IN-SITU RADIOMETRIC MEASURMENT PROTOCOL AND DATA ANALYSIS, INCLUDING THE EFFECTS OF TILT ON DOWNWELLING SOLAR IRRADIANCE

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ABSTRACT

In support of MERIS (MEdium Resolution Imaging Spectrometer) calibration and validation activities, product evaluation and the third MERIS reprocessing, the MERIS data Quality Working Group (QWG) and the MERIS Validation Team (MVT) work closely together to provide quality-controlled in-situ radiometric matchup datasets. The MERIS MAtchup In-situ Database (MERMAID) provides a valuable, centralised tool for these activities, making available concurrent in-situ and MERIS datasets of fully normalised water reflectances, $\rho_{wn}(\lambda)$, for a wide range of water types, atmospheric parameters (e.g. aerosol optical thickness, $\tau_a(\lambda)$, and angstrom exponent, $\alpha(\lambda)$), and in-situ data flagging. MERMAID comprises in-situ ρ_{wn} from several measurement approaches and instruments, from fixed buoys and towers to floating instrumentation rigs, and necessary to the validation is an understanding of the measurement protocols followed by principle investigators (PI). As such, MERMAID is now accompanied by a document of carefully screened protocols. In collaboration with PIs, parallel analysis of protocols and matchup data identified areas of methodologies which are particularly sensitive to measurement errors. Results of such an investigation is presented here, demonstrating how the tilt of irradiance sensors can seriously affect the measurement of surface total downwelling irradiance ($E_s(\lambda)$), and have consequent impacts on the accuracy of ρ_w with potential error propagation to studies using this data. Furthermore, the study highlighted and stressed the need to investigate the potential for tilt correction of E_s.

1 INTRODUCTION

Within the framework of the European Space Agency's (ESA) MERIS data Quality Working Group (QWG) and the MERIS Validation Team (MVT) fall the calibration and validation (CalVal) activities essential for product assessment and quality assurance of MERIS, onboard the Envisat platform. Current activities are focused on the forthcoming MERIS third reprocessing, and an integral requirement of these activities is a reliable source of quality in-situ radiometric data (namely water reflectances, ρ_w) inclusive of the metadata and parameters, with concurrent MERIS matchup data. Vicarious adjustment, for instance, requires in-situ ρ_w for computations of near-infrared (NIR) and visible calibration gains. This requirement has driven the creation and development of the MERis MAtchup In-situ Database (MERMAID) [1], which provides and valuable tool for the CalVal activities, and is the only repository for MERIS:in-situ matchup acquisitions.

The database primarily consists of fully normalised water reflectances, ρ_{wn} (λ) (in-situ and MERIS), and the aerosol optical parameters (AOPs) such as aerosol optical thickness (τ_a(870, 560)) and the Angström exponent in the NIR (α(λ)). MERIS parameters, from the matchup extraction procedure for level 1b (L1b) to level 2 (L2) processing, include (in addition to ρ_{wn} and ρ_w, the aerosol model and AOPs) atmospheric scattering functions (*i.e.*, atmospheric reflectances, ρ_a ($\lambda,\theta_s,\theta_v,\Delta\phi$), the total upwelling, T_u (λ,θ_s), and downwelling, T_d (λ,θ_v), transmittances), water-vapour, ozone content, wind-speed, surface pressure, water constituents and data quality flags (MERIS and in-situ). Users may specify their own extraction criteria on a fully versatile web interface (Figure 1), for dates 2002-present and up to 14 sites including the AERONET-OC sites, NOMAD , MOBY , BOUSSOLE , SIMBADA and a number of coastal sites. Further information is available at http://hermes.acri.fr/mermaid, and in the MERIS Optical Measurement Protocols [2], which details the various measurement systems, protocols and processing of all the datasets in MERMAID. Systems include the AERONET-OC CIMEL network, handheld radiometers, TACCS (Tethered Attenuation Coefficient Chain Sensor radiometer, Satlantic), fixed buoys, and freefall profilers.

