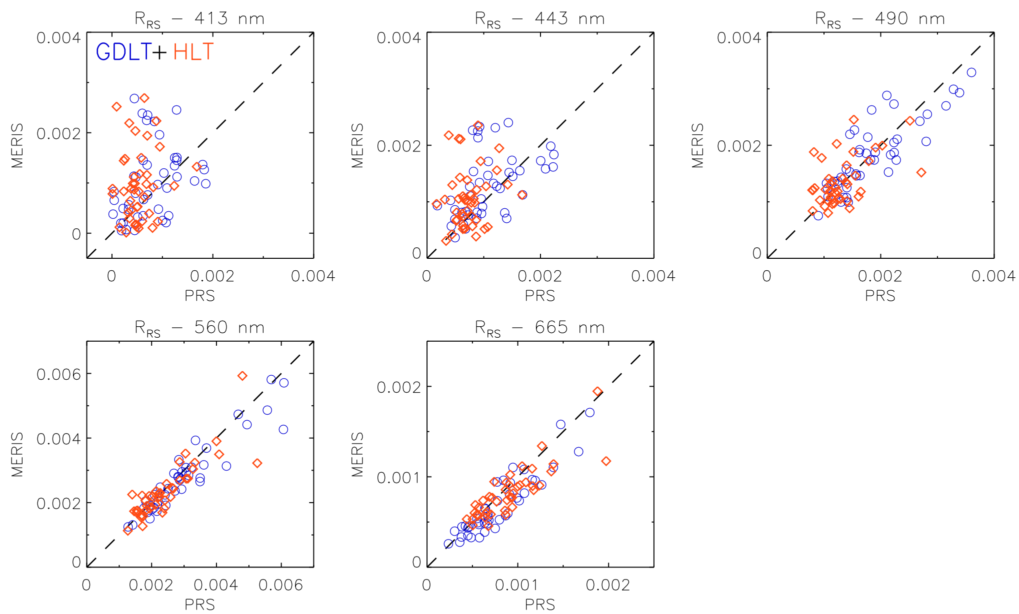

Fig. 3. Comparison of MERIS and SeaPRISM R_{RS} at the GDLT (N=43) and HLT (N=42) sites (blue circles and orange diamonds, respectively).

the English Channel. If Δt is reduced to 3-h, the number of match-ups becomes 64, with $|\psi|$ decreasing by 6% at 413 nm, and 1.0% to 1.6% at the other wavelengths.

From 490 to 665 nm, $|\psi|$ varies between 11% and 19% (Table 2), and is higher in the blue. Large relative overestimates associated with Baltic stations are found in the lower range of R_{RS}. Some of the related stations are located in the Gulf of Bothnia which is characterized by extremely absorbing waters [45]. Considering that almost half the match-ups are found in the Baltic Sea, the comparison statistics are also presented for this subset as well as without the Baltic samples (Table 2). The statistics $|\psi|$ without the Baltic data are very similar to those found at AAOT, from 12% at 560 nm to 23-24% at 413 and 665 nm, but differently the bias is negative across all wavelengths. The 27 match-ups found in the Mediterranean Sea (Ligurian Sea and eastern Mediterranean) display $|\psi|$ of 11-14% between 443 and 560 nm, while $|\psi|$ for the 22 match-ups in the Black Sea is 29% at 412 nm, 18% at 443 nm, approximately 12% at 490 and 510 nm, as low as 8% at 560 nm, and 17% at 665 nm. Both regional subsets show underestimates of R_{RS} at almost all wavelengths (except at 665 nm for the Mediterranean stations, ψ equal to +2%), but they are less pronounced for the Black Sea stations (from -2% to -10% in the domain 413-560 nm). The statistics obtained with the BiOMaP Baltic data share common elements with those found at GDLT and HLT: $|\psi|$ is lowest in the green-to-red spectral domain (as low as 9% at 560 nm) and strongly increases in the blue in relation to large overestimates. The values of *rmsd* are very low for wavelengths longer than 490 nm, decreasing from 0.00044 sr^{-1} at 490 nm to 0.00011 sr^{-1} at 665 nm, while it is comparable to *rmsd* found in the other European basins at 413 and 443 nm (which, combined with low R_{RS} amplitudes, leads to high relative differences $|\psi|$).

