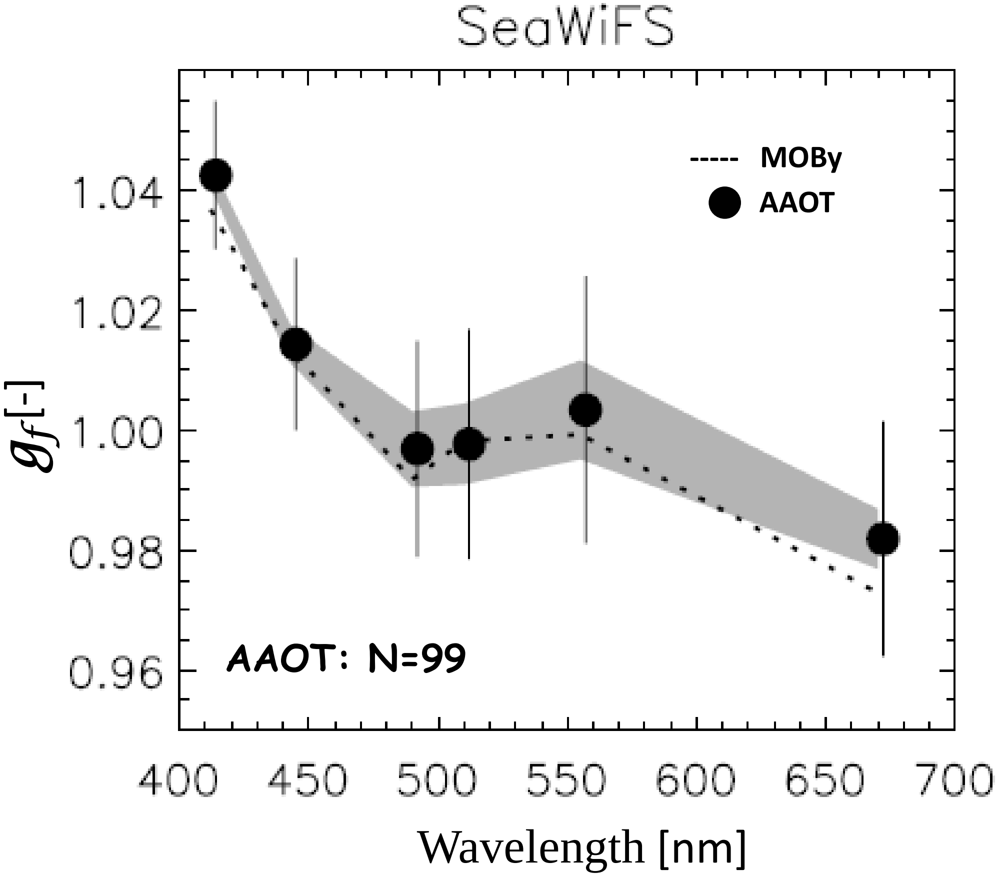
Cross-Mission Validation of L_{WN}

Matchups with +/-1 hr Δt for the period April 2002 till November 2012



G.Zibordi et al. An Assessment of MERIS Ocean Color Products for European Seas. Ocean Science, 9, 521-533, 2013.

Vicarious Calibration (SeaWiFS)



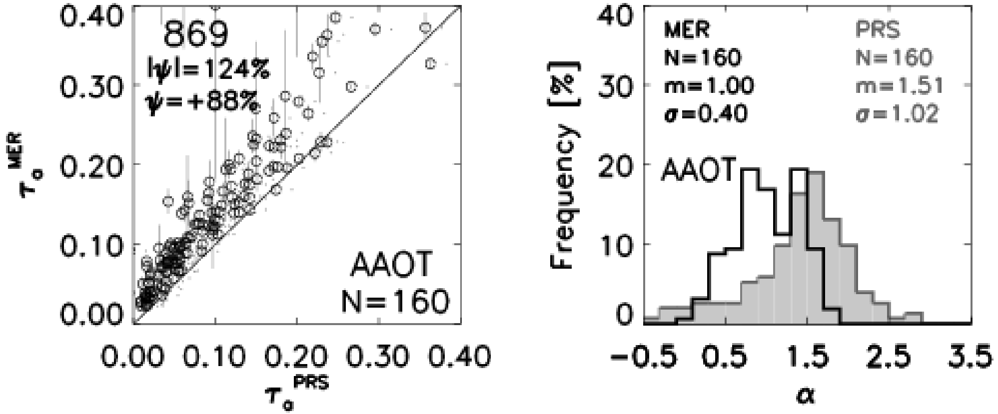
$$g_f(\lambda) = \frac{L_{ToA}^{COMP}[L_{WN}(\lambda)]}{L_{ToA}^{SAT}(\lambda)}$$

