# Is the biological productivity in the Bay of Bengal light limited?

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**Recent measurements of chlorophyll, primary productivity (PP) and nutrients along the central Bay of Bengal (BOB) during summer, fall and spring intermonsoons showed that the northern bay becomes less productive compared to the south in summer and fall intermonsoon, in spite of the nutrient input to the upper ocean by way of river influx as well as eddy-pumping. Along the western boundary also, highest PP in the northern bay did not occur during summer or in the fall intermonsoon, but occurred in the spring intermonsoon. The reason for this was explored using diffuse attenuation ($K_d$(490)) and photosynthetically active radiation (PAR) which indicates the influence of the river flux in curtailing the downward penetration of solar radiation and cloud cover respectively. During summer and fall intermonsoon, biological productivity in the northern BOB is severely limited by the reduced downward penetration of solar radiation due to the large quantities of sediment brought by the adjoining rivers. Though the cloud cover reduces PAR in the northern BOB, this has only a secondary effect in comparison to the light limitation due to turbidity, which showed an order of magnitude increase in the northern Bay.**

**Keywords:** Chlorophyll, diffuse attenuation, light limitation, eddy-pumping, photosynthetically active radiation, primary productivity, nutrients.

THE Bay of Bengal (BOB) is a tropical basin located in the eastern part of the north Indian Ocean. Traditionally, BOB has been considered to be a region of low biological productivity. Based on the data collected during the International Indian Ocean Expedition (IIOE), Qasim[1] showed that though the average surface biological production in the BOB was (~ 1.25 times) higher than its western counterpart, the Arabian Sea, the column production of BOB was much lower. Subsequent studies[2,3] corroborated the notion of low biological productivity of the BOB. However, recent studies show that episodic events such as cyclones[4,5] and meso-scale features such as cold-core eddies[6–8] are capable of enhancing biological productivity in BOB. The enhanced biological production in both cases result from introduction of nutrients from subsurface waters to the surface layers. In the former case, it occurs through intense wind mixing under the influence of strong winds which deepens the mixed layer, while in the latter case it happens through Ekman suction.

The low biological productivity of BOB has been speculated to be due to various reasons such as, narrow shelf, cloud cover during summer monsoon, turbidity resulting from sediment influx, fresh water-induced stratification[1,2,6], etc. On the basis of water column stability computations and one-dimensional turbulent closure model, Prasanna Kumar *et al.*[9] showed that the low biological productivity in BOB during summer monsoon is driven by strong stratification as speculated earlier[6]. However, presently it is not clear whether the biological productivity of BOB is limited by the availability of sunlight. In the present study, we use data collected by clean technique and *in situ* incubation from the central and western BOB following the Joint Global Ocean Flux Study (JGOFS) protocol[10] to determine the primary productivity and constrain it with photosynthetically available radiation and diffuse attenuation coefficient to address the light limitation of biological productivity.

## Data and analysis

### *Observational data*

Measurements were carried out along two transects, one along the central BOB (88°E) and the other along the western boundary of the bay (Figure 1). All 24 CTD (conductivity–temperature–depth) stations were occupied at 1° interval, 14 along the central BOB and 10 along the western boundary. The same 24 CTD stations were occupied three times onboard *ORV Sagar Kanya* during summer monsoon (6 July to 2 August 2001), fall (14 September to 12 October 2002) and spring (12 April to 7 May 2003) intermonsoons. A Sea-Bird CTD was used to obtain profiles of temperature and salinity in the upper 1000 m and the water samples were collected from various depths using a rosette sampler fitted with 13/30L

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Go-Flo bottles. Water samples were analysed for nitrate and silicate with a SKALAR auto-analyser during summer and with spectrophotometer following Grasshoff *et al.*[11] during fall and spring intermonsoons. The sensitivity for nitrate and silicate was 0.1 and 0.5 μM respectively.

