Mapping of Ocean Bio-Geochemical Provinces Using Correlations between Satellite-Derived Winds and Chlorophyll

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Abstract – Global time series of satellite derived winds and surface chlorophyll concentration (*Chl-a*) show patterns of coherent areas with either positive or negative correlations. The correlation between Chl-a and wind speed is generally negative in areas with deep mixed layers and positive in areas with shallow mixed layers. These patterns are interpreted in terms of the main limiting factors that control phytoplankton growth, i.e. either nutrients or light, and are used in objective mapping of the biogeochemical provinces of the world ocean.

Keywords: ocean color, winds, phytoplankton

1. INTRODUCTION

Phytoplankton production and biomass in the world ocean is limited by nutrient (N, P, Si, Fe) concentrations (Chisholm and Morel, 1991) and/or the mean light level due to vertical mixing and seasonal variability in daily insolation (Siegel *et al*., 2002). A number of authors (Platt and Sathyendranath, 1988; Longhurst *et al*., 1995) have proposed the definition and use of quasi-stable biogeochemical provinces as a means of assessing basin scale oceanic productivity and biogeochemical characteristics. We use the correlation between time series of satellite derived winds and surface chlorophyll-a concentration (*Chl-a*, mg m^{-3}) to objectively map the main biogeochemical provinces in the world ocean based on the dominant mechanisms responsible for the variability in phytoplankton biomass.

2. DATA

Satellite-derived Level-3 (i.e. binned and mapped) data sets of chlorophyll-a concentration (*Chl-a*, mg m-3) were obtained from NASA's Ocean Color website (http://oceancolor.gsfc.nasa.gov/) and the European Space Agency's GlobColour project (http://www.globcolour.info). *Chl-a* datasets using standard Case 1 water algorithms (O'Reilly *et al*., 1998; Morel and Maritorena, 2001) were obtained. Daily data from individual sensors (OCTS, Nov-1996 to Jun-1997; SeaWiFS, Sep-1997 to Apr-2002) and those merged from multiple sensors (SeaWiFS, MERIS, MODIS-Aqua) with weighted averaging by the GlobColour project were composited into 5-day and monthly time series from Nov-1996 to Dec-2009. Monthly and 5-day anomalies of *Chl-a* were created as the ratio of the value during the current period to the long-term mean of the respective time period and expressed as percentage anomaly, i.e. 100*(*Anomaly* – 1).
Cross-Calibrated Multi-Platform (CCMP) ocean surface wind data (Ardizzone *et al*., 2009; Atlas *et al*., 2008) derived through cross-calibration and assimilation of data from SSM/I, TMI, AMSR-E, SeaWinds on QuikSCAT, and SeaWinds on ADEOS-II were used. In this study, we used level 3.5 wind speed (*U*, m/s), wind speed squared, zonal and meridional components of wind speed (*u* and *v*, m/s) and pseudostress (*u*U and *v*U, m^2/s^2). Monthly and 5-day anomalies of the wind variables were constructed by subtracting the long-term mean value of the respective period from the value during each individual period. The CCMP wind data were available from Jul-1987 to Dec-2008 and the overlapping period during which both *Chl-a* and wind data were available extended from Nov-1996 to Dec-2008. Mixed layer depth climatology data were obtained from http://www.locean-ipsl.upmc.fr/~cdblod/mld.html (de Boyer Montégut *et al*., 2004) and monthly MLD data from http://www.science.oregonstate.edu/ocean.productivity/ (Behrenfeld *et al*., 2005).

3. RESULTS

The correlation between wind speed and Chl-a anomalies shows coherent and statistically significant patterns over the world ocean (Fig. 1). These patterns can be interpreted in terms of the main limiting factors that control phytoplankton growth, i.e. either nutrients or light. The strength of wind-induced upwelling and mixing is governed by the wind stress. We therefore also calculated the correlations between *Chl-a* anomalies and squared or cubed wind speed (not shown), both of which produced correlation patterns that were identical to those shown in Fig. 1. It is essential that the correlations be calculated for seasonally normalized values (anomalies), as otherwise the annual cycle would have the dominant influence, e.g. at mid-latitudes the typically strong winds and low Chl-a in the winter would produce a strong negative correlation. The correlations between wind speed and SST anomalies (not shown) have a much simpler pattern and are mostly negative, except in areas such as the eastern tropical Pacific and eastern tropical Atlantic where the interannual modes of variability dominate.
The broad features of the correlation patterns between *Chl-a* and wind speed anomalies at mid-latitudes correspond well to the mean depth of the mixed layer in spring. Spring mixed layers are typically the deepest mixed layers observed during the year. The mixed layer shallows during the summer, and water that was contained within the mixed layer in spring becomes the water that can easily be entrained into the mixed layer through summer. Deep spring mixed layers imply that the water below the summer mixed layer has low stratification, and therefore that small increases in summer wind can easily remix the upper ocean and reestablish deep mixed layers. Both in the North Pacific and North Atlantic the correlations between *Chl-a* and wind

