Assessing phytoplankton dynamics in the Aegean Sea: combining remote sensing and field data of Chlorophyll *a*

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Abstract

A compilation of 15 years field data of chlorophyll-a from the Aegean Sea are compared for the first time with respective remote sensing chlorophyll *a* matchups, using the MODIS-Aqua products and the OC3M-547 MODIS operational algorithm, along the trophic N-S gradients of the Aegean Sea. This is a small part of a coordinated study of the optical properties of the Aegean marine waters, undertaken for the first time within the framework of THALES-AegeanMarTech and PERSEUS-IP projects.

Keywords: phytoplankton, Aegean Sea, chlorophyll *a*, remote sensing

1. Introduction

The Aegean Sea, at the northern part of the E. Mediterranean, is a complex marine environment with highly variable hydrology, bottom topography and lateral inputs. In the north, inflow of less saline mesotrophic Black Sea Waters (BSW) in conjunction with significant nutrient inflows from rivers enriches locally the NE Aegean area, creating a N-S trophic and productivity gradient (Ignatiades et al., 2002). The S. Aegean, with higher temperatures and salinities, negligible run-off and intense dust deposition events is an ultra-oligotrophic environment, with surface chlorophyll *a* < 0.4 μg L^{-1} during the spring bloom and primary productivity annual estimates among the lowest in the world ocean (60-80 gC m^{-2}) (Psarra et al., 2000). Over the last 20 years, scientific research focusing on the identification of the key factors controlling phytoplankton dynamics and ecosystem functioning in the Aegean Sea is based on biogeochemical measurements obtained through field oceanographic campaigns. Such data are fundamental for comprehending ecosystem processes but insufficient for assessing long term spatiotemporal phytoplankton and ecosystem dynamics. In this work, in order to fill as many puzzle pieces as possible, a compilation of data from historic campaigns complemented with data from PERSEUS and AegeanMarTech cruises in the N. Aegean, as well as with time series data from the monthly *in situ* monitoring at the POSEIDON E1-M3A station in the S. Aegean Sea are compared for the first time with high spatiotemporal coverage remotely sensed chlorophyll *a*.

2. Materials and methods

2.1 Field data collection & Analytical methods

Historical field data of chlorophyll *a* from the north and south Aegean Sea were obtained through a series of EU projects from 1997 until recently (e.g. MATER 1997-98, ANREC 2003-04, EUROCEANS 2005-06, POSEIDON 2007, SESAME 2008, MedEx 2011). Current projects involve PERSEUS and AegeanMarTech in the north, and the POSEIDON-E1-M3A *in situ* monthly monitoring in the south Aegean, respectively. For comparisons with remote sensing, field samples collected from standard depths (2, 10, 20, 50, 75, 100) were mean integrated over the 0 - 10 m layer. Chlorophyll *a* concentration was measured according to the fluorometric method (Holm-Hansen et al., 1965) for "historical data" and by HPLC analysis for the current projects, PERSEUS and AegeanMarTech (Van Heukelem & Thomas, 2001).

2.2 Remote Sensing

For remote sensing Chl *a*, NASA Goddard Space Flight Center's Ocean Color Data Processing System webpage (http://oceancolor.gsfc.nasa.gov/) was used in order to download MODIS Aqua Level 2 (L2) data products. A Level-2 data product is generated from either a Level-1A (SeaWiFS or OCTS) or Level 1B (MODIS) product. The main data contents are the geophysical values for each pixel, derived from the Level-1 radiance by applying the sensor calibration (for Level-1A), atmospheric corrections, and bio-optical algorithms (NASA OCG, 2014). Analysis and geophysical parameters were derived using SeaDAS GIS program, linux version and IDL programming language. L2 daily data with 1x1km spatial resolution were used with the quality 32 flags provided from the same source, associated with each pixel indicating if any algorithm failures or warning conditions occurred for that pixel. The operational algorithm for deriving near-surface Chl*a* from MODIS-Aqua sensor is OC3M-547 MODIS (O'Reilly et al., 2000).

3. Results and Discussion

When data from the NE Aegean Sea (MedEx project, 2011), under the direct influence of the BSW, are compared with remote sensing weekly matchups, significant divergence is observed with overall 5-fold higher values for the latter (Chl a_{sat} / Chl $a_{in\ situ}$ = 4.92±5.27). This divergence is lowest in March during the spring bloom when *in situ* values are > 1 μg L^{-1}, and highest in the post bloom period (data not shown).

Significant divergence between field and remote sensing data is also observed in the entire N. Aegean Sea. *In situ* data in most cases < 0.2 μg L^{-1} while remote sensing mean monthly (mmo) matchups were several fold higher. Again, minimum divergence was observed when field data attained maximum values (spring bloom, April '06). The overall obtained ratio of Chl α_{sat} / Chl $\alpha_{in\ situ}$ in this case was 4.1±1.9.

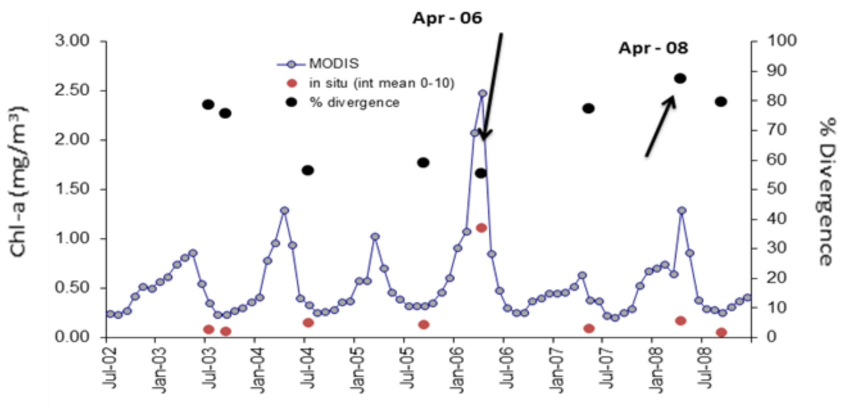

Fig. 1. Comparison of remote sensing (MODIS) mean monthly data with in situ Chl *a* in the N. Aegean Sea.