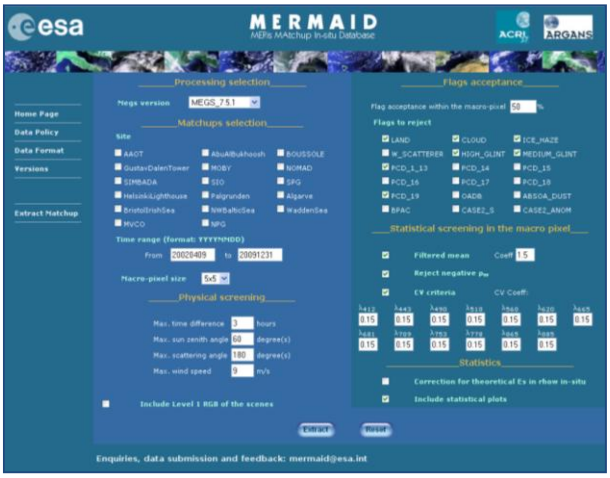

Figure 1: The versatile, user-defined MERMAID data extraction interface on the MERMAID website http://hermes.acri.fr/mermaid

Given the dependence of certain aspects of the third reprocessing on MERMAID data, it is essential to know the accuracy of in-situ ρ_w, which is inherently dependent on the surface irradiance, E_s (λ,θ_s), (Equation (1)): Preparation of the document highlighted some areas of methodologies which are particularly sensitive to measurement errors, with potential consequences for the data being included in MERMAID. In particular, the measurement of E_s, necessary for computing ρ_w, was found to be sensitive to buoy/instrument tilt.

$$\rho_w(\lambda) = \frac{\pi . L_w(\lambda, \theta_v, \theta_s, \Delta\phi_{vs})}{E_s(\lambda, \theta_s)} \quad (1)$$

in which L_w is the water-leaving radiance.

We demonstrate how inaccuracies in E_s may impact on the in-situ ρ_w , discuss current solutions to the issue and the possibility of an operational tilt correction in MERMAID in the future.

2 IMPACT OF SENSOR TILT ON SURFACE IRRADIANCE MEASUREMENTS

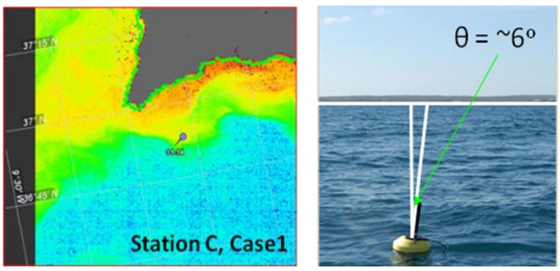

Figure 2: Approximately 6^o tilt on the TACCS buoy at, Sagres, Portugal.

The surface spectral irradiance, E_s (W.m^{-2}.nm^{-1}) collected by a horizontal flat detector at sea level is the sum of two contributions: the direct flux, corresponding to the sunlight extinction, and the diffuse flux from the scattered light by atmospheric particles (aerosols and molecules). Because of wind just above sea level and/or marine currents a surface collector may not always be parallel to a flat sea surface. In this case, the sensor is tilted in an off-nadir direction defined by (θ_t, ϕ_t), the tilt zenith and azimuth angles, respectively, and could be random due to the waves and/or systematic due to wind and currents. When sensor tilt occurs the sky contribution viewed by the irradiance collector differs from the one observed by a perfectly horizontal detector. Consequently, the tilt effect must be accounted for in the computation of the total downwelling flux. Figure 2 illustrates a case of sensor tilt with the TACCS system employed at Sagres (South West Portugal). We can see that even relatively calm waters may cause significant tilt on the sensor.

To illustrate the effect of tilt on the irradiance measurement, assume, for the sake of simplicity that for a perfectly horizontal flat detector (and omitting λ for brevity), in-situ E_s (termed 'E_{s_IS}') is defined as Equations (2) and (3):

$$E_s = F_o \cdot cos(\theta_{s\_IS}) \cdot T_d(\theta_{s\_IS}) \quad (2)$$

with:

$$T_d(\theta_{s\_IS}) = T_R(\theta_{s\_IS}) \cdot T_a(\theta_{s\_IS}) \cdot T_{O3}(\theta_{s\_IS}) \quad (3)$$

where:

- F_0 is the extraterrestrial solar irradiance [3], corrected for the square of sun-earth distance (d^2).
- θ_{s_IS} is the solar zenith angle computed (or measured) at the time of the in-situ measurement,
- $T_R(\theta_{s\_IS})$ is the total downwelling *Rayleigh* transmittance, given by [4]
- $T_a(\theta_{s\_IS})$ is total downwelling aerosol transmittance, given by [4],
- $T_{O3}(\theta_{s\_IS})$) is the ozone transmittance in the downward direction

The atmospheric functions can be extracted from the MERIS L2 atmospheric products if not available from in-situ measurements. See [5], for further details.

