SKY DOME CORRECTION FOR SEAPRISM AND TRIOS ABOVE WATER RADIOMETRIC MEASUREMENTS IN MERMAID

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ABSTRACT

The water reflectance derived from in-situ measurements represents a key element in the validation of MERIS (MEdium Resolution Imaging Spectrometer) atmospheric correction over ocean. This above water radiometry comprises simultaneous acquisitions of surface irradiance, downwelling sky radiance and water-leaving radiance which needs to be corrected for the *Fresnel* reflection of the sky dome by the sea surface. By neglecting the polarization in this correction the reflected sky radiance may induce a bias of several percents in relative error on the marine reflectance. An alternative correction of the sky dome reflection has then been proposed accounting for the polarized nature of the light scattered by the atmosphere and of the *Fresnel* reflection. Two sky dome correction tools have been developed to be implemented in the MERMAID (MERis MAtchup In-situ Database) processing chain of in-situ data from AERONET-OC (SeaPRISM) and MUMM (TriOS). For each data sequence acquired over a matchup, the correction is achieved using the aerosol parameters extracted from the MERIS level-2 product.

1 INTRODUCTION

In the AERONET-OC (AErosol RObotic NETwork - Ocean Colour), the SeaPRISM (SeaWiFS Photometer Revision for Incident Surface Measurements) [1][2] and the TriOS/MUMM (Tri-Optical Sensors from Management Unit of the North Sea Mathematical Models, Brussels – Belgium) [3] field instruments acquire radiometric radiances above water surfaces, providing key measurements for validating the MERIS (MEdium Resolution Imaging Spectrometer) atmospheric corrections over ocean. The Acqua Alta Oceanographic Tower (AAOT, Venice - Italy) is a fixed station making continuous automatic measurements in the Adriatic Sea and the MUMM dataset has been acquired over ten years from cruise campaigns in the North Sea.

During the post-acquisition processing, the standard protocol used to correct for the sky dome *Fresnel* reflection has been initially completed without accounting for the polarization processes, although the in-situ measurements could be collected under geometrical conditions favourable to the appearance of a significant polarization effect. The impact of neglecting the polarization has been fully illustrated in [4], and a simulator (namely, POLREF [5]) has been developed to produce the new *Fresnel* reflection coefficient (R_{pol}). For both the AAOT and the North Sea MUMM cruises datasets, an analysis of parameters useful for the computation of the *Fresnel* reflection coefficient has been conducted over the MERIS matchups. The results stressed that first, the aerosol types were scattered except for the open white ocean hazes, and second, the full ranges of acceptable values for the atmospheric correction were well represented. This verification upstream allowed to define the conditions of applicability of our alternative correction for the sky dome reflection developed for both the SeaPRISM [6] and the MUMMTriOS [7] datasets. These two sky dome correction processors have been implemented in the SeaPRISM and TriOS data processing chains for MERis MAtchup In-situ Database (MERMAID) [8], [9], in order to get the new water-leaving radiances.

The full archives of data sequences collected at AAOT with the SeaPRISM instrument and over the North sea with the TriOS/MUMM radiometer have been processed with the new sky dome correction tools implemented in the respective MERMAID processing chain. This paper describes the verification and validation of the SeaPRISM and TriOS processors in MERMAID, as well as the evaluation of this new correction on the MERIS validation in term of the water reflectance retrieval. This work is essential for the MERIS calibration and validation activities conducted for the quality assurance of the derived products over ocean including the collection of in-situ measurements for matchups with the spaceborne sensor.

2 SKYDOME CORRECTION PROCESSORS

The SeaPRISM and TriOS/MUMM processors are fully detailed in [6] and [7], respectively. For each of the datasets collected with these field instruments, a number of key information are required to run the respective processors:

- The original SeaPRISM or MUMMTriOS file with in-situ radiometric data sequences and their associated auxiliary data: *i.e.*, date, time, instrument number [SeaPRISM only], solar zenith angle (SZA), solar azimuthal angle (SAA) [Sea-PRISM only], latitude and longitude [TriOS only];
- The MERIS file with the relevant parameters to compute R_{pol} in the SeaPRISM or MERIS (in the case of MUMMTriOS) spectral bands: *i.e.*, the 2 bracketing standard aerosol models (SAMs) and the aerosol mixing rate (*aer_mix*), the total aerosol optical thickness (AOT) at 865 *nm* (*AOT865*), the *Angstroem* exponent (α), the wind-speed above sea level (w_s), and the the total ozone amount (u_{O3}) [TriOS only]. All these parameters are available for the (5x5) MERIS reduced resolution (RR) pixels selected as the validation window;
- The new SeaPRISM or MUMMTriOS file with the set of water-leaving radiances corrected for the sky dome reflection and for the slight Sun glint contamination, with the set of new reflection coefficient (R_{pol}) and with the set of Sun glint radiances (L_{glint}) reflected at bottom of the atmosphere (BOA).