Principles

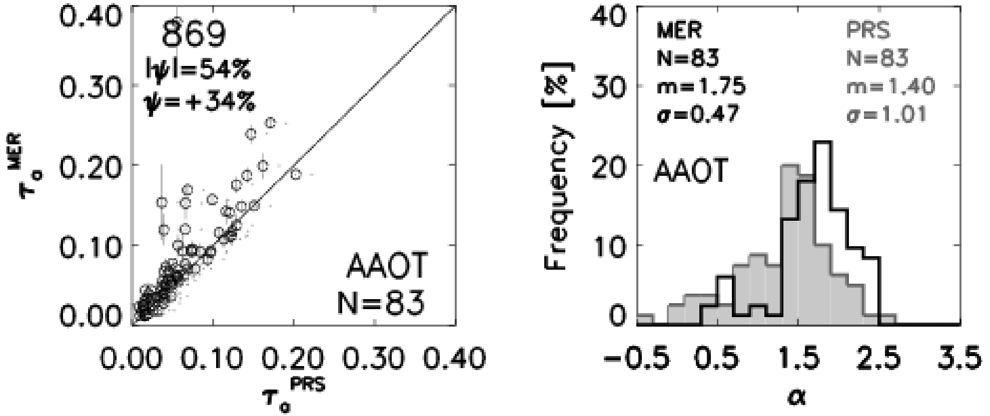
The correction factors g_f are determined by applying the methodology established by Bailey et al. 2008.

F.Mélin and G.Zibordi (2010). Vicarious calibration of ocean color data using coastal sites. *Appl.Opt.*, 49:798-810.

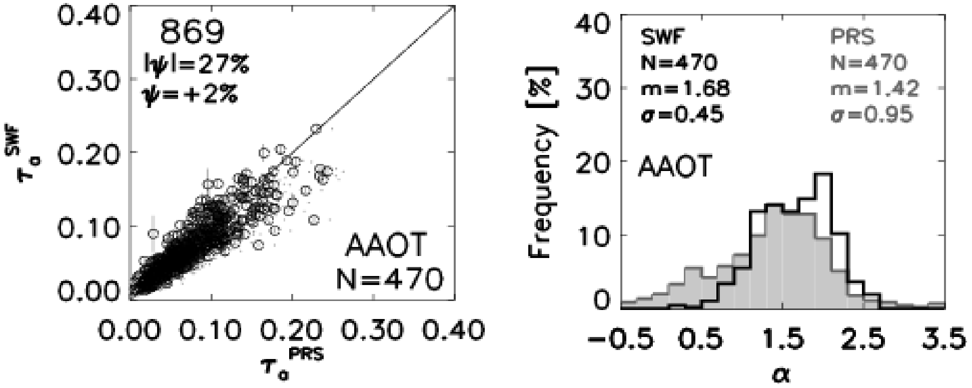
Assessment of aerosol products



MERIS
MEGS-7



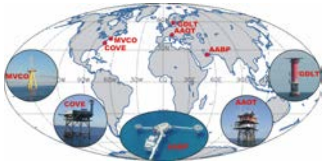
MERIS
MEGS-8



SeaWiFS
SeaDAS 6.2

G.Zibordi et al. An Assessment of MERIS Ocean Color Products for European Seas. Ocean Science Discussion, 2012.

Match-up Performance Matrix



INDICES (0-10) (0=lowest and 10 =highest)	AERONET-OC (AAOT)	CoASTS (AAOT)	BiOMaP (ships)
Measured Quantities	2	10	10
Matchups/Deployment-Time	10	10	10
Accuracy	8	8	8
Temporal Representativity	10	2	1
Geographic Representativity	5	4	10
Matchup/Cost	10	0.5	0.2
Overall	**7.5**	**5.9**	**6.5**

The cost per matchup:

Less than 0.5 KƐ

more than 10 KƐ

more than 25 KƐ

Field and Laboratory Methods

Calibration Equation and Laboratory Characterizations

The conversion from relative to physical units of the radiometric quantity $\Im(\lambda)$ (either $E(\lambda)$ or $L(\lambda)$) at wavelength λ is performed through

$$\Im(\lambda) = C_{\Im}(\lambda)\; I_f(\lambda)\; \aleph(\lambda)\; DN(\Im(\lambda))$$

