MERIS VALIDATION ACTIVITIES AT THE AAOT SITE

Giuseppe Zibordi , Frédéric Mélin, Davide D'Alimonte and Dirk van der Linde

Inland and Marine Waters Unit, Joint Research Centre of the European Commission, 21020 Ispra (VA), Italy

ABSTRACT

Validation activities for the Medium Resolution Imaging Spectrometer (MERIS) primary radiometric products were carried out using data collected at the Acqua Alta Oceanographic Tower (AAOT) in the northern Adriatic Sea. The intercomparison between the normalized water leaving radiances L_{WN} computed from atmospherically corrected MERIS data and above water radiometric measurements taken with the SeaPRISM system, have shown an extremely good agreement for three match ups of October 2002. The intercomparison exhibited average absolute differences within 12% largely explained by the uncertainties of the in situ measurements and by the spatial variability characterizing the measurement site. However, even though the results suggest a good performance of the MERIS system (the spectrometer, its absolute calibration and the applied atmospheric correction scheme), any final conclusion cannot be drawn before analyzing a more extended number of match ups.

1. INTRODUCTION

Since 1995 the Acqua Alta Oceanographic Tower (AAOT), owned and managed by the Italian National Research Council (CNR), has been used as the logistic platform for the Coastal Atmosphere and Sea Time Series (CoASTS) program. The CoASTS measurement program aims at monthly collection of comprehensive atmospheric and marine time series to support the development and validation of remote sensing optical products in coastal waters [1]. Specifically, CoASTS supported the development of bio-optical models [2] and atmospheric correction schemes [3], and, the validation of atmospheric and marine [4] remote sensing products for the Sea Wide Field of view Sensor (SeaWiFS). This work presents the activities carried out for the validation of the MERIS radiometric products within the CoASTS framework.

2. THE AAOT VALIDATION SITE

The AAOT, built in 1970, is owned by the Istituto per lo Studio delle Grandi Masse (ISDGM) of the Italian National Research Council (CNR) in Venice. The tower, mounted on four grounded pillars, develops over four levels. Each level is 7.2 m x 5.2 m in size with the exception of the lowest level which is 5.2 m x 5.2 m. Measurement activities are carried out at the second and fourth level. At the second level, at approximately 7 m above the sea surface, a portable laboratory ensures space for treatment of water samples and for data logging. At the same level an open grid platform 3.5 m wide, extends 6.5 m over the sea toward south-east and it provides mounting points for the instruments to be deployed into the sea. At the fourth level, at approximately 12 m above the sea surface, the above water radiometer, the atmospheric optical instruments, and the meteorological instruments are installed. The electrical power is provided by diesel-powered generators and by lead-acid batteries. The generators provide electrical power when the AAOT is attended. The batteries provide power to the instruments included in continuous measurement activities.

The AAOT site is located 8 nautical miles off the Venice Lagoon in a frontal region that can be characterised by Case 1 or Case 2 water types [2]. The Case 2 water conditions are mostly determined by the inputs from the northern rivers (i.e. Piave, Livenza and Tagliamento). The aerosol type, occasionally maritime, is mostly continental determined by atmospheric inputs from the close Po Valley. The former characters give to the site the property of representing most of the northern Adriatic Sea region.

The horizontal homogeneity around the measurement site, evaluated through SeaWiFS images, has shown [3] cases characterised by high spatial non-homogeneity and cases characterised by high spatial homogeneity. The latter cases allow the punctual AAOT in situ data to be assumed as representative of the area surrounding the measurement site. Table 1 presents the typical values of the most relevant quantities characterising the CoASTS measurement site: the chlorophyll-a concentration *Chla*, the total suspended matter concentration *TSM*, the diffuse attenuation coefficient for downwelling irradiance K_d at 490 nm, the colored dissolved organic matter absorption coefficient a_{ys} at 400 nm and the aerosol optical thickness τ_A at 555 nm.

Quantity	*Chla* [μg l^{-1}]	*TSM* [mg l^{-1}]	$K_d(490)$ [m^{-1}]	$a_{ys}(400)$ [m^{-1}]	τ_A (555)
Average	1.3±1.1	1.1±0.7	0.21±0.09	0.15±0.06	0.14±0.06

Table 1. Average values of quantities characterizing the AAOT site [1]. The ± values indicate the standard deviations.

