APPARENT OPTICAL PROPERTIES OF THE AEROSOLS FOR MERIS/OLCI-SENTINEL-3: SELECTION OF BEST LUTS FOR ATMOSPHERIC CORRECTION OVER OCEAN

Francis Zagolski [1], *Richard Santer* [2,4], *and Ouahid Aznay* [3]

[1] *PARBLEU Technologies Inc., 79 Veilleux street, St Jean-sur-Richelieu (QC), J3B-3W7 – CANADA.*
E-mail: Francis_Zagolski@yahoo.ca

[2] *ADRINORD, Association pour le Développement de la Recherche et de l'Innovation dans le bassin du Nord-Pas-de-Calais, 2 rue des Cannoniers, F59000, Lille – FRANCE.*
E-mail: Santer.Richard@yahoo.fr

[3] *C-S Systèmes d'Information, ZAC de la Grande Plaine, F31506, Toulouse –FRANCE.*
E-mail: Ouahid.Aznay@c-s.fr

[4] *ULCO, Université du Littoral Côte d'Opale, MREN, 32 avenue Foch, Wimereux, F62930 – FRANCE.*
E-mail: santer@univ-littoral.fr

ABSTRACT

Performing a classical atmospheric correction over water requires a well defined climatology representative of the aerosols encountered in the remote areas of oceans. Different climatologies built at the global scale are candidate to be implemented as an auxiliary data file (ADF) including look-up tables (LUTs) of radiative properties of the aerosols. In addition to them, two regional climatologies have been also developed in the 2-Seas region comprising both the Eastern English Channel and the North Sea, and at the Acqua Alta Oceanographic Tower (AAOT) in the Adriatic Sea.

By using the optical data processor of ESA (ODESA), the MEdium Resolution Imaging Spectrometer (MERIS) level-1 data extracted from the MERis MAtchup In-situ Database (MERMAID) have been processed to get the level-2 product. For a given climatology, a processing chain has been fully developed, to generate the MERIS aerosol LUTs compatible with ODESA.

The final step consisted in an analysis of the level-2 products, both for the aerosols and the water reflectance in the frame of the evaluation of the performance of each climatology in the atmospheric correction over oceans.

1. INTRODUCTION

In the aerosol remote sensing algorithm over ocean, the models are deduced from the spectral dependence of the path radiances in the near-infrared (NIR) region. The approach relies on the fact that the water-leaving radiance can be assumed negligible in the NIR spectral bands because of the high absorption coefficient of seawater. Thus, the signal measured at top of the atmosphere (TOA) in the NIR spectral bands carries information on the atmospheric layer only, and can be used to estimate the aerosol inherent optical properties (IOPs) described by the aerosol optical thickness (AOT, denoted as τ_a) and its spectral dependence (*i.e.*, the *Angström* exponent referred as α), defined as:

$$\alpha(\lambda,\lambda') = \frac{\log(\tau_a(\lambda)/\tau_a(\lambda'))}{\log(\lambda/\lambda')} \quad (1)$$

with λ and λ', the given and reference wavelengths used for the computation of α.

Based on these derived optical properties, the atmospheric signal is then extrapolated from the NIR region to the shorter wavelengths in the visible (VIS) domain. The accuracy of such a classical atmospheric correction scheme is then directly related to the ability of the aerosol model to well describe this spectral dependence [1]. A well defined climatology, representative of the aerosols encountered over oceans, is then required for such an atmospheric correction.

Different climatologies are candidate to be implemented as an auxiliary data file (ADF), comprising look-up tables (LUTs) of radiative properties of the aerosols, in the MERIS (MEdium Resolution Imaging Spectrometer) atmospheric correction algorithm over ocean: (*i*) the standard aerosol models (SAMs) completed by the DUST ones used in the last 3rd MERIS reprocessing [2], (*ii*) the new set of AERONET (AErosol RObotic NETwork [3]) derived models characterized by their micro-physical properties [4], and (*iii*) the new set of AERONET derived models described through their IOPs [5]. Both the last two sets have been processed with the MERIS Auxiliary data Tool (MERISAT) [6][7] for generating these «*Ocean-Aerosol*» ADFs for the MERIS Ground-Segment (MEGS) data processing prototype.