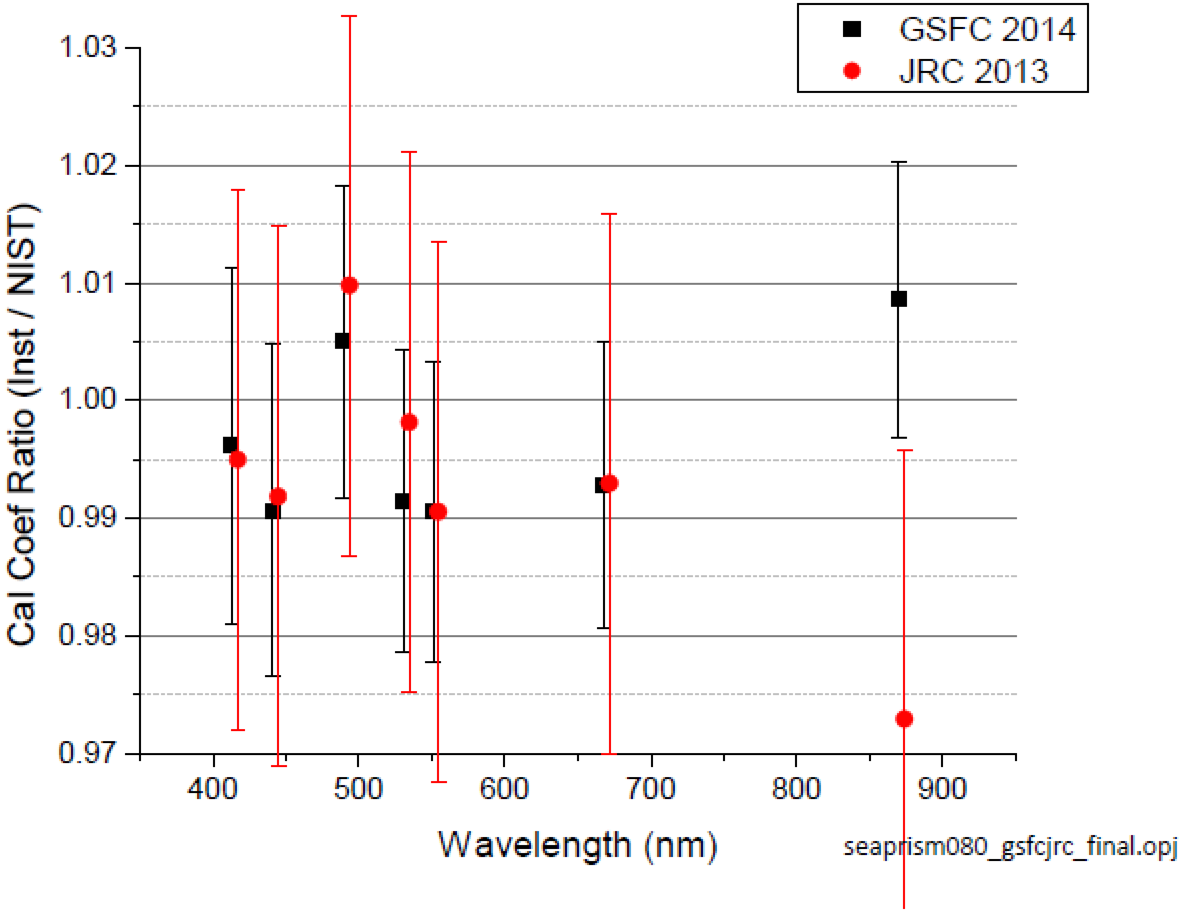
where $DN(\Im(\lambda))$ indicates the digital output corrected for the dark value, $C_{\Im}(\lambda)$ is the in–air absolute calibration coefficient (i.e., the absolute responsivity), $I_f(\lambda)$ is the immersion factor accounting for the change in responsivity of the sensor when immersed in water with respect to air, and $\aleph(\lambda)$ (for simplicity only expressed as a function of λ) corrects for any deviation from the ideal performance of the measuring system.

In the case of an ideal radiometer $\aleph(\lambda)=1$, but in general

$$\aleph(\lambda)= \aleph_i(i(\lambda))\; \aleph_j(j(\lambda))\; \ldots \aleph_k(k(\lambda))$$

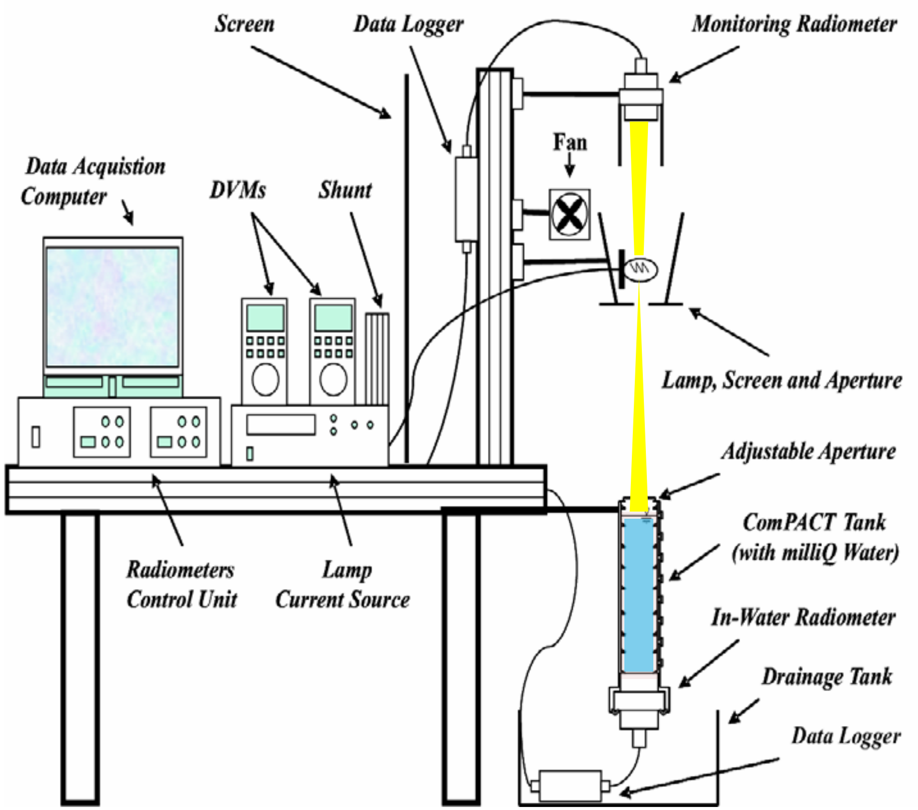
where $\aleph_i(i(\lambda))$, $\aleph_j(j(\lambda))$, …, and $\aleph_k(k(\lambda))$ are correction terms for different factors indexed by i, j, …, k affecting the non-ideal performance of the considered radiometer (e.g., linearity, temperature response, polarization sensitivity, stray-light perturbations, spectral response, geometrical response, …).