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3. IN SITU INSTRUMENTATION

The CoASTS program includes measurements of various atmospheric and marine quantities required for the development and validation of optical remote sensing products. The most relevant quantities are:

- The aerosol optical thickness $\tau_A(\lambda)$, as derived from measurements of direct sun irradiance $E_s(\lambda)$ taken by a CIMEL (Paris, France) CE-318 automatic sun photometer at nominal center-wavelengths λ=440, 500, 670, 870 and 1020 nm.
- The water leaving radiance $L_w(\lambda)$ as computed from above water radiometric measurements taken with a modified CE-318 automatic sun photometer (SeaPRISM version [5]) at nominal center-wavelengths 412, 440, 500, 555, 670, 870 and 1020 nm.
- Above water total $E_d(\lambda,0^+)$ and diffuse $E_i(\lambda,0^+)$ downward irradiance taken with a Satlantic (Halifax, Canada) Multichannel Visible Detector System (MVDS) at nominal center-wavelengths λ=412, 443, 490, 510, 555, 665 and 683 nm.
- Profiles of in-water upward nadir radiance $L_u(\lambda,z)$, upward irradiance $E_u(\lambda,z)$, and downward irradiance $E_d(\lambda,z)$, taken with the Wire-Stabilized Profiling Environmental Radiometer (WiSPER, composed of Satlantic OCI-200 and OCR-200 radiometers) at nominal center-wavelengths λ=412, 443, 490, 510, 555, 665 and 683 nm, and corrected for instrument self-shading and tower-shading effects.
- Profiles of seawater beam attenuation, $c(\lambda,z)$, and absorption, $a(\lambda,z)$, coefficients, taken with a WETLabs (Philomat, Oregon) AC-9 absorption/attenuation meter at nominal center-wavelengths λ=412, 440, 488, 510, 555, 630, 650, 676 and 715 nm.
- Profiles of seawater backscattering coefficient $b_b(\lambda,z)$, taken with a HOBILabs (Watsonville, California) HYDROSCAT-6 at nominal center-wavelengths λ=442, 488, 510, 555, 620, 676 nm and used to compute the backscattering probability of the hydrosols scattering phase function, $B_p(\lambda,z)$.
- Measurements of *i*) Total Suspended Matter (TSM) through the dry weighting technique, *ii)* pigment concentration through High Performance Liquid Chromatography (HPLC) analysis, *iii*) *in vivo* particulate absorption coefficient $a_p(\lambda)$ through spectrometric analysis of particles retained on filters, *iv)* Color Dissolved Organic Matter (CDOM) absorption coefficient $a_{ys}(\lambda)$ through spectrometric analysis of filtered water.
- Ancillary field data (i.e., profiles of seawater temperature $T_w(z)$ and salinity $S_w(z)$, atmospheric pressure P_a, air temperature T_a, wind speed W, cloud cover C, sea state M).

All the former quantities are collected during monthly measurements campaigns lasting for a few days. From July 1995 to December 2002, CoASTS have ensured the execution of 95 field campaigns and the gathering of 500 measurement stations. Outside the normal CoASTS field campaigns, the only quantities collected on a continuous basis, are the aerosol optical thickness $\tau_A(\lambda)$ and the water leaving radiance $L_w(\lambda)$ from above water radiometry through the SeaPRISM system.

4. ABOVE-WATER RADIOMETRY

The SeaWiFS Photometer Revision for Incident Surface Measurements (SeaPRISM) system is based on the CE-318 radiometer [5], developed for sun-photometry and sky radiance measurements, added with above water radiometric measurement capabilities.

The CE-318 radiometer is a fully autonomous system that measures: a) the direct sun irradiance $E(\lambda,\theta_0,\phi_0)$ as a function of wavelength λ, sun zenith θ_0 and sun azimuth ϕ_0, as required for the retrieval of aerosol optical thickness; and b) sky radiance $L_i(\lambda,\theta,\phi)$, in a wide range of angles identified by the viewing angle θ and the azimuth plane ϕ, as required for the retrieval of the aerosol scattering phase function. The added sea-viewing measurement protocol (specific of SeaPRISM) ensures measurement of the total above-water radiance $L_T(\lambda,40°,\phi_0+90°)$ and $L_i(\lambda,140°,\phi_0+90°)$ in agreement with the S95 protocol [6]. Measurements are performed with 1.2° full angle field of view optics in eight channels with center-wavelength λ in the 340–1020 nm spectral range.

