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5 **Ocean color response to wind forcing in the**

6 **Alboran Sea: a new forecasting method.**

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12 Jordi Solé (1), Simón Ruiz (2), Ananda Pascual (2), Samuel Somot (3), Joaquín Tintoré

13 (2)

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15 (1) Institut de Ciències del Mar (CSIC), 08003 Barcelona, Catalunya, Spain

16 (2) IMEDEA (CSIC-UIB), Miquel Marqués 21, 07910 Esporles, Mallorca, Spain

17 (3) Centre National de Recherches Météorologiques, Météo-France, CNRS, CNRM-

18 GAME, Toulouse, France

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ABSTRACT

This work proposes a new method to reconstruct and forecast surface Chlorophyll (Chl) from remotely sensed (SeaWiFS) data in the Alboran Sea, based on the correlation between zonal wind velocities and satellite Chl concentrations. First, the spatial and temporal variability of Chl and zonal wind have been characterized using standard statistics. Second, the annual cycle and trends are removed from the original time series and the residuals submitted to an EOF computation scheme. Then, the correlations between the amplitudes of the first temporal modes of Chl-wind couple have been quantified. Using the most highly correlated pair (Chl-zonal wind, with $r = 0.63$), a simple linear relationship is proposed to reconstruct and forecast the Chl field. This forecasting method is more efficient than persistence for forecast horizons longer than 100 days, with a mean correlation between original and predicted field of 0.73 as compared to 0.5 for persistence for all the year round. In particular, this new method gives a 0.95 mean correlation for periods from 100 to 290 days (while persistence gives 0.5). However, for a constant 8-days prediction horizon the persistence performs marginally better than the proposed method (0.79 vs. 0.68), giving some insight into the temporal scales of the features studied. These results may have significant implications for both short-term operational applications and seasonal forecasts.

Keywords: EOF, zonal wind, SeaWiFS, forecasting.

1. Introduction

An open question in the study of coupled ocean-atmosphere systems concerns the role played by atmospheric variability in influencing ocean circulation and consequently marine ecosystems [Taucher and Oschlies, 2011]. Some oceanic structures, which can be influenced or enhanced by atmospheric forcing, incorporate horizontal and vertical motions that affect biological processes [McGillicuddy et al., 2008a,b; Rodríguez et al., 2001]. The horizontal distribution of these oceanic features and their intensity is influenced by meteorological variables such as wind and atmospheric pressure. The upwelling and frontal areas are characterized by higher vertical velocities, which bring more nutrients to the photic zone. This nutrient enrichment, enhances the phytoplankton growth and, in consequence, the increase on biomass in the ecosystem through the lower trophic levels (Macías et al. 2009). Therefore, one method for understanding how biological activity is affected by the atmosphere is to study ocean systems where atmospheric variables have a strong influence on such marine features. For this purpose, it is useful to identify areas that can be used as a 'laboratory' system in order to isolate and to analyse common key ocean/atmosphere interactions. The Alboran Sea (Western Mediterranean) is an excellent area to study such effects of atmospheric forcing on the marine ecosystems, as the dynamics of this zone is strongly influenced by the atmospheric variables, which enhance the main features of the ocean surface circulation [García-Gorriz and Carr, 1999]. Also due to the interaction of the Atlantic and Mediterranean waters there is strong frontogenesis activity in this area. The Alboran Sea has a high level of mesoscale activity [Tintoré et al., 1991; García-Lafuente et al., 1998; Vargas-Yáñez et al., 2002] that is partially controlled by the changes in the main driving meteorological variables: zonal wind and atmospheric pressure are shown to be the most important [Candela et al., 1989; García-Lafuente et al., 2002, Macías et al., 2007].

76 Inter-annual and intra-annual variability of the atmospheric processes in the Alboran
77 Sea can influence their intrinsic internal oceanographic dynamics and, in turn, the
78 marine ecosystem behaviour. Macías et al. [2007; 2008; 2011] have demonstrated how
79 dynamics affects the pattern of Chlorophyll (hereafter Chl) distribution and García-
80 Lafuente et al. [2007] showed a mean of assessing the impact of climate variability on
81 the ecosystems of the area.