2.1 Verification of Fresnel reflection coefficients

The standard output corresponds to the three above files in text format for each MERIS matchup. To conduct an extensive analysis over all the matchups, we need to open these three output files for a given date and to merge them with data from the other sequences (or dates). For the extensive AAOT SeaPRISM file, 2003 was selected (a sunny year). The *Fresnel* reflection coefficient from *Mobley* (R_{Mobley}), Fig. 1, is driven by the wind-speed and a 2nd order polynomial [10]. The correction for the Sun glint contribution is included in R_{Mobley} but this is not the case for the new coefficient, R_{pol}, also shown in Fig. 1. The driving parameter of this new *Fresnel* reflection coefficient is the SZA (Fig. 2), mainly in the blue region (412 *nm*) because of the predominance of the *Rayleigh* scattering. For the SeaPRISM, whatever the atmosphere and the surface roughness level, R_{pol} remains lower than the *Mobley*'s one, mostly at the large SZA's. In the near-infrared region (NIR), the SZA influence is less pronounced because of the wind-speed and the 2 bracketing SAM's. For the MUMMTriOS dataset, the results displayed in Fig.2 indicate a large dispersion making difficult the observation of a trend. The in-situ TriOS/MUMM database presents a very large range of wind-speed and a large variety of aerosol type which main explain the dispersion observed in Fig. 2. New R_{pol}, computed with POLREF, are presented for each dataset in Fig. 3.

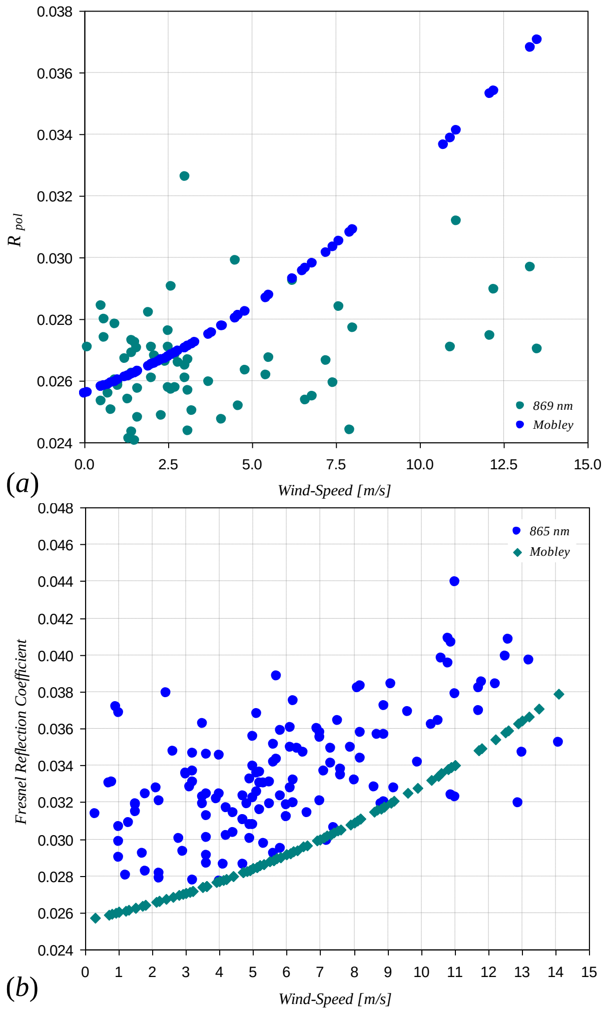

Figure 1: Reflection coefficient as function of the wind-speed: (i) estimated with the Mobley's approximation, and (ii) computed with (a) the SeaPRISM processor and (b) the TriOS/MUMM processor, at 865 nm.

2.2 Geometry influence

A strong azimuthal dependence was noted for the MUMMTriOS dataset (Fig. 4) emphasising the requirement to account for the relative azimuthal angle (RAA) in the R_{pol} computation for TriOS, whether or not it is