During each sea-viewing sequence eleven values of $L_T(\lambda,40°,\phi_0+90°)$ and three values of $L_i(\lambda,140°,\phi_0+90°)$ are sequentially collected at each channel with the same gain. The water leaving radiance $L_W(\lambda)$ is then computed according to

$$L_W(\lambda)=\overline{L}_T(\lambda,40°,\phi_0+90°)-\rho(40°)\,\overline{L}_i(\lambda,140°,\phi_0+90°) \qquad (1)$$

using the average values $\overline{L}_T(\lambda, 40°, \phi_0+90°)$ and $\overline{L}_i(\lambda, 140°, \phi_0+90°)$ of the independent $L_T(\lambda, 40°, \phi_0+90°)$ data (after filtering out those values affected by large wave effects) and $L_i(\lambda, 140°, \phi_0+90°)$ data, taken during each measurement sequence. The value of the sea surface reflectance $\rho(40°)$, theoretically computed for different sky conditions, wind speeds, and solar zenith angles [7], accounts for both sun- and sky-glint radiance contributions in $L_T(\lambda, 40°, \phi_0+90°)$.
The use of $\phi=\phi_0\pm135°$ was recently recommended [7], however due to deployment restrictions at the AAOT, the SeaPRISM data can only be taken with $\phi=\phi_0+90°$. This is not considered a source of uncertainty because, for $\theta=40°$, wind speed $W < 5$ m s^{-1} and with θ_0 within 20–80°, the measurements taken at $\phi=\phi_0+90°$ and $\phi=\phi_0+135°$ are characterized by almost identical values of $\rho(\theta)\approx0.028$ [7].
The absolute spectral uncertainties in $L_w(\lambda)$ measurements from SeaPRISM were estimated accounting for uncertainties in the absolute calibration (source and calibration repeatability) [5], perturbations induced by the superstructure of the deployment platform [8], and the environmental perturbations [5]. Assuming independent the former sources of uncertainty, the total uncertainty is given by their quadrature sum. The estimated uncertainty values are given in table 3 at the SeaPRISM center-wavelengths in the 412-670 nm spectral interval.

Major uncertainties [%]	412	440	500	555	670
Absolute calibration	2.6	2.5	2.3	2.3	2.2
Tower perturbations	1.0	1.0	1.0	1.0	1.0
Environmental perturbations	4.0	3.5	3.0	3.0	12.0
Quadrature sum	4.9	4.4	3.9	3.9	12.2

Table 2. Uncertainties in L_w SeaPRISM measurements

5. MERIS VALIDATION MATCH-UPS

Validation activities on MERIS data were carried out with SeaPRISM measurements matching three images of October 18, 19 and 24, 2002. To ensure comparability between MERIS and SeaPRISM values, their data were both converted to normalized water leaving radiances. The $L_w(\lambda)$ from SeaPRISM were converted to normalized water leaving radiance $L_{WN}^{PRS}(\lambda)$ according to

$$L_{WN}^{PRS}(\lambda) = L_W(\lambda)\frac{C(\lambda, 40^0, W)}{t_d(\lambda)} \tag{2}$$

where $t_d(\lambda)$ is the atmospheric diffuse transmittance and $C(\lambda, 40^0, W)$ is a correction factor accounting for the off nadir viewing angle of the radiometer (i.e., 40^0) as a function of λ and W [9].
The MERIS irradiance reflectance $R_{MER}(\lambda)$ data, resulting from the atmospheric correction of the top of the atmosphere data, were converted to normalized water leaving radiances $L_{WN}^{MER}(\lambda)$ according to

$$L_{WN}^{MER}(\lambda) = R_{MER}(\lambda)\frac{E_0(\lambda)}{\pi}C(\lambda, \theta, W) \tag{3}$$

where $E_0(\lambda)$ is the average extra-atmospheric sun irradiance, and $C(\lambda, \theta, W)$ is the correction factor accounting for the off nadir viewing angle θ of the sensor [9].