One of the main challenges in using ocean-color imagery is to determine the degree of correlation between the *in situ* measurements and the satellite-derived data. Ideally, *in situ* measurements should be collected at the same time as the radiometric measurements required for validating ocean-color algorithms. However, it is difficult to obtain an ideal matchup in space and time. Most importantly, the different scales in both space and time, applied for the two measurements play a critical role and have to be taken into account in these comparisons (e.g., *in situ* measurements are generally based on ~1 L of sea water, while remotely-sensed estimations are obtained from an area of ~1 km^2). In our case, weekly and mean monthly remote sensing Chl *a* data are compared with synoptic field data.

In an attempt to improve this comparison, corresponding daily (± 1 day) matchups were retrieved for the precise station coordinates for PERSEUS and AegeanMarTech projects for the NE Aegean (Oct. 2013, March, July 2014). On the same time, HPLC Chl *a* estimates were used instead of the fluorometric ones. In this case, the divergence was lower and Chl a_{sat} / Chl $a_{in\ situ}$ was 2.51±0.74. Always, the divergence becomes minimum when *in situ* Chl *a* is maximum and > 1 μg L^{-1} (March 2014, data not shown).

Finally, mmo MODIS matchups from the S. Aegean for a period of 4 years (03/2010 - 05/2014) are compared with the *in situ* monthly Chl *a* values from the E1-M3A station (Fig. 2). This station is part of the POSEIDON network of multi-sensor arrays and operates since 2000 (Petihakis et al., 2007). In this case, a much better coupling was observed and Chl a_{sat} / Chl $a_{in\ situ}$ was 1.07±0.6, although again a significant difference in time scales was applied (mmo satellite vs. synoptic *in situ* data).

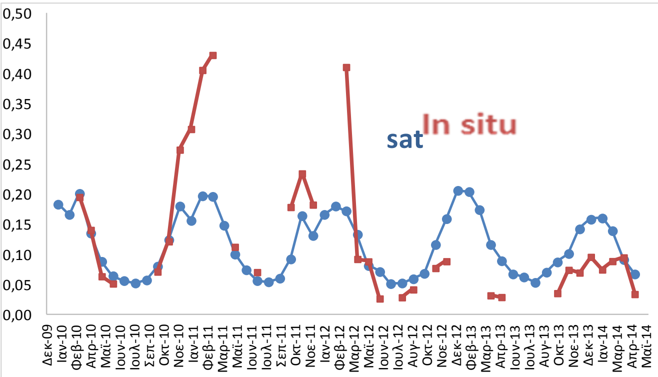

Fig. 2. Comparison of remote sensing (MODIS) mean monthly data with in situ Chl *a* in the S. Aegean Sea (Cretan Sea, E1-M3A site).

It is known that the accuracy of Chl *a* values estimated by remote sensors decreases when global algorithms are used in coastal waters. Especially in the Mediterranean Sea, standard algorithms lead to a significant overestimation of Chl *a* concentration (normal error >70%, for Chl *a* < 0.2 μg L^{-1}) (Bosc et al., 2004). This overestimation is attributed to atmospheric correction and the presence of Sahara dust in the water column or the presence of coccoliths.

In the NE Aegean, phytoplankton dynamics are governed by a dual mechanism; the typical seasonal variability recorded in the Mediterranean Sea (D'Ortenzio & Ribera d'Alcala, 2009) with thermally stratified water column and nutrient depleted surface layers, alternating with short term mixing during winter, replenishing surface layers and leading eventually to subsequent spring phytoplankton blooms in one hand, and the seasonal variation of BSW flux, usually following a different temporal pattern, in the other. Surface layers in the NE Aegean are many times associated with elevated particulate organic mater (POM) loads advected with the BSW inflow, culminating at late spring-early. Thus, it is hypothesized here, that in this area, considerable interference of substances other than Chl *a*, i.e. dissolved and particulate organic matter, as well as coccoliths associated with excessive *Emiliania huxleyi* concentrations in the advected BSW (Triantaphyllou et al., 2014) may interfere with the inherent optical properties and the resulting reflectance at surface, generating remote sensing ocean color readings that overestimate Chl *a*. Based on the above findings, a series of further steps will complement this study, involving application of the regional Mediterranean algorithm Med-OC3 (Santoleri et al., 2008) for the matchup retrievals, comparative use of HPLC and fluorometry Chl *a* measurements and downscaling the remote sensing data with increased spatial and temporal (daily matchups) resolution.

4. Conclusions

In the N. Aegean, and particularly in the area most affected by the BSW, remotely sensed Chl *a* tends to be significantly overestimated with the use of global algorithm, whereas in the more oligotrophic south a much better fit with field data is observed. In depth analysis of these data coupled to recent *in situ* measurements of a suite of optical properties within PERSEUS and AegeanMarTech projects will consolidate these comparisons of field and remote sensing data and allow a better assessment and prediction of phytoplankton dynamics in the Aegean Sea.

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