For a tilted collector, with small angles of zenith tilt ($\theta_t < 5^o$), the direct surface irradiance can be expressed as Equation (4):

$$E_s \approx F_0 \cdot [\ \cos(\theta_s) \cdot \cos(\theta_t) - \sin(\theta_s) \cdot \cos(\phi_s - \phi_t)\ ] \cdot t_d(\theta_s) \quad (4)$$

in which ϕ_s and ϕ_t stand for the solar and tilt azimuth angles, respectively, and $t_d(\theta_s)$ is the direct downward transmittance, defined as: $e^{-\tau/\cos(\theta_s)}$. The total optical thickness (τ) is computed as is computed as the sum of the aerosol, molecule and ozone contributions. The relative error (wavelength dependent) on E_s due to the tilt effect is thus approximated by Equation (5):

$$\frac{\Delta E_s}{E_s} \approx -tan(\theta_s) \cdot \theta_t \cdot cos(\phi_s - \phi_t) . t_d(\theta_s) / T_d(\theta_s) \quad (5)$$

In the worst case where the sensor tilt is in the solar plane, we can expect for θ_t=5^o, a relative error from 5% (θ_s=30^o) up to 15% (θ_s=60^o) on E_s by assuming that the ratio *t*/T is close to 1 for small aerosol optical thicknesses (AOT, τ_a).

2.1 ERROR ON E_s INDUCED BY SENSOR TILT

A dataset of E_s measured in-situ with a Satlantic radiometer Sagres was compared with theoretical E_s computed from MERMAID MERIS extractions, with Equation (2). Figure 3*a* displays the comparison between computed and measured E_s, in which it clearly appears that the theoretical E_s is overestimated by about 20% in relative value, whatever the wavelength. Tilt on the sensor appeared to be the cause of this error and this was verified further by simulations of E_s with tilt added, as shown in Figure 3*b*. Tilt was added in the half of the solar plane (ϕ_s- ϕ_t=0^o), and the red curve represents the E_s spectrum simulated, for a tilt angle (θ_t) of 10^o above the sun direction, while the yellow one stands for the case of a tilt of -10° below the sun direction. Deviations up to 40% in relative value clearly appear between each of these two spectra with the nominal spectrum without tilt (thin black curve). Moreover, the measured E_s spectrum (thick black curve) from the TACCS (Satlantic) remains very close to the E_s spectrum simulated with a tilt of -10°, implying that this TACCS spectrum was affected by tilt.

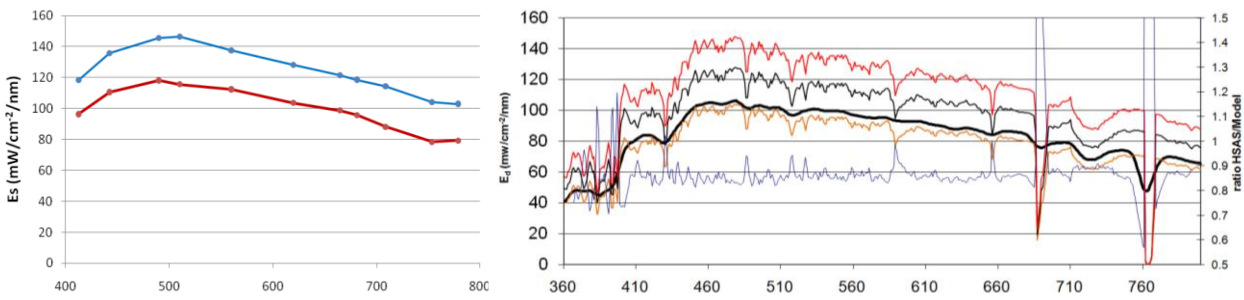

Figure 3: a) Comparison between theoretical Es value (blue line) using MERIS extractions and measured Es (red line) by a tilted irradiance collector at station 'C' (Sagres, Portugal). b) Comparison of Es measured by the TACCS buoy at station C (Sagres, Portugal) on 2nd October 2008. Legend: - in-situ E_s; *Modeled E_s with -10° tilt; Modeled E_s with +10° tilt; total E_s (modeled, no tilt); ratio in-situ: modeled (no tilt).*