The intercomparison between SeaPRISM and MERIS normalized water leaving radiances was restricted to data collected within a time difference Δt=60 minutes. Results are presented in Fig. 1 at the closest SeaPRISM and MERIS wavelengths (where the SeaPRISM 500 nm data were intercompared with the average of the MERIS 490 and 510 nm data). The MERIS data presented in Fig. 1 are the average of the 3x3 elements centered at the AAOT site. The uncertainty bars for SeaPRISM are the quadrature sum values given in Table 2. The uncertainty bars for the MERIS data are the standard deviation of the 3x3 elements used for computing the average values. Some flags related to the MERIS image elements used for the comparison with SeaPRISM data, are given in Table 3 together with the in situ aerosol optical thickness at 865 nm.

The scatter plot of MERIS versus SeaPRISM normalized water leaving radiances does not show any relevant deviation from the one to one line. However, even though the MERIS data exhibit average absolute differences of d=12% with respect to the SeaPRISM data, justified by the uncertainties on in situ measurements and by the non-homogeneity of the site, no real conclusion can be drawn on the space system accuracy.

	18/10/2002	19/10/2002	24/10/2002
$\tau_A(865)$ [1]	0.024±0.003	0.042±0.007	0.105±0.020
ABSOA_CON			True
ABSOA_DUST	True		
CASE2_S	True		
CASE2_ANOM	True	True	
MEDIUM_GLINT			True

Table 3. In situ aerosol optical thickness at 865 nm $\tau_A(865)$, and relevant flags characterizing the MERIS data used for the intercomparison for the considered days.

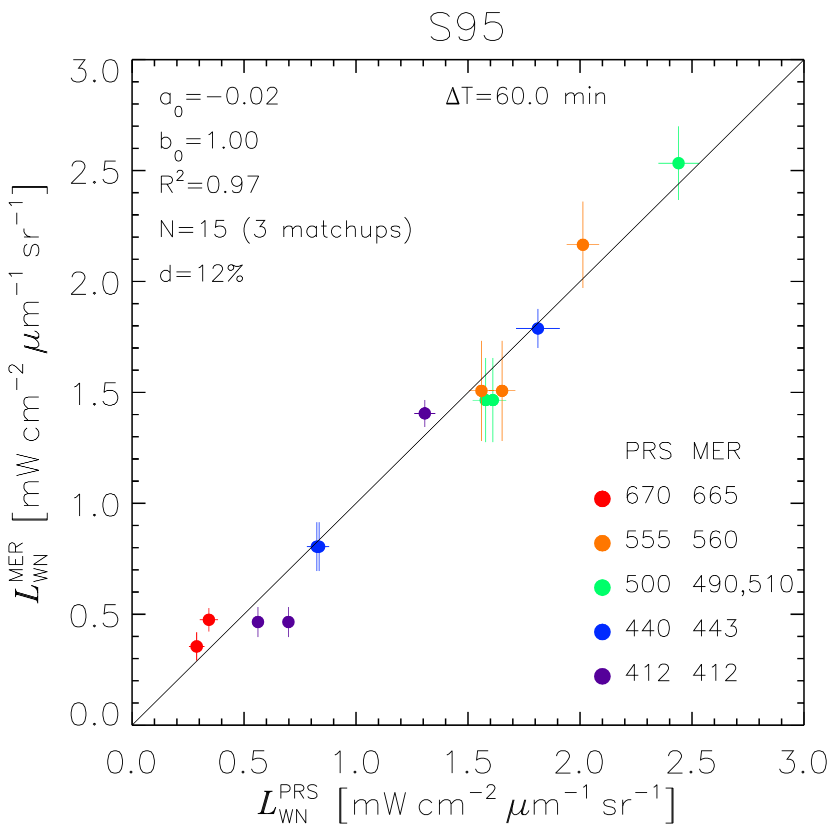

Fig. 1 Scatter plot of MERIS versus SeaPRISM derived L_{WN}

6. DISCUSSION

In order to provide sensitivity to the MERIS radiometric validation exercise, a similar analysis has been made with SeaWIFS data from the same days of the considered MERIS data. In this case the SeaWiFS top of the atmosphere data were processed with the REMBRANDT code [4]. The scatter plot of SeaWiFS versus SeaPRISM normalized water leaving radiances given in Fig. 2 with a Δt=30 minutes, exhibits results similar to those observed for the MERIS data. Exception is given by one sample at the SeaPRISM wavelengths 500 nm and 555 nm, that increases up to ~16% the average difference between SeaWiFS and SeaPRISM data. It is emphasized the fact that the SeaPRISM data used for the MERIS and SeaWiFS intercomparison are different because of the different overpass time of the two space sensors at the AAOT site.

