Collection, analysis and on-line experimentation of ocean color remote sensing data

An appraisal off the Southwestern Iberian Peninsula

Davide D'Alimonte and Tamito Kajiyama
Centre for Marine and Environmental Research CIMA
University of Algarve
8005-139 Faro, Portugal
davide.dalimonte@gmail.com

Carolina Sá and Vanda Brotas
Marine and Environmental Sciences Centre MARE
Faculty of Sciences, University of Lisbon
Campo Grande, 1749-016 Lisbon, Portugal

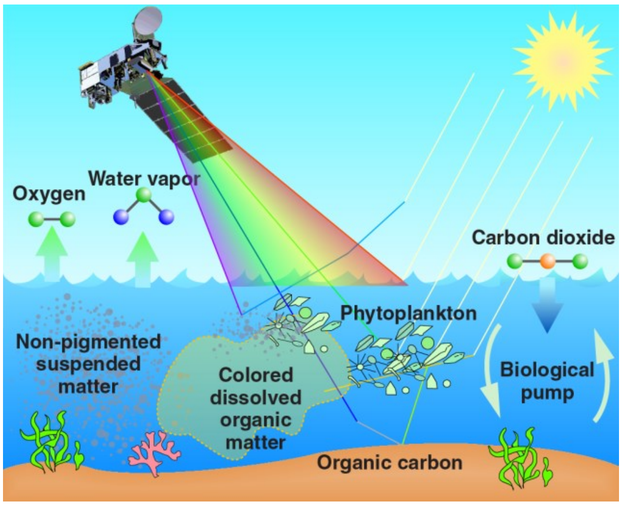
***Abstract*—This document concerns the collection, analysis and on-line experimentation of ocean color data off the Western Iberian Peninsula. Field measurements have been acquired during the BIOMETORE field campaign in summer 2016 to evaluate and enhance Earth observation capabilities of the Copernicus program. Deliverables of the Ocean and Land Colour Instrument on board of the Sentinel-3 satellite of the European Space Agency are of specific interest. Preliminary evaluations confirm the quality of the in situ measurements to address the match-up future analysis of radiometric values and derived data products. On-line experimentation undertaken with the Web-Enhanced Service To Ocean Color demonstrates the feasibility of enabling in a transparent way the user's access to complex functionalities such as neural network applications.**

Keywords*—*Ocean color remote sensing; in situ data collection; on-line experimentation.

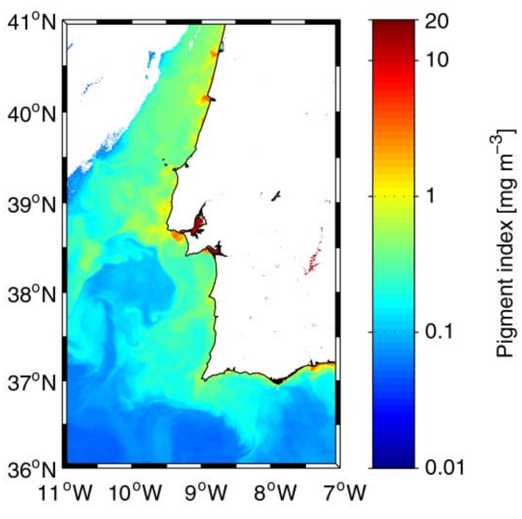
I. Introduction

Optically significant constituents of seawater affect the light back-scattered from the ocean according to their type and concentration and this is basis of ocean color applications to address marine monitoring tasks [1, 2]. Remote sensed quantities are conventionally grouped, according to their different optical characteristics and their specific bio-geo-chemical origin, into: 1) pigmented (biological) matter or phytoplankton; 2) non-pigmented suspended matter; and 3) colored dissolved organic matter. The use of sensors located on orbiting platforms for measuring remote sensing reflectance (R_{rs}) values is a unique way to obtain large-scale product maps over the Earth's surface (Fig. 1).

