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Research Article

CHLOROPHYLL CONCENTRATIONS IN RESPONSE TO MONSOONAL CHANGES ALONG THE WEST COAST OF LUZON, PHILIPPINES

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ABSTRACT
The Philippines are located in the typhoon belt and circulation at the surface layer is in response to changes in wind direction. These study investigatesmonthly fluctuations of satellite derived chlorophyll concentrations in relation to ocean surface currentsthat were retrieved from the Ocean Surface Current Analyses Real Time (OSCAR) System in the region off the island of Luzon. In addition, an objective wasto detect changes in chlorophyll patchiness in response to surface flow for the period December 2009 to March 2010. The distribution of chlorophyll for January 2010 suggests that part of the enhanced chlorophyll concentration was a result of advected water from Manila Bay and the transport of water through the Verde Island Passage. The circulation at around 15^0 N was rather weak in December but in January a strong west component developed. The evolution of flow reversal was evident during the investigated period that eventually led to an anticyclonic water movement in March 2010. The corresponding chlorophyll distribution and its patchiness areinterpreted in connection with the changes in the circulation due toepisodic wind surges that might be responsible for offshore transport of water masses with high chlorophyll values, and a fast response of the biological system to the reversal of flow is observed.

Key Words: *Monsoonal Response, Chlorophyll, Surface Circulation, Luzon, Manila Bay*

INTRODUCTION
The Philippines has a tropical marine climate dominated by the monsoon seasons that brings heavy rains to most of the archipelago from May to October, whereas the winter monsoon brings cooler and drier air from December to February, and a drier season for Manila and most of the lowland areas from March to May. As an island country, the Philippines depend highly on marine resources, in particular fisheries, but analyses of the various fishing areas in the Philippines indicates that many of these areas are to a certain degree already overexploited (Silvestre, 1989).Although the Philippines is the 11th top fishing nation in theworld with an estimated annual fisheries worth of about US$2.5 billion (Barut *et al.*, 1997), the total estimated loss from overfishing is at around US$420 million per year that includes the impact on demersal and small pelagic fisheries (Trinidad *et al.*, 1993).Therefore, for proper management of marine resources, a better understanding of ecosystem and the relationship between seasonal changes in surface circulation and biomass in terms of chlorophyll is highly desirable.
The monsoon winds are the most important factor for the formation, maintenance and seasonal variation of the circulation in the South China Sea (SCS) (Yang and Liu, 1998). Furthermore, changes in solar radiation received at the ocean's surface as a function of the monsoonal changes in connection with the bathymetry, are the major factors that develop the circulation in SCS. This means that the circulation within the Philippine Archipelago is the result of the influences of oceanic and atmospheric origin (Gordon *et al.*, 2011). In reviewing the seasonal circulation in the South China Sea, Hu *et al.*, (2000) pointed out that during the summer monsoon a cyclonic/anticyclonic circulation at the surface layer of the SCS is in response to the wind direction. With changes in wind direction to northeasterly in winter, the circulation reverses westward according to the wind direction, resulting in Ekman drift that affects the upper layer from the surface to about 200 m and leads to a cyclonic circulation in winter. Eddy formation at a mesoscale appears in winter, for instance in the western part of the island of Luzon.

A major environmental concern in the Philippines is the serious impact of pollution and in particular in Manila Bay where eutrophication is the result from high discharge of nutrients (Reyes and Bedoya, 2008). According to the National Economic and Development Authority (NEDA), it is estimated that about 37% of the total water pollution originates from agricultural practices, which include use of animal waste, fertilizer and pesticide runoff (Food and Agriculture Organization of the United Nations, FAO 2004). In particular, the discharge of untreated sewage enters directly the waterways and there is the indication that the high release of nutrients affects not only Manila Bay but also impacts the near coastal region. Outbreaks of red tide and other harmful toxic algal blooms in coastal waters are observed with an increasing frequency (Wang et al. 2008). Within Manila Bay, nutrient levels and oxygen consumptions are indicators for environmental degradation. For instance, average concentrations reached for dissolved inorganic nitrogen; nitrate, nitrite and ammonium in near surface water were 0.90 ± 0.53, 0.10 ± 0.16 and 8.00 ± 1.35µM l^{-1}, respectively, (Chang *et al.,* 2009, Velasquez and Jacinto, 1995). As an outcome of increased eutrophication, occasional hypoxia was observed in the bay (Jacinto *et al.,* 2011, Manila, 2004).The high level of eutrophicationin Manila Bay and its impact on the coastal region make the use of remote sensing attractive because large areas can be covered and bloom extension can be recognized easily. Conventional observations in the seas around the Philippines are rare or sporadic and therefore fluctuations of chlorophyll concentrations in relation to the surface circulation can hardly be resolved with ship measurements. Satellite observations on the other hand have the capability to cover large areas almost synoptically and allow repetitive coverage as well. Therefore, satellite observations have been used to follow changes in chlorophyll concentrations in relation to changes in the circulation in the SCS. However, persistent cloud coveris a hindrance for the investigated region and a monthly average of data was the best data setto resolve the time scale of about four weeks.

