

Observation of biological manifestation of physical forces with synergistic use of IRS P4 OCM & MSMR

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ABSTRACT:

Primary productivity of the ocean is basically governed by two limiting factors; light and nutrients. In tropical waters where generally light is not a limiting factor, nutrients play an important role in causing changes in productivity of the region. Availability of nutrients is strongly influenced by turbulence of water. Wind induced turbulence is one of the causes for transport of nutrients to euphotic zone that gives rise to high productivity. Multi-date primary productivity images were generated for the period February-March, 2000-2001 in the northeastern Arabian Sea to verify this hypothesis. This is the period when winter bloom occurs in the Northern Arabian Sea (NAS). Species identification through water samples collected from the ship indicated that this bloom is dominated by *noctiluca millaris* of *dianofleggele* class. Literature describes this bloom to be result of winter cooling and increased density of surface waters due to evaporation by prevailing northeasterly winds. An attempt was made to relate observed variability in productivity with magnitude of wind forces.

Primary Productivity images were generated with OCM (Ocean Colour Monitor)/Oceansat I and wind fields using MSMR (multi frequency scanning microwave radiometer)/Oceansat I data. Northeastern Arabian Sea (Gujarat coast) was selected as the study area. A common grid of $1^0 \times 1^0$ was selected for the synergistic study of OCM and MSMR. Analytical model based on photosynthesis-Light relation was used to compute mixed layer primary productivity of the Arabian Sea. P-I parameters were measured for the Northeastern Arabian Sea from the ship. These inputs along with the OCM derived chlorophyll and diffuse attenuation coefficient were used to compute mixed layer primary production of area for middle of February to March for the years 2000 and 2001. Mixed layer primary production images were generated for the northeastern Arabian Sea and weekly MSMR winds were processed for the February and March months respectively for both the years. It was observed that primary productivity varies in concert with magnitude of wind speed. This shows that productivity in the Arabian Sea is coupled with physical forcing action. The synergistic analysis of OCM and MSMR showed that a variation in the wind speed has influence on primary productivity of the study area. This complies with the expected physical-biological coupling.

1. INTRODUCTION

Time series observations of chlorophyll pattern from Oceansat I / OCM earlier in February-March, 2000 had shown large scale increase in abundance of phytoplankton in the open ocean waters at depths greater than two thousand meters in NAS. Banse and McClain, 1986, Banse, 1987 and Prasanna Kumar et al., 2000 have reported this event to be winter bloom of phytoplankton. Time series chlorophyll images generated from OCM demonstrate that this bloom occurs every year in NAS during specific time slot from January end to middle of March and extends over almost entire Northern Arabian Sea from northern most up to 15^0N latitude. It develops as a result of enrichment of nutrients, which is created by vertical mixing in winter. Cooling of surface waters due to seasonal effect as well as due to evaporation caused by northeasterly winds generates convection and it causes vertical mixing of water mass. As a result, nutrients can cross thermocline and enter shallower waters in euphotic zone giving rise to high productivity of phytoplankton. This forcing mechanism is required to activate photosynthesis in tropical waters where growth of phytoplankton is controlled by availability of nutrient. Pattern of chlorophyll, SST and wind was studied for the period of winter bloom using OCM, AVHRR, MSMR, Quikscat and ship data. It was observed that the three parameters co-vary, which confirms that wind generated physical forcing controls productivity in NAS during the season of winter bloom. Biological influence of physical forces on water mass was studied from two angles.

- i. Influence of wind on spatial pattern of primary productivity
- ii. Study of temporal variations in productivity due to temporal variations in wind force using time series chlorophyll/OCM and wind speed /Quikscat.

Spatial variations in productivity levels revealed overall correspondence between Primary Productivity and magnitude of wind whereas study of seasonal pattern of the two parameters indicated time lag in chlorophyll of about four days typically in most cases.