In addition, nine biological stations (five in the central BOB and four along the western margin, Figure 1) were also occupied for 24 h for measuring chlorophyll *a* and primary production (PP) according to an *in situ* incubation protocol[10]. Water samples were collected at pre-dawn from eight discrete depths (near surface, 10, 20, 40, 60, 80, 100 and 120 m) and used for measuring PP and chlorophyll *a*. Water samples from each depth were collected in four 300 ml polycarbonate (Nalgene, Germany) bottles (three light and one dark). One ampoule of $NaH^{14}CO_3$ (specific activity of 185 kBq; Board of Radiation and Isotope Technology, Mumbai) was added to each bottle. Subsequently, all bottles were tied on to a mooring system before dawn, and incubated *in situ* at respective depths. The mooring was *in situ* from just before sunrise to half hour past sunset. Uptake of $^{14}C$ was measured by filtering 100 ml of sample from each bottle through GF/F filters (25 mm diameter, 0.7 mm pore size; Whatman, USA); filters were transferred into scintillation vials and exposed to HCl (0.5 N) fumes overnight in a closed container. Five millilitre liquid scintillation cocktail (Sisco Research Laboratory, Mumbai) was added to each vial and assayed for radioactivity in a scintillation counter (Wallac 1409 DSA, Perkin Elmer, USA). The PP rate was calculated and expressed as mg C $m^{-3}$ $d^{-1}$, 12 h being considered as a day[10]. For the chlorophyll *a* concentrations, a 1 litre sub-sample was used from the samples collected at all the depths mentioned here. The samples were filtered through 47 mm GF/F filters, and the chlorophyll *a* was extracted in 10 ml 90% acetone in the dark for 24 h in a refrigerator and its concentration determined using a fluorometer (Turner Designs, USA).

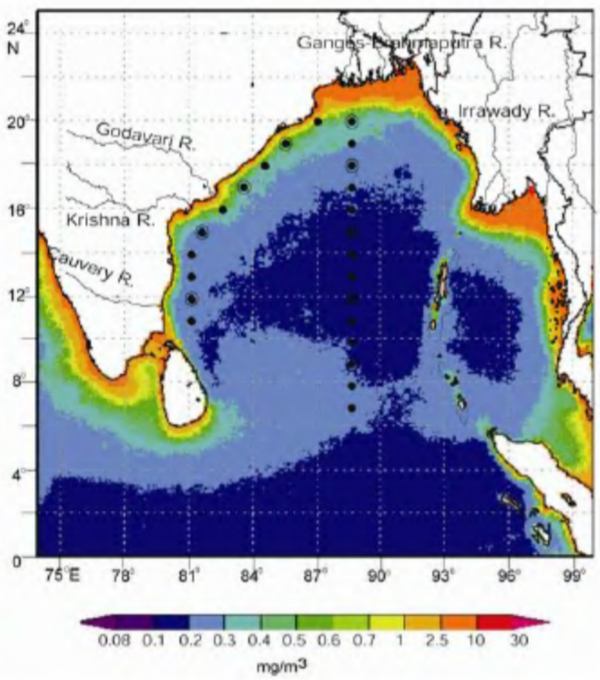


**Figure 1.** Location of CTD (filled circle) and biological (small open circle) stations occupied along the central and western boundary of the Bay of Bengal during summer monsoon (6 July to 2 August 2001), fall (14 September to 12 October 2002), and spring (12 April to 7 May 2003) intermonsoons overlain on annual mean climatology (1998–2006) of chlorophyll pigment concentration (mg/$m^3$) obtained from SeaWiFS. Chlorophyll pigment concentration map was generated by NASA's Giovani (giovani.gsfc.nasan.gov).

## *Remote sensing data*

Photosynthetically active radiation (PAR) is an important parameter which regulates the carbon fixation by phytoplankton and hence the marine primary productivity. Similarly the downward penetration of solar radiation is important for determining the photic zone within which bulk of the primary production takes place. Since the diffuse attenuation coefficient ($K_d$) is an indicator of the turbidity of water column, there is an inverse relationship between the diffuse attenuation coefficient and the traditionally used 'Secchi depth'. Thus, the diffuse attenuation coefficient gives an indirect measure of how many metres the light penetrates the water column.

In the present study, we used satellite-derived spectral diffuse attenuation coefficient $K_d(490)$ and PAR from the sea-viewing wide field of view sensor (SeaWiFS) having a spatial resolution of ~ 9 km and temporal resolution of a week (http://oceancolor.gsfc.nasa.gov/) were also used. The $K_d(490)$ data used was for 2001 and 2002 while to generate the monthly mean climatology of PAR data, the period 1998–2006 was used.

## Results and discussion

To address the role of light limitation in regulating the biological productivity in BOB, we first analysed the vertical distribution of chlorophyll *a* and integrated PP up to 120 m of the water column during spring intermonsoon when the river discharge and associated sediment load was the least followed by summer and fall intermonsoon when the river influx was the highest.