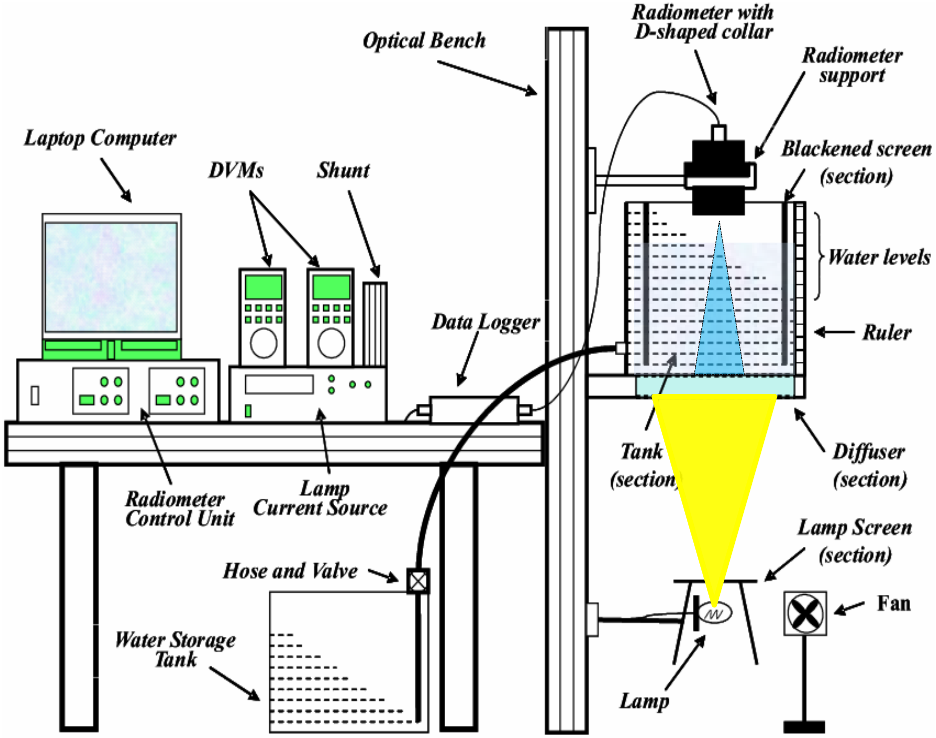
JRC (FEL plus Plaque) and NASA-GSFC (Sphere) vs NIST (CIRCUS) Absolute Radiance Calibration



Courtesy of Carol B. Johnson (NIST)

Measuring the Immersion Factor I_f



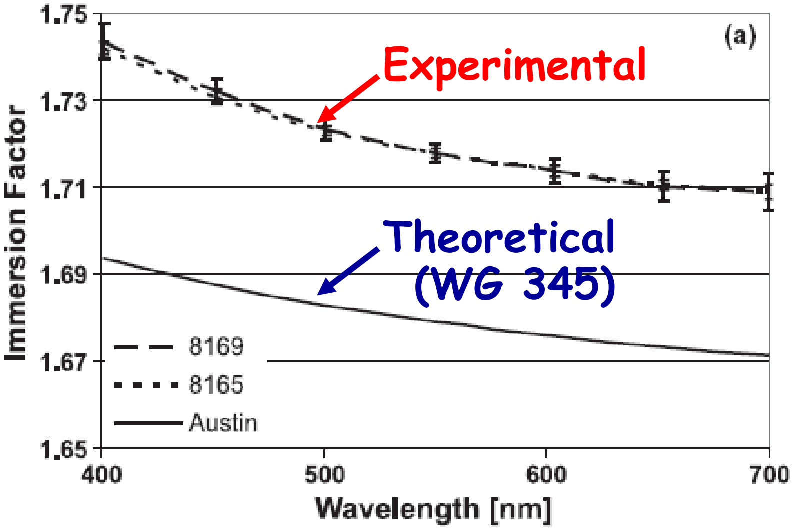


G.Zibordi et al. Characterization of the immersion factor for a series of in–water optical radiometers. *Journal of Atmospheric and Oceanic Technology*, 21:501-514, 2004.

G.Zibordi. Immersion factor of in-water radiance sensors: assessment for a class of radiometers. *Journal of Atmospheric and Oceanic Technology*, 2006.