Data Used

The data used in this study included chlorophyll measurements and visualization was produced with the Giovanni online data system, developed and maintained by the NASA GES DISC.Giovanni is a Web-based application that allows accessingthe data without downloading.Chlorophyll concentration is expressed throughout this paper in units of mgm^{-3}.

Ocean surface currents were retrieved from the Ocean Surface Current Analyses Real Time (OSCAR) System that is based on calculation of ocean surface velocities from satellite fields. Final data were accessed through the NOAA. That provides currents on a one degree global grid. The OSCAR product is a computation of global surface currents using satellite sea surface height, wind and temperature. The available final products are presented in current charts and are based on calculations using a quasi-steady geostrophic model together with an eddy viscosity based wind-driven ageostrophic component and a thermal wind adjustment. The model estimates surface currents that are averaged over the top 30 meters of the upper ocean (Dohanand Maximenkol, 2010).

RESULTS

Analysis of data for the Manila Bay verifies eutrophication with values of chlorophyll concentration sat around 30 mg m^{-3} and values for the offshore region can reach concentrations of about 10 mg m^{-3}. It is apparent that high chlorophyll concentrations in the bay and in the offshore area are encountered during all monsoon seasons as well as during the transition phase of wind change. This means that eutrophication of Manila Bay and its surrounding coastal regime is a year-round event and is independent of the monsoon seasons. It is therefore of interest to estimate the regional influence and extension of Manila water or define the origin of eutrophication if different from Manila Bay. As very elevated chlorophyll concentrations were observed in regions far from Manila Bay, a detailed analysis was conducted by setting a concentration threshold range from 0.08 to 0.3 mg m^{-3} for the color bar. This range was considered in order to recognize patchiness in the offshore area with lower concentrations and also to connect to regions where the sources of increased chlorophyll levels could be found.

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For some months in 2012, the persistence of cloud coverage did not allow to composite a complete yearly cycle and therefore missing monthly data due to cloud contamination were included from previous years. This generated assembly of chlorophyll maps in Figure 1shows that high concentrations of chlorophyll in Manila Bay are apparent throughout the year and that occasional eutrophication of the coastal area is a result of discharged water from Manila Bay. Nearcoastal eutrophication therefore can be connected to elevated nutrient levels in the out flowing water from Manila Bay.