The phytoplankton pigmented matter, estimated in terms of Chlorophyll-*a* concentration (Chl-*a*) is the basis of the marine food web. The fact that the ocean carbon fixation depends on the phytoplankton component underlines the importance to retrieve this quantity. Several processes can lead to the detritus. Micro-organism shells, such as those of Coccolitophore, are an example of the non-pigmented matter in open ocean. In coastal waters, either waves or tidal action can raise particles from the sea bottom. Transport of particles by rivers and wind represents another important source. The pigmented and non-pigmented suspended particles are jointly quantified as Total Suspended Matter (TSM). The Colored Dissolved Organic Matter (CDOM) can be generated either by



(a)



(b)

Fig. 1 (a) Schematic of the influence of the optically active seawater components on the water leaving radiance. (b) Example of Chl-*a* distribution in the Atlantic off the Southwestern Iberian Peninsula. Source: MERIS sensor on board of the ENVISAT/ESA satellite. (MER_FRS_2PPDSI20100825_104458_000005122092_00223_44365_7013.N1).

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the degradation of the phytoplankton or other organic substances. Its origin can be marine or terrestrial, via rivers, and in the latter case the CDOM can represent an important tracer of the dynamics in the river deltas.

The contribution of ocean color remote sensing to Earth observation and monitoring has seen an increase in the last decade. The Copernicus program represents a main example where data collected by orbiting sensors are acquired and processed to complement information derived from in situ measurements. Copernicus is now planning new ocean color remote sensing services thanks to the Ocean and Land Colour Instrument (OLCI) on board of the Sentinel-3A space platform [3]. The satellite was launched in February 2016, and the mission is now completing the commissioning phase prescribed by the European Space Agency (ESA) and the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). Sentinel-3A will be complemented by additional satellites hosting sensors equivalent to OLCI for an increased ocean color observation efficiency. The launch of Sentinel-3B is scheduled for 2017, and Sentinel-3C shall be put in space before 2020.

Within this application framework, research scientists of the Centre for Marine and Environmental Research (CIMA), University of Algarve, and the Marine and Environmental Sciences Centre (MARE), Faculty of Sciences, University of Lisbon are conducting a number of ocean color studies in the Atlantic off the Western Iberian Peninsula [4-8]. Scope of this document is to: 1) describe the procedure adopted for the field data collection; 2) analyze the performance of bio-optical algorithms for the study region; and 3) overview the functionalities of a web-based application designed to verify which set of wavelengths is most relevant to derive data products from space-born radiometric values.

II. IN SITU DATA COLLECTION

Field operations presented in this document took place from the 18th of August to the 5th of September 2016 on board of the Noruega research vessel [Fig. 2(a)] of the Portuguese Institute for Sea and Atmosphere (IPMA) during the BIOMETORE field campaign. Each optical station took about 30 minutes to acquire radiometric data and collect water samples. The scope of this section is to detail the field work activity and discuss future developments.

A. Rationales to the field work

The water-leaving radiance $L_w(\lambda)$ is the spectral power per unit solid angle emerging from below the sea-surface at the λ wavelength as a function of the illumination conditions, optically significant seawater constituents and viewing geometry. $L_w(\lambda)$ cannot be directly measured from above the sea surface because when the radiometer points to the water, it also collects photons that coming from the sky or the sun are reflected within the sensor field-of-view (FOV) [9]. These sky- and sun-glint effects are highlighted in Fig. 2(b). To determine L_w, it is then necessary to take the sea-surface reflectance factor ρ into account as addressed in the next paragraphs (where the spectral dependence of radiometric quantities is omitted for brevity of notation).