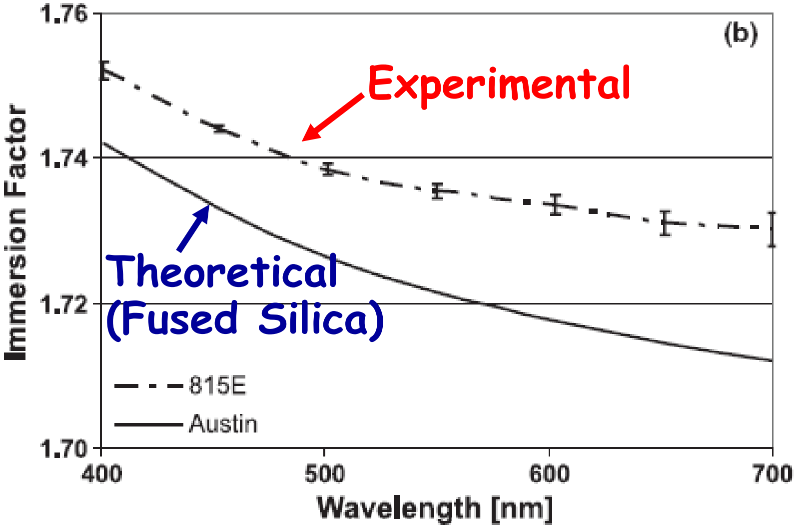
Results from I_f measurements of RAMSES radiometers

Radiance Sensors



Experimental

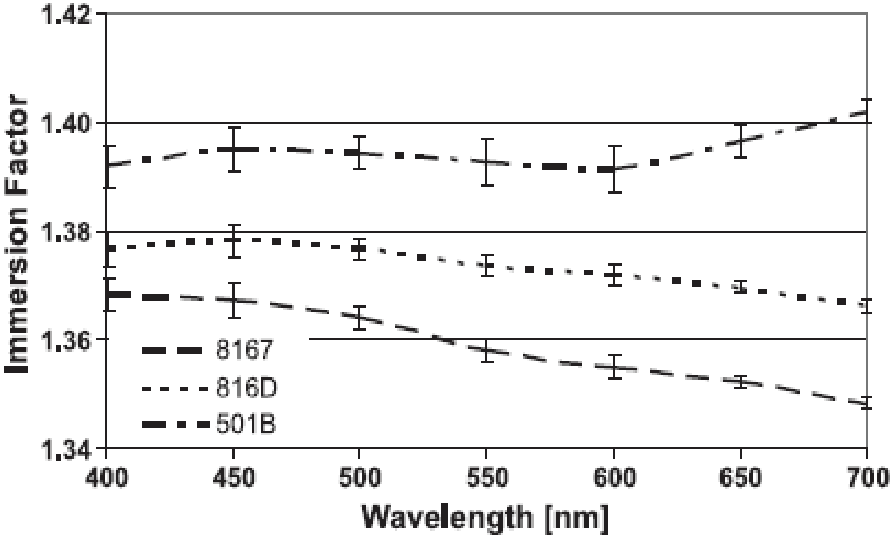
Theoretical (WG 345)



Experimental

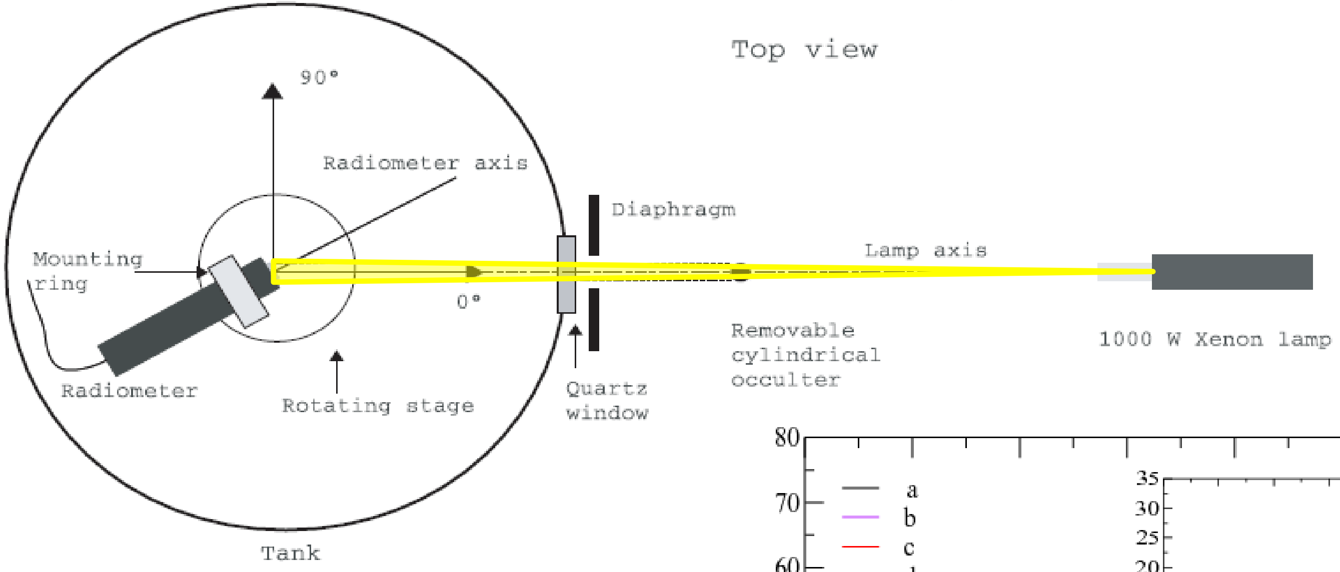
Theoretical (Fused Silica)

