SPATIO-TEMPORAL VARIABILITY OF PHYTOPLANKTON FUNCTIONAL TYPES IN ALBORAN SEA FROM REMOTE SENSING IMAGES

Gabriel Navarro [(1)], Pablo Almaraz [(1)], Isabel Caballero[(1)], Águeda Vázquez[(1)] y I. Emma Huertas[(1)].

(1) ICMAN-CSIC, Polígono Río San Pedro, 2, Puerto Real, Cádiz, gabriel.navarro@icman.csic.es, pablo.almaraz@csic.es, isabel.caballero@icman.csic.es, emma.huertas@icman.csic.es
(2) Escuela Superior de Ingeniería, Universidad de Cádiz, Puerto Real, Cádiz, agueda.vazquez@uca.es

ABSTRACT

During the last two decades, several satellite algorithms have been proposed to retrieve information about phytoplankton groups using ocean color data. One of these algorithms, the so-called PHYSAT-Med, has been developed specifically for the Mediterranean Sea due to the optical peculiarities of this basin. The method allows detection from ocean color images of phytoplankton groups, such as nanoeukaryotes, *Prochlorococcus, Synechococcus* and diatoms. In this work, the PHYSAT-Med updated version has been used to analyze the annual cycles of major phytoplankton groups in the Alboran Sea and extract periodic components of variability using wavelet analysis. According to the PHYSAT-Med OC-CCI outputs, the algorithm represents a useful tool for the spatio-temporal monitoring of dominant phytoplankton groups in Alboran Sea.

***Index Terms*—** PHYSAT-Med algorithm, OC-CCI database, Phytoplankton functional types, Alboran Sea, wavelet analysis

1. INTRODUCTION

Since the launch of the Coastal Zone Color Scanner (CZCS) in the late 1970s, ocean color remote sensing has deeply improved our understanding of the ocean system by providing global estimations of the surface chlorophyll concentration (Chla), a parameter known to be a good proxy of phytoplankton biomass. During the last 40 years, observations of regional-to-global Chla data have been acquired by different ocean color sensors (IOCCG, 2012), such as Sea-viewing Wide Field-of-view Sensor (SeaWiFS), Moderate Resolution Imaging Spectroradiometer (MODIS), Medium-Resolution Imaging Spectrometer (MERIS) and Visible Infrared Imager Radiometer Suite (VIIRS). In order to extend the existing time series beyond that provided by a single satellite sensor, the European Space Agency (ESA) has recently generated the Ocean Colour—Climate Change Initiative (OC-CCI), a multisensor, global, ocean-color product mainly devoted to climate research (Storm et al., 2013) that merges observations from four different sensors: SeaWiFS, MODIS, MERIS, and VIIRS. As an ESA-funded CCI project, the OC-CCI focuses specifically in creating a consistent, error-characterized time-series of oceancolor products, with a strong focus in climate-change studies (Brewin et al., 2015).

Even though remote sensing derived phytoplankton types does not provide a full description of the marine ecosystem, its spatio-temporal distribution, and identification of key groups give powerful insights on the dynamics of the marine food web and the ocean's role in climate regulation in the context of the global change (Bracher et al., 2017). Over the last decade, several remote sensing algorithms have been developed to characterize the global distribution patterns of phytoplankton functional types (PFT) or size classes (PSC) (see recent summary in Table 2 in (Bracher et al., 2017 and Table 3 in Mouw et al., 2017). A complete guide of the available approaches can be found in Mouw et al. (2017).

One of these algorithms exploits the second-order anomalies of reflectance spectra, called PHYSAT, and was developed at a global scale (Alvain et al., 2005; 2008). The PHYSAT approach relies on the identification of specific signatures in the normalized water leaving radiance (nLw) spectra measured by an ocean color sensor (Alvain et al., 2005, 2008), thereby enabling the identification of nanoeukaryotes, haptophytes (a major component of the nanoflagellates), *Synechococcus* like cyanobacteria, diatoms, *Prochlorococcus*, Phaeocystis-like phytoplankton, and coccolithophorids. The PHYSAT method has been successfully validated with phytoplankton in situ data and extensively used by many authors (Navarro et al., 2014 and references therein). This algorithm was later modified and validated for Mediterranean basin (PHYSAT-Med) by Navarro et al. 2014; 2017. The main utility of the PHYSAT-Med is that it allows for the tracking of specific features of phytoplankton community structure occurring in the basin, along with their associated bio-optical relationships that are heavily affected by continental inputs, such as desert dust events and rivers discharge

In this study, we applied the PHYSAT-Med algorithm (Navarro et al., 2017) to extract the PFT distribution in Alboran Sea (Figure 1). Later, wavelet analysis is applied to the retuned version in order to analyze the contributions of different temporal cycles of dominance variability of the major phytoplankton groups in the Alboran Sea.