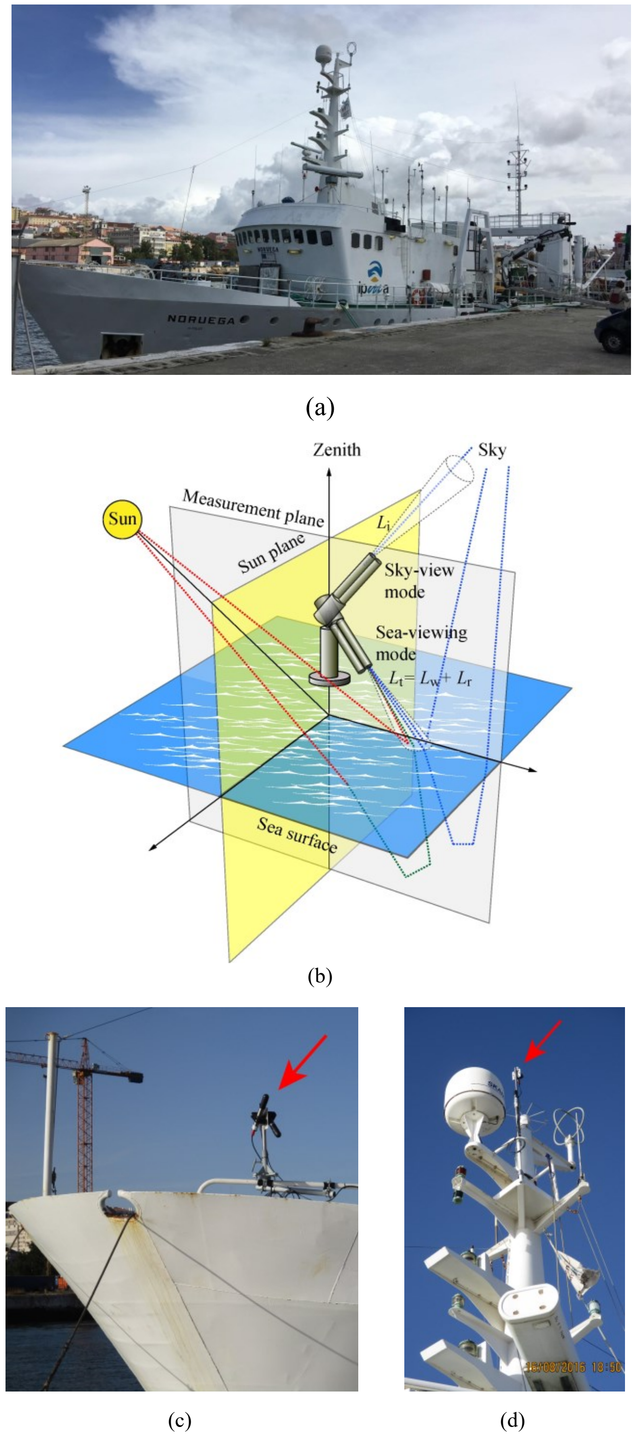


Fig. 2 (a) The Noruega research vessel of IPMA. (b) Schematics of the sky- and sea-viewing measurement geometry. (c) and (d) Radiance and irradiance sensors, respectively.

Above-water radiometry computes L_w based on the total radiance L_t and the incident radiance L_i measured in the sea- and sky-viewing setting, respectively [Fig. 2(b)]. The total radiance L_t collected with the sea-viewing geometry is

$$L_t = L_w + L_r, \quad (1)$$

where L_r is the radiance reflected at the sea surface. In order to estimate the water leaving radiance as

$$L_w = L_t - L_r, \quad (2)$$

it is then necessary to determine the reflected radiance L_r. This is done based on the incident radiance L_i measured in the sky-viewing mode

$$L_r = \rho \cdot L_i, \quad (3)$$

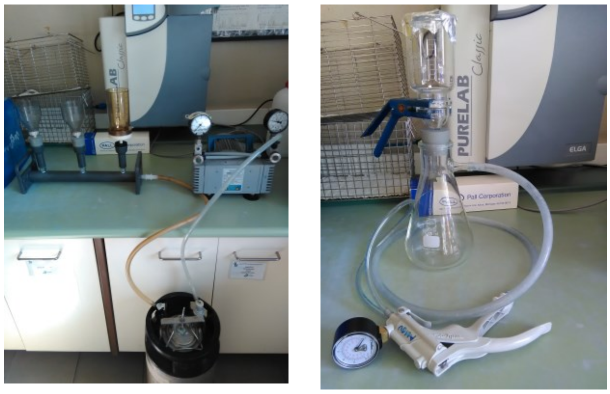
where the sea-surface reflectance factor ρ is obtained from look-up tables as a function of the measurement settings and environmental conditions [10]. Combining Eq. (2) and Eq. (3) finally allows for determining L_w as

$$L_w = L_t - \rho \cdot L_i. \quad (4)$$

The water leaving radiance is a function of the seawater optically significant constituents, but it can also depend on the viewing geometry and the illumination condition. To minimize this undesired dependences, the bidirectional reflectance distribution function is firstly taken into account to express the water leaving radiance in the zenith reference direction $L_w^{\uparrow}$ [11]. A new quantity, the remote sensing reflectance R_{rs}, is hence defined as

$$R_{rs} = \frac{L_w^{\uparrow}}{E_S}, \quad (5)$$

where E_S is the total downward irradiance including the sun and sky contribution. R_{rs} is the fundamental quantity to derive ocean color data products. The determination of R_{rs} from space-born data requires correcting for the atmospheric contribution. It is then of primary importance to collect high-quality in situ measurements that coincide in time and space with the satellite overpass (match-ups) for future validation of space-born R_{rs} values and derived data products (e.g., Chl-*a*, TSM and CDOM).