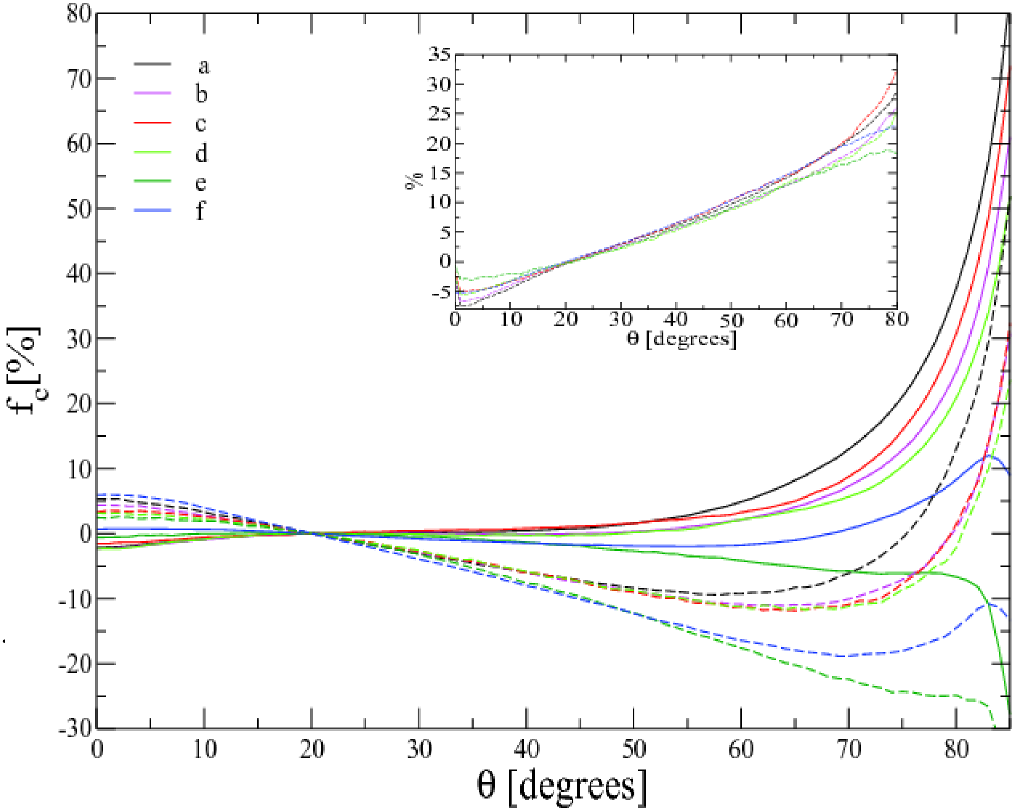
Irradiance Sensors



G.Zibordi and M.Darecki. Immersion factor for the RAMSES series of hyper-spectral underwater radiometers. *Journal of Optics A – Pure and Applied*, 8: 252-258, 2006.