## *Spring intermonsoon*

The characteristic feature of vertical structure of chlorophyll *a* during spring intermonsoon was the presence of subsurface chlorophyll maxima (SCM) along both central and western boundary of BOB, situated between 50 and 80 m (Figure 2, top). The chlorophyll *a* concentrations within the SCM were, in general, between 0.25 and 0.40 mg/m$^3$. However, north of 18°N along the central BOB (Figure 2, top left) and between 16°N and 18°N along the western boundary of BOB (Figure 2, top right) where SCM was located in the shallower depth (20–60 m), the chlorophyll *a* concentrations were about two-times higher. Though the surface chlorophyll *a* concentrations did not vary much (0.06–0.21 mg/m$^3$), it was marginally higher along the western boundary of BOB. The nutrient distribution (Figure 3, top) showed that the upper 30 m water column was devoid of nitrate

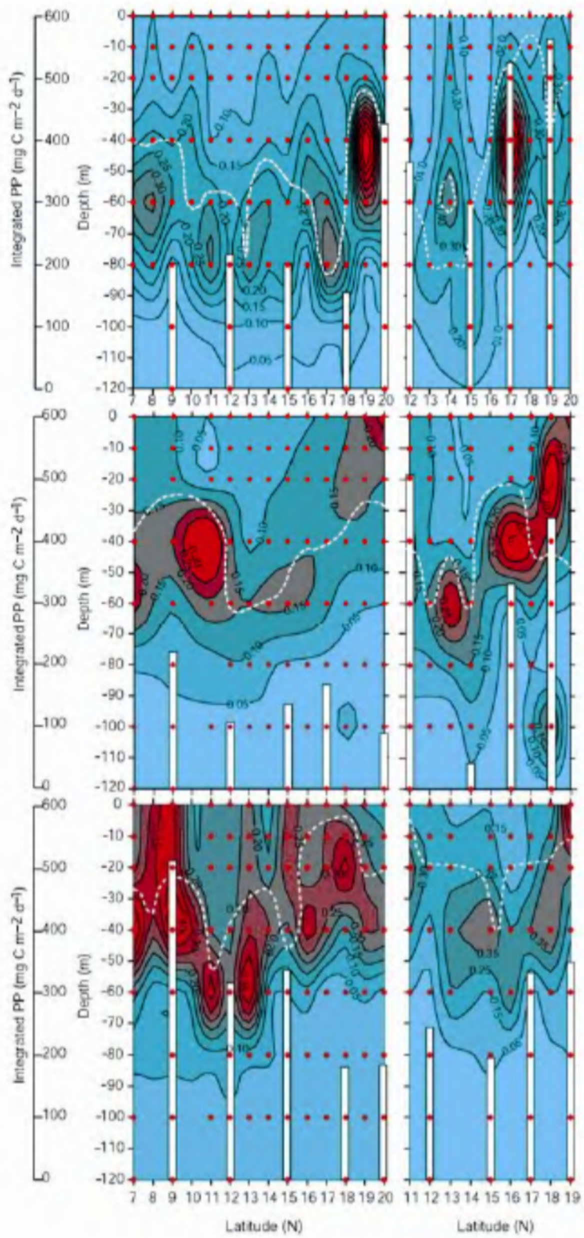


**Figure 2.** Vertical distribution of chlorophyll *a* (mg/m$^3$) during (top) spring intermonsoon, (middle) summer and (bottom) fall intermonsoon. The white bar represents the column integrated (up to 120 m) primary productivity (mg C m$^{-2}$ d$^{-1}$) and the white broken line denotes the depth of 1 μM nitrate isopleth. The left side of the figure is for the central Bay of Bengal transect (along 88°E) and the right side for that along western boundary. Dark circles indicate sample location.