(a) (b)

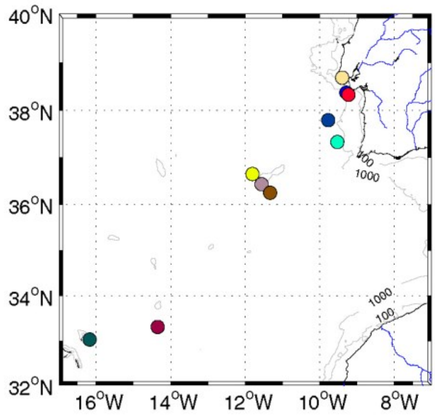
Fig. 3 Setting for filtering seawater samples.

B. Radiometric data collection

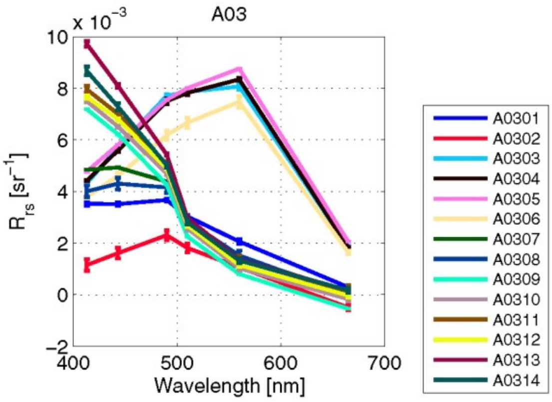
In situ R_{rs} measurements have been performed in the course of the BIOMETORE campaign with the RAMSES above-water system manufactured by TriOS, Rastede, DE. The radiometric data collection requires stable illumination conditions during either clear sky or complete overcast. The sea state can be up to four in the Beafourt scale. Two radiance sensors, set in the sky- and sea-viewing mode respectively, have been placed close to the bow of the Noruega research vessel [Fig. 2(c)]. Values of L_i and L_t have been acquired in accordance with measurements protocols by: 1) orienting the radiance meters at 90° from the sun plane [Fig. 2(a)]; and 2) adopting 40° and 140° as nadir angles, respectively, for the incident and total radiance viewing geometry [11]. The additional irradiance meter has been positioned on the ship mast in a place free of superstructure shading and perturbations to measure the E_S value [Eq. (5), Fig. 2(d)].

TABLE 1 LOCATIONS AND SATELLITE OVERPASS DURING THE OPTICAL STATIONS.

Code name	Date, time and position				Satellite overpass		
	Date	Time[GMT]	Lat.[deg.dddd]	Lon.[deg.dddd]	OLCI	MODIS	VIIRS
A0301	18/08/2016	10:29:53	38.3740	9.2825	X		
A0302	18/08/2016	13:50:16	38.3317	9.2250		X	
A0303	22/08/2016	10:34:12	38.6883	9.3957	X		
A0304	22/08/2016	13:59:07	38.6879	9.3948		X	X
A0305	23/08/2016	13:12:02	38.6876	9.3951	X		
A0306	23/08/2016	14:43:56	38.6873	9.3950		X	
A0307	24/08/2016	11:39:45	37.7956	9.7675	X		
A0308	24/08/2016	13:54:42	37.7956	9.7675		X	X
A0309	27/08/2016	12:38:55	37.3342	9.5234			
A0310	28/08/2016	11:54:09	36.4315	1.5577	X		
A0311	28/08/2016	13:40:45	36.2500	1.3281		X	X
A0312	29/08/2016	14:32:33	36.6508	1.8013		X	
A0313	03/09/2016	14:36:30	33.3100	4.3484		X	
A0314	04/09/2016	11:30:48	33.0293	6.1742	X		
					6	7	3



(a)



(b)

Fig. 4 (a) Sampling stations. (b) Measured R_{rs} spectra, error bars indicate the within station standard deviation when applicable.