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speed anomalies change from negative to positive where the spring mixed layer becomes shallower. Also, in comparison with the North Pacific, the North Atlantic has deeper mixed layers and more negative correlation between *Chl-a* and wind speed anomalies. In the Southern Ocean spring mixed layers are particularly deep in the regions of intermediate or mode water formation along the northern flank of the ACC in the Indian and Pacific Oceans. Within these regions, *Chl-a* is negatively correlated with wind speed, and to the north, where mixed layers are shallower, *Chl-a* is positively correlated with wind speed. A number of patches with positive wind speed/*Chl-a* correlations occur inside the Southern Ocean, e.g. the Scotia Sea, north-east from the Antarctic Peninsula, and these regions tend to have shallower spring mixed layers. Correlation patterns of *Chl-a* anomaly with the eastward and the northward wind pseudostress also show coherent and characteristic patterns (not shown) that are used in the classification of the ocean domains.

K-means and hierarchical cluster analyses were applied to the global correlations between *Chl-a* anomaly and wind speed, wind speed anomaly, eastward and northward pseudostress and the correlation between SST anomaly and wind speed anomaly. The derived clusters are similar to the patterns shown in Fig.1but the exact number of clusters and other details depend on the details of the clustering method.

4. CONCLUSION

The large-scale correlation patterns between winds and surface *Chl-a* concentration are determined by the main controlling factors of phytoplankton growth (nutrient or light) and allow objective mapping of the main bio-geochemical regimes in the world ocean. Areas where phytoplankton growth and biomass are primarily controlled by the upward flux of nutrients from below the euphotic zone show positive correlation with wind speed and areas with a deep mixed layer show negative correlation between *Chl-a* and wind speed. More complicated patterns are evident in the equatorial zone.

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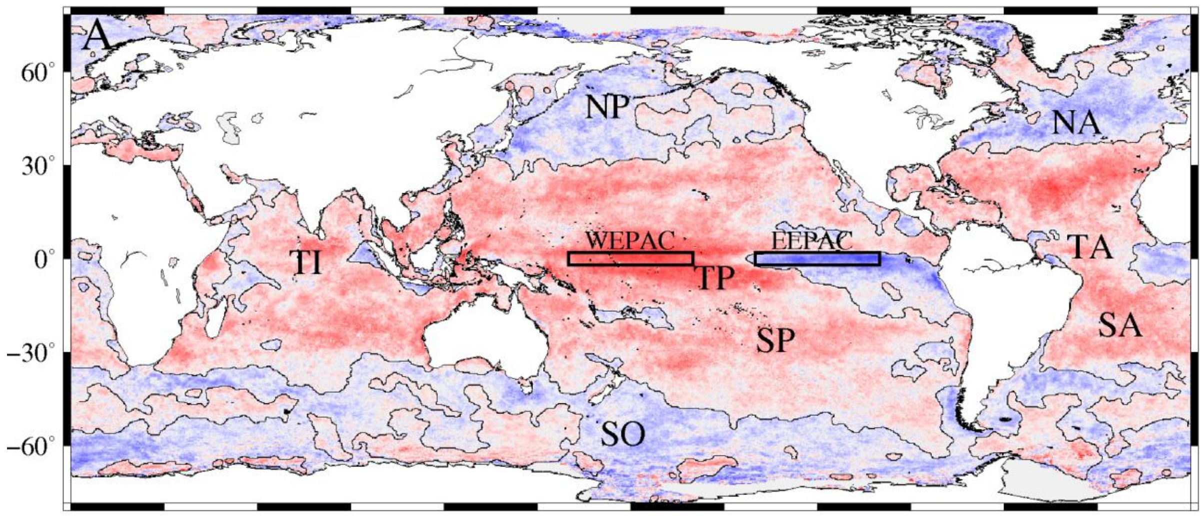

Figure 1. Correlation coefficient (R) between monthly wind speed anomaly and Chl-a anomalies. N = 144, the critical value, R_{crit} (0.95) = 0.164, R_{crit} (0.99) = 0.214, i.e. the correlation in most of the red and blue areas is statistically significant. Western Equatorial Pacific (WEPAC, 2ºN-2ºS, 160ºE-160ºW), Eastern Equatorial Pacific (EEPAC, 2ºN-2ºS, 140ºW-100ºW). The black curves are contour lines of R = 0 and separate regions with positive correlations (red) from those with negative correlations (blue). TI = Tropical Indian Ocean, NP = North Pacific, TP = Tropical Pacific, SO = Southern Ocean, SP = South Pacific, NA = North Atlantic, TA = Tropical Atlantic, SA = South Atlantic.

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