82 Previous research into variability in the Alboran Sea has focused on the interactions
83 between mesoscale features and the main circulation patterns (Bormans and Garret,
84 1989; García-Lafuente et al., 1998, Lacombe, 1971; Arnone et al., 1990).
85 Schematically, the Alboran Sea upper layer dynamics (Viúdez et al. [1998] and
86 references therein) is controlled by a strong baroclinic jet (AJ) of Atlantic water (AW)
87 which, entering the basin through the Strait of Gibraltar, can form one or two
88 anticyclonic gyres: the Western Alboran Gyre (WAG) and the Eastern Alboran Gyre
89 (EAG), see Fig. 1. The convergence of this AW with the saltier and denser
90 Mediterranean Surface Water (MSW) creates an intense density front, the Almeria-Oran
91 Front (AOF), oriented NW to SE. The temporal behaviour of the AJ influences the
92 dynamics of the area. In this sense, it has been reported a seasonal behaviour of the AJ
93 (Macías et al. 2007), conditioned by both, winds and atmospheric pressure. Essentially,
94 two situations can be distinguished: absence and presence of easterly winds. With the
95 absence of easterlies the AJ is closer to the Iberian Peninsula, and then, the upwelling of
96 nutrient rich water along the Iberian Peninsula coast on the northern side of the WAG is
97 activated [Gascard and Richez, 1985; García-Gorriz and Carr, 1999]. Under the
98 influence of easterlies the AJ is drifted to the south, and a secondary upwelling is
99 detected offshore. These two situations link the variability of the Chl patterns in the area
100 with the variability of the AJ. Therefore, the variability in Chl is mainly driven by wind

intensity and atmospheric pressure distribution (Sarhan et al., 2000; Vargas-Yañez et al., 2002; Macías et al., 2007; 2008). Such a driven mechanism is confirmed, recently, by an inter-comparison between sampled data, satellite data and model simulations (Macías et al., 2011).

Following previous works [Baldacci et al., 2001; Macías et al., 2007], in this paper we study the effect of atmospheric forcing on oceanic ecosystem variability in the Alboran Sea. In particular, our objective is to better understand the links between wind forcing (in particular zonal wind) and Chl and to obtain empirical relationships between these components. Such relationships can then be used to produce forecasts or hindcasts using a low cost algorithm, which is less computationally expensive than using a coupled physical-biological model. First, the basic statistics of satellite ocean colour images and the zonal wind data is calculated. Then, in a second step, the most significant spatial modes of the residual field (original minus trend and seasonal cycle) are computed for the satellite Chl and zonal wind variables using an Empirical Orthogonal Function (EOF), and the correlation of their temporal amplitudes is evaluated. Based on this correlation we then propose a new method to reconstruct the Chl field distribution from the zonal wind field and analyse its effectiveness as a forecasting tool.

The paper is structured as follows. The data set and methodology are described in Section 2. Section 3 is devoted to the results from the EOF analysis, including the basic statistics of the data set and the performance of the proposed method for the reconstruction of the Chl field. Section 4 contains the summary and discussion of the results.

2. Data set and methodology

2.1 Atmospheric data set

The zonal wind velocity forcing used in this study is part of the ARPERA database (Herrmann and Somot, 2008). A high resolution climate model spectrally driven by ERA40 forcing fields for the large scales is used to provide the ARPERA dynamical downscaling dataset covering the 1958–2001 period. The spatial and resolution of the wind data is $\frac{1}{2}^{\circ} \times \frac{1}{2}^{\circ}$ and outputs are available every 6 hours. The period selected for wind data overlaps completely the Chl data time-span (from January 1998 to December 2006). Original model outputs have been averaged to produce 8-day values at each grid point, in order to generate a time series with the same frequency as the Chl data described below. The data domain used is: from 5.6 E to 0 W and from 35.8 N to 38.5 N.

