MEASURING AND MODELLING THE OPTICALPROPERTIES IN THE CRETAN SEA

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Abstract

The main objectives of Hellenic Center for Marine Research (HCMR) optical work during the MARRE project were the collection of in situ optical data, radiative transfer modelling and thus the improvement of ocean colour algorithms and satellite validation as well. This was designed to contribute to one of MARRE 's general objectives of ensuring accurate monitoring of the marine environment using ocean colour satellite data. Therefore, the present work took a comparative approach to the calculation of a key apparent optical property in ocean colour validation, remote sensing reflectance, in three different ways: (a) in situ measurement (b) satellite data; and (c) Hydrolight modelling. The study area was the Cretan Sea during the MARRE project research cruise. The methodology followed during both the acquisition of the in situ measurements and the post - processing was in accordance with international protocols. Our results, in addition to their intrinsic value for an area of high interest to the ocean colour satellite validation and optical oceanography community, will alsocontribute to the improving of the individual assessment methods towards a more accurate calculation approach for the Cretan Sea and the wider area of the oligotrophic eastern Mediterranean.

Keywords: marine optics, apparent optical properties, remote sensing, hydrolight, satellite ocean colour validation, Eastern Mediterranean.

1. Introduction

The study of optical properties is a particularly critical factor in a number of studies concerning the marine environment. This is especially important in an ultra-oligotrophic environment such as that of the wider region of the eastern Mediterranean (Karageorgis *et al.*, 2008; Banks *et al.*, 2020b; Chaikalis *et al.*, 2021) and more specifically for the marine periphery of the island of Crete. From this point of view, the study of the optical properties of this area acquires its own special value as it adds valuable information to the understanding of satellite ocean colour products and the marine optics of oligotrophic areas in general.

The remote sensing reflectance [$R_{rs}(\lambda)$] parameter is a measure of how much of the downwelling light that is incident onto the water surface is eventually returned through the surface, so that it can be detected by a radiometer pointed in the opposite direction. R_{rs} (λ) is the fundamental measurement from which satellite ocean color (OC) products, such as phytoplankton chlorophyll concentration, are developed. In addition, the variation of the Inherent Optical Properties (IOP) estimates, as a description of the light absorption and scattering in the water column, are an important basis for understanding the levels of R_{rs}. These were also measured and will be presented in a relatively independent way.

The in situ measurements used for the MARRE project were carried out in September 2020. The optical measurements were made with the integrated HCMR optics suite system at specific stations, so that they coincided with the overpass of the Sentinel-3 OLCI satellite. Figure 1 shows the stations for the MARRE research cruise.

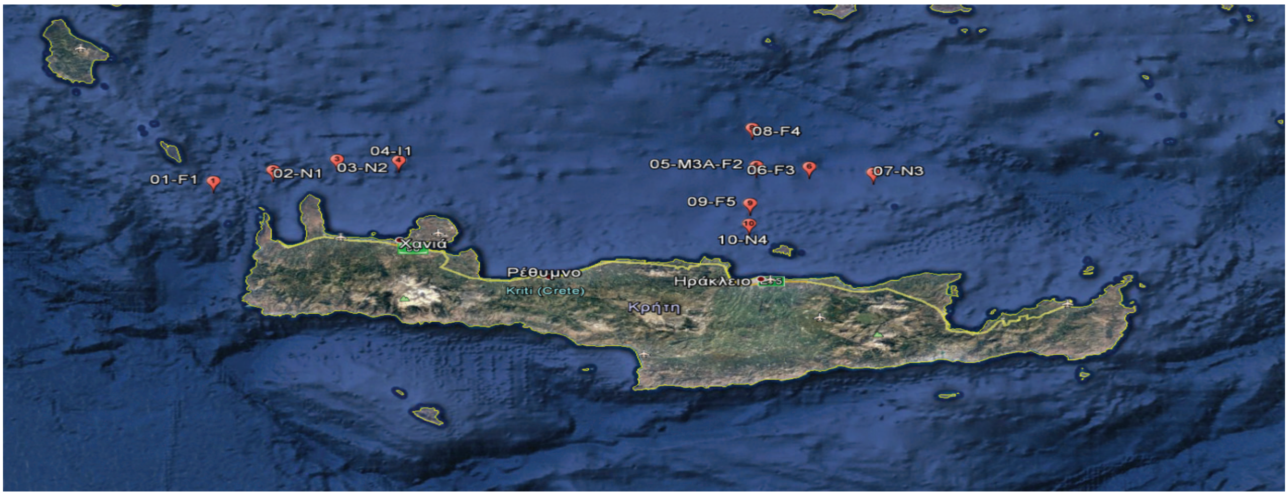

Fig. 1: Marine optics stations during the MARRE cruise.

2. Material and Methods

The in situ measurements used for the MARRE project were carried out in September 2020. The optical measurements were made with the integrated HCMR optics suite system at specific stations, so that they coincided with the overpass of the Sentinel-3 OLCI satellite.