Determination of the Cosine Error



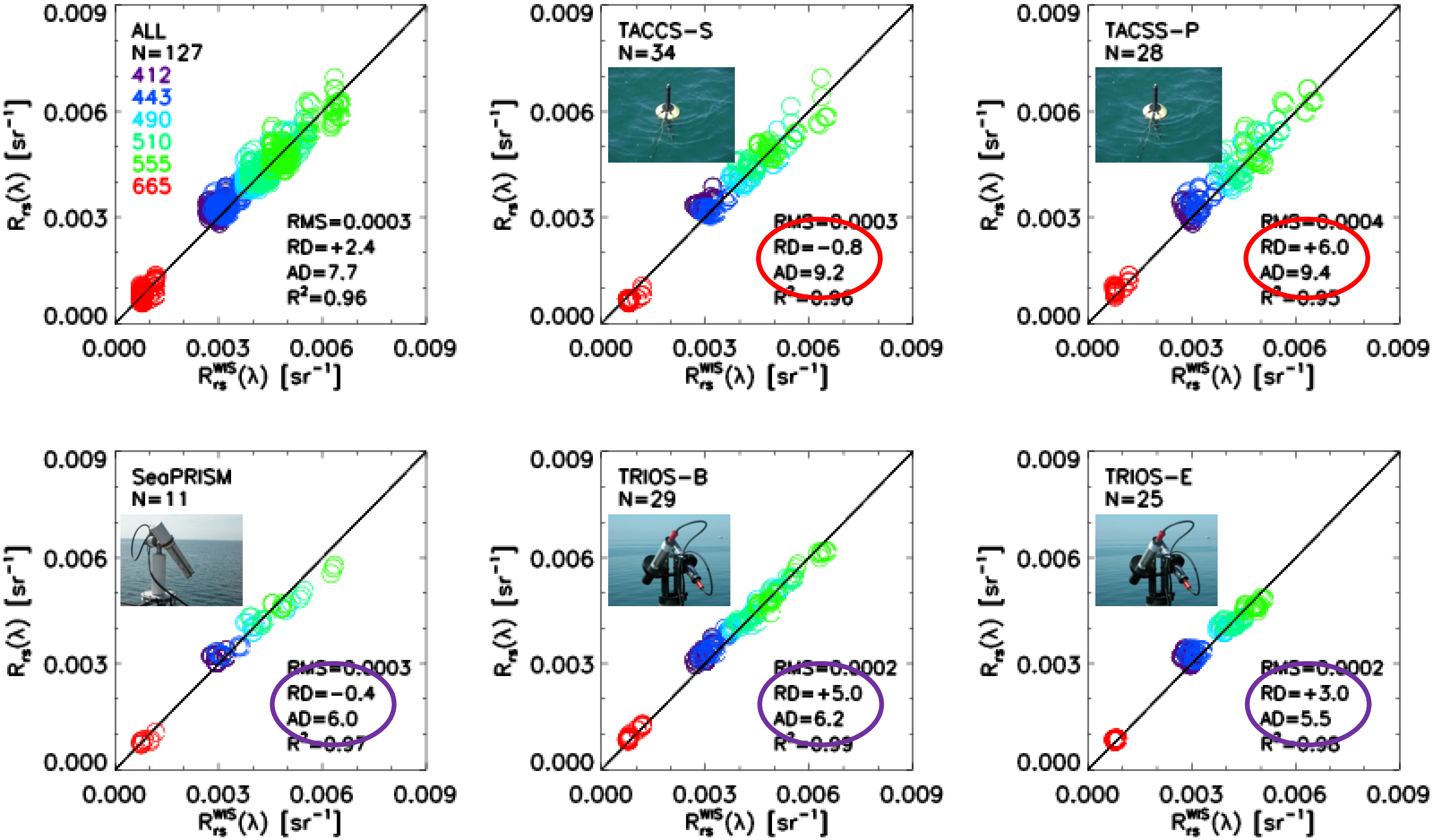


$$f_c(\lambda,\theta,\varphi) = 100\left[\frac{E(\theta,\varphi,\lambda)}{E(0,\varphi,\lambda)cos\theta} - 1\right]$$

S. Mekaoui and G. Zibordi. Cosine error for a class o hyperspectral irradiance sensors. *Metrologia*, 50, 187--199, doi:10.1088/0026-1394/50/3/187, 2013.

Joint Research Centre

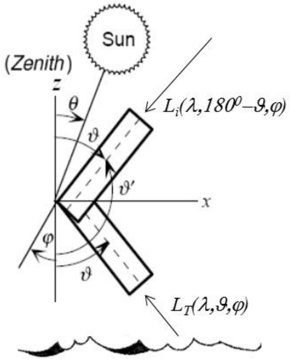
ARC-2010 inter-comparisons



$$L_{wn}(\lambda) = R_{rs}(\lambda)E_0(\lambda)$$

G.Zibordi et al. *In situ* determination of the remote sensing reflectance: an inter-comparison. *Ocean Science* D, 2012.

L_{WN} uncertainties



Considering the measurement equation for L_{WN}

$$L_{WN} = L_W\, C_A\, C_Q \quad \textit{with} \quad L_W = L_T - \rho\, L_i, \quad \textit{i.e.}\ L_{WN} = f(L_W, L_T, L_i, C_A, C_Q, \ldots)$$

where L_T is the total radiance measured above the sea surface, L_i is the sky radiance, ρ is the surface reflectance, C_A removes the basic dependence on sun zenith, atmosphere and sun-earth distance, and C_Q removes the dependence from the viewing geometry and bidirectional effects.

The combined standard uncertainty of the normalized water-leaving radiance $u(L_{WN})$ is the composition in quadrature of any independent uncertainty due to sources ε_i affecting L_{WN}:

$$u^2(L_{WN}) = \sum u^2(L_{WN}(\varepsilon_i))$$

Alternatively, following the *Guide to the Expression of Uncertainty in Measurement (GUM)* and neglecting correlations and non-linearity, the combined standard uncertainty of the normalized water-leaving radiance $u(L_{WN})$ is given by ;

$$u^2(L_{WN}) = (C_Q C_A)^2 u^2(L_W) + (L_W C_A)^2 u^2(C_Q) + (L_W C_Q)^2 u^2(C_A)$$

with

$$u^2(L_W) = u^2(L_T) + L_i^2 u^2(\rho) + \rho^2 u^2(L_i)\,.$$

The uncertainties $u(L_T)$ and $u(L_i)$ should account for contributions due to the following sources ε_i: absolute calibration, sensitivity change during the deployment period of the measuring system, and environmental perturbations caused by sea surface roughness and environmental changes during measurements.