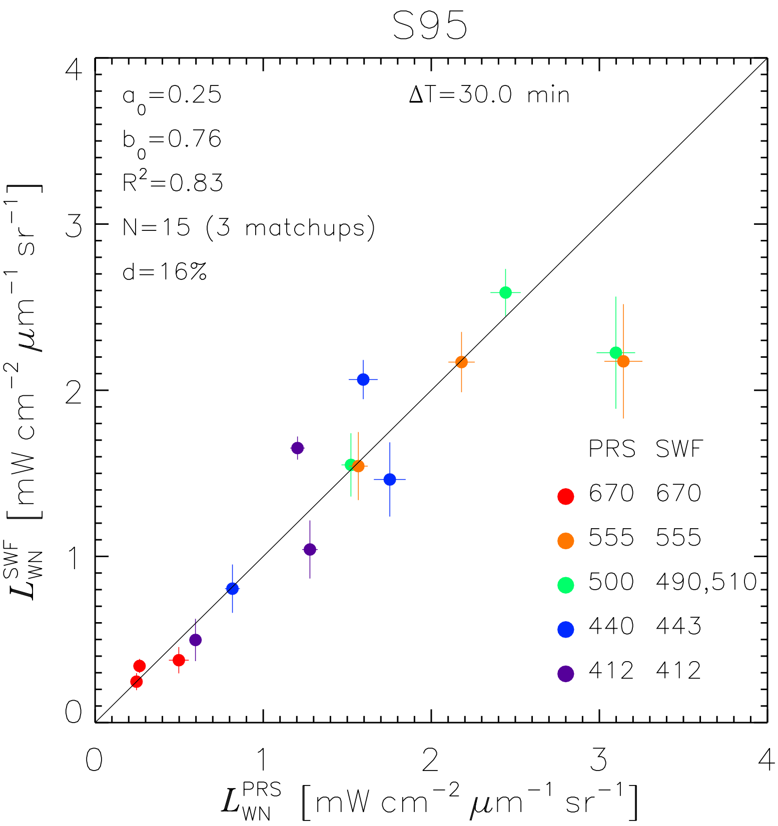

Fig. 2 Scatter plots of SeaWiFS versus SeaPRISM derived L_{WN}.

To further on investigate the MERIS radiometric products, MERIS and SeaWiFS normalized water leaving radiances from images of the northern Adriatic Sea, were intercompared. Results are given in Fig. 3 and Fig. 4 for regions close to the AAOT extracted from images of October 18 and October 19, respectively. A similar comparison was not attempted for October 24 because of the presence of clouds preventing the selection of a wide portion of the images. The larger scattering characterizing the normalized water leaving radiances of October 18 (see Fig. 3), could be explained by a poor co-registration of the MERIS and SeaWiFS data. The most striking element emerging from the scatter plots presented at 443, 555 (corresponding to MERIS 560) and 670 nm, is a significant overestimate of MERIS versus SeaWiFS normalized water leaving radiances at 670 nm. This result, not directly supported by the data presented in Fig.1 and Fig.2, would suggests the need of a detailed analysis of the atmospheric correction process in presence of absorbing aerosols or turbid waters. The latter element is also supported by a significant overestimate of the aerosol optical thickness at 865 nm observed for the MERIS data with respect to the in situ measurements (results not presented here).