2.2 Ocean Color data set.

The Chl level-1A data were acquired from the Istituto di Scienze dell'Atmosfera e del Clima (Rome, Italy). The SeaWiFS Data Analysis System (SeaDAS) was used to process and obtain Level-3 data, which includes the standard correction applied to Level-1A data (Siegel et al., 2000). Additionally, the MedOC4 regional algorithm (Volpe et al., 2007, 2011) is applied to the data, in order to produce more realistic values for the Mediterranean Sea. The Chl fields were then interpolated onto a $1/16^{\circ}$ grid, by performing an initial spatial average from the original 1.1 x 1.1 km. Eight-day averages were then produced and final complete fields were obtained by applying a Data Interpolating Empirical Orthogonal Functions (DINEOF), following the method developed by Beckers and Rixen (2003). This method allows the efficient removal of data gaps due to cloud cover, while still preserving the variability in different scales of Chl concentrations between coastal areas and the open ocean (see Volpe et al., 2011, section 3.3, for details). The original Chl data covers all the Mediterranean Sea in the

period comprised from January 1998 to December 2006. In this work we only use the Chl data corresponding to our area of interest (same domain described in wind data). Chl data (log-normal distribution) have been log-transformed to ensure a Gaussian distribution.

2.3 Methodology

As a first approach to the data statistics, the temporal and spatial means, variances, trends and annual and semi-annual cycles have been computed. Then, as the study focus on the variability associated to a non-seasonal nor trended signal, original data are detrended fitting a linear function by a non-linear least squares regression and the annual and semi-annual cycle is removed from the original data by fitting two harmonic functions using a least squares method (Pascual et al. 2008):

$$y(t) = A_a \cos\left(\frac{2\pi}{365.25} t - \varphi_a\right) + A_{sa} \cos\left(\frac{2\pi}{182.63} t - \varphi_{sa}\right) \quad (1)$$

Where A_a and φ_a are the amplitude and phase of the annual cycle and A_{sa} and φ_{sa} are the amplitude and phase of the semi-annual cycle. Phases are expressed in days and a zero time lag indicates January 1st.

After removing the trend, annual and semi-annual cycle for each grid point, the EOFs (Empirical Orthogonal Functions) of each variable are computed. EOFs are calculated using a Singular Value Decomposition (SVD) of the covariance matrix of data, and retaining as EOFs the eigenvectors associated to non-zero eigenvalues as it is explained in Navarra et al. 2010. The main EOF modes of variability of both variables, wind and Chl were computed using the Lanczos strategy, an iterative Eigensolver based on a Krylov-type method, as proposed by Toumazou et al. (2001). This gives, at each grid-point, a time series that can be expressed as:

$$\theta(x,y,t) = \sum_{j=1}^n m_j(x,y) A_j(t) \quad (2)$$

Where $\theta(x, y, t)$ is the residual (original data minus trend and annual and semi-annual cycle) of the variable, and for each index j , m_j corresponds to the j th spatial EOF mode and A_j is its temporal amplitude.

3. Results

3.1 Basic statistics

The spatial distribution of the temporal mean and variance of Chl and zonal wind are shown in Figure 2. The Chl mean field reveals three zones, corresponding to the three main hydrological structures in the area; the coastal upwelling, the gyre and the Atlantic jet zone. The higher variance in Chl concentrations, $\sim 0.14 (\log_{10} \text{ mg m}^{-3})^2$, is associated with the coastal zone in the south of Iberian Peninsula (see Figure 2b). While the WAG area has a lower variance in Chl concentration, $\sim 0.04 (\log_{10} \text{ mg m}^{-3})^2$, indicating the signature of a well defined gyre structure. In the zone of influence of the Atlantic jet, variability reaches values of about $0.08 (\log_{10} \text{ mg m}^{-3})^2$. For the zonal wind, the spatial distribution of the time mean is uniform over the whole Alboran Sea and this mean value is around 0.5. The variance is less homogeneous and higher than $40 (\text{m s}^{-1})^2$, along the centre of the basin, see Figure 2d.