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

Joint Research Centre

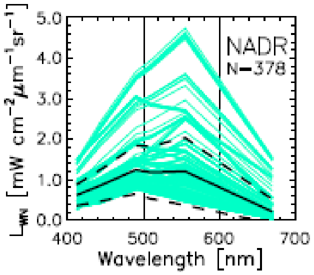
L_{WN} *relative uncertainties at different AERONET-OC sites*

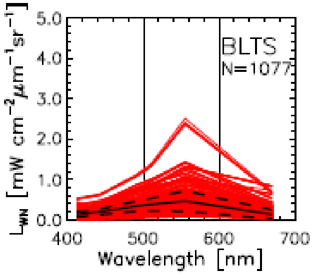
$u(L_{WN})$: combined uncertainty (defined as “combined standard uncertainty” when referred to 1σ)

$u(L_{WN})/L_{WN}$: relative combined uncertainty

Above water	$u(L_{WN})/L_{WN}$**[%]**		
	443	**551**	**667**
Absolute calibration	2.7	2.7	2.7
Sensitivity change	0.2	0.2	0.2
Corrections	2.0	2.9	1.9
t_d	1.5	1.5	1.5
ρ	1.5	0.6	2.5
Environmental var.	2.1	2.1	6.4
Quadrature sum	**4.5**	**4.7**	**7.8**

GUM 4.8 4.9 7.3





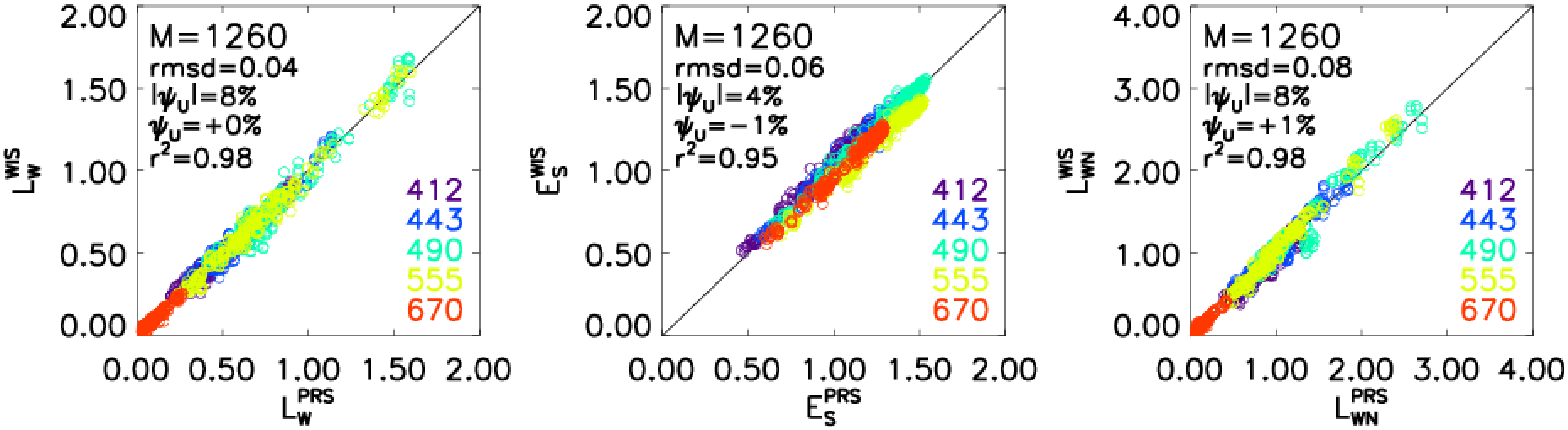
$u(L_{WN})/L_{WN}$ $u(L_{WN})$

λ	412		443	488	551	667
AAOT	5.3	[0.038; 0.71]	4.8 [0.043; 0.87]	4.6 [0.056; 1.20]	4.9 [0.049; 1.00]	7.3 [0.010; 0.13]
GLR	8.6	[0.027; 0.31]	7.1 [0.030; 0.41]	5.5 [0.036; 0.63]	5.6 [0.038; 0.67]	9.6 [0.011; 0.11]
AABP	11.1	[0.050; 0.44]	8.4 [0.047; 0.54]	7.4 [0.055; 0.73]	6.8 [0.033; 0.47]	9.5 [0.009; 0.08]
GDLT	16.3	[0.018; 0.11]	10.2 [0.018; 0.17]	6.3 [0.021; 0.33]	5.7 [0.027; 0.47]	6.4 [0.007; 0.10]
HLT	27.4	[0.016; 0.06]	13.7 [0.014; 0.10]	7.8 [0.017; 0.22]	6.7 [0.026; 0.39]	6.9 [0.008; 0.12]

Relative combined uncertainties $u(L_{WN})/L_{WN}$ (%) and (in square brackets) combined standard uncertainties $u(L_{WN})$ and median L_{WN} (mW cm^{-2} sr^{-1} μm^{-1}), respectively, at different λ (nm) for various AERONET-OC sites.

M. Gergely and G. Zibordi, “Assessment of AERONET L_{WN} uncertainties,” Metrologia **51**, 40–47 (2014).
G.Zibordi and K.J.Voss, Field Radiometry and Ocean Color Remote Sensing. In *Oceanography from Space, revisited.* V.Barale, J.F.R.Gower and L.Alberotanza Ed.s, Springer, Dordrecht, pp. 365-398, 2010.

Consistency of AERONET and BiOMaP/CoASTS L_{WN}



$$L_{wn}(\lambda) = L_w(\lambda) / E_s(\lambda)$$

G.Zibordi. Comment on "Long Island Sound Coastal Observatory: assessment of above-water radiometric measurement uncertainties using collocated multi and hyperspectral systems". *Applied Optics*, 51, 3888-3892, 2012.

European
Commission

Thank you!

Joint
Research
Centre