2.2 PREDICTION OF TILT IMPACT ON E_s WITH RTC/SO

The impact of tilt on surface irradiance has been further investigated [6] with a more physical approach based on the use of a radiative transfer code (RTC), accounting for both the polarisation and the coupling between the wind-roughened sea surface. This method employs the Successive Orders (SO) of scattering code to compute separately the two contributions of E_s: the direct solar flux (Φ_D) corresponding to the attenuated part of the solar beam weighted by the cosine of the incident angle to the collector (θ_t), and the diffuse flux (Φ_d) from the scattered light by the atmospheric particles (aerosols and molecules). The RTC/SO solves numerically the radiative transfer equation within the coupled ocean-atmosphere system by expanding the radiance field (L) into a Fourier series as function of the azimuth (ϕ). Simulations were made of the total downwelling irradiance ($E_s = \Phi_D + \Phi_d$) at bottom of the atmosphere for a realistic maritime atmosphere (MAR90 + Continental +H_2SO_4) with two AOT-550 (0.2 and 0.5) over a wind-roughened black sea surface (ws=3 m/s), which would be measured by a horizontal flat sea detector and a tilted collector. The relative error ($\Delta E_s/E_s$) in the surface irradiance (E_s) has

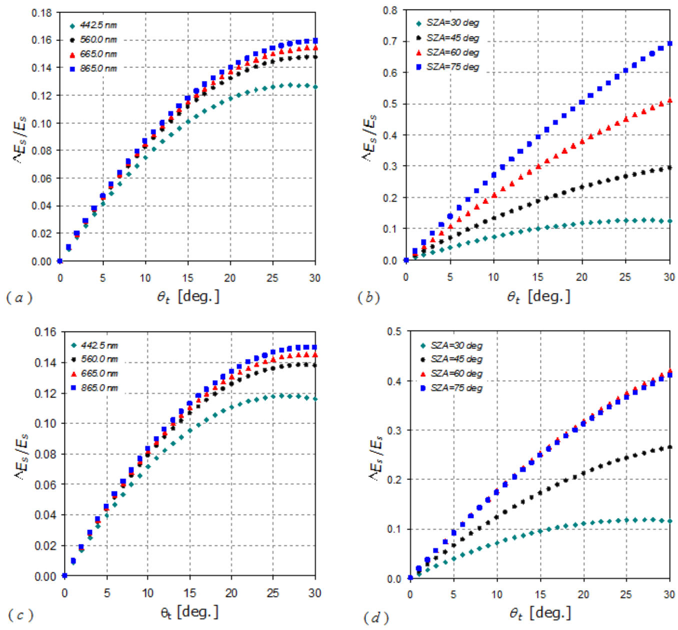

Figure 4: Relative error ($\Delta E_s/E_s$) on surface irradiance caused by a sensor tilt (φ_t) ranged within [0; 30o] included in solar plane (φ_t = 0°) for the backscattering region. Simulations are completed with the SO code: a, c: for θ_s=30° and 4 wavelengths, where τ_a(550)=0.2 ; b, d: for 442.5 nm and 4 θ_s and where τ_a(550)=0.5.

been then computed between the tilted collector and the horizontal flat detector.

Results displayed in Figure 4 clearly stress that the relative error in E_s, and consequently in water reflectance (ρ_w), increases with the tilt angle, whatever the atmosphere and the solar zenith angle. As expected, for a given tilt larger the θ_s is and greater will be this error on E_s. Moreover, while the aerosol loading (aerosol optical thickness) increases in the atmosphere the increasing of the surface diffuse irradiance remains less sensitive to the tilt.

In summary, the above observations (Figures 3 and 4) indicates that data submitted to MERMAID might contain serious errors that will propagate through to ρ_w and to any models using in-situ E_s and/or ρ_w and it is therefore essential to any downstream uses of MERMAID to ensure the best quality data.