The MERIS level-1 data have been extracted from the MERis MAtchup In-situ Database (MERMAID) [8], to be processed through the optical data processor of ESA (ODESA), in order to get the level-2 products. The Acqua Alta Oceanographic Tower (AAOT, Venice - Italy), being a reference station for MERIS Cal/Val activities, this site will be then selected to evaluate the MERIS level-2 aerosol product as well as the retrieved marine reflectance, obtained for each of the three sets of «*Ocean-Aerosol*» ADFs.

2. GENERATION OF MEGS-ADF FOR ODESA

2.1. Input file with aerosol IOPs

Tab. 1 provides the name used for each of the aerosol families considered in this study, as well its origin (or reference) and its family number (i_{fam}).

The SAM family includes the 12 models from *Shettle and Fern* (*i.e.*, maritime, coastal and rural models with four relative humidities (RH): 50%, 70%, 90% and 99%), a particulate model (whiter than white) with a MAR99 (RH=99%) in the boundary layer and a free-aerosol upper atmospheric layer [2], and the so-called «*blue*» aerosol models to account for the strong spectral dependence of the AOT. The three «*blue*» aerosols have been extracted with an approach combining the micro-physical properties through the introduction of standard modes (accumulation mode and coarse mode) and an analysis of the AERONET data to define the mixing ratio [9]. All these models are fully described by their micro-physical properties and their IOPs (*i.e.*, scattering phase function, extinction coefficient, and single scattering albedo), have been pre-computed with the *Mie*'s theory in the 15 MERIS spectral bands.

The IOPA family consists in 16 α-classes of aerosols built through an analysis of the AERONET database at a global scale. In summary, 25 stations over ocean and coastal areas have been selected over the world to collect a huge amount of CIMEL data sequences during the period from 1998 to 2003. These radiometric measurements were composed of solar extinctions and sky radiances both in the solar plane and in the almucantar geometry. All these sequences have been inverted with our aerosol phase function retrieval (APFR) algorithm (namely, WOPAER [10]) to get a very large database of aerosols IOPs over oceans. A classification in aerosol models through their IOPs has then been suggested using filtering techniques and statistical methods [5].

For the other families, the aerosol models correspond to two analyzes of the AERONET database at a regional scale: *i.e.*, at the AAOT site (Venice, Italy) and in the 2-Seas region comprising the Eastern English Channel and the North Sea. The first three families (AEROPA) are built using the IOPs as provided by the AERONET inversions [11], whereas the last three ones (WOPAER) are derived from the direct inversions of AERONET measurements with our APFR tool. Each climatology is finally built into 16 α-classes [12].

For both the last seven families, the IOPs were provided at three wavelengths (440, 675 and 870 *nm*). A spectral interpolation has then been applied to get them at the 15 MERIS wavelengths. While a spectral linear interpolation was achieved on the IOPs for the IOPA classes, a spectral spline interpolation was employed for the others.

Table 1: The aerosol families (denomination, reference and numbering).

Family name		*Reference*	i_{fam}
SAM		[2][9]	1
IOPA		[5]	2
AEROPA	*mean*	[12]	3
AEROPA	*max*	[12]	4
AEROPA	*min*	[12]	5
WOPAER	*mean*	[12]	6
WOPAER	*max*	[12]	7
WOPAER	*min*	[12]	8

According to the climatology provided by the AOT, the more likely value of α is -1.6. It corresponds to RUR70 (*i.e.*, the rural model with RH=70%) in the SAM family and to the class #11 for the other ones. In the NIR region, the MERIS aerosol reflectance (ρ_{aer}) is extracted from the TOA reflectance. ρ_{aer} is proportional to the aerosol phase function time the AOT ($\tau_a P_a$). For this type of aerosols, Fig. 1 clearly stresses that the aerosol phase functions (P_a) in the MERIS band #13 (865 *nm*) remain close to each other, when comparing what we got from the AERONET database at the global scale (IOPA) or at AAOT from AEROPA and WOPAER. The rural phase function is substantially below mainly in the backward scattering. RUR70 is close to the minimum values of AEROPA and WOPAER. On a practical point of view, it means that MEGS should overestimate the AOT for these coastal aerosols.