The HCMR optics suite was deployed using one of the winches of the research vessel of the cruise (R/V Aegaeo) following the NASA and FRM4SOC protocols to retrieve in water measurements of upwelling radiance and downwelling irradiance (Mueller *et al.*, 2003; Ruddick *et al.*, 2019a, 2019b; Banks *et al.*, 2020a). For data processing the IOCCG protocols (Zibordi *et al.,* 2019) were applied.

In addition to the HCMR optics suite, for a few stations on the MARRE cruise, the portable above water radiometry system from the University of West Attica was used to take measurements for comparison with those from the in-water Trios radiometry. For the above water measurements, the Skylight Blocked Approach was followed (Drakopoulos *et al.,* 2015; Banks *et al.,* 2020a).

Hydrolight is a numerical model based on solving the radiative transfer equation; it calculates AOPs (apparent optical properties) through six different models of IOPs (inherent optical properties) (Mobley and Sundman, 2001). The use of the Hydrolight 5.0 numerical model was run using chlorophyll data as input, which were sampled at discrete depths during the oceanographic cruise.

3. Results

The satellite data were filtered using the L2 flags to remove any matchups where the satellite reflectance retrieval was not meeting minimum quality standards (e.g. pixels containing cloud/cloud shadow, suspect or erroneous atmospheric correction due to very high dust aerosol load in the atmosphere, etc). In total6 stations met all the necessary criteria, both in situ and satellite. The initial R_{rs} comparisons for two of these stations are shown in Figure 2.

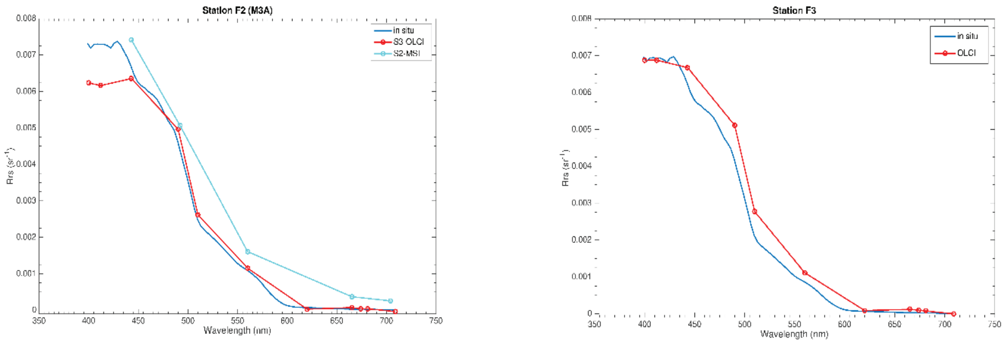

Fig. 2: Initial comparisons of R_{rs} spectra between in situ and satellite data.

As already mentioned, during the MARRE project, we also aimed to test the coherence between the in water and above water profiles. The results of an R_{rs} spectral comparison between the two systems are shown in Figure 3.

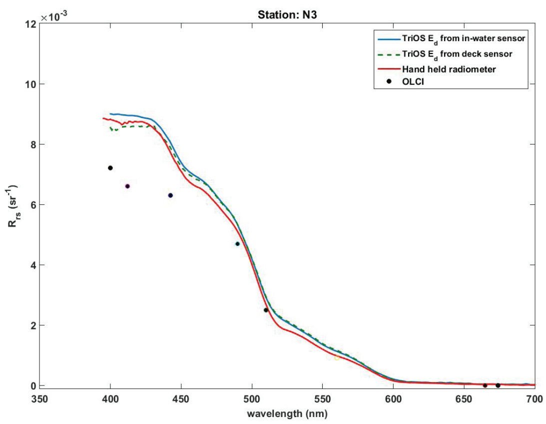

Fig. 3: Extracted R_{rs} at MARRE N3 station as measured by 3 different instrument configurations and approaches: (a) Use of in water TriOS radiance and irradiance profiles to calculate R_{rs}; b) Use of in water TriOS radiance and above water TriOS irradiance to calculate R_{rs}; c) using the handheld portable radiometer over the water.

Additionally, modelling the optical radiation transmission of oligotrophic waters can also help us better understand marine optics and thus to develop more accurate satellite retrieval algorithms. The results of the first comparison between in situ and satellite data, and the simulations based on the Hydrolight radiative transfer model for the two above - mentioned stations of the MARRE cruise are shown in Figure 3.