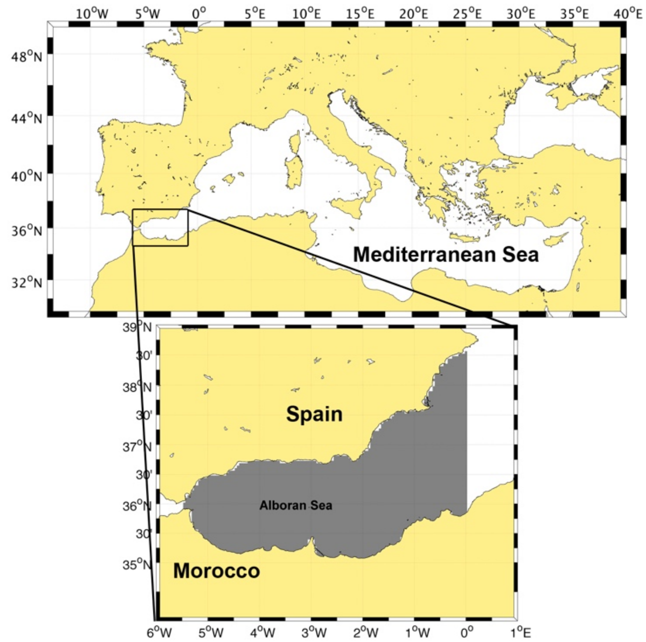

Figure 1. Map of the Mediterranean Sea (above panel). Gray area (below panel) shows the Alborán Sea.

2. MATERIAL AND METHODS

2.1. PHYSAT-Med OC-CCI Algorithm

Daily level 3 remote sensing reflectance data (Rrs) at 412, 443, 490, 510, 555, and 670 nm and diffuse attenuation coefficient (Kd490) were downloaded from the OC-CCI website covering the period from January 1998 to December 2015 (see Figure 2 in Navarro et al., 2017). These products were displayed on a regular 4 km grid, with an equi-rectangular projection with constant longitude and latitude steps. In a second step, the Chla concentration in the Mediterranean Sea was calculated using a regional algorithm (MedOC4, Mediterranean ocean color four-bands, Volpe et al., 2007) developed for the basin for SeaWiFS bands:

$$\text{MedOC4-Chla} = 10 \wedge (a - bR + cR^2 + dR^3 - eR^4)$$

where a, b, c, d and e are 0.4424, 3.686, 1.076, 1.684 and 1.437 respectively. R is calculated using the Maximum Band Ratio (MBR):

$$R = \log_{10}[\text{MAX}\ (Rrs_{443/555}, Rrs_{490/555}, Rrs_{510/555})].$$

At the third step, the Rrs was converted to nLw using the nominal band solar irradiance (Fo, in mW cm−2 μm−1) for any specific spectral band (λ) of the SeaWiFS sensor:

$$nLw_{(\lambda)} = Rrs_{(\lambda)} * F_{o(\lambda).}$$

During step 4, a Look-Up-Table (LUT, Figure 2) of nLwref (λ, Chla) was empirically generated for the Mediterranean Sea from a large dataset of OC-CCI Chla and nLw pixels for all daily images contained within the study period (January 1998 to December 2015).

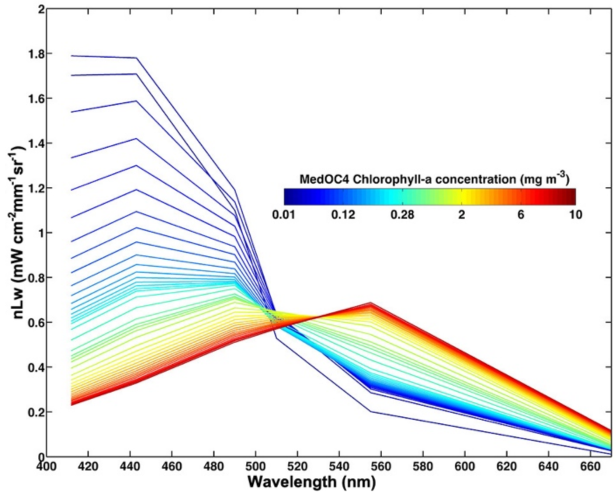

Figure 2. Look-Up-Table for PHYSAT-Med OC-CCI algorithm. Normalized water-leaving radiance nLw as a function of wavelength for various MedOC4-Chla concentration (color scale) for the Mediterranean Sea (excluding Black Sea) during the study period (January 1998–December 2015).