The spatial mean of the trend in the Chl field (Fig. 3) shows a near zero slope along the nine years analysed. The spatial distribution of the trend for Chl field shows roughly the same areas appearing in the mean original field previously cited: the coastal upwelling, the gyre and the Atlantic jet zone (trend error: 0.005). Then, values in coastal upwelling zone (South-Eastern part of the Iberian Peninsula) are the highest while the mean temporal trend decreases in the gyre until minima values in the eastern domain. For the zonal wind, the trends (data not shown) are not statistically significant, being of the

same order of magnitude as the associated error computed through a bootstrap method after Efron and Tibshirani (1993).

The time evolution of the spatial mean of the original Chl data, and the annual and semi-annual cycle plus trend for the nine years analysed is shown in Figure 4. The sum of the annual and semi-annual cycles of spatial mean reveals a maximum in February and a minimum in August while the total mean original field shows a yearly first maximum by the end of February-early March and a second maximum in June. The temporal evolution of the first peak of Chl (captured by the seasonal cycle) is in good agreement with previous results reported by Macías et al (2007), who shows a spatial climatological mean with a Chl maximum in March. However, the second peak (not captured by the seasonal cycle) in May-June may be due to the wider area considered for this study in comparison with the area evaluated by Macías et al. (2007). It is however worth noting that while the total variance of the original mean of Chl is $0.045 (\log_{10} \text{ mg m}^{-3})^2$, the seasonal variance is $0.03 (\log_{10} \text{ mg m}^{-3})^2$ and the residual variance is $0.015 (\log_{10} \text{ mg m}^{-3})^2$, which means that the seasonal cycle accounts for about 66% of the total variance (in contrast to the variance reported to previous works of 20%, Macías et al. 2007 mainly because they use no log transformation). This analysis confirms that the seasonal signal is the dominant feature in the Chl concentration time series. It is however the remaining 33% of the variance of the original Chl field that is crucial to better understanding the inter-annual variability of the spring blooms (Macías et al. 2007).

3.2 EOF results and correlations between amplitudes

Table 1 shows the percentage of variance accounted for by the first three modes for the Chl and zonal wind. The first EOFs of Chl and zonal wind account for more than 74.7% and 53.7% of the total variance respectively, the second EOFs explain 13.7% and

25.6% and the third only 6% and 8.2%. In the first Chl mode (Fig. 5) two main areas are observed. Firstly, the positive values covering most of the area including the upwelling area south of Iberian Peninsula and secondly, values around 0 or negative corresponding to the oligotrophic region of the AGs and baroclinic jet of Atlantic water. For the zonal wind, the first spatial mode presents a pattern associated with a minimum in the centre of the domain (Fig. 5).

Figure 6 shows the 9-year time series of the first mode amplitudes of Chl and zonal wind and the filtered curves (using a 10 points running average) of both variables (bold lines) clearly show a similar pattern of behaviour in the timing of maxima and minima across the study period. Indeed, Pearson's linear correlation coefficient is 0.63, with $p < 0.01$ for the original (without smoothing) series. The significance of the calculated correlation coefficient has been tested. Therefore, we computed the auto-correlation of each mode variable and a correlation with a time shift (time lag correlation). The maximum normalized values of auto-correlations for zonal wind and Chl are, respectively, 0.15 and 0.16 while the correlation between both series considering a time shift gives a maximum value of about 0.63 for non-shifted series. Then, these results show as significance of the correlation between variables initially calculated. Based on these results, and on the fact that in previously published bibliography the strong correlation between the Chl and zonal wind is also evidenced (Macías et al. 2007), we propose a new reconstruction and forecasting method that is detailed below.

3.3 A new method for Chl field reconstruction

The significant correlation found between zonal wind and Chl concentration may indicate that part of the Chl variability is driven by wind forcing.

Applying equation (2) to zonal wind and Chl we may write equation (2) as:

$$U'(x, y, t) = \sum_{j=1}^n A_j^u(t) m_j^u(x, y) \quad (3)$$

$$Chl'(x, y, t) = \sum_{j=1}^n A_j^{Chl}(t) m_j^{Chl}(x, y)$$

Where $U'(x, y, t)$ and $Chl'(x, y, t)$ are the residual of zonal wind and Chl, $m_j^u(x, y)$, $m_j^{Chl}(x, y)$ are respectively the spatial modes of the residual of zonal wind and Chl and $A_j^u(t)$, $A_j^{Chl}(t)$ the corresponding time amplitudes. This method seeks a relationship between the amplitudes, $A_j^{Chl}(t) = f(A_j^u(t))$. Considering the significant correlation between the zonal wind and Chl amplitudes (0.63), we used a linear regression between the amplitudes of the first mode: $A_j^{Chl}(t) = a A_j^u(t) + b$. This relationship enables to estimate the amplitude of the Chl field from the zonal wind amplitude at a given time, provided this last one is known.