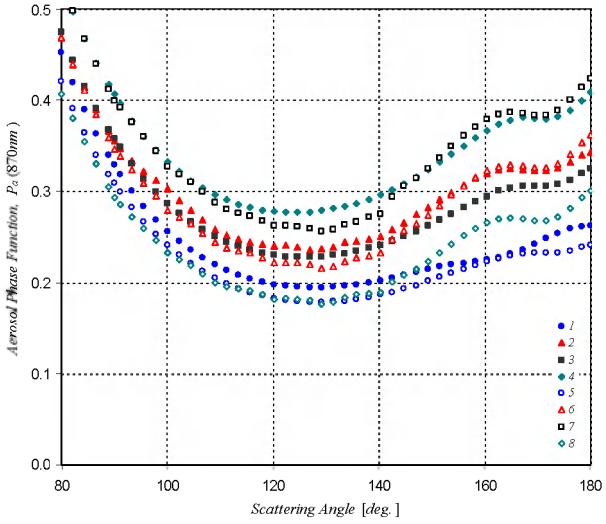

Figure 1: Aerosol phase function at 870 nm versus the scattering angle, for each of the 8 models associated with class #11 in the 8 aerosol families.

The performance of the atmospheric correction has not to be judged on the retrieval of the AOT but on the possibility to predict ε, the spectral dependence of the

aerosol reflectance, from the blue region towards the NIR domain, which is defineds as:

$$\varepsilon(\lambda,\lambda') = \frac{\log(\rho_a(\lambda)/\rho_a(\lambda'))}{\log(\lambda/\lambda')} \quad (2)$$

More exactly, the aerosol reflectance (ρ_{aer}) is extracted in the NIR domain, and the issue would consist to estimate it correctly in the blue region. In the primary scattering approximation, ρ_{aer} is proportional to $\tau_a.P_a$. Fig. 2 displays the multiplicative factor to apply to ρ_{aer} in MERIS band #13 (865 *nm*) in order to get it in band #2 (442.5*nm*). It clearly appears that RUR70 overestimates the atmospheric correction while the models derived from AERONET well compare.

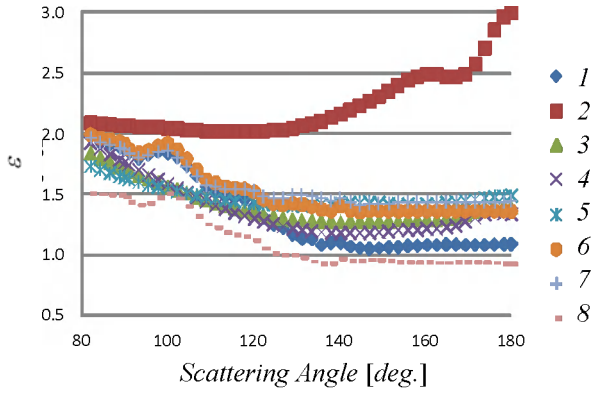

Figure 2: Ratio of aerosol reflectances between the MERIS band #2 (442.5 nm) and #13 (865 nm) versus the scattering angle, for each of the 8 models associated with class #11 in the 8 aerosol families.

2.2. RTC/SO

The successive orders of scattering (SO) code [13][14] has been used to produce the aerosol apparent optical properties (AOPs): *i.e.*, the path atmospheric radiances and transmittances computed in the 15 MERIS spectral bands, for all the 8 aerosol families, using a set of 7 AOT550's (*i.e.*, 0, 0.01, 0.03, 0.1, 0.3, 0.5, 0.8). The difference between the SAMs and the other families is in the vertical profile of the aerosols. For the SAM family, the two upper layers are frozen (*i.e.*, the troposphere and the stratosphere are optically fixed with respectively, continental and H2SO4 aerosols). The 16 SAMs are in the boundary layer below an altitude of 2 *kms*. For the other climatologies, because the AERONET measurements are integrated values for the whole atmospheric column, then only one model has been considered for both the three aerosol layers (*i.e.*, boundary layer, troposphere and stratosphere), keeping the same fixed value of AOT550 in the upper atmosphere as for the SAMs. The potential impact of this vertical structure is foreseen in the blue region.

MERISAT [6][7] is the suitable tool both to generate the MERIS LUTs with the AOPs and to format the «*Ocean-Aerosol*» ADFs for the MEGS processor.