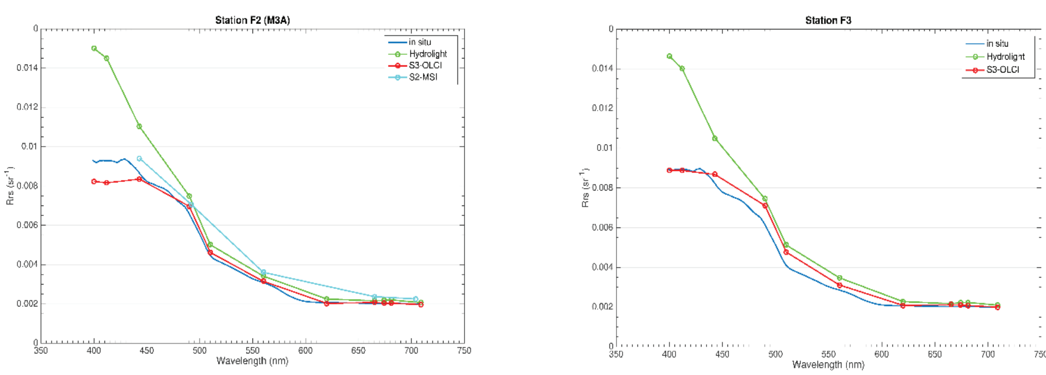

Fig. 4: Comparison of R_{rs} spectra between Hydrolight simulations and data from in situ and satellite data.

These simulated spectra show a reasonable fit for longer wavelengths (> 500nm), but much more work is needed to constrain the model for shorter wavelengths (<500nm). A further simulation error may be due to the inaccurate simulation of the atmospheric dust model dealing with Saharan dust, and this needs further matchup data to examine.

4. Discussion/Conclusion

As already indicated by previous marine optics studies in the Eastern Mediterranean region, the specific area is highly oligotrophic and also is an under-sampled region in terms of optics measurements. Thus there is a need for systematic measurements in the area.

The first attempt to calculate the apparent optical property of remote sensing reflectance in multiple ways gave encouraging results, especially at wavelengths larger than 500nm.

In addition, the observance of the fiducial reference measurement and processing protocols is estimated to help significantly for the better and fairer comparison of the results.

This study instigates the potential of using the inherent optical properties as input to the Hydrolight model towards more accurate results at lower wavelengths as well.

5. Acknowledgements

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6. References

Banks, A.C., Vendt, R., Alikas, K., Bialek, A., Kuusk, J. *et al.,* 2020a. Fiducial Reference Measurements for Satellite Ocean Colour (FRM4SOC). *Remote Sensing*, 12, 1322.

Banks, A.C., Drakopoulos, P.G., Chaikalis, S., Spyridakis, N., Karageorgis, A.P. *et al.,* 2020b. An in situ optical dataset for working towards fiducial reference measurements based satellite ocean colour validation in the Eastern Mediterranean. *Proceedings SPIE Volume 11524. Eighth International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2020), 1152424 (26 August 2020).*

Chaikalis, S., Parinos, C., Möbius, J., Gogou, A., Velaoras, D. *et al.,* 2018. Optical properties and biochemical indices of marine particles in the open Mediterranean Sea: the R/V Maria S. Merian cruise, March 2018. *Frontiers in Earth Science* Volume 9, Article 614703.

Drakopoulos, P.G., Banks, A.C., Kakagiannis, G., Karageorgis A.P., Lagaria, A. *et al.,* 2015. “Estimating chlorophyll concentrations in the optically complex waters of the North Aegean Sea from field and satellite ocean colour measurements,” *Proceedings of SPIE Third International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2015), 19 June 2015, Paphos, Cyprus (2015).*

Karageorgis, A.P., Gardner, W.D., Georgopoulos, D., Mishonov, A.V., Krasakopoulou, E. *et al.,* 2008. Particle dynamics in the Eastern Mediterranean Sea: A synthesis based on light transmission, PMC, and POC archives (1991-2001). *Deep-Sea Research I*, 55 (2), 177-202.

Mobley, C.D., Sundman, L.K., 2001. *Hydrolight 4.2: Users' Guide*, (Sequoia Scientific, Redmond, WA, USA).

Mueller, J.L. *et al.,* 2003. *Ocean Optics Protocols for Satellite Ocean Color Sensor Validation, Revision 4, Volume III: Radiometric Measurements and Data Analysis Protocols*; (NASA/TM; NASA Goddard Space Flight Space Center: Greenbelt, MD, USA, 2003).

Ruddick, K.G., Voss, K., Banks, A.C., Boss, E., Castagna, A. *et al.,* 2019a. “A Review of Protocols for Fiducial Reference Measurements of Downwelling Irradiance for the Validation of Satellite Remote Sensing Data over Water,” *Remote Sensing,* 11(15), 1742.

Ruddick, K.G., Voss, K., Boss, E., Castagna, A., Frouin, R. *et al.,* 2019b. “A Review of Protocols for Fiducial Reference

Measurements of Water-Leaving Radiance for Validation of Satellite Remote-Sensing Data over Water," *Remote Sensing*, 11 (19), 2198.

Zibordi, G., Voss, K.J., Johnson, B.C., Mueller, J. L., 2019. *[Protocols for Satellite Ocean Colour Data Validation: In Situ Optical Radiometry (v3.0), in IOCCG Ocean Optics and Biogeochemistry Protocols for Satellite Ocean Colour Sensor Validation, Volume 3.0]*, (IOCCG, Dartmouth, NS, Canada).