To test the proposed method we used the January 1998 - December 2005 period for computing the EOFs and the regression between Chl and zonal wind, and the period between January and December 2006 for validation purposes. Two different timescales for validating the reconstruction methodology are considered, in the first instance, we analyse the performance of the method for short-term prediction, i.e. with a forecast horizon of only 8 days, which is the smaller period we can choose (time bin is 8 days). In the second analysis, the prediction horizon ranges from 8 days to one year, so that at each time step the prediction is carried out using all previous fields until the start of the forecast. We compare the performance of the forecasted fields using our proposed reconstruction method with other fields forecasted using i) the persistence, ii) the trend of the field data and iii) the seasonal cycle plus trend. For all the methods we consider

the available field (AF) as the actual time-step and the forecasting field (FF) as the prediction in the future, then the four methods tested (the three above mentioned and the new method proposed) differ only on how the FF is constructed. For the persistence approach the FF is directly the AF. For the method based on the trend of the data, the FF is obtained multiplying the time by the AF trend. The seasonal cycle technique uses the time evolution of the annual and semi-annual cycle plus trend at each pixel to obtain the FF. The accuracy of the methods is assessed in all the cases by calculating the Pearson's linear correlation (ρ) between the two fields (the original Chl and the FF).

Figure 7 shows the temporal variability of ρ for the different reconstructed fields assuming a 8 days forecast horizon. In this case, our proposed method shows better results than those obtained from the trend and annual cycle plus trend, while the persistence gives better results almost for all the time period tested. It is worth noting that ρ is far from constant all year round and that for the prediction horizon used (8 days) the persistence forecast appears to be a good method. The values of ρ (Fig. 7) for all the methods have a sharp decrease around 300 days forecast. Figure 8 presents the temporal evolution of ρ for the forecasted fields with a prediction horizon increasing from 8 days to one year as we advance through the year. In this case, our method shows better results than all the methods tested for prediction horizon greater than around 100 days, included the persistence. It is worth noting the improvement of the Chl prediction. Quantitatively, this gives a correlation coefficient of 0.95 averaged over prediction horizons comprised between 100 and 290 days, which implies a relative improvement of 44 % with respect to persistence (with 0.5 correlation coefficient over this period). Indeed, the persistence gives worse results than the other three methods tested. The spatial performance of the method is qualitatively illustrated in Figure 9, with the reconstructed and observed patterns of Chl shown for three different dates. These two

specific snapshots have been selected as they correspond to marked different situations. In the first case, the signature of an intense upwelling is clearly depicted with strong gradients indicating the presence of the WAG. In the second case, the gradients are very weak and almost no significant features are detected. In the third case although patterns are identifiable Chl values are closer to zero. Note that the good agreement between the original and reconstructed field is remarkable for the two first cases while the last case although the gradients have a good correspondence the concentrations are underestimated.

4. Discussion and conclusions

This work proposes a new method to reconstruct and forecast the Chl field in the Alboran Sea based on the correlation between EOFs modes of zonal wind and satellite Chl data. The significance of the correlation results is tested against the auto-correlation of the time series and also doing a shifting-correlation test of the variables. The proposed methodology has the following steps. Firstly, the basic statistic of the data (Chl and wind) reveals that we can decompose the original fields in two main contributions: an annual cycle plus trend field and a residual component. In this study the annual and semi-annual contributions have constant amplitude. With this functionality we try to capture a constant annual contribution as the system has a main climatological behaviour. However, Macías et al. 2007 suggested an inter-annual variability of the seasonal cycle in the Chl field. Here, in order to keep the assumptions as simpler as possible we keep constant amplitudes, which gives us (Fig. 4) reasonably good results. Secondly, the trends, annual cycle and dominant EOF modes of the residual field of Chl concentration and zonal wind have been estimated. After that, the correlation between the temporal EOF amplitudes of Chl and wind residual is assessed.

