Above and in-water remote sensing reflectance measurements during the AegeanMarTech project: A first appraisal

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Abstract

The optically complex properties of NE Aegean Sea were studied during the AegeanMarTech project. Simultaneous above and in-water ocean colour measurements were validated with chlorophyll concentration field data and compared against concurrent MODIS images. It was found that the Med-OC3 algorithm outperforms the operational OC3M-547 algorithm and produces the least bias when compared against HPLC derived *in situ* [Chl]. Satellite derived concentrations tend to underestimate [Chl] by >10% at best, the greatest uncertainty arising due to CDOM absorption below the 488 nm band. Relevant reflectance ratios indicated that there is always an excess of yellow mater present in the study area and the water type could not be characterized optically as “typical open ocean” Case 1. Further investigation is under way.

Keywords: ocean optics, ocean color, remote sensing, NE Aegean Sea

1. Introduction

The upper layer of the NE Aegean Sea water body is characterized by the presence of a variable outflow of brackish Black Sea waters through the Dardanelles which lie on the top the high salinity Levantine intermediate waters. They carry nutrients and the abundance of CDOM in the area is believed to be linked to them (Zeri et al., 2015). Therefore the question that arises is whether the optical properties of this water body follow phytoplankton (typical open ocean) or are characterized by a more complex structure.

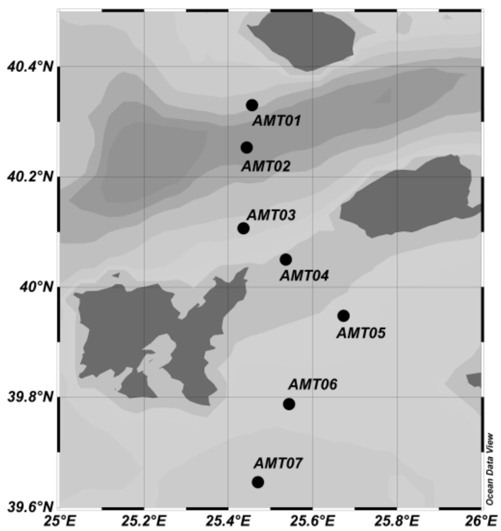

Fig. 1. Stations visited during the Aegean MarTech cruises.

Drakopoulos et al. (2003; 2014) investigated the performance of various ocean colour satellite products and existing chlorophyll concentration algorithms in the oligotrophic Case 1 south Aegean waters and found discrepancies between field and reflectance derived matchups when the SeaWiFS operational and the regional algorithms were implemented. Similar uncertainties have been reported by others (Psarra, 2014 (personal communication)) for the apparently more optically complex North Aegean Sea. Within the framework of the AegeanMarTech project a series of ocean colour spectra have been collected during March and July 2014 cruises at a representative set of stations (see Fig. 1) and preliminary results are reported here. The present work is part of a major effort, never undertaken before in the area, that will lead to the optical characterization of the North Aegean water body and eventually to finer tuned local ocean colour algorithms.

2. Materials and methods

The quantity that is monitored by satellites and that can be used in the estimation of chlorophyll concentration [Chl] is the remote sensing reflectance, defined as the ratio of the water leaving spectral radiance to the downwelling spectral irradiance, both just above the water surface. It can be determined *in situ*, with either above or in-water radiance and irradiance measurements.

Above surface radiance spectra were collected aboard R/V Aegaeo with a handheld portable spectroradiometer (JAZ Ocean Optics), with a range of 200-890 nm, 1.3 nm spectral resolution attached to a 3^o FOV Gershun tube via a flexible optical fiber. Radiance reference was provided by a calibrated 10% reflectance Spectralon© plate. The measurement sequence, according to the Mobley protocol (Mobley, 1999), comprised a series of spectra acquisitions in the following order: plate reflected radiance, dark spectrum, upwelling sea radiance at an azimuth viewing direction of 135^o and a zenith angle of 40^o, sky radiance at the same angles (needed to correct for the sky glint) and finally another dark spectrum. In addition, a novel scheme (i.e. Lee et al., 2010) was also followed. A small black tube (4.5 cm diameter 55 cm long) was attached in front of the Gershun tube and was dipped just below the sea surface, thus removing the surface reflected light. For both protocols an average of ten spectra were collected and the complete measuring sequence (lasting less than a minute) was repeated at least four times. An advantage of using a single radiometer is that there is no need for calibration.

For in-water radiance data a pair of TriOS Ramses spectroradiometers, one for the downwelling irradiance (unit 1) and another for upwelling radiance (unit 2) were used to collect vertical profiles. In addition, another zenith looking TriOS Ramses irradiance spectroradiometer (unit 3), was attached to a pole at the bridge of the vessel. These radiometers monitor the spectral range 318-952 nm, with a resolution of ~3.3 nm. All three TriOS radiometers where factory calibrated prior to the cruise.