2.3. Generation of MERIS level-2 data with ODESA

The whole MERIS level-1 data archive have been extracted from MERMAID for the AAOT site and the the stations located in the 2-Seas region (*i.e.*, Eastern English Channel, Helgoland, MAREL, MUMMTriOS and SIMBADA). Using the default processor (MEGS-v8.1) implemented in ODESA, each matchup has then been processed within a (5x5) pixels window in reduced resolution (RR) mode, without applying the vicarious adjustment in order to unmask the impact of the climatology selected for the atmospheric correction. Thus, we got as outputs the MERMAID level-2 data files for all the matchups and for each of the 8 aerosol families.

2.4. Generation of the new MERMAID data files

The MERMAID level-1 data file to be processed with ODESA, does not include (*i*) the *in-situ* radiometric measurements acquired with the field sensor such as the SeaPRISM radiometer and the TriOS instrument, and (*ii*) the MERIS normalized water reflectance (*i.e.*, for a Sun at zenith and a nadir view geometry). Because these information are stored in the MERMAID level-2 data file, then we proceeded to this level-2 extraction (using the MEGS-v8.0 processor) for each matchup within a MERIS-RR (5x5) pixels window, in order to copy these *in-situ* radiometric values in the ODESA level-2 data file (*i.e.*, into a new MERMAID data file). More, a correction for the bidirectionality effect in the normalized water reflectance has been achieved on the MERIS water reflectance (*RHOWN*) from the MEGS-v8.0 level-2 data file by applying the ratio between the MERIS water reflectances (*RN*) derived from MEGS-v8.1 and MEGS-v8.0. At the end, we get a new standard MERMAID level-2 data file without vicarious adjustment for each of the 8 «*Ocean-Aerosol*» ADFs.

To make easier the analysis, we generated on the MERIS level-1 & 2 data, three output files including some statistics, based on the selection criterion used in the MERIS validation of the water reflectance: *i.e.*, no '*land*', no '*cloud*', no '*ice-haze*', no '*white-scatters*', no '*high-glint*', no '*medium-glint*', no '*PCD-13*' and no '*PCD-15*'. Once this filtering applied, the following three files have been provided with: (*i*) the number of pixels used for each MERIS product, (*ii*) their averaged values and (*iii*) their standard deviation values. The last data file offers the possibility to apply *a posteriori* selection criterion on the spatial homogeneity within the MERIS-RR (5x5) pixels window.

3. EVALUATION OF IMPACT OF OCEAN-AEROSOL ADF ON LEVEL-2 PRODUCTS

3.1. TheAAOT databases

Starting with a total of 1078 matchups concurrent to the MERIS overpassess, and after applying the filtering

as described above and the need to get the *in-situ* atmospheric measurements, we got finally 152 match-ups over AAOT as reported in Tab.2. Statistics displayed on the AOT at 870 *nm* (AOT870) indicates that most of the *in-situ* acquisitions have been completed under very clear-sky conditions knowing that the limit to perform the atmospheric correction is for an AOT550 of 0.8. As for the spectral dependence of the AOT, the *Angstroem* exponent (α) in NIR is characteristic of the coastal aerosols.

Table 2: Number of selected matchups (N), mean and rmse on the AOT at 870 nm, and on the Angstroem exponent (α) in the NIR region, over the AAOT site.

N	*AOT870 (mean)*	*AOT870 (rmse)*	*α (mean)*	*α (rmse)*
152	0.077	0.050	1.385	0.921

3.2. Evaluation of the aerosol product

The MERIS aerosol product provides the AOT at 865 *nm* and α(779,865). As a break point, the AOT550 is suggested here. The level-2 aerosol products are then generated for the SAMs, IOPAs and the three regional AEROPAs (*mean*, *min*, *max*). We observed that the three regional IOPAs are similar to the AEROPAs.

The AERONET measurements correspond to the AOT at 440, 675 and 870 *nm* for two sets of acquisitions which bracket the time of the MERIS overpass. The AERONET data are matched with the MERIS AOTs with: (*i*) a temporal interpolation at the time of the MERIS overpass, (*ii*) a spectral interpolation on the AOT between 675 and 870 *nm* to get the two AOTs at 778.75 and 865 *nm*, and (*iii*) a spectral interpolation on the AOT between 440 and 675 *nm* to get the AOT at 550 *nm*.