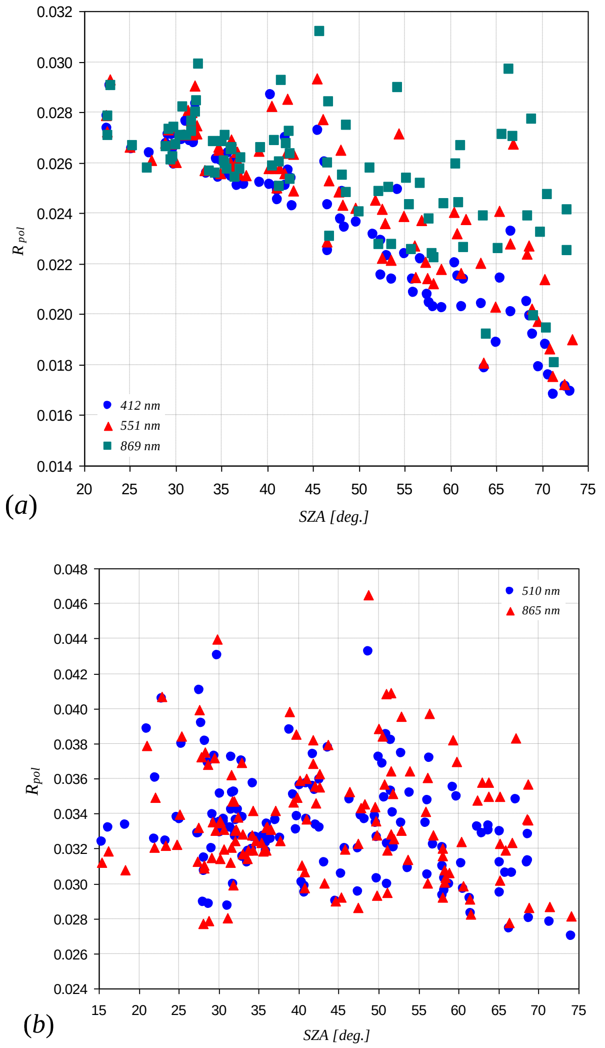

Figure 2: Fresnel reflection coefficient (R_{pol}) as function of SZA, computed with (a) the SeaPRISM processor at 412, 551 and 869 nm, and (b) the TriOS/MUMM processor at 510 and 865 nm.

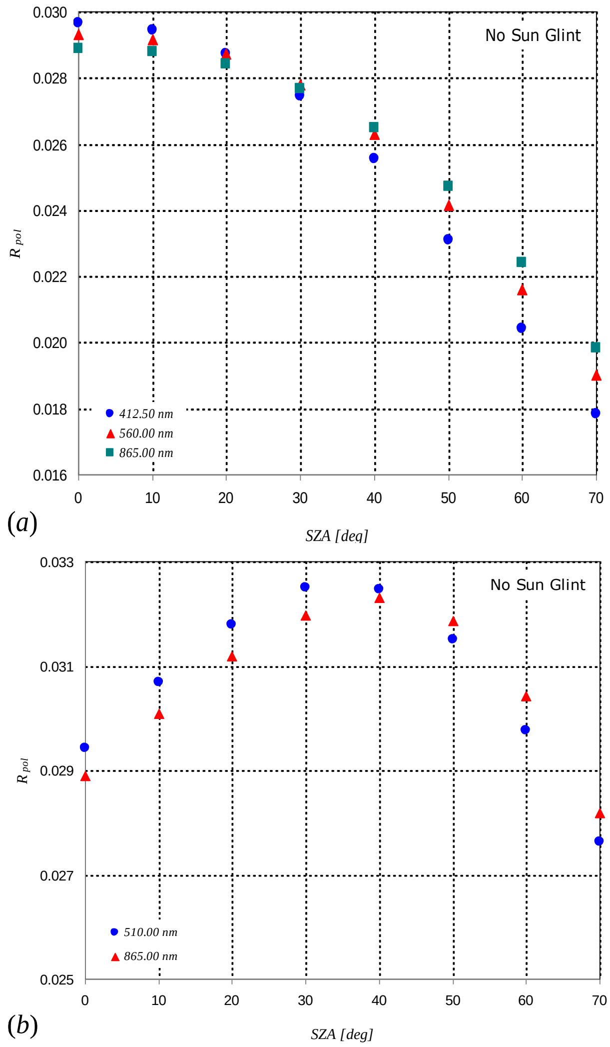

Figure 3: R_{pol} as function of SZA, computed with POLREF, using RUR90, AOT865=0.1 and w_s=2 m/s, for the SeaPRISM (a) and TriOS (b) geometries.

fixed at a nominal value (*e.g.*, 135 *deg*) or computed. POLREF was used to check the new computation of R_{pol} with the TriOS/MUMM processor even if the azimuth was not set to its nominal value. This calculation is an average of individual R_{pol} values associated with each of the (5x5) MERIS-RR pixels for which the aerosol product exists and indicate that R_{pol} can be correctly computed even if RAA departs from 10 *deg.* with its nominal value. Occasionally, the R_{pol} value associated with each of the (5x5) MERIS-RR pixels for which the aerosol product exists, indicates that R_{pol} can be correctly computed even if RAA departs from 10 *deg.* with its nominal value. Occasionally, the R_{pol} value is set to a default value of -999 when none of the two bracketing aerosol models belong to the set of 16 MERIS SAMs or when the sky dome correction failed, for both all the pixels within the (5x5) MERIS-RR pixels window. To reduce the number of cases with undefined R_{pol}, the sky dome correction was tested with a default SAM and *AOT865* when both the two bracketing aerosol models are either DUSTs or undefined. The default SAM has been determined as the most representative of the aerosol types for all the data sequences acquired both over the AAOT and North Sea sites [11]. Thus, the default aerosol option has been implemented in the TriOS/MUMM processor, *i.e.*, the RUR90 assemblage (*iaer*=12) with a standard *AOT865* of 0.1 as default option, and an output flag as an indicator about the sky dome process.