2. METHODOLOGY

2.1 Mixed Layer Primary Production

In the present work, non-spectral analytical model of Platt et al. (1990) was implemented in the Arabian Sea. It makes use of photosynthesis-light relationship to compute the mixed layer primary production. It requires chlorophyll, diffuse attenuation coefficient, P-I (photosynthesis-light) parameter and day length as its inputs. The mixed layer column production is given by an expression with depth and time integrals,

$$P_{Z,T} = \int_0^D \int_0^Z B(z,t) p^B(I(z,t)) dz dt.$$

Non-spectral approach used to compute the mixed layer primary production for the study area uses solution of the above

equation through dimensional analysis (Platt and Sathyendranath, 1993). The solution is of the form,

$$P_{Z_m, T} = (B D P_m^B) / K * (\sum \Omega_x (I_s^m)^x - \sum \Omega_x (M I_s^m)^x),$$

where

$$A = BDP_m^B / K$$

B = phytoplankton biomass given as the concentration of chlorophyll-a (mg Chl m⁻³)

D = day length (h)

Pm^B = Assimilation number

K = vertical diffuse attenuation coefficient

Ω = Weights for fifth-order polynomial fit (x=5)

I_s^m = dimensionless irradiance calculated as I₀^m / I_k (I_k = α^B / Pm^B)

M = exp^{-K_z} is the optical transmittance of mixed layer of thickness Z_m.

This approach assumes uniform biomass throughout the mixed layer, uniform diffuse attenuation coefficient and a sinusoidal variation of surface irradiance. When winter convection is active, mixed layer depth is greater than euphotic depth and hence, the assumption holds good and mixed layer production represents total production.

2.1.1 Pre-processing of OCM data

Atmospheric correction of OCM data was performed using long wavelength approach (Gordon and Wang, 1994, Chauhan et al., 2001).

Chlorophyll was estimated from the retrieved spectral water leaving radiance by the application of suitable bio-optical algorithms. An empirical algorithm also known as Ocean Chlorophyll 2 or OC2 (O'Reilly et al., 1998) was used with OCM data, on the basis of results of a study done on inter-comparison of different bio-optical algorithms. It was found that this algorithm captures the inherent sigmoid relationship between R_{rs}490/ R_{rs}555 band ratio and Chlorophyll concentration C, where R_{rs} is remote sensing reflectance. The algorithm was shown to retrieve low as well as high chlorophyll concentration, which means a better retrieval even in case 2 waters.

2.1.2 Computation of light available at sea surface

Light available at sea surface was computed using radiative transfer model. For the given location, date and time, solar elevation was calculated by standard procedures (Paltridge and Platt, 1976). The local noon surface irradiance I₀^m under cloud-free skies was estimated using Bird's model (Bird, 1984). Reflection losses at the air-sea interface were computed assuming Fresnel reflectance at a flat sea surface.

2.1.3 Computation of parameter of light transmission or diffuse attenuation coefficient

Vertical attenuation coefficient K was estimated from water leaving radiance of OCM bands using modified algorithm by Muller et. al., 1994. K(490) has been computed by assuming case -1 waters where changes in phytoplankton biomass is

considered to be the most important factor for changes in optical properties of water.

2.1.4 Estimates of photosynthetic parameters and mixed layer depth

The Hastenrath and Greisher (1989) climatology was used to define monthly mixed layer thickness.

2.2 Wind speed

Wind speed of the same area was calculated using MSMR data. The MSMR provides global brightness temperature measurements at 6.6, 10.65, 18 and 21 GHz frequencies with dual polarisations. Weekly wind speeds were generated for the same time span at the resolution of 75 km. MSMR data were not available in 2002 for the same duration in February-March, therefore, Quick scat data were used for the latter period.

IRS P4 OCM derived Primary Production and MSMR derived wind speed images were generated for the study area and corresponding duration.

3. RESULTS AND DISCUSSION

Large-scale increase in abundance of phytoplankton (winter bloom) occurs every year during specific period in February-March in NAS. Weekly averaged chlorophyll images, generated from OCM data of March 1st week, 2000-2004, representing typical high productivity pattern in deep waters of NAS are shown in Figure 1.