According to Tab.3, MEGS clearly overestimates the AOT with the SAM family both in the NIR and blue regions. The results are much better with the aerosol models derived from AERONET both on the mean and on the dispersion, even if they are far to be perfect.

Table 3: Number of matchups (N), mean ratio and rmse (σ) on the AOT between MERIS and AERONET at 865nm (upper set) and at 440 nm (lower set). Results are reported for a total of 5 different sets of MERIS «Ocean-Aerosol» ADFs.

	SAM	*IOPA (global)*	*AEROPA mean*	*AEROPA max*	*AEROPA mean*
N	157	156	153	154	155
mean	1.82	1.37	1.38	1.35	1.41
σ	1.02	0.71	0.66	0.66	0.67
N	149	148	146	148	146
mean	1.50	1.48	1.17	1.14	1.21
σ	0.50	0.54	0.29	0.29	0.30

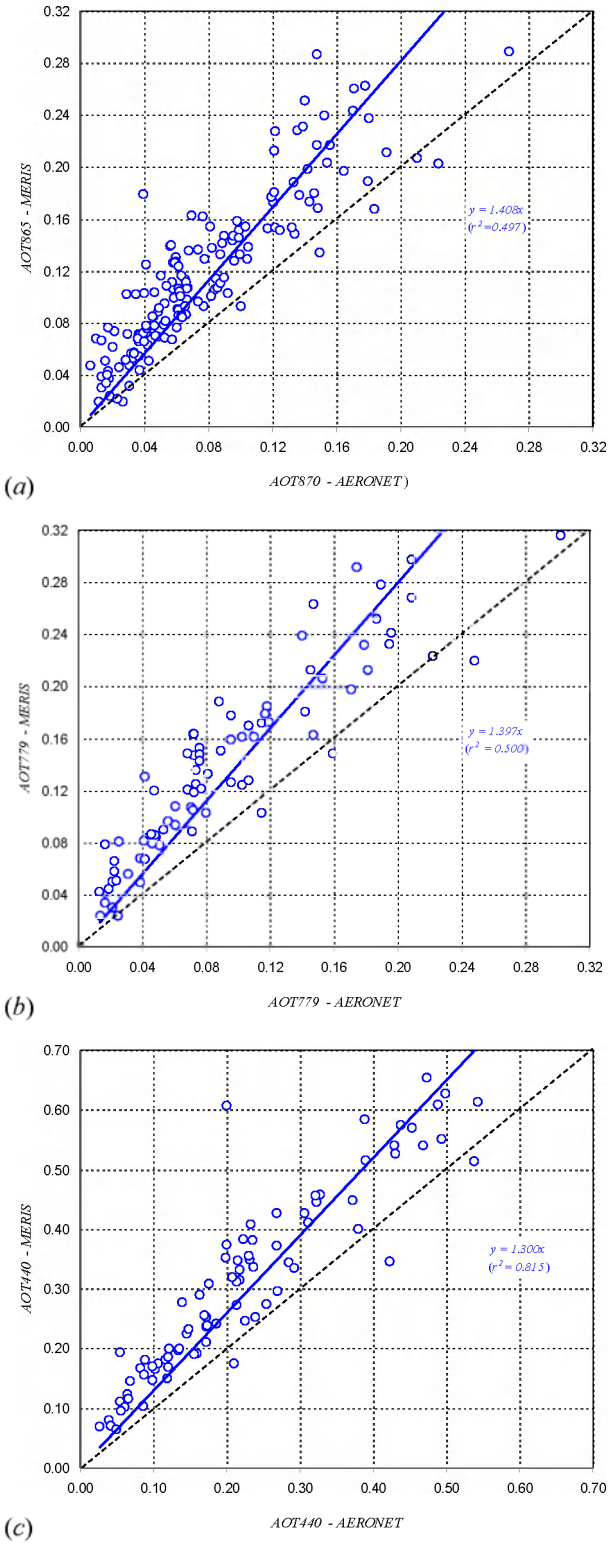

Figure 3: Comparison between AOTs extracted from in-situ measurements (AERONET) and computed with ODESA/MEGS-v8.1 (MERIS), using the SAMs. The plots are given at 3 wavelengths: (a) 865 nm, (b) 778.75 nm, and (c) 440 nm.