The azimuth issue has been addressed by setting:

- R_{pol} to the default value of -999 if RAA from the MUMM-TriOS data sequence is not ranged within [125;145] *deg.*;
- An additional flag as a MERMAID indicator when the RAA from the MUMMTriOS data sequence is out of range.

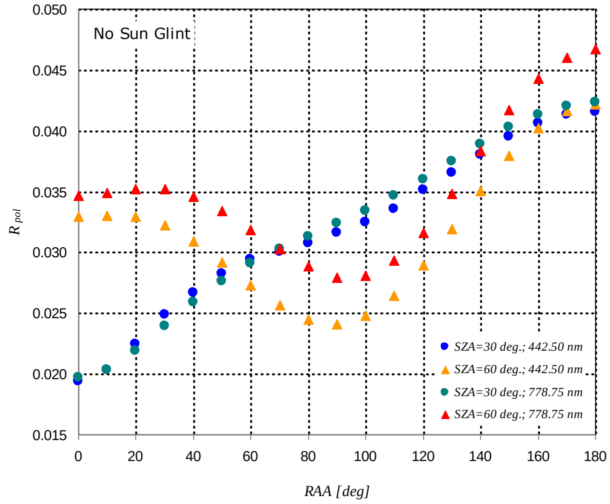

Figure 4: R_{pol} as function of RAA, computed with POLREF for 2 SZAs (30 & 60 deg.) at 442.5 & 778.75 nm, with RUR90, AOT865=0.1, and a wind-speed of 2 m/s.

A future evolution of the MUMM-TriOS processor should enable to process the TriOS data sequences for any RAA value.

2.3 Verification of the implementation of sky dome correction processors in MERMAID

The POLREF simulator was also used to check the new computation of R_{pol} with each of the 2 processors (SeaPRISM and TriOS/MUMM). As an example, the verification of the implementation of the SeaPRISM processor in the MERMAID data processing chain can be conducted for the case where a dominant SAM is present for most of pixels in the (5x5) MERIS-RR window. This is more or less the case of the SeaPRISM data sequence acquired on the *Julian* day 308 of the year 2003, where the so-called *«blue-IOP»* aerosols (*iaer*=31, 32 or 33) dominate. The spectral dependence of R_{pol} is reported in Fig. 5. At this large SZA (63.45 *deg.*), the atmospheric scattering is highly polarized and the direction of polarization is almost in the reflection plane. Accounting for the polarization reduces the reflection mostly in the blue region because of the dominance of the *Rayleigh* scattering. Except for the wavelength at 1020 *nm*, whatever the SeaPRISM spectral band, the computed value of R_{pol} with the blue aerosols are in-line with those corresponding to the first *«blue-IOP»* SAM (*iaer*=31). In the NIR region, the blue aerosols are quite polarized, certainly more than those defined in the RUR70 assemblage (*iaer*=10), and slightly decrease R_{pol} from the red to the NIR region. The computed R_{pol} values with the SeaPRISM processor results from spectral spline interpolation of R_{pol} calculated at the 15 MERIS wavelengths. The extra-polated R_{pol} value observed at 1020 *nm* does not look like to this slight spectral decrease based on the use of a spline line interpolation at 753.75, 778.75 and 865 *nm*. Same kind of verification has been also conducted with the TriOS/MUMM processor (*see* [12] for more details).

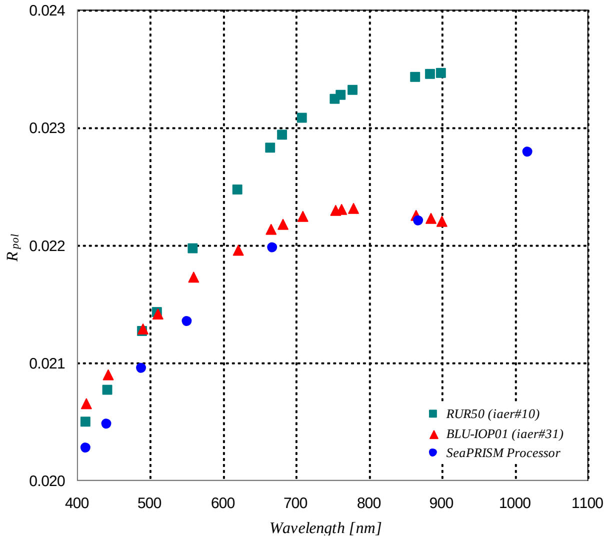

Figure 5: R_{pol} as function of the SeaPRISM wavelength, (a) computed with the POLREF simulator for each of the 2 likely SAMs (iaer=10 and 31), and (b) calculated with the SeaPRISM processor, using the in-situ data sequence acquired on Julian day #308 of the year 2003.