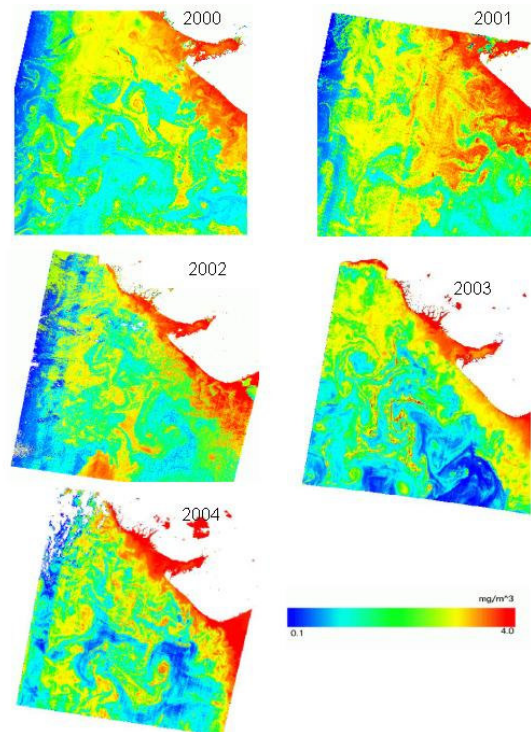


Fig. 1 Chlorophyll pattern from Oceansat I/OCM for 1st week of March, 2000-2004 indicate occurrence of winter bloom every year in NAS

Figure 1. Chlorophyll pattern from Oceansat I/OCM for 1st week of March, 2000-2004 indicating occurrence of winter bloom every year in NAS

Similar observations were made using OCM data from 2000 to 2004 also from weekly images of February. The period February-March coincides with northeasterly winds. Hence, the observed bloom is believed to have occurred due to annual cycle of convection favourable winds. This has been verified in the study reported here. Trade winds from the northeast are predictable and therefore, the observed bloom is also predictable in nature.

Weekly averaged wind speed was estimated from MSMR data of 1st week of March 2001 for the oceanic waters of NAS and weekly averaged Mixed Layer Primary Production images for the same period. This can be seen in Figure 2A and 2B.

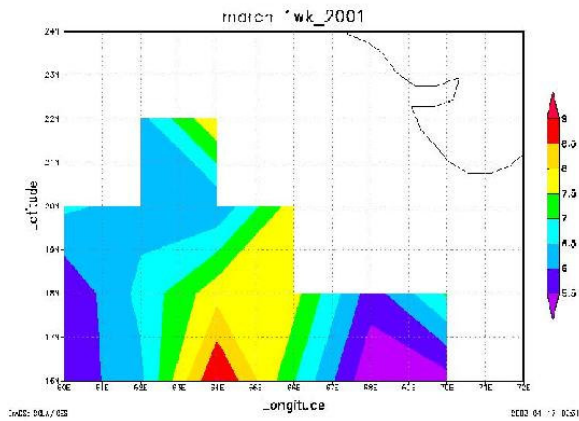


Figure 2A. Weekly averaged (March 1st week, 2001) wind speed from MSMR

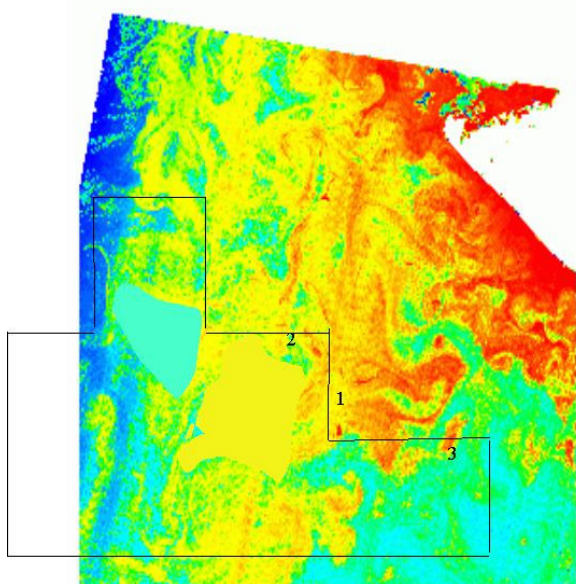


Figure 2B. Weekly averaged (March 1st week, 2001) Primary production from OCM with window showing location of wind speed estimates in Figure 2A.