3.3. Spatial variability of the aerosol product

One indicator of the quality of the selected aerosol family is its ability to do not amplify the natural spatial variability of the signal. The inputs to the aerosol remote sensing module are the MERIS aerosol reflectances (ρ_{aer}) at 778.75 *nm* (band #12) and 865 *nm* (band #13). These ρ_{aer} values, obtained after the correction for the gaseous absorption and after the bright pixel atmospheric correction (BPAC), are independent on the MERIS «*Ocean-Aerosol*» ADF. The optical continuity of the aerosol models in a given family, results in a relative dispersion on the AOT that should be comparable with the dispersion of the aerosol reflectances in bands #12 and 13.

In MEGS, two models bracket the aerosol reflectance in the NIR region. The optical discontinuity between these two models yield to some noise in the retrieved AOT. Fig. 4 clearly illustrates that the IOPA family offers a better spatial homogeneity on the AOT compared to the SAMs.

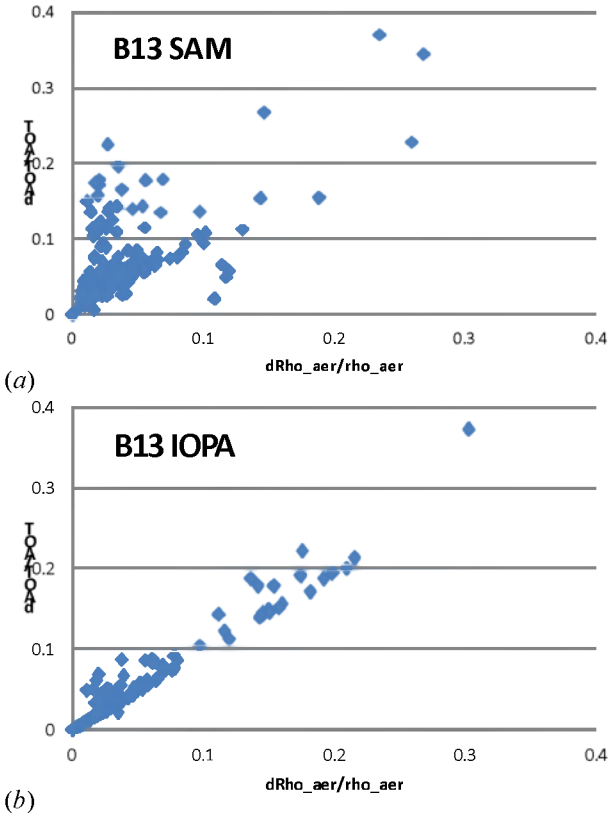

Figure 4: Relative variation in the MERIS-RR (5x5) pixels window of the AOT versus the relative variation of the aerosol reflectance in band #13 (865 nm): (a) for the SAM family, and (b) for the IOPA family.

3.4. Evaluation of the water reflectance retrieval

The water reflectance is derived form *in-situ* radiometric measurements acquired in five spectral bands centred at 412, 443, 490, 560 and 665 *nm*. Comparison with the MERIS derived water reflectance has then be conducted in these five spectral bands. The first comparison between *in-situ* and MERIS water reflectances is achieved in band #2 (442.5 *nm*) and band #5 (560 *nm*) with MEGS and the SAM family without applying the vicarious adjustment.

The MERIS water reflectance is above the *in-situ* one in band #2 and remains very scattered. The results in band #5 appear to be more acceptable (Fig. 5).