3 SURFACE IRRADIANCE AND WATER REFLECTANCE IN MERMAID DATASETS

3.1 E_s RATIO: IN-SITU TO MERIS

PIs provide to MERMAID their E_s data along with the ρ_w and L_w. E_s is not retained in the database, but as explained later, it is used to generate a new parameter, ρ_{wn_ISME} (ρ_w computed from MERIS derived E_s). ρ_{wn_ISME} can then be used to study the ratio between E_{s_IS} and E_{s_MERIS} from which we can identify potential tilt impacts – the close the ratio is to 1, the closer is it to the theoretical E_s value which corresponds to the MERIS E_s. To make clear the two different E_s values in-situ E_s is hereafter termed E_{s_IS} and MERIS E_s is termed E_{s_MERIS}. As an example of the possible accuracy, the majority of the non-buoy AAOT site E_s matchups (computed as in Equation (2)) fall within a relative error of ±10% (Figure 5), but for other sites such as at Sagres errors may reach ± 20% (as in Figure 2) due to the tilt.

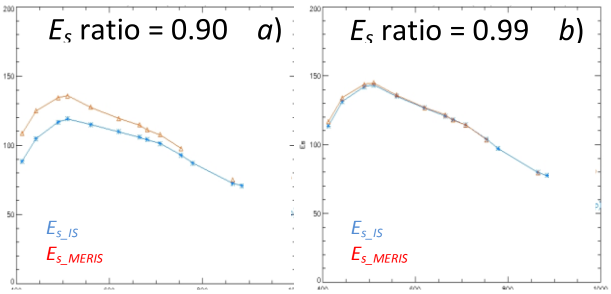

Figure 5: Comparison between $E_{s\_ISME}(\lambda)$ computed with MERIS transmittance LUTs and $E_{s\_IS}(\lambda)$ measurements over AAOT a) E_s ratio is 0.90 (10%) and b) E_s ratio is 0.99 (1%).

A preliminary analysis of the ratio between E_{s_IS} and E_{s_MERIS} was made for 2 sites for which tilt is a potential issue, MOBY and Sagres. The analyses completed so far led to MERMAID evolution and aided the activities in the CalVal operation for MERIS.

The sites have a varying range of bandsets, none reaching into the NIR but providing good coverage of the blue and green MERIS bands. E_s is measured in-situ at both sites, and in the MERMAID matchup process the MERIS E_s is exactly determined at sea surface level using the atmospheric look-up tables (LUTs) implemented in the MERIS processor, and interpolated to the θ_s corresponding to the time of the matchup to compute T_d (i.e. in-situ $T_d = T_{d\_MERIS}{}^{(\cos(\theta s\_MERIS)/\cos(\theta s\_in\text{-}situ))}$). The LUTs, which comprise $T_d(\lambda,\theta_s)$ and $T_u(\lambda,\theta_v)$, have been generated with the RTC/SO code for a set of 16 standard aerosol models (SAMs), a set of 7 AOT-550 values including the full Rayleigh case. MERMAID extractions are 5x5 pixels and from the second MERIS processing version (MEGs 7.4), and include ρ_{wn_ISME} .The MERMAID extractions were filtered for cloud, and a range of ratios was selected to capture the assumptions of tilt up to 10^o. For instance, for a tilt angle of 10^o we can expect a 10% of error in relative value for $\theta_s=30^o$ and 30% for $\theta_s=60^o$. No θ_s exceeds 60^o for MOBY or Sagres, so this 30% range is a logical selection if we assume that the error does not come from the atmosphere (i.e. mainly the aerosols), as explained later.

Figure 6a displays the spectral E_s ratio averaged for over 600 pixel extractions at Sagres between 2008 and 2009, for τ_a values 0 – 0.8 and for $\theta_s \leq 60^o$. The error bars are of 1 standard deviation and describe the dispersion around the mean value of E_s ratio. Whatever the wavelength, E_{s_IS} is overestimated by about 20% of the theoretical value of E_{s_MERIS} in mean value, and discrepancies can reach up 40% at 708.75 and 753.75 nm, inferring that this E_s dataset was acquired with sensor tilt larger than 10^o. Figure 6b shows mean values of E_s ratio for MOBY, for over 12,000 pixel extractions between 2005 and 2008, and for τ_a values 0 – 2 and $\theta_s \leq 60^o$. Here, almost all ratios fell within the 30% error range; there is a good agreement between the E_{s_IS} measurement and the theoretical value with mean E_s ratios very close to 1. Except for the 560 and 620 nm the dispersion on the E_s ratio remain lower than 20%, which largely includes the impacts caused by tilt up to 10^o. At MOBY the data is filtered to remove tilt beyond 5%, so the increased ratios may imply error from other sources. At Sagres, we know a large contribution to these ratios come from tilt, as the measurements were made before the tilt was identified as a problem at this site.