It can be seen from Figure 2B that Primary Production varies from low productivity zone (blue) to high productivity zone (yellow, red). High productivity can be seen dominating in off shore waters (> 2000 m) that is unusual. Also, it can be noticed that where wind speed is high (Figure 2A), Primary Production is also high correspondingly (Figure 2B). On the other hand, relatively weaker winds correspond to low productive zone.

Pattern of relatively higher wind speed at the centre of image (yellow and red patch at locations 1 and 2, Figure 2A) is correspondingly accompanied by patches of high productivity (Figure 2B). However, right corner of productivity image (blue at location 3, Figure 2B) is less productive supported by a pattern of relatively lower wind speed (Figure 2A) for the same area.

This means that, in open NAS, wind generated mixing could be important mechanism by which nutrients are entrained into surface layers.

Figure 3 shows time series chlorophyll and SST images generated from OCM and AVHRR data respectively.

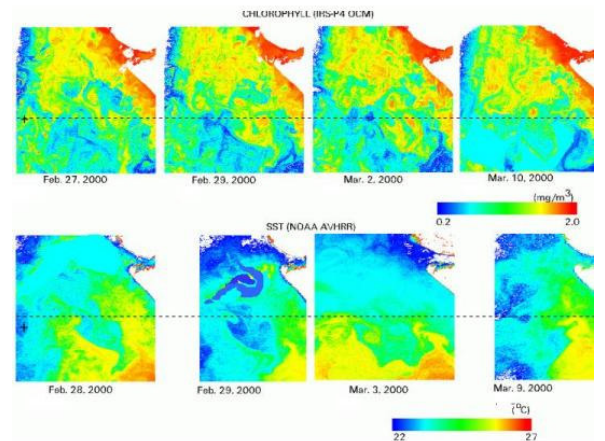


Figure 3. Time series chlorophyll and OCM images generated from OCM and AVHRR data

A clear demarcation (dotted lines) between high and low productivity can be made in upper and lower portion of series of chlorophyll images. Corresponding to higher chlorophyll concentration on upper side, SST images show relatively cooler waters over all in this portion, which is influenced by bloom. Converse to this, lower chlorophyll and signature of warm water masses can be seen in the lower portion pertaining to non-bloom waters. These observations from satellite data comply with the hypothesis that describes coupling between increase in Primary Productivity and cooling of surface waters due to wind force and resulting convection. The observed pattern of inverse correlation between chlorophyll and SST is due to this forcing action. Otherwise, the waters being studied is off shore waters at depths greater than 2000 m in NAS where so-called biological-physical coupling often breaks down.

Temporal profile of variations in chlorophyll and wind speed using OCM and Quick scat data is shown in Figure 4.

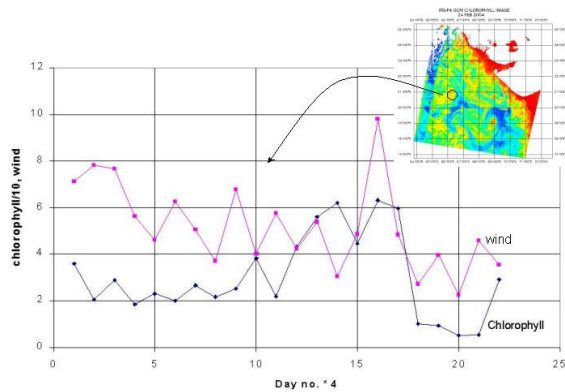


Figure 4. Four days' averaged chlorophyll and wind profile generated from OCM and Quikscat data

Each point represents average of chlorophyll and wind speed over four consecutive days in bloom waters in NAS (19.75° N latitude, 66.25° E longitude) for the period January to March 2003. It can be seen that chlorophyll pattern responds to increasing or decreasing wind speed with time lag of four days in most cases. There is an exception when there is sudden increase or decrease in wind speed by a large magnitude. Response of chlorophyll in accordance with wind force is observed without any time lag in this case. A sequence of actions followed by wind force acting on a water mass include cooling of water mass, increase in density leading to sinking of surface waters, convection, transport of bottom nutrients to euphotic zone which, in due course, causes active photosynthesis. The observed delay in response of chlorophyll to wind may be attributed to time taken for all these processes.