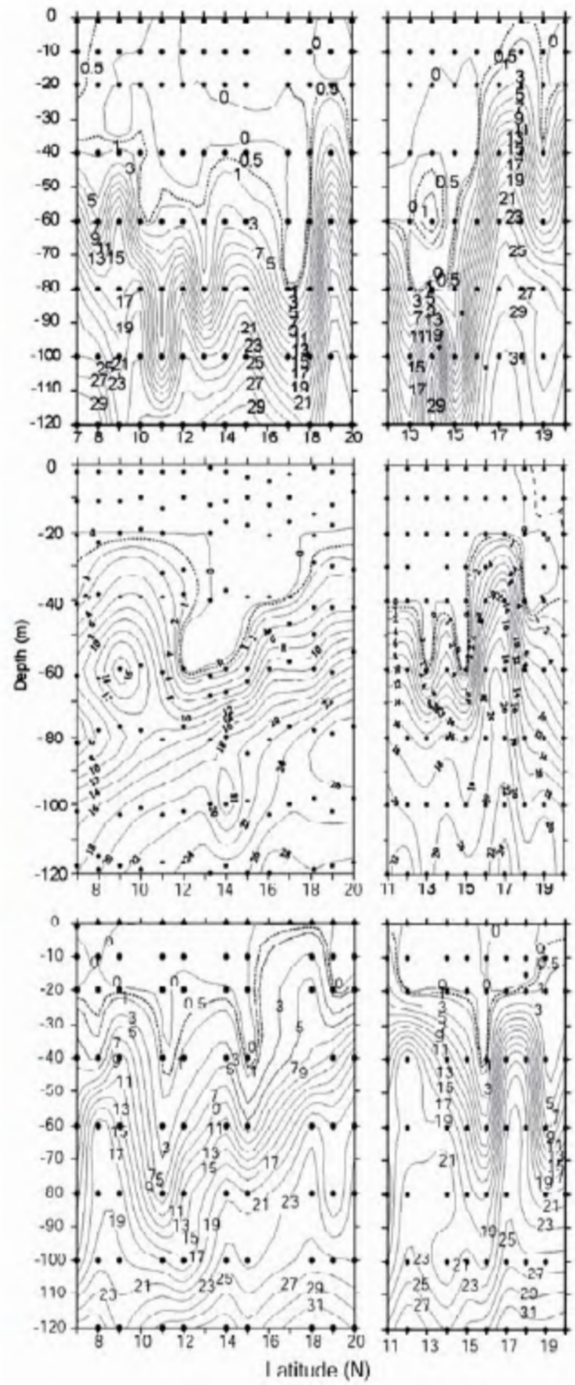


**Figure 3.** Vertical distribution of nitrate (μM) during (top) spring intermonsoon, (middle) summer and (bottom) fall intermonsoon. Zero (0) indicates concentration below detection level. The left side of the figure is for the central Bay of Bengal transect (along 88°E) and the right side for that along western boundary. The broken line represents 0.5 μM contour. Dark circles indicate sample location.

except in the region where the SCM was shallower (Figure 2, top). Notice the shoaling of 1 μM nitrate in Figure 2 (top) where SCM was shallow. In fact, shoaling of SCM was caused by eddy-pumping as could be inferred from the thermal structure discussed here. Thus, the low surface chlorophyll and the SCM was the characteristic feature arising out of the oligotrophic condition of the upper water column where the phytoplankton growth was limited by the availability of nutrients. An examination of the thermal structure along the above two transects (Figure 4, top) showed oscillations within the thermocline with doming of isotherms centred at 11°N, 16°N and 19°N along the central BOB transect (Figure 4, top left) and at 14°N and 17.5°N along the western boundary of the BOB (Figure 4, top right) respectively. These are the signatures of subsurface cold-core eddies, the most prominent being the one centred at 19°N along the central BOB and at 17.5°N along the western boundary of BOB. For a detailed description of the subsurface cold-core eddies and associated biological productivity along the mentioned two transects, see ref. 12. Note that the shoaling of the SCM occurred at the location where the eddy signatures were most prominent. The column integrated PP along the central BOB showed a two-fold increase in the northernmost station compared to south (white bars in Figure 2, top left), while the increase was one-and-half times in the north along the western boundary of the BOB compared to south (white bars in Figure 2, top right). Here again, the highest PP occurred in the vicinity of most prominent eddies. But the PP along the western boundary of the BOB was higher than that along the central BOB. Thus, the non-availability of nutrients either by river input or through upwelling to the upper ocean during spring intermonsoon led to the oligotrophic conditions, which limited the surface biological productivity. However, the subsurface eddies present during this period enhanced the biological productivity as reflected in the column integrated PP values in the vicinity of eddies.