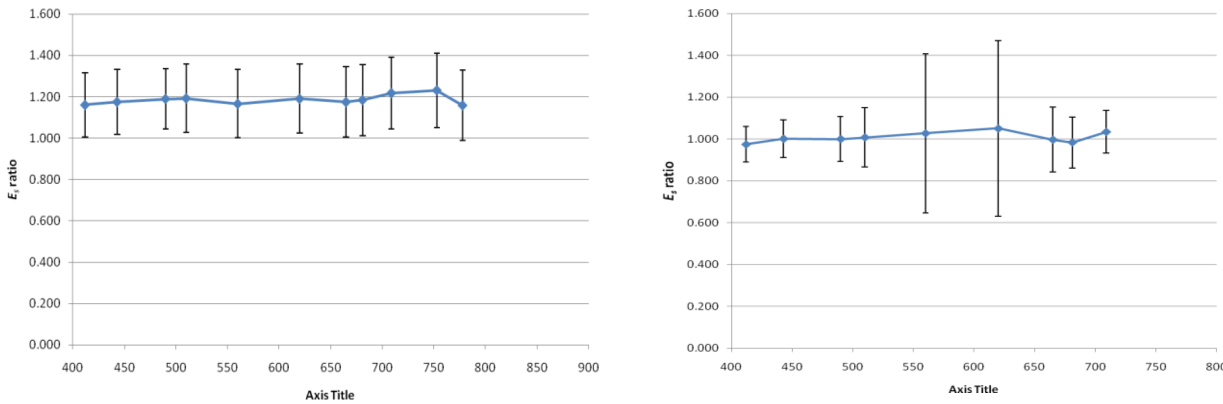

Figure 6: E_s ratio means and variation (1 standard deviation) at a) Sagres and b) MOBY.

From Figure 7 we can infer that the atmospheric condition has some influence on the E_s ratios observed, that might remove some dependence on tilt as a source. For small aerosol optical thickness the diffuse part of the incoming light field is due to molecular diffusion and can be considered isotropic, at least for the sake of the argument, so the assumptions behind Equation (5) are verified. When the aerosol optical thickness increases, the anisotropy of the diffuse incoming light field increases, and the results have to be interpreted with the more complete analysis developed in section 2.2.

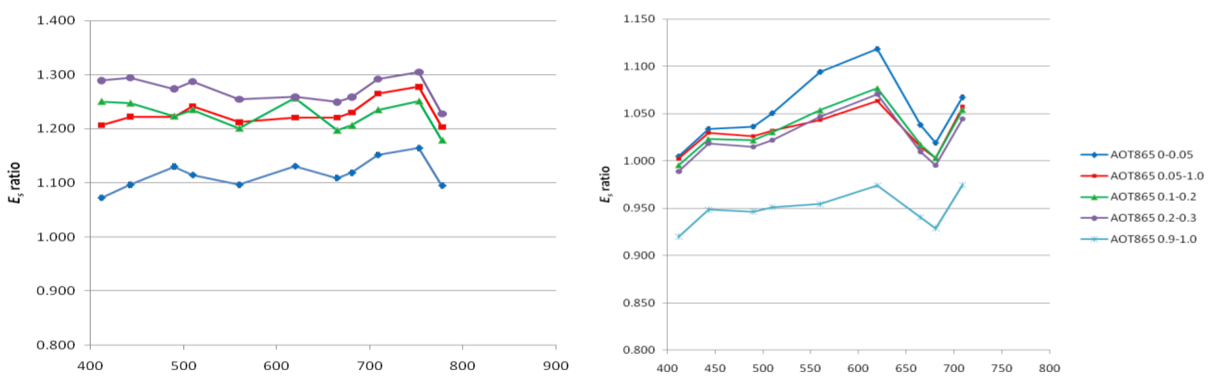

Figure 7: Relationship of E_s ratio with $\tau_a(865)$, the aerosol optical thickness at 865nm at a) Sagres and b) MOBY.