The remote sensing reflectance and the physical quantities linked to it are given by:

$$R_{rs}(0^+) \equiv \frac{L_w(0^+)}{E_d(0^+)} \cong \frac{[L_u(0^+) - \rho L_{sky}(0^+)]R_g}{\pi L_d(0^+)} \cong 0.546\rho_{rs} \cong \frac{0.5 r_{rs}}{1-1.7 r_{rs}},\ \ \rho_{rs} \equiv \frac{L_u(0^-)}{E_d(0^+)},\ \ r_{rs} \equiv \frac{L_u(0^-)}{E_d(0^-)}$$

Here L_u(0+) is the upwelling radiance, $L_d(0^+)$ is the radiance measured by viewing the spectralon plate and $L_{sky}(0^+)$ the sky radiance. The quantity R_g is the known reflectance of the plate, ρ a wind speed and sun elevation depend parameter, $L_u(0^-)$ is the upwelling radiance monitored by unit 2, $E_d(0^+)$ the downwelling irradiance monitored by unit 3, and $E_d(0^-)$ by unit 1. Chlorophyll concentration is derived by: $C_{mod} = 10^{(a_0 + a_1 R + a_2 R^2 + a_3 R^3 + a_4 R^4)}$, $R = \log_{10}\left(\frac{R_{rs}^{443} > R_{rs}^{488}}{R_{rs}^{547}}\right)$ where R is the logarithm of the maximum reflectance ratio at the denoted MODIS bands centered at 443, 488 and 547 nm. The *a* coefficients depend on the specific algorithm used; for the NASA operational OC3M algorithm they can be found at oceancolor.gsfc.nasa.gov/REPROCESSING/R2009/ocv6 and for the regional MedOC3 algorithm in Santoleri et al. (2008). In order to evaluate these algorithms with *in situ* reflectances, the collected spectra were convolved with the spectral response functions of the MODIS-Aqua bands. The quantity C_{mod} is directly comparable to the mean *in situ* concentration C_w within the penetration depth τ (the inverse of diffuse attenuation coefficient K_d at 490 nm) weighted for the exponential attenuation of light twice (during its downward and upward propagation (Gordon & Clark 1980). K_d(490) was estimated from the depth derivative of E_d(z,490).

The independent datasets used for the analysis were six: HPLC *in situ* chlorophyll, fluorometric *in situ* chlorophyll, remote sensing reflectance estimated from the above surface procedure after glint was removed, from direct above surface reflectance (using the tube), from r_{RS}, and from ρ_{RS}. Sky glint was removed according to M99 (Mobley, 1999) and M80 (Morel, 1980) protocols. Standard statistics were used for the analysis of the datasets: *r* the sample correlation coefficient indicative of linearity, RMS that quantifies the spread of the data compared to best agreement, and BIAS the mean bias error.

3. Results/Discussion

Due to the small sample size (n_{max}=19), the normality of the distribution of the variables is only assumed as such, and therefore the statistics can be considered just indicative of trends. The results of the statistical analysis are presented in Table 1. All algorithm derived [Chl] were compared against both HPLC and fluorometric derived C_w. Overall the correlations are high, with satellite derived data having the lower correlation with field values as expected.

Table 1. Results of the statistical analysis.

	r	HPLC RMS	BIAS	r	FLUOR RMS	BIAS
			OC3M-547			
MODIS	0.73	0.12	0.06	0.72	0.16	0.13
DIRECT	0.85	0.18	0.16	0.87	0.24	0.24
M99	0.87	0.16	0.13	0.87	0.21	0.20
M80	0.89	0.15	0.12	0.89	0.20	0.19
$\boldsymbol{\rho_{RS}}$	0.81	0.15	0.11	0.75	0.25	0.23
$\mathbf{r_{RS}}$	0.82	0.16	0.11	0.81	0.24	0.21
			Med-OC3			
MODIS	0.73	0.12	-0.05	0.72	0.10	0.02
DIRECT	0.85	0.10	0.05	0.87	0.14	0.12
M99	0.88	0.09	0.02	0.89	0.11	0.09
M80	0.91	0.08	0.01	0.92	0.10	0.08
$\boldsymbol{\rho_{RS}}$	0.80	0.13	0.03	0.75	0.20	0.15
$\mathbf{r_{RS}}$	0.83	0.13	0.02	0.82	0.18	0.12

The direct method proved to be the most stable since the standard deviation (not shown here) for each subset of reflectances at every station was the lowest when was compared against the methods that included the sky sun glint component. However the overall reflectance (gain) was much lower (~1.5x). A simple analysis (Gordon & Ding, 1992) indicated that self-shading was responsible for less than 1% error in L_u. Similar underestimation is observed in all underwater (TriOS) measurements. It is believed that low reflectance was the result by the vessel induced shading. However, keeping in mind that the algorithms are functions of band ratios, the effect cancels out (assuming an ideal spectrally flat shading). Another source of error for the in-water dataset is that at this stage no attempt was made to extrapolate the upwelling radiance at null depth - a complicated procedure which is underway. Instead, the 1 m bin average was used.