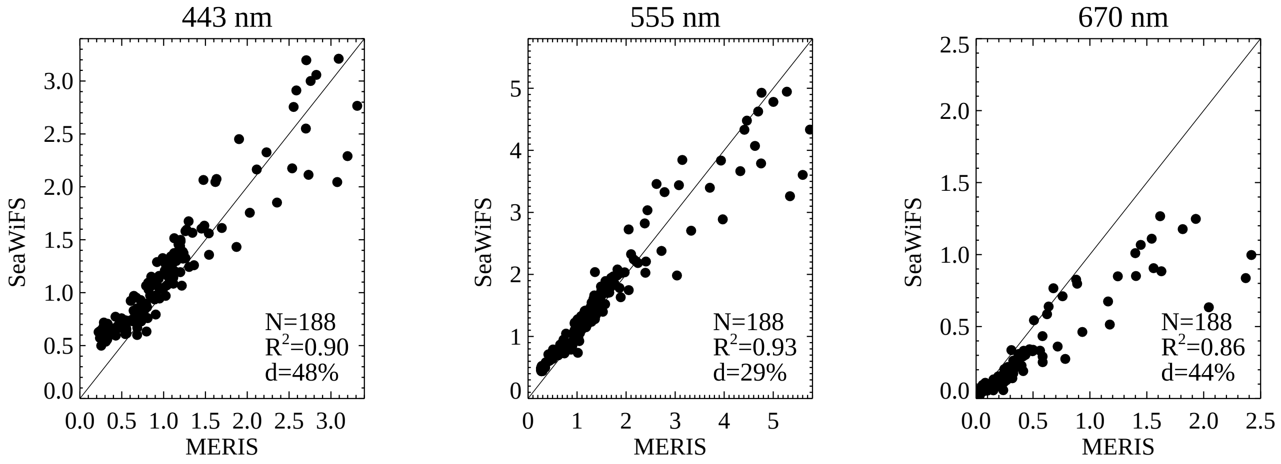

Fig. 3 Scatter plots of SeaWiFS versus MERIS L_{WN} (October 18, 2002)

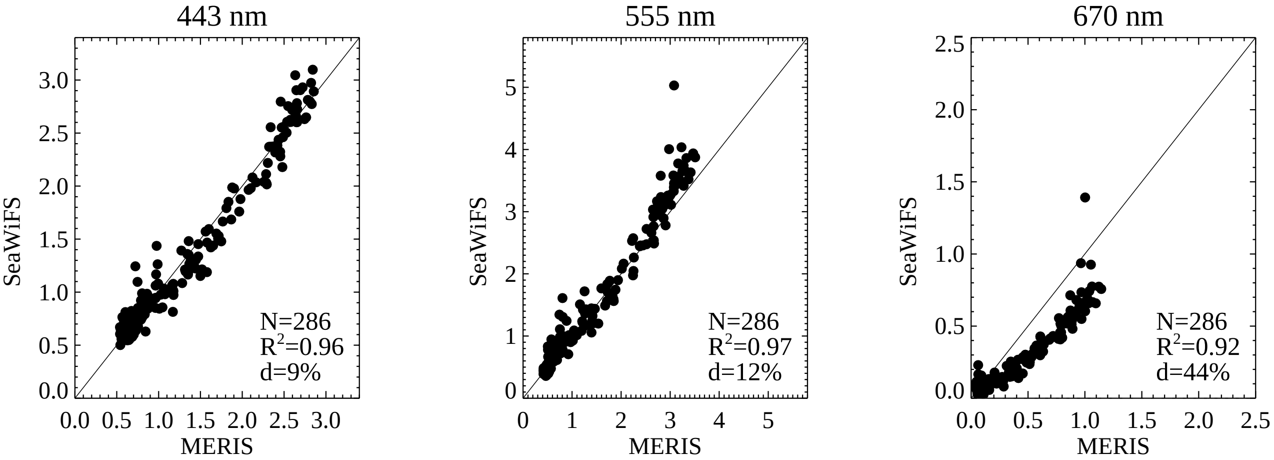

Fig. 4 Scatter plot of SeaWiFS versus MERIS L_{WN} (October 19, 2002)

7. CONCLUSIONS

Normalized water leaving radiances computed from MERIS data were compared with in situ data from the SeaPRISM autonomous radiometer operated at the AAOT within the framework of the CoASTS measurement program. The intercomparison results from three different days of October 2002 showed an average absolute difference of ~12%. Even though any quantitative conclusion cannot be drawn due to the small number of match ups, results suggest a good performance of the MERIS system (i.e., spectrometers, absolute calibration and atmospheric correction).

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