These results represent an initial analysis of the MERMAID datasets and more work is to be done. However, it exemplifies the problem and raises the following issues:

- Even with no tilt, a mean E_s ratio different from 1 would still be expected (as shown in FIG AAOT), because there maybe calibration/installation issues with the E_s sensor (~3-4%) and ~5% due to the fact that the MERIS transmittance can differ from the real atmospheric one. Discrepancies observed between E_{s_IS} and E_{s_MERIS} stress the difficulty to get an agreement between the in-situ and MERIS acquisitions. The stability of the atmospheric conditions relies on the aerosol variability; therefore, as observed over AAOT, the difficulty in achieving good agreement may be also explained by the temporal and spatial variability of aerosols over a given site, during concurrent acquisitions (MERIS and in-situ) even if they were close in time
- Random excursions of the ratio away from the mean infer tilt.
- The mean of E_s during a measurement sequence does not remove tilt effects, even in the absence of mean tilt.
- Further relationships of E_s ratio should reveal more, such as that with θ_s and seasonality and also with the atmospheric extractions from MERIS.

3.2 ρ_{wn_ISME}: CONSISTENCY WITH MERIS IN MERMAID

As a consequence of initial studies of E_s the importance of consistency with MERIS L2 definitions was recognised and the new parameter recently included in MERMAID: ρ_{wn_ISME} (λ) (where '$_{IS}$' is for 'in-situ' and '$_{ME}$' is for 'MERIS'). This new reflectance parameter is derived from the ratio of the in-situ E_s (E_{s_IS}) and MERIS equivalent surface irradiance (E_{s_MERIS}) as in Equation (6):

$$\rho_{w\_ISME}(\lambda) = \rho_{w\_IS}(\lambda) \cdot \frac{E_s^{IS}(\lambda)}{E_s^{MERIS}(\lambda)} \qquad \textbf{(6)}$$

ρ_{wn_ISME} is fully normalised and is included in MERMAID in parallel to ρ_{wn_IS} and at the same 13 bands. In this way all in-situ water reflectances are given the same definition in MERMAID and the MERIS vicarious adjustment is based on this homogeneous dataset. This approach, currently considered as the most appropriate for MERMAID, negates error propagation through to ρ_w. Additionally, the separate in-situ components used to compute ρ_w, i.e. L_w and E_s (either computed as in Equation (2) or measured) are also collected from the PI. For the sites using the CIMEL sun-photometer instruments (namely AERONET-OC), an extra stage was included to the pre-matchup processing: E_s is computed as in Equation (2).

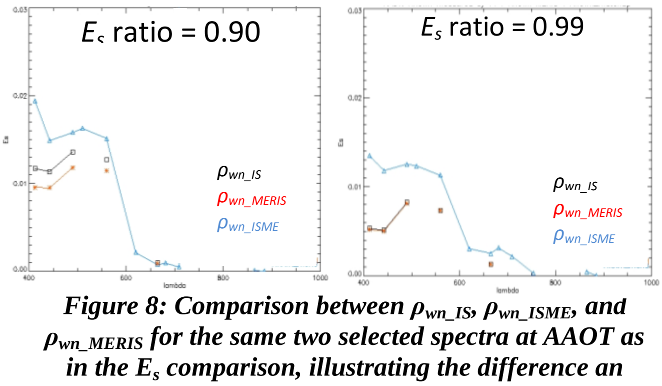

Figure 8: Comparison between ρ_{wn_IS}, ρ_{wn_ISME}, and ρ_{wn_MERIS} for the same two selected spectra at AAOT as in the E_s comparison, illustrating the difference an adjustment with the E_s ratio may induce, even for measurements without tilt. **impact.**

As an example of this adjustment, Figure 8 shows, using the same matchup spectra as in Figure 6 the difference between ρ_w and ρ_{wn_ISME}, i.e. the difference induced by the E_s ratio adjustment. The larger the relative error on E_s the greater will be the adjustment, and although relative errors observed over AAOT are largely lower than 5%, for $\rho_{wn}(\lambda)$ at other sites, this may prove significant and ultimately necessary to bring in-situ $\rho_{wn}(\lambda)$ in-line with the MERIS definitions.

3.3 IN_SITU DATA FLAGGING

Two flags have been designed and implemented in MERMAID to define the level of quality control (QC) applied to the in-situ data. The MQC (Measurement Quality Control) flag defines the quality control checks and protocol aspects of the PI, prior to submission. The PQC (Processing Quality Control) flag defines the post-submission quality control, one of which indicates the extent of error on E_{s_IS} based on the ratio with E_{s_MERIS}. Five options for the flag are available (Table 1).