Scatter of ship measured chlorophyll; SST and wind speed has been generated in three parts and is shown in Figure 5.

The purpose was to study inter relation between the three parameters to understand if influence of wind was there on productivity during the event of bloom. Scatter of wind versus SST shows an inverse trend over all. This is expected because as wind speed increases, evaporation of surface water increases and hence, temperature decreases. However, wind is not the only factor influencing surface temperature and hence, it is not proper to attempt polynomial fit.

Scatter of SST versus chlorophyll also shows an inverse relation illustrating biological-physical coupling. Low SST results from convection triggered by some physical forcing, wind in this case. Hence, enrichment of nutrients occurs and productivity (chlorophyll) is expected to correspond to low SST. Production and grazing of phytoplankton occurs simultaneously in practice and the measured chlorophyll from the ship is net effect of this. For this reason, scatters gives only approximate idea of influence of physical parameter (SST) on biology of the water mass.

Scatter of wind versus chlorophyll shows that the two parameters co vary and nature of relation is direct. Figure 4 brought out time lag in response of chlorophyll to wind. Where as, the scatter shown in Figure 5 is generated from simultaneous ship measurements of the two parameters and therefore, scatters is relatively wider. However, it does indicate that wind force influences chlorophyll / productivity pattern in

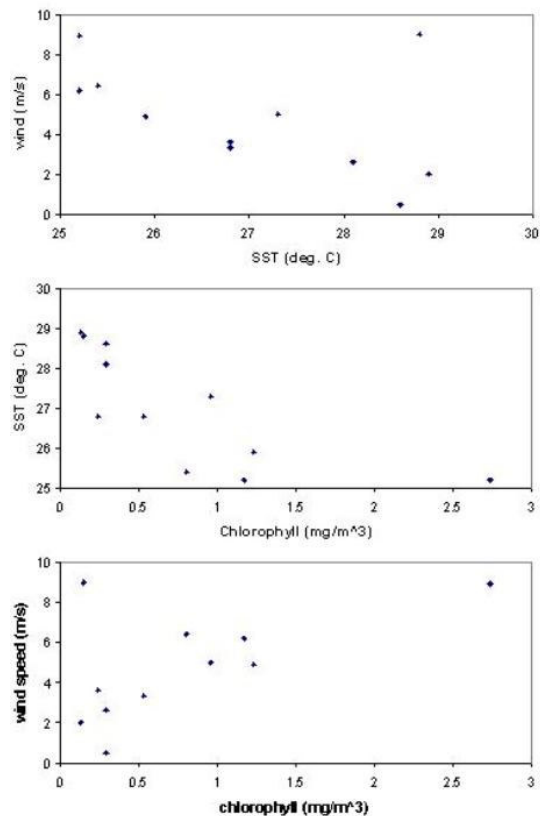


Figure 5. Scatter of chlorophyll, wind speed and SST from the ship data recorded during winter bloom in the Northern Arabian Sea (Period : 21 February – 11 March, 2004, Locations : different ship stations located in the off shore waters of NAS under influence of bloom)

NAS during the bloom. One outlier point is showing low chlorophyll in presence of high wind speed. This could happen either due to heavy grazing of phytoplankton or rigorous mixing of water column that might dilute chlorophyll concentration.

4. CONCLUSION

Using chlorophyll, SST and wind derived from satellite data and ship data, it has been shown that biological productivity of NAS is coupled with physical forcing mediated through nutrient availability during the period of bloom.

The observed time lag in productivity in response to wind force was about four days in most cases. The delayed response of phytoplankton against wind stress can be explained as time taken in sinking of surface waters as a consequence of increase in surface density and in transport of bottom nutrients in euphotic zone. Occasionally, in case when wind speed increased or decreased suddenly by a large magnitude phytoplankton pattern responded without any time delay.

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