Finally, the radiance anomalies [Ra(λ)] were computed for all daily OC-CCI wavelengths analyzed using

$$[Ra_{(\lambda)} = nLw_{(\lambda)} / nLw_{(ref\lambda)}]$$

for all available wavelengths (412, 443, 490, 510, 555, and 670 nm). Ra(λ) is an adimensional parameter independent of the Chla level, and hence also independent of the biomas. The labellization step was performed using the thresholds of Ra for each of the six phytoplankton groups examined in PHYSATv2008 (see Table 5 in Alvain et al., 2008), which is specifically set up for SeaWiFS channels. These thresholds were used to process daily images to calculate daily PFTs map. For a spectrum to be associated with one group, all criteria must be fulfilled. Thresholds (Table 5 in Alvain et al., 2008) were fixed in order to avoid any overlapping. Pixels with nLw values that were not classified for any phytoplankton groups were cataloged as "unidentified (unid.)," and this can sum up a significant fraction (Navarro et al., 2014).

PHYSAT-Med retrieves the dominant group for a given satellite image pixel (4 km) for Mediterranean Sea, where a given phytoplankton group is the major contributor to the radiance anomaly. From this database (near to 6,600 daily images), 10-day and monthly maps of dominant phytoplankton groups were obtained by calculating the phytoplankton group that was present more days during the integration period (10-day or monthly, respectively) at each geographical pixel, not including "unidentified" pixels. To estimate the proportion of each phytoplankton group in the

Alboran Sea, the number of the pixels of each PFT during 10-day or 1 month was calculated for this area in proportion to all the identified pixels, excluding the unidentified pixels.

2.2. Wavelet Analysis

Wavelet analysis has emerged as a tool for characterizing periodicities in non-stationary time series, as it decomposes a time series both in the frequency and time domains (Percival and Walden, 2000). In this study, wavelet analysis has been used to characterize the different periodic components of the variability in dominance of the major phytoplankton groups in the Alboran Sea across time. Wavelet analysis performs a time-scale decomposition of the signal by estimating its frequency characteristics as a function of time (Torrence and Compo, 1998). We used Matlab R toolbox provided by Torrence and Compo (1998). The wavelet power spectrum identifies the periods that are the most important sources of variability across time. Wavelet analysis was performed over the 10-day times series of nanoeukaryotes, *Prochlorococcus*, *Synechococcus* and diatoms for the Alboran Sea.

3. RESULTS AND DISCUSSION

Figure 3 shows the monthly climatology in the percentage of dominance of the four phytoplankton groups for Alboran Sea. It is evident that *Synechococcus* and *Prochlorococcus* are the most abundant groups detected at the Alboran Sea and particularly during spring and summer months respectively, whereas nanoeukaryotes seem to dominate during autumn-winter months. During this season, primary production by the picoplankton exhibits a maximum (Navarro et al., 2017 and references therein). It is well known that due to their high surface/volume ratio, *Synechococcus* (and also *Prochlorococcus*) can cope optimally with nutrients impoverished environments.

However, the diatoms prevail during the spring season. This last finding agrees with the microplankton distribution provided by Sammartino et al. (2015) and Di Cicco et al. (2017) who concluded that the fraction of microplankton increase in spring season. As expected, diatoms were the least abundant of the four phytoplankton groups analyzed in the Alboran Sea. In fact, the percentage of abundance of diatoms fell within the range of 0–10% in the Alboran Sea. A moderate spring maximum could be still detected, coinciding with the seasonal blooms normally described for this phytoplankton group along the Mediterranean (Marty and Chiavérini, 2002).

The abundance of nanoeukaryotes and *Synechococcus* in the Alboran Sea follows recurrent 12-months cycles across time, as suggested by the power of the wavelet spectrum at this cycle (Figure 4). However, *Prochlorococcus* present some weaker 6-months cyclic components during certain particular years (2008, 2012) (Figure 4).