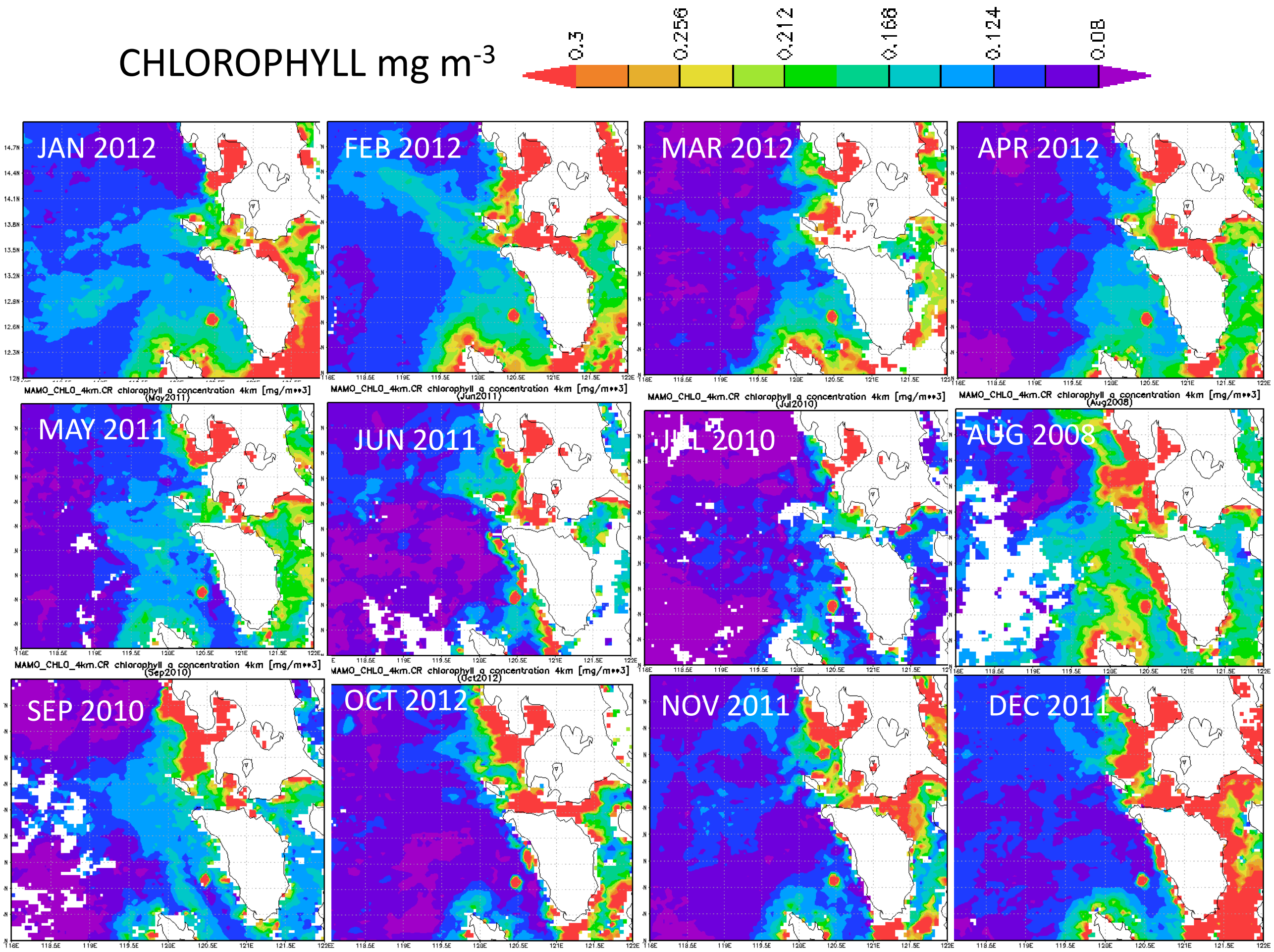

Figure1: Monthly mean chlorophyll concentrations in the Philippine Sea. The color bar has a threshold level at 0.3 mg m^{-3}. Manila Bay has concentrations that exceed the threshold and values are close to 30 mg m^{-3}.

The distribution of chlorophyll for January 2012 also suggests that part of the water masses with elevated chlorophyll concentrations west of Luzon area contribution of advected water from the Verde Island Passage. For that reason, it can be deducted that the observed offshore chlorophyll patches are a result of our flowing water from both the passage and the Manila Bay. Elevated chlorophyll concentrations in the offshore region appear especially during the winter season and were observed in consecutive years but for different months. From these observations, it is evident that the lifespan of those patches must be less than the temporal scale of four weeks of the analyzed data. There is also confirmation that the increased chlorophyll values in the offshore region are advected from the Verde Island Passage and are not necessarily a result from discharge from the Manila Bay alone.

The observed location and the changes of augmented chlorophyll distribution need to be viewed in connection with the prevailing wind and current systems. Pullen *et al.*, (2008) demonstrated there sponse of mesoscale eddies off Mindoro and Luzon dueto fastwind surges in this region that are subsequently detached by wind events. These eddies were found to move away from the coast and travel westward across the South China Sea, interacting with the complex offshore eddy field along the way.