4.4. Discussion

Similar validation statistics have been derived for the SeaWiFS and MODIS missions in previous studies [15, 19, 32, 46]). The RMS difference (*rmsd*) is used here as a basis for comparison

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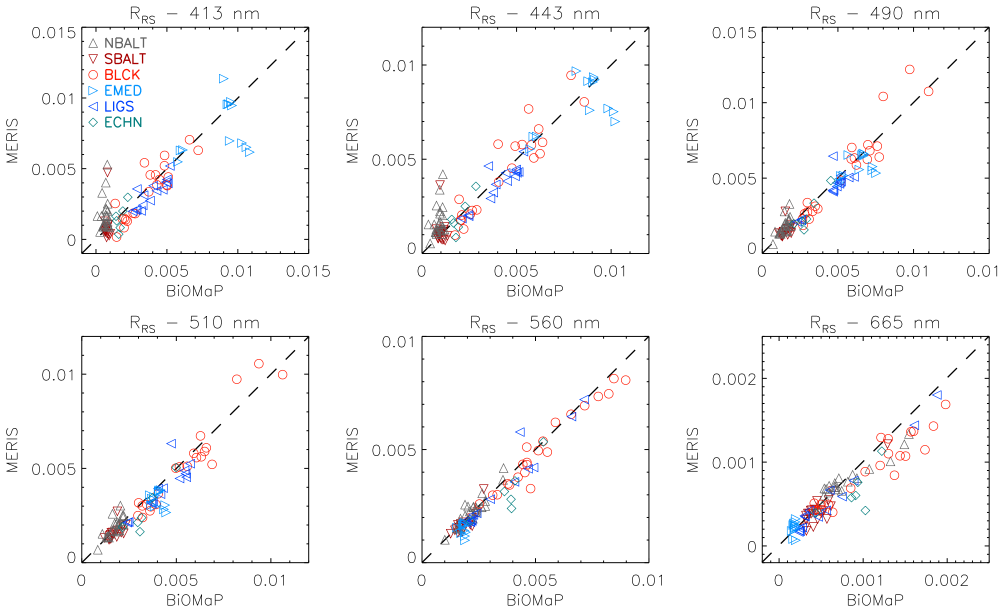

Fig. 4. Comparison of MERIS and BiOMaP R_{RS}. Different colors and symbols are associated with the northern and southern Baltic Sea (NBALT, N=24, and SBALT, N=21), the Black Sea (BLCK, N=22), the eastern Mediterranean (EMED, N=12), the Ligurian Sea (LIGS, N=15) and the English Channel (ECHN, N=6).

since it is less affected by the variations that might be found for relative differences (like $|\psi|$) when R_{RS} amplitudes cover different ranges (particularly when they are low). Fig. 5 shows *rmsd* found for the three match-up subsets described here and for the three satellite missions as obtained with consistent selection criteria over similar time periods. For the AAOT set, there is a local maximum observed in *rmsd* for MODIS at 531 nm, which might be at least partly due to the lower number of match-up points at that wavelength (201 versus 486 for the other wavelengths) and to the band shift correction that relies on SeaPRISM records at approximately 500 and 550 nm [47]. The results for that band are thus to be taken with more caution.

Generally, the *rmsd* curves obtained for the three missions appear relatively consistent, even though some differences can be noticed and at least partly explained by the differences in the match-up sets as well as the various elements that are specific for each mission in terms of sensor design, observation geometry or processing code. The lowest values are usually shown for the Baltic sites GDLT and HLT, and the highest for AAOT. The *rmsd* spectra are broadly contained in an envelop decreasing from 0.0008-0.0015 sr^{-1} at 412-413 nm to 0.0002-0.0004 sr^{-1} in the red. The results obtained at corresponding bands can be compared for the 3 sensors using the letters M, A and S as superscripts for MERIS, MODIS and SeaWiFS, respectively. The ratio of *rmsd* associated with MERIS and MODIS (i.e., $rmsd^M/rmsd^A$) is in the interval 0.69-0.83 for the Baltic sites (i.e., *rmsd* lower for MERIS), and in the interval 0.81-1.25 for the 2 other data sets, being noticeably larger than 1 only at 412 nm (1.25) in the case of BiOMaP. If the Baltic stations are excluded from the BiOMaP data set, this ratio is between 0.96 and 1.17. The *rmsd* found for SeaWiFS tends to be higher than for MERIS or MODIS, which might be explained by a lower signal-to-noise ratio for that mission. The ratio of *rmsd* associated with MERIS and SeaWiFS ($rmsd^M/rmsd^S$) is mostly in the interval 0.64-0.84, except 0.58 for $rmsd^M(560)/rmsd^S(555)$ at AAOT, and approximately 1 for $rmsd^M(560)/rmsd^S(555)$