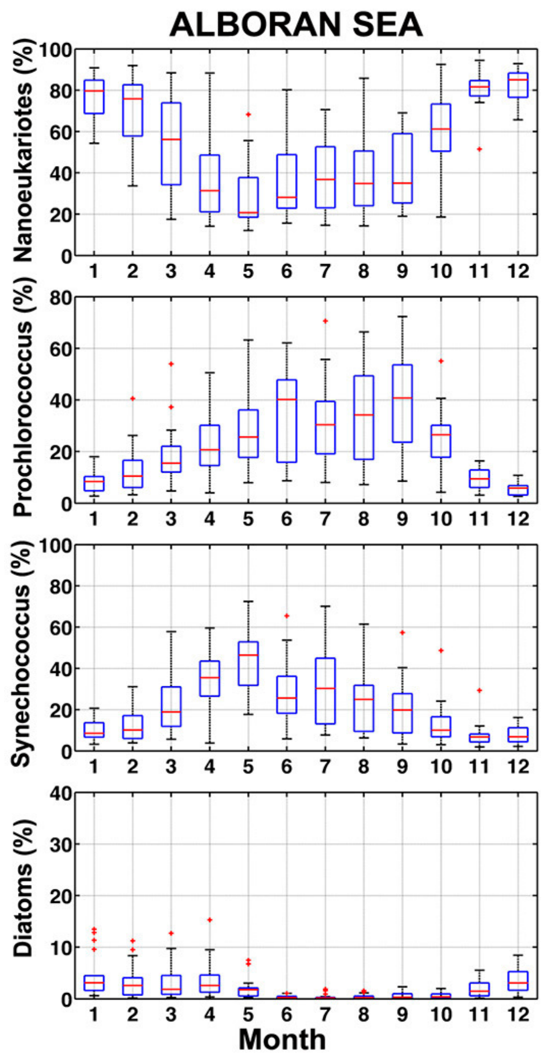

Figure 3. Box plot for monthly climatology for each group in Alboran Sea. In the box plot figure red lines stand for the median, blue box spans from the first to the second quartiles, and black lines represent 5th and 95th percentiles, respectively, of monthly climatology for each group.

4. CONCLUSIONS

This work presents an updated version of the PHYSAT-Med algorithm that has been specifically developed using the OC-CCI database. This ESA initiative aims at gathering ocean color measurements from four sensors since 1997. The distribution of the major phytoplankton groups in the Mediterranean basin during a 18 years period was consistent with the previous knowledge on the distribution patterns of phytoplankton in the basin.