A trend curve observed in R_{pol} as function of SZA, has been defined with the full data archive of in-situ measurements acquired over the given MERIS matchup at AAOT. This is illustrated on Fig. 6 at two SeaPRISM wavelengths (*i.e.*, 441 and 668 *nm*). This plot depicts the SZA dependence of the new R_{pol} coefficient computed with the SeaPRISM processor for all the in-situ data sequences acquired at AAOT between 2002 and 2010. As expected, the trend curve clearly appears very close to what is observed in Fig. 3*a*, with a decreasing of R_{pol} when SZA increases.

3 MARINE REFLECTANCE

3.1 The new in-situ water reflectance

The new *Fresnel* reflection coefficient (R_{pol}) computed with the SeaPRISM (*resp.*, TriOS/MUMM) processor being smaller (*resp.*, larger) than the *Mobley*'s one, then we can expect larger (*resp.*, smaller) values of the in-situ water reflectance, $\rho_w(\lambda)$. Fig. 7 displays the diffe-rence between the new and old (*Mobley*'s correction) water reflectances versus the SZA which is the driving parameter. For the MUMMTriOS dataset, no trend with

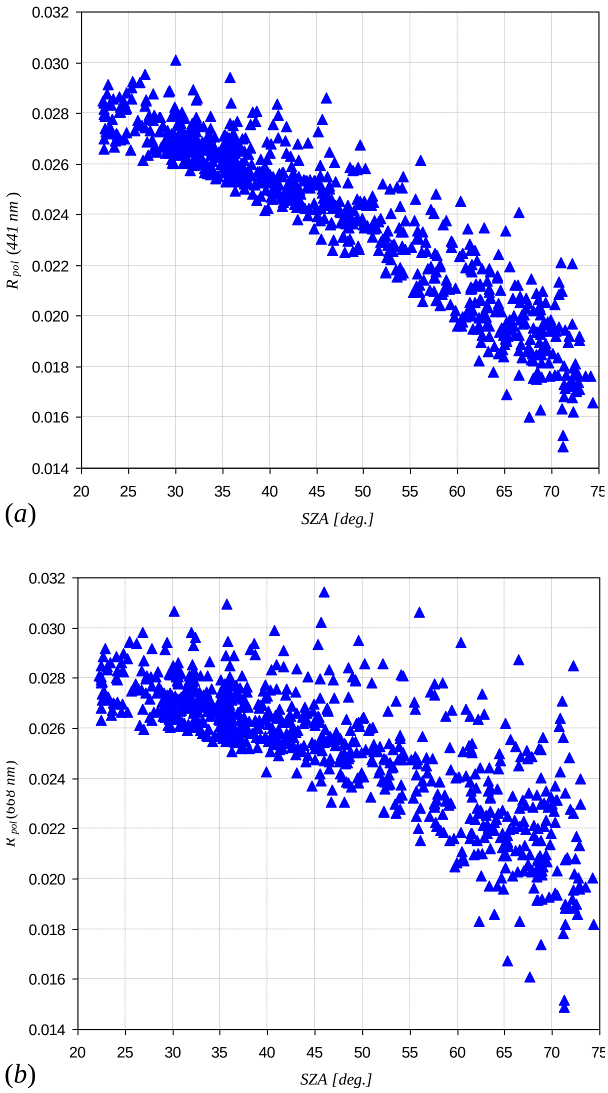

Figure 6: R_{pol} as function of SZA, computed with the SeaPRISM processor at 441 and 668 nm, for the whole set of AAOT data sequences acquired in 2002-2010.