C. *Collection and analysis of seawater samples*

Seawater samples were collected at each optical station as close as possible to the time of the radiometric measurements. This operation took about 10 minutes. Surface water was then filtered and stored for analysis at the laboratory (Fig. 3). Parameters of interest and related protocols are presented hereafter.

Chlorophyll-a (Chl-a). For phytoplankton pigments determination with High Performance Liquid Chromatography (HPLC), 2–3 l of seawater were filtered in GF/F filters (0.7 µm pore size) of 25 mm diameter. Filters were then immediately stored in liquid nitrogen until laboratory analysis.

Total Suspended Matter (TSM). GF/F filters of 47 mm diameter ash-freed were prepared in the laboratory prior to the campaign and each filter was numbered and weighted. These filters were then used during the campaign to determine TSM concentration in the seawater. About 1–2 l of surface seawater need to be filtered for this purpose. Filters were then washed with 50 ml of Milli-Q water and stored at -20° C for laboratory analysis. Triplicates were done for each station.

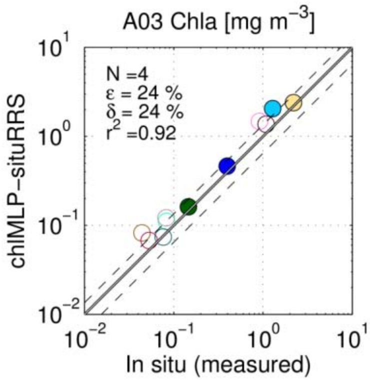


Fig. 5 Scatter plot of estimated and reference Chl-*a* values based on the data collected during the BIOMETORE field campaign (color shades of data points as in Fig. 1; see text for details). Note the limited validity of statistical figures have due to the low number of data points.

Coloured dissolved organic matter (CDOM). For the determination of the absorption spectrum of the CDOM, seawater samples (approximate volume 100 ml) were filtered on Nuclepore filters, 47 mm in diameter, 0.2 μm pore size. The first 2 or 3 ml were used to rinse the material and eliminated. The filtrate was then stored in brown glass bottles kept refrigerated in darkness until laboratory analysis.

D. *Ancillary data*

The following set of ancillary data was also recorded: longitude, latitude, wind speed, wind direction, atmospheric pressure, cloud cover, air humidity, air temperature and sea state.

E. *Sampling stations*

The naming adopted for the optical stations (Table TABLE 1 and Fig. 4) of the BIOMETORE campaign is as follows: 1) the first letter "A" denotes the Atlantic region; 2) the next two digits "03" indicates the sequential campaign number (*i.e.*, this is the third ocean color campaign taking place in the investigated oceanographic area); and 3) the last two digits represent the sequence number of the optical station during the BIOMETORE campaign. Sampling times and positions reported in Table TABLE 1 also give an indication of the overpassing of OLCI, MODIS and VIIRS space sensors. Measured spectra presented in Fig. 4 document the variety of marine optical regimes encountered during the BIOMETORE campaign.

III. BIO-OPTICAL ALGORITHMS FOR THE STUDY REGION

Field measurements described in Sec. II have been used as a test dataset for evaluating the performance of a combined version of two different regional algorithms for Chl-*a* retrieval in the study region. The considered ocean color inversion schemes are Multilayer Perceptron (MLP) neural networks [12] trained with field measurements acquired: 1) during a field campaign executed in an oceanographic area between Lisbon and Figueira da Foz in 2011 [7]; and 2) in the Sagres region since 2008 (the coefficients of this latter MLP are reported in [8]; for additional information see also [13]).