*Summer monsoon*

In the summer monsoon, SCM was present only in the southern part of the central BOB transect, south of 12°N, the core of which was located at 40 m (Figure 2, middle left). A patch of chlorophyll *a* with concentrations greater than 0.2 mg/m$^3$ was seen close to the surface in the upper 10 m in the northernmost region. In contrast, SCM was present all along the western boundary section, the core of which was deep (~ 60 m) in the south and shoaled to 20 m in the north (Figure 2, middle right). However, during summer monsoon, the chlorophyll *a* concentrations within the SCM never exceeded 0.35 mg/m$^3$, which was less-than-half of that encountered during spring intermonsoon. The upper 30 m of the water column during summer monsoon was also nitrate depleted (Figure 3, middle) as in the case of spring intermonsoon but showed a concentration of about 0.5 μM in the northernmost region along the western boundary of BOB. An examination of the thermal structure revealed two prominent

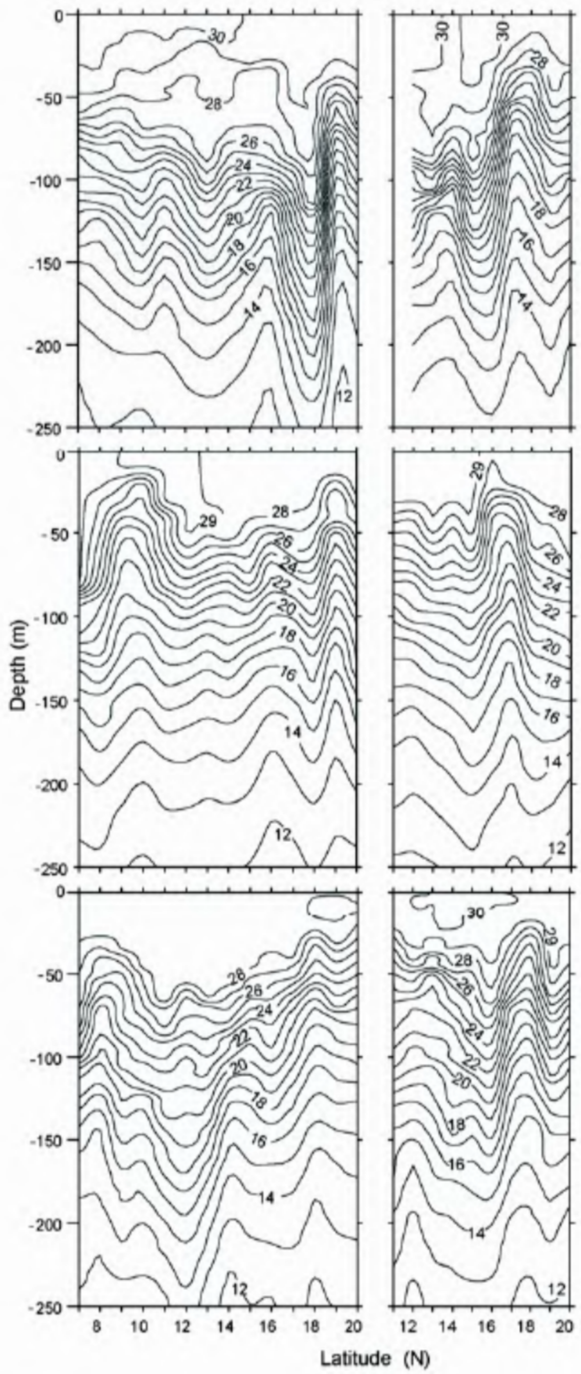


**Figure 4.** Vertical distribution of temperature (°C) during (top) spring intermonsoon, (middle) summer and (bottom) fall intermonsoon. The left side of the figure is for the central Bay of Bengal transect (along 88°E) and the right side for that along western boundary.

doming of isotherms along the central BOB track centred at 10°N and 19°N (Figure 4, middle left), and at 17°N along the western boundary of the BOB (Figure 4, middle right). These were identified as subsurface cold-core eddies[7]. The shallow SCM, noticed at 10°N along the central BOB as well as that at 17°N along the western boundary of the BOB, resulted from the doming of nitracline (Figure 3, middle), as indicated by the 1 μM nitrate isopleth in Figure 2 (middle). The occurrence of chlorophyll *a* in excess of 0.2 mg/m$^3$ in the upper 10 m in the northernmost region along both transects suggests availability of nutrients and its biological uptake. River runoff could transport nutrients to the upper waters of the open ocean. However, the concentration of nitrate in the upper 20 m of the water column along the central BOB was below detection level, though the northernmost station along the western boundary showed the presence of 0.5 μM in the upper 10 m. This indicated that though large portion of the river transported nitrate is biologically consumed within the estuarine and coastal region, some amount of nitrate must be available for the biological production in the open BOB. Earlier study by Padmavati and Satyanarayana[13] indicated that the nitrate concentration from the Godavari River showed a decreasing trend from estuarine to coastal region, with a net removal of 14–16% due to their uptake at the surface. The column integrated PP showed that along the central BOB transect, the highest value of 220.6 mg C m$^{-2}$ d$^{-1}$ occurred in the south at 9°N, whereas the lowest value of 89.4 mg C m$^{-2}$ d$^{-1}$ was in the north at 20°N (Figure 2, middle left). However, the column integrated chlorophyll *a* did not vary much with values of 11.1 and 11.4 mg m$^{-2}$ d$^{-1}$ respectively at those locations. Thus, the large north–south variation of PP along the central BOB with no apparent concomitant variation in the chlorophyll biomass is intriguing.