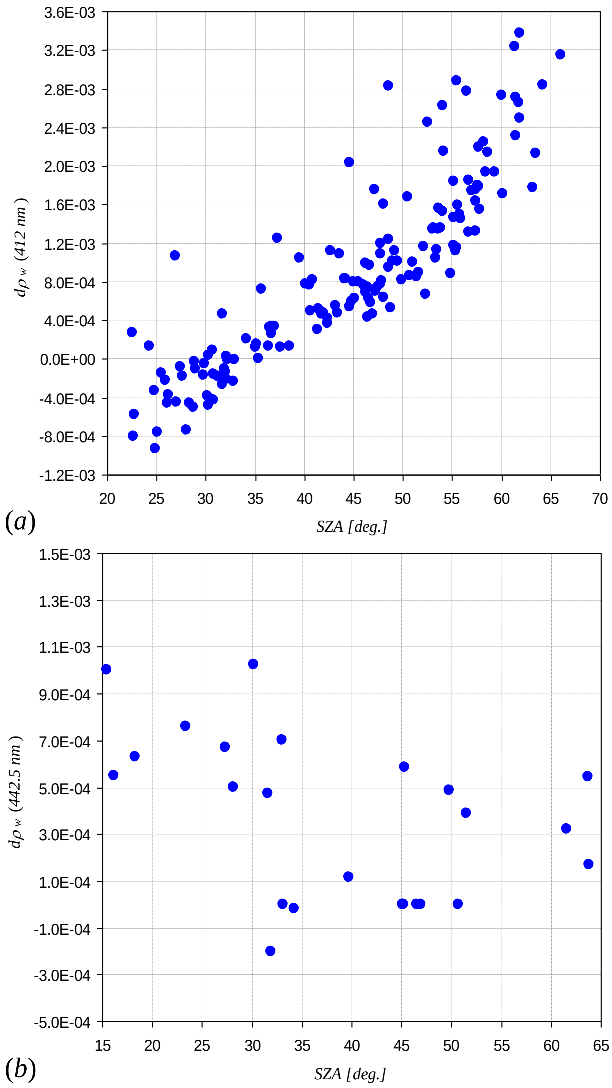

Figure 7: Difference between ρ_w computed with (a) the SeaPRISM processor over AAOT at 412 nm, or (b) the TriOS/MUMM processor on in-situ radiometric measurements acquired in 2003 over the North Sea at 442.5 nm, and derived from standard protocol.

SZA appears because of the small differences between the new and old water reflectances (Fig. 7*b*). The plot remains very scattered mainly caused by the wind-speed effect (mean at 5.2 *m/s* or a root mean square error of 2.4 *m/s*). Moreover, a slightly decrease is observed in these differences when increasing the wavelength, and the theoretical R_{pol} value remains very close to what the processors output (*see* [11] & [12] for more details).

Fig. 8 displays a comparison between the SeaPRISM old (or current) ρ_w and the newly corrected one for the MERMAID matchup days. The spectral behaviour of this comparison is summarized in Tab. 1. The polarization reduces the sky dome correction more effectively at short wavelengths mainly for the *Rayleigh* scattering. At 665 *nm*, R_{pol} increases because the *Rayleigh* component is undepolarized by the multiple scattering and the aerosol polarization may then appears.

Table 1: Slope and correlation coefficients resulting from a linear regression applied to new (SeaPRISM processor) versus old (standard protocol) ρ_w, for the whole AAOT database and for each MERMAID SeaPRISM wavelength.

λ (nm)	412.5	442.5	490	560	665
Slope	1.059	1.036	1.017	1.009	1.020
r^2	0.955	0.985	0.996	0.998	0.990

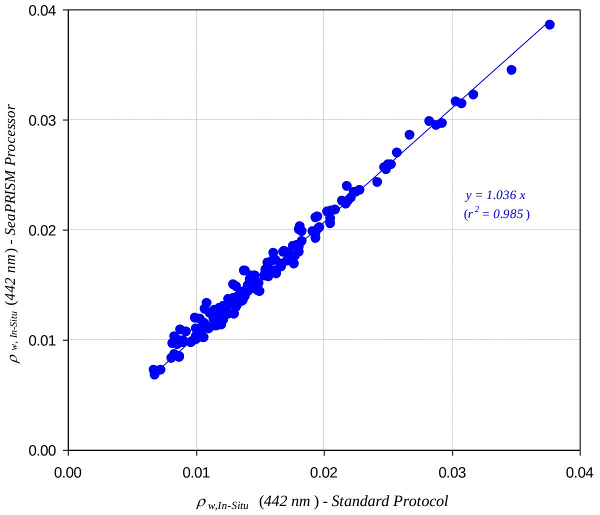

Figure 8: New versus old ρ_w at 442 nm, for AAOT database.

3.2 Comparison between MERIS and in-situ ρ_w

Matchups were extracted from MERMAID (Fig. 9) according to the standard default set of criteria (*http://hermes.acri.fr/mermaid/matchup/matchup.php*). Further screening was applied to a (15x15) pixels window, using the ICOL (Improved Contrast between Ocean and Land) indicators [13] in order to eliminate the scene contaminated by clouds.

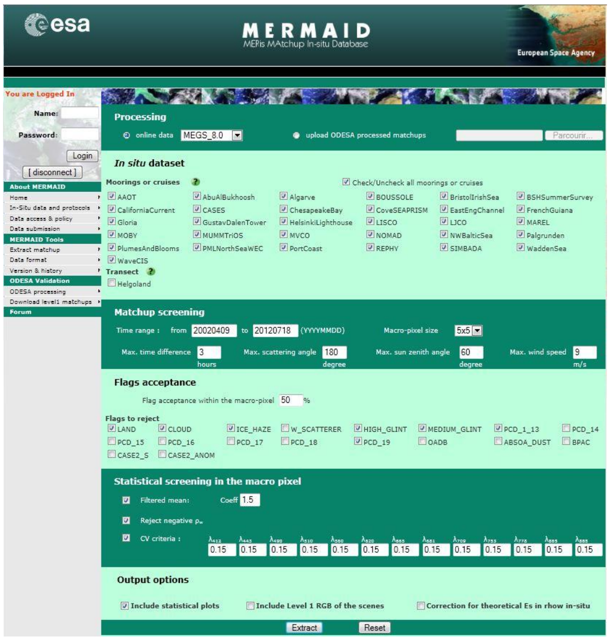

Figure 9: Screen shot of the MERMAID front page.