According to the statistical analysis, the best agreement was achieved when concentrations were estimated with the regional Med-OC3 algorithm and compared against matchups obtained with the HPLC procedure. Among the modeled data the M80 subset gave best results, i.e. higher linearity (*r*), accuracy (RMS) and precision (BIAS). It should be mentioned here that as a matter of fact, the bias is always positive, i.e. on the average, there is overestimation of ground truth. Nevertheless it is interesting to note as is evident in Fig. 2, that when matchups related to high concentrations are considered, the bias switches to negative values.

Following the approach of Morel & Gentili (2009) the reflectance ratios R(412)/R(443) and R(490)/R(555) were evaluated and the factor Φ estimated (Φ may be below or above unity, so that the departure may be either a deficit or an excess of CDOM with respect to its reference Chl-dependent value). It ranges from 2 to over 10 indicating that in the area there is always present a surplus of yellow mater independent of the chlorophyll concentration. As expected, measurements point to a low Φ factor - high [Chl] relationship.

Summarizing, this work is a first attempt to link some of the local inherent optical properties with the *in situ* measured apparent optical properties. When the complete final optical dataset will be available, the analysis will proceed further, hopefully leading to a local radiation transfer closure.

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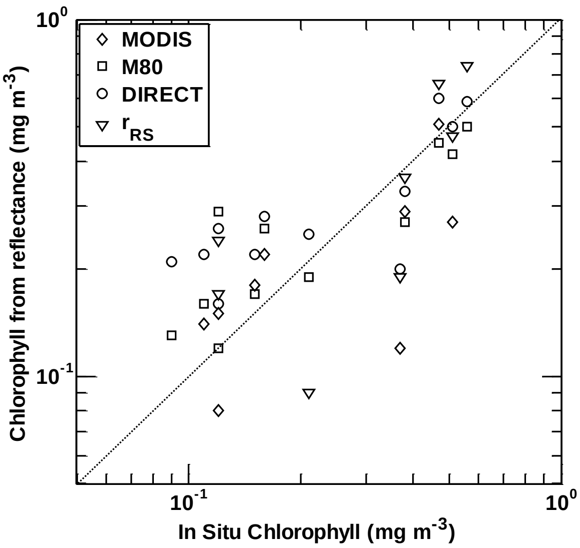

Fig. 2. Validation of remotely sensed chlorophyll estimates against concurrent field measurements (HPLC method).

5. References

Drakopoulos, P.G., Nittis, K., Petihakis, G., Kassis, D., Pagonis, P. *et al.* 2014. Monitoring chlorophyll concentrations with POSEIDON system's optical instruments. p. 358-362. In: *6th International Conference on EuroGOOS - Sustainable Operational Oceangraphy. 4-6 October, 2011, Sopot, Poland. Proceedings.*

Drakopoulos, P.G., Petihakis, G., Valavanis, V., Nittis, K. and Triantafyllou, G. 2003. Optical variability associated with phytoplankton dynamics in the Cretan Sea during 2000 and 2001. p. 554-561. In: *Building the European capacity in operational oceanography, Proceedings of the 3rd International Conference on EuroGOOS*. Dahlin, H., Flemming, N.C., Nittis, K and Petersson, S.E. (eds). Elsevier Oceanography Series, Vol. 69, Elsevier BV, Amsterdam.

Gordon, H.R. and Clark, D. 1980. Remote sensing optical properties of a stratified ocean: an improved interpretation. *Applied Optics*, 19, 3428-3430.

Gordon, H.R. and Ding, K. 1992. Self-shading of in-water optical instruments. *Limnology and Oceanography*, 37, 491-500.

Lee, Z.P., Ahn, Y.H., Mobley, C., and Arnone, R. 2010. Removal of surface-reflected light for the measurement of remote-sensing reflectance from an above-surface platform. *Optics Express*, 18, 26313-26324.

Mobley, C.D. 1999. Estimation of the remote-sensing reflectance from above-surface measurements. *Applied Optics*, 38, 7442-7455

Morel, A. 1980. In-water and remote measurements of ocean color. *Boundary-Layer Meteorology*, 18, 177-201.

Morel, A. and Gentili, B. 2009. A simple band ratio technique to quantify the colored dissolved and detrital organic material from ocean color remotely sensed data. *Remote Sensing of Environment*, 113, 998-1011.

Santoleri, R., Volpe, G., Marullo, S. and Buongiorno Nardelli, B. 2008. Open Waters Optical Remote Sensing of the Mediterranean Sea. p. 103-114. In: *Remote Sensing of the European Seas*. Barale, V. and Gade, M. (eds). Springer Science+Business Media B.V., Heidelberg.

Zeri, C., Beşiktepe, Ş., Giannakourou, A., Krasakopoulou, E., Tzortziou, M. *et al.* 2014. Chemical properties and fluorescence of DOM in relation to biodegradation in the interconnected Marmara-North Aegean Seas during August 2008. *Journal of Marine Systems,* 135, 124-136.