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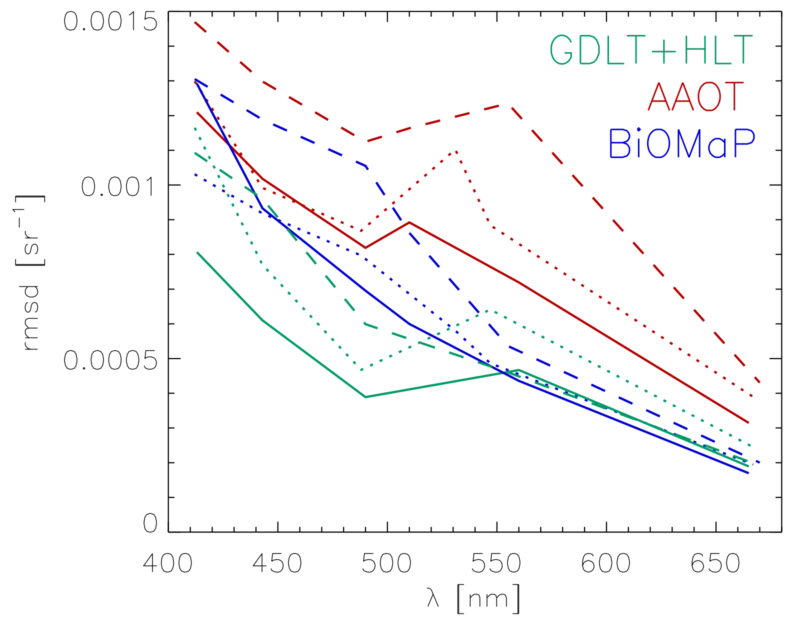

Fig. 5. Spectrum of the RMS difference for MERIS (continuous line), MODIS (dotted line) and SeaWiFS (dashed line) for the three match-up subsets. For the GDLT and HLT sites, AAOT and BiOMaP, the total number of match-ups is 236 (not plotted at 531 nm), 486 (201 at 531 nm) and 155 for MODIS, and 67, 484 (250 at 510 nm), and 147 for SeaWiFS.

and $rmsd^M(665)/rmsd^S(670)$ for the Baltic sites, and $rmsd^M(413)/rmsd^S(412)$ for the BiOMaP validation set. The ratio associated with BiOMaP considered without its Baltic stations is in the interval 0.73-1.01. Overall using the *rmsd* metric, the uncertainties associated with MERIS are generally comparable with those of MODIS and lower than those of SeaWiFS.

5. Conclusion

This work is an early assessment of the use of SeaDAS to process MERIS imagery. A set of vicarious calibration coefficients has been derived at the MOBY site, which was used for the same purpose for SeaWiFS and MODIS. Using this set of coefficients is recommended for processing MERIS imagery with SeaDAS (version 6.2). The validation data are associated with measurements collected in the European seas and cover a large gradient of optical properties, from oligotrophic areas to coastal sediment-dominated or CDOM-dominated waters. While recognizing that the accuracy of the atmospheric correction should still be improved, the encouraging results documented here provide a solid ground for future developments aiming at fine-tuning the MERIS+SeaDAS system.

Excluding the Baltic Sea, the mean absolute relative difference $|\psi|$ is between 10% and 14% for the spectral interval 490-560 nm, 16-18% at 443 nm, and 24-26% at 413 nm. The $|\psi|$ values are much higher for Baltic waters for the blue bands, but similar or lower at 560 and 665 nm. The validation statistics presented here show differences lower than those documented for MERIS R_{RS} derived from the MEGS version 7.4 processor [30, 48–50]. These differences are likely to be affected by a recent update (MEGS version 8 [51]) that includes vicarious calibration performed with in situ data from two target sites (MOBY and the BOUSSOLE

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system in the Ligurian Sea [52]).

Importantly, the present validation results document uncertainties that appear at least as good as those associated with SeaWiFS and MODIS. The *rmsd* values given here for MERIS as well as those documented for SeaWiFS and MODIS, are required information to generate merged records of R_{RS} [2, 53, 54]. With a view on creating a multi-sensor data stream for the European seas, this works leads to processing imagery collected by the major ocean color satellite missions with a common processing environment producing ocean reflectance spectra of very comparable accuracy.

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