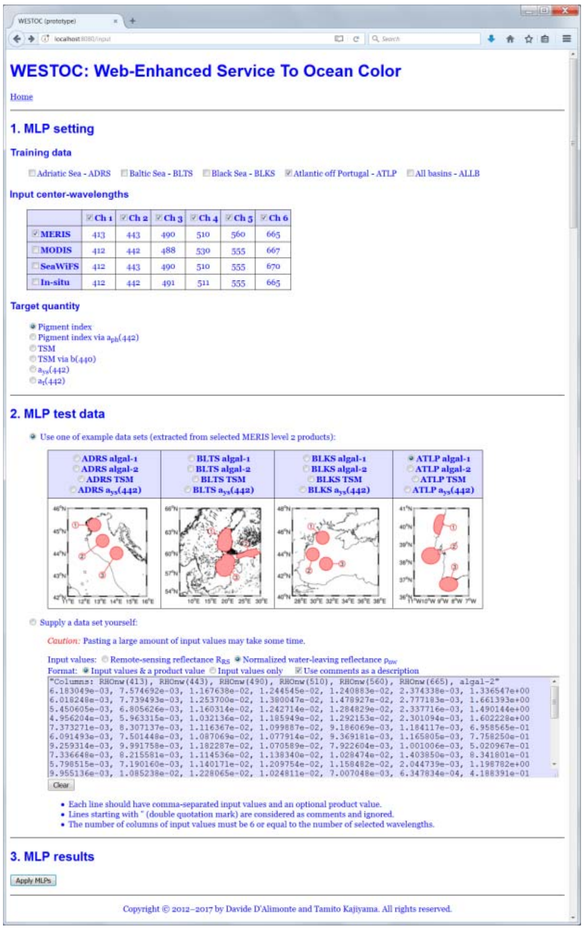


Fig. 6 The WESTOC web-based application has been designed to verify which wavelengths set is most relevant to derive data products from space-born radiometric values.

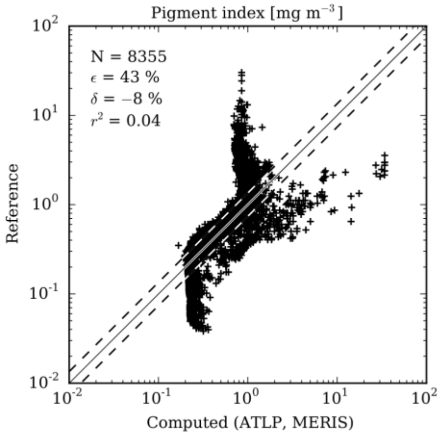
The data comparison is undertaken by: 1) utilizing the BIOMETORE in situ measurements of R_{rs} at 490, 510 and 560 nm as MLP input to obtain Chl-*a* estimates; and 2) using the result of seawater samples analysis as reference Chl-*a* value. Results are presented in Fig. 5 by identifying with filled (empty) data points cases within (outside) the applicability range [14] of the combined regional MLP for the Atlantic off the Western Iberian Peninsula [4-6, 13, 15-17]. Statistical figures are expressed in terms of data scattering ε and bias δ defined as

$$\varepsilon = \frac{1}{N}\sum_{i=1}^{N}\frac{|t_i - y_i|}{t_i} \quad (6)$$

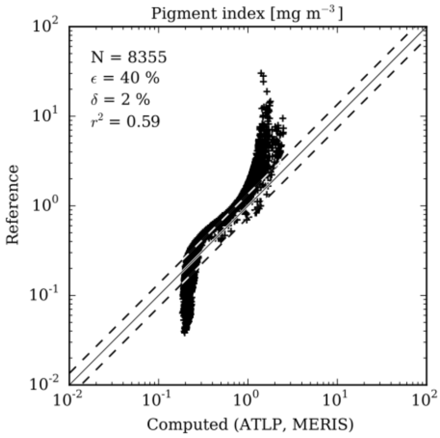
$$\delta = \frac{1}{N}\sum_{i=1}^{N}\frac{t_i - y_i}{t_i}, \quad (7)$$

where y and t are respectively the estimated and the reference Chl-*a* values, i is the sample subscription and N is the number of samples.

Preliminary results, still based on a limited number of samples (work in progress), indicate a high coefficient of determination (r^2=0.92) but also a systematic bias (δ =24%). It is then noted that: 1) the Chl-*a* assessment is within the 35%



(a)



(b)

Fig. 7 Comparison between standard MERIS Chl-a results (Algal1) and equivalent values computed using bottom-of-the-athmosphere R_{rs} values as MLP input. (a) All input wavelengths are considered. (b) only R_{rs} values at 490, 510 and 560 nm are used.

uncertainty commonly considered as a benchmark to evaluate the performance of ocean color algorithms; and 2) the Chl-*a* values involved in this analysis have been obtained from different field campaigns adopting varying protocols. This can partially explain the observed bias (specific details are however out of the scope of the present discussion). The agreement between Chl-*a* estimated from R_{rs} values and the reference determined from the water samples analysis confirms the quality of the ocean color data collected during the BIOMETORE campaign, as well as it supports the use of these data for the development of bio-optical algorithms and to conduct the match-ups analyses with space-born deliverables.