SeaPRISM

Fig. 10 displays a comparison at 490 *nm* between the normalized ρ_w, denoted as ρ_{wn}, extracted from the MERIS level-2 product and the in-situ values derived from water-leaving radiance measurements corrected for the sky dome reflection with the *Mobley* and new *Fresnel* reflection coefficients. Tab. 2 summarizes results of this comparison at 5 MERIS wavelengths.

Table 2: *Validation of the in-situ water reflectance in 5 MERIS spectral bands: number of in-situ data sequences (N), slope of a linear regression (MERIS versus in situ water reflectances), and r^2 for the old (standard protocol) and the new (SeaPRISM processor) set of water reflectances.*

λ (nm)	*412.5*	*442.5*	*490*	*560*	*665*
N	144	145	149	116	43
Old sky dome correction					
slope	0.820	0.882	0.920	0.928	1.003
r^2	0.802	0.848	0.880	0.949	0.947
New skydome correction					
slope	0.876	0.918	0.902	0.936	1.027
r^2	0.832	0.869	0.868	0.952	0.951

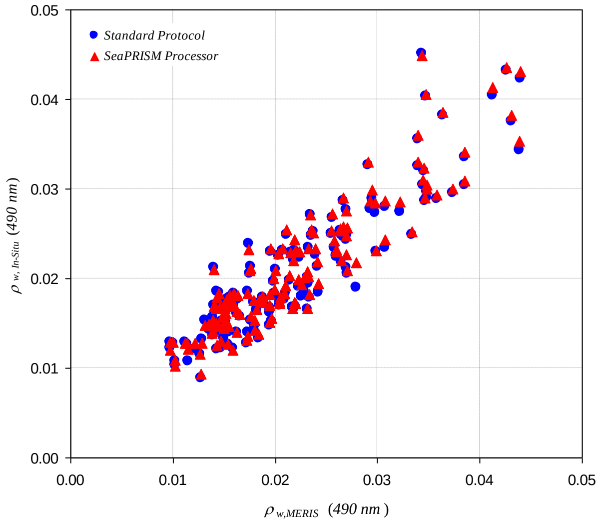

Figure 10: *Comparison between the in-situ ρ_w (derived from SeaPRISM processor and from standard protocol) and the MERIS ones at 490 nm, for the whole database extracted at AAOT from MERMAID.*

Impact of the MERIS vicarious adjustment

By using the ODESA (Optical Data processor of the ESA system) processor in its nominal configuration for the 3rd MERIS reprocessing, the water reflectances have been extracted without vicarious adjustment for the whole AAOT database included in MERMAID. Because the POLREF simulator uses the MERIS SAMs, the *Fresnel* reflection coefficient and the sky dome correction depend upon the vicarious adjustment. Fig. 11 illustrates the impact of MERIS vicarious adjustment on R_{pol}. It clearly appears that the vicarious calibration produces smaller aerosols with larger polarization at the high SZA values. Therefore, R_{pol} is in mean smaller when the MERIS vicarious adjustment is applied.

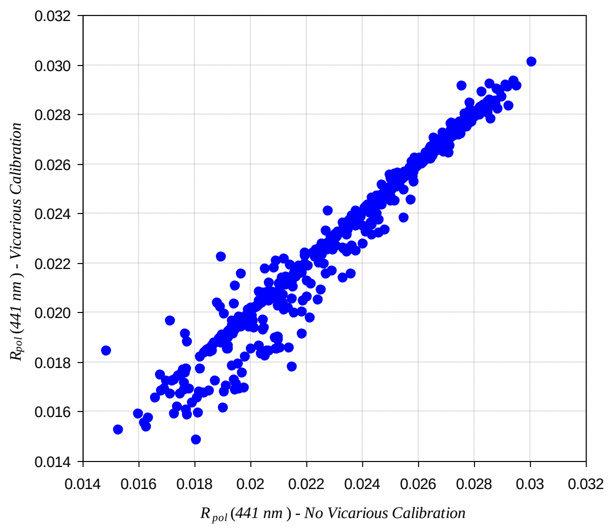

Figure 11: Comparison between the new R_{pol} computed with the SeaPRISM processor using the whole AAOT database extracted from MERMAID, by applying or not the MERIS vicarious calibration at 441 nm.

Using the same approach as in Fig. 10, the comparison between MERIS and in-situ ρ_w in the case with vicarious adjustement applied is depicted on Fig. 12. It remains difficult to conclude at least on the impact of the new ρ_w values.