Along the western boundary of the BOB, the highest PP of 502.01 mg C m$^{-2}$ d$^{-1}$ was in the south at 12°N, and the second highest value of 433.8 mg C m$^{-2}$ d$^{-1}$ was in the north at 19°N (Figure 2, middle right). The column integrated chlorophyll *a* in the given locations was 12.7 and 18.7 mg m$^{-2}$ d$^{-1}$ respectively. This high productivity in the south away from high surface chlorophyll *a* and also away from the vicinity of cold-core eddy needs further explanation. A careful examination of the thermal structure along the western boundary of the BOB revealed an isotherm oscillation and small doming centred at 12°N (Figure 4, middle right) which was also evident in the shoaling of 1 μM nitrate isopleth towards 40 m (Figure 3, middle right). A strong wind-mixing capable of deepening the mixed layer can make this nitrate available to the upper layers. Increased wind-forcing and advection of high salinity waters from the Arabian Sea during summer monsoon reduces the stratification of the upper layers in the southern BOB and give rise to mixed layer deeper than 40 m (ref. 14). Thus, thermocline oscillation coupled with reduced stratification and increased wind-induced mixing appears to be the mechanism that supplied the nutrients to the euphotic zone and resulted in the observed high productivity. In spite of the relatively high concentration of chlorophyll *a* in the upper layer and some amount of nutrient supply through river runoff in the northern BOB during summer monsoon, the biological productivity in the northern BOB along both central and western boundary transects (89.39 and 443.85 mg C m$^{-2}$ d$^{-1}$ respectively) were lower than that during spring intermonsoon (427.32 and 469.21 mg C m$^{-2}$ d$^{-1}$ respectively) which is an anomaly.

## *Fall intermonsoon*

In fall intermonsoon also SCM was present along both the central and western boundary transects of BOB. The chlorophyll *a* within SCM along the central BOB varied from 0.3 to 0.4 mg/m$^3$, whereas the core of SCM which was located at 40 and 60 m in the south shoaled to 20 m in the north (Figure 2, bottom left). The chlorophyll *a* concentrations at the surface varied from 0.12 to 0.37 mg/m$^3$ with higher values towards south. Along the western boundary of the BOB, however, the core of SCM did not show significant variation and was located at about 40 m with a concentration of 0.35 mg/m$^3$ (Figure 2, bottom right). A patch of high chlorophyll *a* with concentrations greater than 0.4 mg/m$^3$ was seen close to the surface in the upper 20 m in the northernmost region. The surface chlorophyll *a* in this region was 0.77 mg/m$^3$, whereas in the south it was 0.13 mg/m$^3$. The upper 20 m of the water column along both the central and the western boundary of BOB was devoid of nitrate (Figure 3, bottom) except where the nitracline shoaled under the influence of cold-core eddy. In fact, a close correspondence was noticed between the shoaling of SCM with that of 1 μM nitrate isopleth (Figure 2, bottom). The thermal structure revealed three distinct doming of thermocline centred at 8°N, 14°N and 18°N along the central and two along western boundary of the BOB at 12°N and 18°N respectively (Figure 4, bottom), which were identified as cold-core eddies[12]. Thus, the shoaling of nitracline and SCM occurred under the influence of cold-core eddy present at these locations. Note that nitracline shoaling was more intense in the north than that in the south (Figure 3, bottom). In spite of the nitracline shoaling and the nitrate concentrations reaching up to 1 μM in the upper 10 m in the north along the central bay, the column integrated PP values were the least (181.73 and 184.14 mg C m$^{-2}$ at 18°N and d$^{-1}$ at 20°N respectively). The maximum PP of 512.85 mg C m$^{-2}$ d$^{-1}$ occurred in the south where the nitrate concentrations in the upper 20 m was below detectable levels but that in the 20–30 m of the water column had a concentration of ~3 μM. Hence, the occurrence of low PP in the north where the nitrate concentrations in