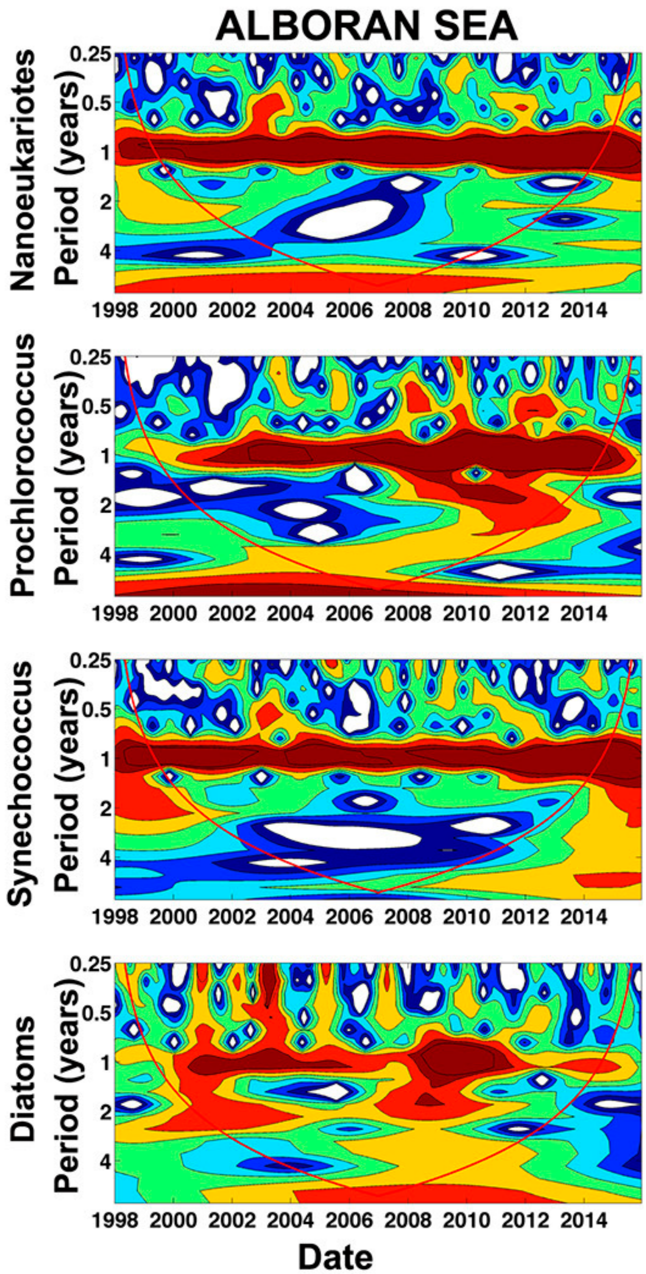

Figure 4. Continuous wavelet power spectrum for the 10-day time series for each group. Each row represents each phytoplankton group (nanoeukaryotes, Prochlorococcus, Synechococcus, and diatoms). Red line indicates the region of time and frequency affected by the edges of the data and should not be considered.

5. ACKNOWLEDGMENTS

The authors acknowledge the Ocean Colour Climate Change Initiative dataset, Version 3.0, European Space Agency, available online at http://www.esa-oceancolour-cci.org/, for providing access to remote sensing reflectance products. This work was financially supported by the National Project CTM2014-58181-R.

5. REFERENCES

Alvain, S., Moulin, C., and Dandonneau, Y. Seasonal distribution and succession of dominant phytoplankton groups in the global ocean: a satellite view (SeaWiFS 1998–2006). Global Biogeochemical Cycles, 22, GB3001, 2008.

Alvain, S., Moulin, C., Dandonneau, Y., and Breon, F. M. Remote sensing of phytoplankton groups in case 1 waters from global SeaWiFS imagery. Deep-Sea Research I, 1, 1989–2004, 2005.

Bracher, A., et al. Obtaining Phytoplankton Diversity from Ocean Color: A Scientific Roadmap for Future Development. Frontiers in Marine Science, 4:55, 2017.

Di Cicco, A., Sammartino, M., Marullo, S. and Santoleri, R. Regional empirical algorithms for an improved identification of Phytoplankton Functional Types and Size Classes in the Mediterranean Sea using satellite data. Frontiers in Marine Science, doi: 10.3389/fmars.2017.00126, 2017.

Marty, J.C. and Chiavérini, J. Seasonal and interannual variations in phytoplankton production at DYFAMED time-series station, northwestern Mediterranean Sea. Deep Sea Research II, 49, 2017-2030, 2002

Mouw, C.B., et al. A Consumer's guide to satellite remote sensing of multiple phytoplankton groups in the global ocean. Frontiers in Marine Science, 4:41, 2017.

Navarro, G., Alvain, S., Vantrepotte, V., and Huertas, I.E. (2014). Identification of dominant phytoplankton functional types in the Mediterranean Sea based on a regionalized remote sensing approach. Remote Sensing of Environment, 152, 557-575, 2017.

Navarro et al. Reproduction of spatio-temporal patterns of major mediterranean phytoplankton groups from remote sensing OC-CCI data, Frontiers in Marine Science, 2017.

Percival, D. B. and Walden, A. T. Wavelet methods for time series analysis. Cambridge, UK: Cambridge University Press, 2000.

Sammartino, M., Di Cicco, A., Marullo, S., and Santoleri, R. Spatio-temporal variability of micro-, nano- and pico-phytoplankton in the Mediterranean Sea from satellite ocean colour data of SeaWiFS, Ocean Sci., 11, 759-778, 2015.

Storm, T., Boettcher, M., Grant, M., Zühlke, M., Fomferra, N., Jackson, T. and Sathyendranath, S. Product User Guide, Ocean Colour Climate Change Initiative, 51, 2013.

Torrence, C. and Compo, G. P. A practical guide to wavelet analysis.Bull. Am. Meteorol. Soc. 79, 61–78, 1998.

Volpe, G., Santoleri, R., Vellucci, V., Ribera d'Alcalà, M., Marullo, S., and D'Ortenzio, F. The colour of the Mediterranean Sea: Global versus regional bio-optical algorithms evaluation and implication for satellite chlorophyll estimates, Remote Sensing of Environment, 107, 625-638, 2007.