IV. On-line Experimentation

The Web-Enhanced Service To Ocean Color (WESTOC©) is a prototype designed for online assessment of the MLP performance by using input R_{rs} values at different sets of wavelengths to derive data products. WESTOC is not an open-access service and it is referred in this venue with the sole aim of documenting web-based experimentations conducted by CIMA and MARE ocean color scientists in regions-of-interest (ROIs) of the Atlantic off the Western Iberian Peninsula.

The WESTOC paradigm is to make transparent to the user any complexity related to the development and use of MLP neural networks for ocean color data products retrieval. This is achieved by implementing all functionalities through simple operations such as check-box selections in the web-interface (Fig. 6). Test data can be easily uploaded or even input with a copy-paste operation. The user can select the nominal wavelength of different space-born sensors and verify the corresponding agreement between estimated and reference values when a specific set of input wavelengths is employed.

An application example is presented in Fig. 7(a) considering the MERIS data and the Chl-*a* product (Algal1, [18]) as a case study. The scatter plot of Fig. 7(a)—which is a standard WESTOC output—is obtained using the full set of channels (R_{rs} at 413, 443, 490, 510, 560, and 665 nm). Statistical figures indicate ε=43% and δ=-8% as data scattering and bias. A low coefficient of determination (r^2=0.04) is also documented. The scatter plot Fig. 7(b) is instead obtained by only accounting for R_{rs} at 490, 510 and 560 nm as MLP input. In this case the agreement between estimated and reference Chl-*a* values improves especially for what concerns the bias and the coefficient of determination (ε=40%, δ=2% and r^2=0.59). The rationale is the larger uncertainties that affect radiometric data at the extremes of the visible spectral range. These results hence highlight the need of refining atmospheric correction schemes in order to take advantage of R_{rs} values at all channels.

V. Summary and Concluding Remarks

This document has presented and discussed optical stations executed during the BIOMETORE oceanographic cruise in the Atlantic off the Iberian Peninsula during summer 2016. Field measurements have been collected with the aim to: 1) derive match-up data for the analysis of space-born products obtained from the OLCI, MODIS and VIIRS orbiting sensors; and 2) improve regional inversion schemes for retrieving ocean color products. Preliminary analyses confirm the capability to perform validation studies of relevance to the Sentinel-3 space missions. Similarly, the complementarities of marine optical regimes encountered during the BIOMETORE field campaign with respect to the former samples collected in the Atlantic off the Western Iberian Peninsula will be exploited for improving the performance of bio-optical algorithms tuned to regional specificities. Application to remote sensing data will also take advantage from on-line experimentation capabilities of the Web-Enhanced Service To Ocean Color concerning the selection of input R_{rs} values at specific nominal wavelengths to foster remote sensing results in the study region.

VI. Acknowledgments

The Portuguese Institute for the Sea and Atmosphere (IPMA) is duly acknowledged to allow for hosting the RAMSES/TriOS system on the Noruega Research vessel during the BIOMETORE field campaign.

References

[1] I. S. Robinson, *Discovering the Ocean from Space*. Springer, 2010.

[2] S. Sathyendranath, “Remote sensing of ocean colour in coastal, and other optically-complex waters,” IOCCG Report NUMBER 3, pp. 1–140, 2000.

[3] C. Donlon, B. Berruti, A. Buongiorno, M.-H. Ferreira, P. FÃ©mÃ©nias, J. Frerick, P. Goryl, U. Klein, H. Laur, C. Mavrocordatos, J. Nieke, H. Rebhan, B. Seitz, J. Stroede, and R. Sciarra, “The global monitoring for environment and security (gmes) sentinel-3 mission,” *Remote Sensing of Environment*, vol. 120, pp. 37 – 57, 2012, the Sentinel Missions - New Opportunities for Science.