Then, zonal wind temporal EOF is used to reconstruct the Chl field by adjusting a simple linear relationship between both temporal amplitudes. The strong correlation between zonal wind and Chl (0.63) could be due to the fact that the main variability in Chl is associated with the coastal area (as seen in Fig. 2), which is strongly influenced by coastal upwelling. This upwelling is, in turn, enhanced by zonal wind (Macías et al. 2007 and Macías et al. 2011).

To test the forecasting method we have proposed two cases: an 8-day and a variable (increasing) horizon forecast. The persistence has provided good results estimating the Chl field in the 8-day forecast horizon. However our method shows a good performance in the central period of the year (from 100 to 300 days). And particularly, for horizons between 150 and 170 days. For the growing horizon test (Fig. 8a and b) the persistence method is clearly a poor forecasting technique for forecast horizons longer than around 70 days. It is worth noting that there seems to be a ‘persistence window’ through the year. The persistence of the fields in winter seems to affect to the next season (the end of 2006 shows also a good performance of persistence). This could be explained taking into account the strong seasonality of the Chl field (Macías et al. 2007). These results provide us some information about the time period over which the system retains and loses memory of previous characteristics, indicating that the system memory does not go farther than approximately three months. Our proposed method gives a reasonably high correlation compared with the other methods throughout the year, even during the periods where all the methods give low correlations. This result is in good agreement with the results of the general statistics described in Section 3.1, where the variance of the original field in the periods of high values is mainly represented by the residual contribution (see Fig. 4). Note also the sudden correlation decrease around 300 days shown for all methods. These two previously mentioned effects could be related to the

characteristic time-scale of variability of the circulation patterns and regime shifts documented in the area (Macías et al. 2007). The new forecasting method is evaluated and found to be more efficient (0.73 mean of the ρ) than simply persistence (0.5 mean of ρ) for forecast horizons longer than 100 days. Particularly interesting is the fact that the proposed method is able to provide accurate forecasts, even for cases in which the Chl field has low gradients. On the contrary, for an 8-day prediction horizon, the persistence appears to perform better as compared to the proposed method (0.79 vs. 0.68 of ρ). A biological question arises looking at the ‘instantaneous’ interaction between wind and the Chl, which does not show any time lag from wind. The time lag between two processes seems to be masked by the time bin (8 days) of the data used.

The main oceanographic patterns identified in the study area, as seen in the spatial first mode of Chl, are characterized by the WAG, the upwelling along the South Iberian Peninsula (Malaga coast) and the Atlantic jet. These patterns are in agreement with those results obtained in the previous studies (Macías et al. 2007; Baldacci et al. 2001). Macías et al. (2007) correlate Chl in the WAG with the absence of easterly winds, which have a positive effect on the upwelling zone along the Malaga coast and further south near the Gibraltar Strait. While the presence of easterlies shifts the AJ to the South, and activates a secondary upwelling offshore. In our study, the temporal evolution of the spatial variance (not shown) and spatial mean field (Figure 4) presents a marked annual cycle with maximum values in winter and minimum in summer, which is also as described by Macías et al. (2007).

Further analysis using SST images (Vargas-Yáñez et al. 2002) reveals the existence of two main regimes in the dynamics of Alboran Sea. The first regime is from October to March and the second from April to September. This second period is characterized by strong easterlies and also low Chl values (Macias et al. 2007). Physical mechanisms

related to oceanographic circulation can explain the results obtained in the Chl concentration, through linking the absence or presence of strong circulation patterns (which in turn, are related to the Atlantic inflow through Gibraltar) to the surface Chl. The jet of Atlantic water has a strong impact on Chl variability due to the development of intense fronts, which create vertical velocities associated with the mesoscale structures (Rodríguez et al., 2001, Macías et al. 2007). Different authors (Sarhan et al., 2000; Vargas-Yáñez et al. 2002; Macías et al. 2007, 2008, 2011) have evidenced that the southward drift of the Atlantic jet causes the secondary upwelling of cooler, sub-surface, nutrient rich waters offshore the South Iberian Peninsula (Malaga coast). That enhances the phytoplankton growth and so the surface Chl patchiness detected by the satellite sensors.