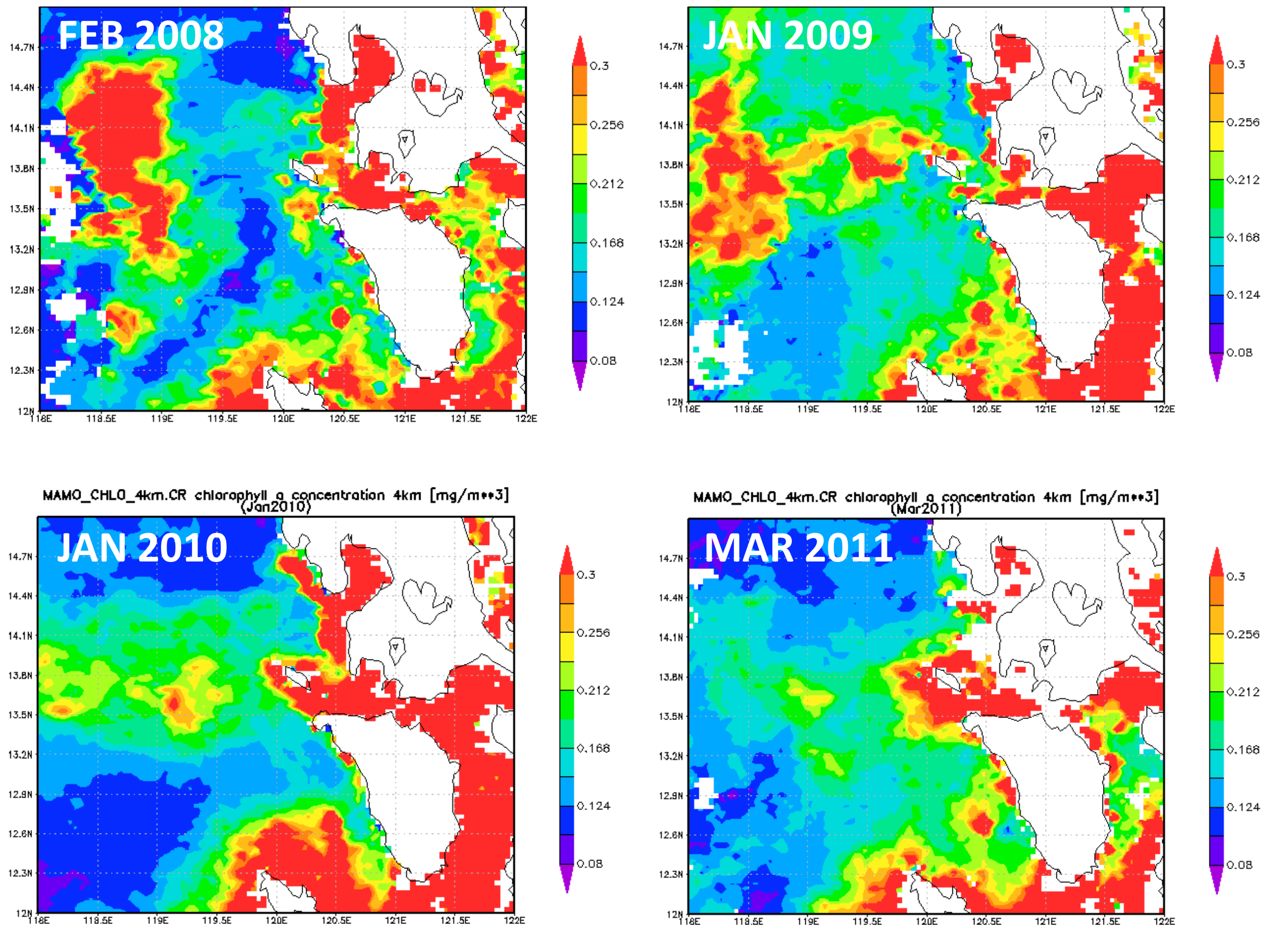

Figure 2: Chlorophyll patchiness for the years 2008 to 2011.

Rypina *et al.*, (2010) found that Manila Bay and its surrounding coastline regions were source waters for the eddies but stated that flow from the Verde Island Passage that separates the islands of Mindoro and Luzon was not a significant factor in feeding the eddies. However, the chlorophyll distribution shown in Figure 2 implies that contribution of river discharge other than the discharged effluent from Manila Bay and the episodic wind surges might be responsible for offshore transport of water with increased chlorophyll values.

In order to highlight this observation, mean ocean currents were analyzed to detect changes in the surface flow in relation to chlorophyll patchiness for the period December 2009 to March 2010as shown in Figure 3. Due to the low spatial and temporal resolution of the current data, the near-coastal regime is not fully resolved; however, the general current system can be elucidated. In particular, it is evident that changes in the circulation can appear at rather short time scales and reversal in currents is documented with observations for January and February2010. Based on the monthly averaged current data,variation of the circulation is certainly at a smaller temporal-space relation although reversal of the currents and building of the anticyclonic gyre were resolved in March 2010.