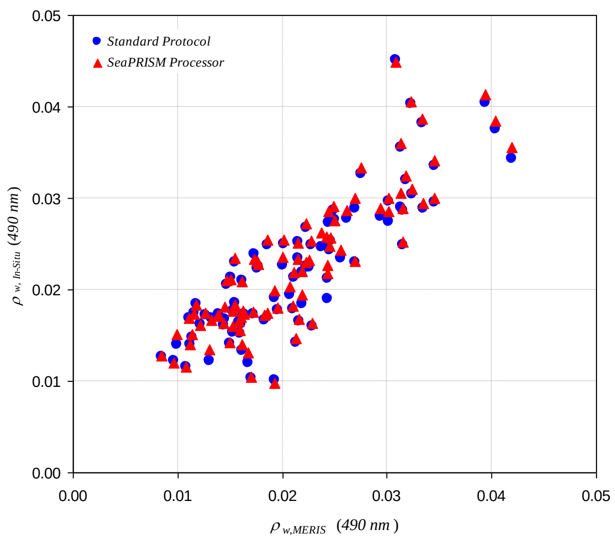

Figure 12: Same legend as in Fig. 10, but with the MERIS vicarious adjustment applied.

TriOS/MUMM

A total set of 26 in-situ data sequences collected with the TriOS/MUMM instrument over the North Sea have been selected for this analysis. Tab. 3 suggests that the impact of the new sky dome reflection correction is negligible for this data set. 25 MERIS matchups correspond to the MERMAID and ICOL criterions. If Fig 13 is the traditional approach to evaluate the performance of the MERIS atmospheric correction over water, then the new sky dome correction does not bring much on this data set: it remains difficult to distinguish the two plots.

Table 3: Slope and correlation coefficients resulting from a linear regression applied to new (TriOS/MUMM processor) versus old (standard protocol) ρ_w, for the whole database acquired over the North Sea and for each MERMAID MERIS wavelength..

λ (nm)	*412.5*	*442.5*	*490*	*510*	*560*	*620*	*665*
Slope	0.980	0.986	0.991	0.992	0.994	0.995	0.995
r^2	0.998	0.999	1.000	1.000	1.000	1.000	1.000

4 CONCLUSIONS AND PERSPECTIVES

The standard sky dome correction approach from *Mobley* clearly stresses some deviations with the new one which fully accounts for the polarization. This is well observed mostly in the blue region where the *Rayleigh* scattering dominates and may be important at the large SZA's.

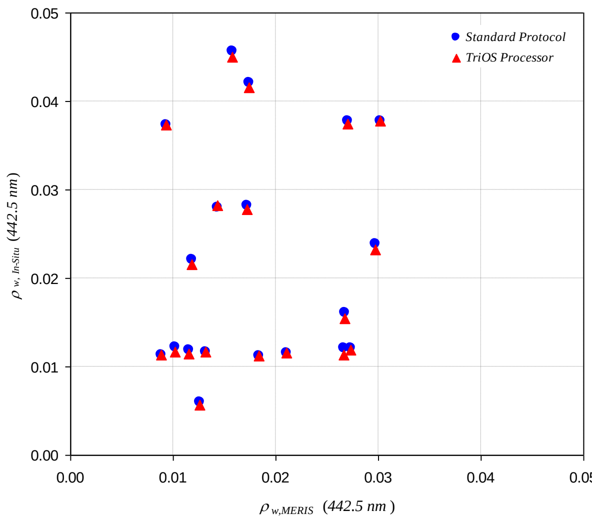

Figure 13: Comparison between the in-situ water reflectances (derived from TriOS/MUMM processor and from standard protocol) and the MERIS ones at 2 wavelengths (442.5 and 560 nm), for the whole database extracted over the North sea from MERMAID.

The MUMMTriOS dataset is not large enough to derive conclusive observations. In order to analyze a significant number of MERIS matchups (or data sequences), this new processing chain needs to be updated to other TriOS instruments at any viewing geometry, both in zenith and azimuthal directions. This is the case of TriOS instruments onboard «*ferries of opportunity*» using the same experimental protocol to get radiometric measurements above sea water. The objective would be to make this new methodology of sky dome correction available as well as the processor (source code) in order to offer the possibility to apply this new correction more widely.

For the SeaPRISM, although the validation set with the MERIS level-2 product over ocean (*i.e.*, water reflectance) is not conclusive, we have to note that the influence of the MERIS vicarious adjustment is such that it masks the impact of the new sky dome correction.

Moreover, this alternative sky dome correction is completed for the MERIS matchups in order to fulfill the need to know the aerosol optical properties (AOPs), *i.e.*, the *AOT550* and the *Angstroem* exponent. However, the CIMEL ground based instrument from AERONET being more informative on the atmospheric conditions, the SeaPRISM data processing chain could be updated with the AOPs (model and *AOT550*) derived from measurements with this field radiometer [14].

A total of 11 sites have been processed, and will soon be available to users through MERMAID: *AAOT*, *Abu Al Bukhoosh*, *CoveSEAPRISM*, *Gloria*, *Gustav Dalen Tower*, *Helsinki Lighthouse*, *LISCO*, *LJCO*, *MVCO*, and *Palgrunden*.

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