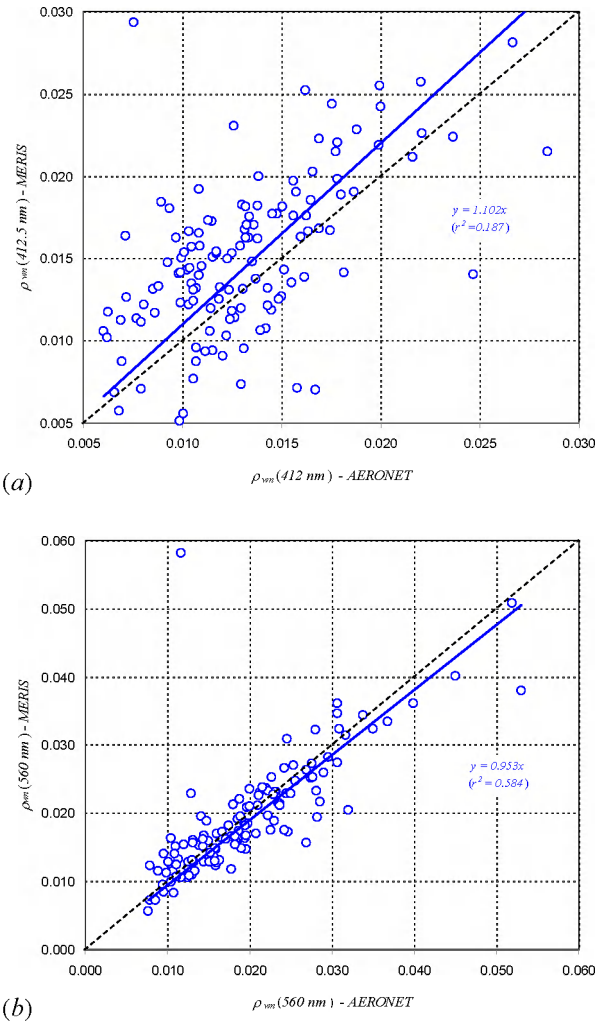

Figure 5: Comparison between water reflectances, derived from in-situ measurements (AERONET) and computed with MEGS-V8.0 (MERIS), for the SAM family, at two wavelenghts: (a) 412.5 nm, and (b) 550 nm.

The choice of the criterion to intercompare the results is controversial. For each of the ADF, we report in Tab. 4, the number of matchups, the mean and the *rmse* of the MERIS / *in-situ* ratio of the water reflectance in bands #2 and #5. The difference "*in situ* – MERIS" is also reported. The salient point is the high dispersion

which illustrates the difficulty to make the atmospheric correction over the coastal areas, as well to interpret these results.

Table 4: Number of matchups, and statistics (mean, rmse) on (a) the ratio of "MERIS/in-situ" water reflectances, and (b) the difference "in situ–MERIS" water reflectances, at 442.5 nm (band #2)) & 560 nm (band #5).

		MERIS/in-situ		*in situ – MERIS*	
Family	*N*	*band #2*	*band #5*	*band #2*	*band #5*
SAM	129	1.097 (0.354)	0.943 (0.333)	-0.001 (0.004)	-0.002 (0.007)
IOPA	129	0.878 (0.358)	1.073 (0.459)	-0.002 (0.005)	0 (0.008)
AEROPA mean	123	1.645 (0.527)	0.778 (0.411)	-0.009 (0.006)	-0.007 (0.011)
AEROPA min	123	1.646 (0.530)	0.732 (0.238)	-0.009 (0.006)	-0.008 (0.007)
AEROPA max	124	1.617 (0.523)	0.767 (0.396)	-0.008 (0.006)	-0.007 (0.007)

4. CONCLUSIONS AND PERSPECTIVES

This paper reports, for the full in-situ data archive acquired at AAOT (Venice, Italy), results from a preliminary study conducted on the impact of the aerosol models on some of MERIS level-2 products.

Whatever the set of aerosol models (or family) selected as candidate to build the MERIS «*Ocean-Aerosol*» ADF to be used as input to the MEGS processor, it clearly observed that a large dispersion on the AOT appears between *in-situ* and MERIS. This is explained by the natural variability of the aerosol IOPs. This dispersion is strongly reduced when selecting the set of aerosol models locally defined on their IOPs, as for the AEROPA climatology. Moreover, the spatial homogeneity being driven by the optical continuity of the aerosol models as function of the *Angstroem* exponent (α), the SAM family has been identified as the worst one.

For the water reflectance retrieval, we cannot firmly conclude because of the large error bars. With the current algorithm implemented in MEGS, the aerosol model would need to be better identified. However the only small hope which one can have, would be to use the relative humidity. Alternatively, a combined approach to retrieve both the aerosols and the water colour has been suggested.

This study needs to be consolidated and extended by starting with the AERONET Ocean Colour database. A large amount of matchups could be processed in order to conduct an analysis for each type of aerosols (*i.e.*, oceanic and coastal) and for different domains of scattering angle. Compared with MERIS, OLCI will have the great advantage to allow the exploitation of the backscattering region which is particularly difficult in terms of the variability of the aerosol IOPs.