Our work reinforces the previous evidence (Vargas-Yáñez et al. 2002; Macías et al. 2007, 2011) of the role played by the wind on the behaviour of Chl variability through the influence of the Atlantic inflow jet in Alboran Sea and the structures directly related to this inflow. Furthermore, this work goes beyond past studies such as Garcia et al. (1999), Baldacci et al. (2001), and Macias et al. (2007) in proposing a forecasting method for Chl, which is, to our knowledge, the first that reconstructs Chl images from atmospheric fields. Alternative approaches to forecasting have previously been developed and tested using empirical methods but these have been more focused on forecasting the common properties of oceanographic variables, such as SST (Alvarez et al., 2000), relating SST and Chl (Nieves et al., 2007) or forecasting sea level variability (Tsimplis et al., 2008; Suselj et al. 2004).

This study provides insights into the relationship between atmospheric forcing and marine ecosystems variability in the Alboran Sea and a forecasting method for Chl with important applications to the seasonal forecast and inter-annual reconstruction of Chl fields. The proposed method is a powerful and straightforward tool for forecasting Chl data, at a much lower computational cost as compared to using coupled physical and biogeochemical models (Raybaud et al., 2011, Macías et al. 2011). Future studies could explore the applicability of the methodology developed in this work to other ocean areas where the system is strongly driven by a meteorological variable.

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FIGURE CAPTIONS

Figure 1. Schematic view of the main surface circulation features in the Alboran Sea. WAG: Western Alboran Gyre, EAG: Eastern Alboran Gyre, AOF: Almeria-Oran Front, AC: Algerian Current.

Figure 2. Spatial distribution of a) temporal mean Chl ($\log_{10}(\text{mg m}^{-3})$), b) temporal variance of Chl field ($\log_{10}(\text{mg m}^{-3})^2$), c) temporal mean zonal wind velocity (cm s^{-1}) and d) temporal variance zonal wind velocity ($(\text{cm s}^{-1})^2$).

Figure 3. Trend of Chl ($\log_{10}(\text{mg m}^{-3})$). a) spatial mean of trend (right y axis) and Chl field (left axis) b) time mean of trend field.

Figure 4. Time evolution of spatial mean of the original ($\log_{10}$) Chl field (continuous black line) and the spatial mean of the sum of the seasonal cycle (annual + semiannual) and the trend (dashed blue line) for the 9 years analyzed.

Figure 5. First spatial mode for Chl (top) and zonal wind (bottom) in the Alboran Sea. The percentage of variance accounted by each mode is shown in Table 1.

Figure 6. First mode amplitudes of Chl and zonal wind (thin line) and smoothed signals (bold line) for both fields.

Figure 7. Correlation (ρ) of the forecasted vs. original field, using: the proposed method (light blue), trend (green), trend plus annual cycle (red) and persistence (dark blue) calculated in the last year of data (2006). The forecasted field is constructed using the information of the previous fields and the prediction horizon is always 8 days.

Figure 8. Correlation (ρ) of the forecasted field vs. original, using: proposed method (blue light), trend (green), trend plus annual cycle (red) and persistence (blue dark). The forecasted field is constructed using the information of the previous eight years

(from January 1998 to December 2005) then, the prediction horizon grows as we advance in time along the year.

Figure 9. (a) Original Chl field for day 20th September 2006 and (b) the reconstructed field (b). (c) and (d) identical but for day 23th November 2006. (e) and (f) identical but for day 12th March 2006. Units are $\log_{10} \text{mg m}^{-3}$.

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685 Table 1

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	Chl	Wind U
Mode 1	74.7	53.7
Mode 2	13.7	25.6
Mode 3	6.0	8.2

687 Table 1. Percentage of variance accounted for by each mode for each variable.

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