[4] D. D’Alimonte, G. Zibordi, J.-F. Berthon, E. Canuti, and T. Kajiyama, “Performance and applicability of bio-optical algorithms in different European seas,” *Remote Sens. Environ.*, vol. 124, no. 0, pp. 402–412, 2012.

[5] T. Kajiyama, D. D’Alimonte, and G. Zibordi, “Regional algorithms for European seas: a case study based on MERIS data,” *IEEE Geosci. Remote Sens. Lett.*, vol. 10, no. 2, pp. 283–287, 2013.

[6] D. D’Alimonte, G. Zibordi, T. Kajiyama, and J.-F. Berthon, “Comparison between MERIS and regional high-level products in European seas,” *Remote Sens. Environ.*, vol. 140, pp. 378–395, 2014.

[7] C. Sá, D. D’Alimonte, A. Brito, T. Kajiyama, C. R. Mendes, J. Vitorino, P. B. Oliveira, J. C. B. da Silva, and V. Brotas, “Validation of Standard and Alternative Satellite Ocean-Colour Chlorophyll Products off Western Iberia,” *Remote Sens. Environ.*, vol. 168, pp. 403–419, 2015.

[8] S. Cristina, D. D’Alimonte, P. C. Goela, T. Kajiyama, J. Icely, G. Moore, B. Fragoso, and A. Newton, “Standard and regional bio-optical algorithms for Chlorophyll a estimates in the Atlantic off the southwestern Iberian Peninsula,” *IEEE Geosci. Remote Sens. Lett.*, vol. 13, no. 6, pp. 757–761, June 2016.

[9] G. Zibordi and K. Voss, *Field Radiometry and Ocean Colour Remote Sensing*. Springer, 2010, ch. 18, pp. 307–334.

[10] C. D. Mobley, “Estimation of the remote-sensing reflectance from above-surface measurements,” *Appl. Optics*, vol. 38, no. 36, pp. 7442–7455, Dec 1999. [Online].

[11] G. Zibordi, B. Holben, I. Slutsker, D. Giles, D. D’Alimonte, F. Mélin, J.-F. Berthon, D. Vandemark, H. Feng, G. Schuster, B. E. Fabbri, S. Kaitala, and J. Seppälä, “AERONET-OC: A network for the validation of ccean color primary radiometric products,” *J. Atmos. Oceanic Tech.*, vol. 26, no. 8, pp. 1634–1651, 2009.

[12] C. M. Bishop, *Neural Networks for Pattern Recognition*. Oxford University Press, 1995.

[13] P. C. Goela, S. Cristina, T. Kajiyama, J. Icely, G. Moore, B. Fragoso, and A. Newton, “Technical note: Algal pigment index 2 in the atlantic off the southwest iberian peninsula: standard and regional algorithms,” *Ocean Science*, vol. 12, no. 6, pp. 1279–1288, 2016.

[14] D. D’Alimonte, F. Mélin, G. Zibordi, and J.-F. Berthon, “Use of the Novelty Detection Technique to Identify the Range of Applicability of Empirical Ocean Colour Algorithms,” *IEEE Trans. Geosc. Rem. Sens.*, vol. 41, pp. 2833–2843, 2003.

[15] D. D’Alimonte, T. Kajiyama, and A. Saptawijaya, “Ocean color remote sensing of atypical marine optical cases,” *IEEE Trans. Geosc. Rem. Sens.*, vol. 54, no. 11, pp. 6574–6586, May 2016.

[16] T. Kajiyama, D. D’Alimonte, and G. Zibordi, “Match-up analysis of MERIS radiometric data in the Northern Adriatic Sea,” *IEEE Geosci. Remote Sens. Lett.*, vol. 11, no. 1, pp. 19–23, 2014.

[17] D. D’Alimonte, G. Zibordi, J.-F. Berthon, E. Canuti, and T. Kajiyama, “Bio-optical Algorithms for European Seas: Performance and Applicability of Neural-Net Inversion Schemes,” JRC-IES Scientific and Technical Reports, Tech. Rep. JRC66326, 2011.

[18] A. Morel and D. Antoine, “Pigment index retrieval in case 1 waters,” Laboratoire d’Océanographie de Villefranche, Algorithm Theoretical Basis Document PO-TN-MEL-GS-0005, 2007.