Table 1: PQC flag 5 criteria for the E_s ratio – used as the indication of error on E_s_IS and so on ρ_{wn_ISME}

PQC flag 5 String	*Range of error in % based on E_{s_IS} / E_{s_MERIS}*
0	no in-situ E_s data available
1	[15 – 20]
2	[10 – 15]
3	[5 – 10]
4	[0 – 5]

3.4 TILT CORRECTION POTENTIAL

At present no correction for the tilt impact is carried out in the MERMAID data processing; however tilt correction of E_s is potentially feasible to obtain reliable estimates of E_s. As an approximation of sensor tilt effect two E_s measurements with and without sensor tilt and close enough in time to consider the same acquisition conditions would be needed (i.e. the in-situ atmosphere and sea surface state). A corrective factor can then be computed as the ratio between these two measurements to be applied to other E_s measurements acquired in the *same* conditions. However, this represents a crude approximation that cannot be systematically used for all sites. Further, tilt correction requires information about the azimuth and zenith tilt angle and direction, and presently little information is known regarding some of the in-situ measurement systems.

A more feasible option for operational tilt correction to be implemented in MERMAID would be the use of a synthetic database composed of LUTs of downwelling diffuse fluxes generated at the 15 MERIS bands. The RTC/SO better accounts for the coupling between the wind-roughened sea surface and the atmosphere. The MEROS database [7] is a subset of these LUTs, composed with LUTs of sky radiances at bottom of the atmosphere (BOA) and of reflected sky radiances by wind-roughened black sea surfaces, and of the diffuse irradiances for computing corrective factors of tilt. MEROS is particularly relevant for studying the aerosol influence and the impact of sea surface roughness on the tilt of an E_s collector. For a MERIS matchup, if unavailable in-situ, the L2 product provides all the required aerosol (aerosol type and model, α,τ_a) and surface (w_s, ρ_w) parameters to apply a correction of the surface irradiance measurements for the tilt effect at any site by using this synthetic database. Thus, the atmospheric transmittances, with and without tilt may be predicted, and a simple weighting (*i.e.*, a corrective factor) computed as the ratio between theses transmittances applies to the measured E_s. A tool is under development for computing this, using as input the aerosol parameters and surface parameters, and will be soon implemented in the MERMAID in-situ data processing.

4 DISCUSSION AND CONCLUSIONS

Bio-optical modelling of in-situ parameters relies on ρ_w for inherent optical property modelling and computation of, for example, chlorophyll-a. Without E_s this is difficult to do, and it becomes essential to ensure the best quality in-situ E_s data. Requesting the E_s from PIs is a necessary addition to MERMAID QC processing and can be used with MERIS L_w to create an ideal and consistent parameter, ρ_{wn_ISME}. Knowledge that tilt may impact E_s measurement is not new; however, this initial analysis of the E_s ratios and the realisation of error potential indicates a need to understand further the measurements in the database, with a view to maximising quality for the MERIS CalVal activities. Inclusion of ρ_{wn_ISME} in MERMAID as an initial precaution was important for in the evolution of the QC of the MERMAID database, and any downstream use of MERMAID will benefit from this additional stage in the QC process.

At present, the best approach to be adopted for MERMAID is to make the database consistent with MERIS processing, by using E_{s_MERIS} and the ratio with $E_{s\_IS,,}$ and including ρ_{wn_ISME}. This was an important and timely inclusion, in regard to the third MERIS reprocessing and quality checking in regard to the downstream application. For example, the MERIS vicarious adjustment studies have found comparable results in visible gains computation between use of ρ_{wn_IS} and ρ_{wn_ISME}; however, only those data with lower than 10% E_s ratio are selected. ρ_{wn_ISME} presents the advantage of consistency with MERIS, accuracy due to LUT use, and it standardises the datasets which derive from a variety of sources. Furthermore, it provides the basis for tilt correction, for which MEROS presents a potentially viable approach for systematic, operational implementation MERMAID and additional an additional QC stage. Investigations will continue into this, and it is a recommendation that where tilt angles (azimuth and zenith) are measured and available, that they are also provided to MERMAID as ancillary information.

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