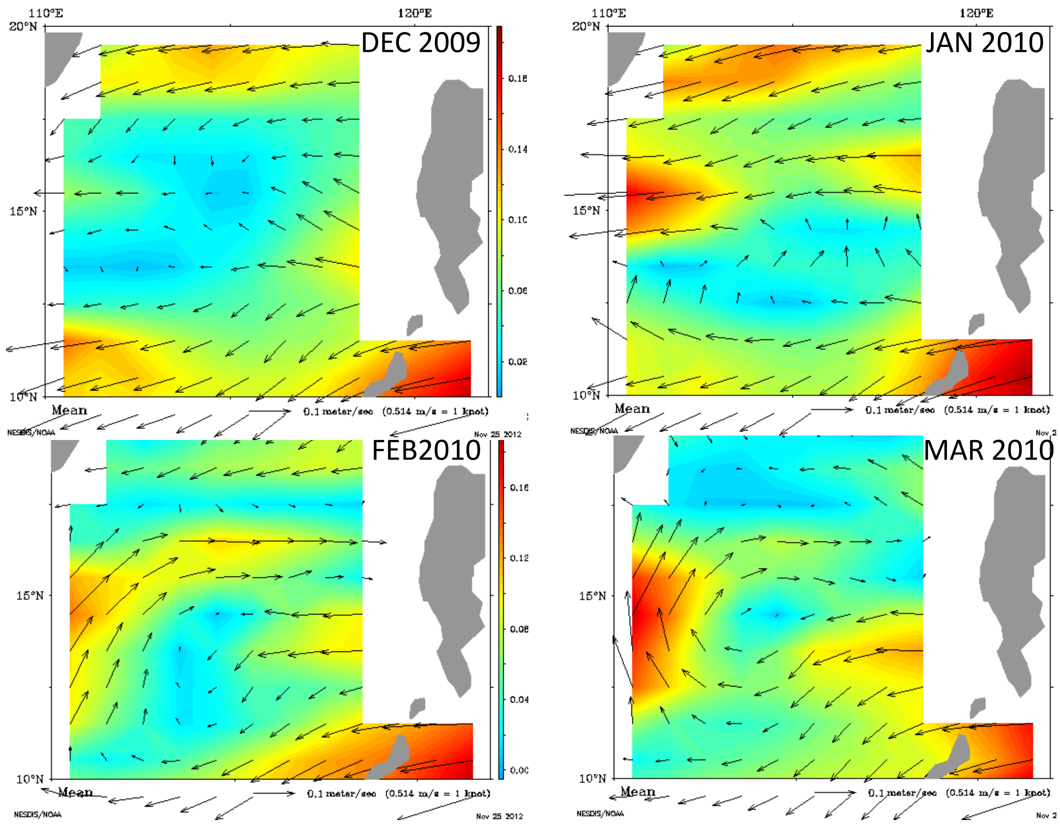

Figure 3: Monthly mean currents based on OSCAR from December 2009 to March 2010

CONCLUSION

The changes in chlorophyll concentrations and itspatchinessare related to the reversal of the monsoon seasons andassociated processes.For December 2009, the circulation at around 15^{0}Nwas rather weak but in January a strong west-component was recognizable. The evolution of flow reversal was evident in March that eventually led to the anticyclonic circulation. The impact of flow direction on the biological system, as described in terms of chlorophyll,is interpreted in connection with the changes in circulation as given in Figure 3. The December and January currents signify westward transport away from the regions around the western coasts of Mindoro and Luzon and transport of water through the Verde Island Passage,a fact that was also documented by Gordon et al. (2011).Appearance of high concentrations of biomass based on the offshore transport of water from Manila Bay and the Verde Island Passage and reversal of circulation therefore explains the isolated patches found in the chlorophyll distribution.The reversal in circulation consequently explains also the rather low concentration of chlorophyll in the offshore region and is a result of eastward transport of water from the South China Sea that can be regarded as low in nutrients as well as in biomass. With respect to the dynamics of offshoreLuzon, it was demonstrated that the circulation reverses very rapidly and that the biological system, described here in terms of chlorophyll, responds very quickly to hydrographic changes.

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