ACKNOWLEDGMENTS: The authors thank all the PIs for the AERONET stations we used: G. Zibordi for AAOT, K. Ruddik for Oostende, R. Doerffer for Helgoland, B. Holben for Lannion, and Jean-Francois Leon and Philippe Goloub for Dunkerque. This work was partially supported by the INTERREG 2-Seas program

REFERENCES

[1] Gordon, H. R., and T. Zhang, 1996. "How well can radiance reflected from the ocean-atmosphere system be predicted from measurements at the sea surface", *Applied Optics*, **5** (33): 6527-6543.

[2] Antoine, D., and A. Morel, 1999. "A multiple scattering algorithm for atmospheric correction of remotely sensed ocean color (MERIS instrument): Principle and implementation for atmospheres carrying various aerosols including absorbing ones", *International Journal of Remote Sensing*, **20**: 1875-1916.

[3] Holben, B., T. Eck, I. Slulutsker, D. Tanré, J. P. Buis, A. Setzer, E. Vermote, J. Reagan, Y. Kaufman, T. Nakajima, F. Lavenu, I. Jankowiak, and A. Smirnov, 1998. "AERONET – A federated instrument network and data archive for aerosol characterization", *Remote Sensing of Environment*, **66**: 1-16.

[4] Dubovik, O., and M. D. King, 2000. "A flexible inversion algorithm for retrieval of aerosol optical properties from Sun and sky radiance measurements", *Journal of Geosphysical Research*, **105**: 20673–20696.

[5] Zagolski, F., R. Santer, and O. Aznay, 2007. "A new climatology for atmospheric correction based on the aerosol inherent optical properties", *Journal of Geophysical Research*, Vol. **112**, No. D14, D14208.

[6] Nunes, L., and F. Zagolski, 2008. "MERISAT porting in linux – MERISAT Detail Design of Optimization & Complementary Recipes for LUTs Generation", *SKYSOFT/PARBLEU report (D-06), MERISAT-SKS-SDD-006-1A*, Lisbon, Portugal, July 2008: 158p.

[7] Neiva, P., and F. Zagolski, 2011. "MERISAT Porting in Linux, Phase-II – MERISAT Software Requirements Specification for 3rd LUTs Generation", *GMV-Skysoft/PARBLEU report (D-02), MERISAT-SKS-REQ-SRS-1B*, Lisbon, Portugal, February 2011: 37p.

[8] Barker, K., C. Mazeran, C. Lerebourg, M. Bouvet, D. Antoine, M. E. Ondrusek, G. Zibordi, and S. J. Lavender, 2008. "MERMAID: The MERis MAtchup In-situ Database". In *ESA proceedings of 2nd MERIS (A)ATSR Users Workshop*, Frascati (Italy), Sept. 2008.

[9] Zagolski, F., and R. Santer, 2010. "Inherent optical properties of the aerosols – The blue aerosols", ESA/PARBLEU/ADRINORD Technical Report: 20 p.

[10] Santer, R., F. Zagolski, and O. Aznay, 2009. "Aerosol phase function derived from CIMEL measurements", *International Journal of Remote Sensing*, **31** (4): 969-992.

[11] Dubovik, O., and M. D. King, 2000. "A flexible inversion algorithm for retrieval of aerosol optical properties from Sun and sky radiance measure-

ments", *Journal of Geosphysical Research*, **105**: 20673–20696.

[12] Santer, R., F. Zagolski, and O. Aznay, 2012. "Inherent optical properties of the aerosols for OLCI-Sentinel3: From micro-physical properties to optical properties using AERONET ", *Proceedings of MERIS / (A)ATSR & OLCI / SLSTR Preparatory Workshop*, Frascati (Italy): 15-19 Oct., 2012.

[13] Deuzé, J.L., M. Herman, and R. Santer, 1989. "Fourier series expansion of the transfer equation in the atmosphere-ocean system", *Journal of Quantitative Spectroscopy & Radiative Transfer*, **41** (6): 483-494.

[14] Lenoble, J., M. Herman, J.L. Deuzé, B. Lafrance, R. Santer and D. Tanré, 2007. "A successive order of scattering code for solving the vector equation of transfer in the Earth's atmosphere with aerosols", *Journal of Quantitative Spectroscopy & Radiative Transfer*, **107**: 479-507.