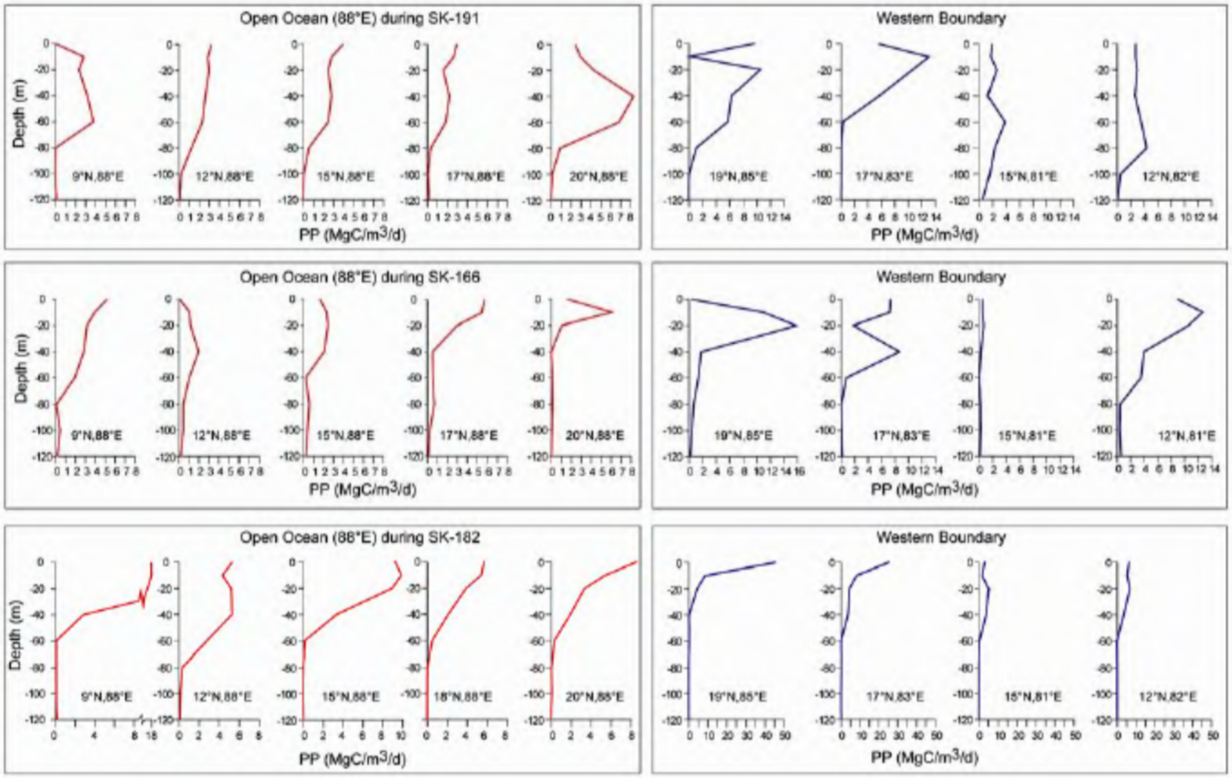


**Figure 5.** Vertical distribution of primary productivity (mg C $m^{-3}$ $d^{-1}$) during (top) spring intermonsoon, (middle) summer and (bottom) fall intermonsoon. The left side of the figure is for the central Bay of Bengal transect (along 88°E) and the right side for that along western boundary.

the upper 10 m was ~1 μM and that in the 20–30 m water column was ~5 μM, was an anomaly. Along the western BOB, however, the highest PP was in the north (350.46 mg C $m^{-2}$ $d^{-1}$) and lower values were towards south (196.43 mg C $m^{-2}$ $d^{-1}$ at 15°N and 244.63 mg C $m^{-2}$ $d^{-1}$ at 12°N respectively). Though the maximum PP occurred in the north along the western boundary of the BOB, the values were not dramatically high compared to those in the south. In fact, along the western boundary PP in the north was only about one-and-half times greater than that in the south. In contrast along the central bay, the PP value in the north was two-and-half times less than that of the south.

Thus, of all the three seasons, the column integrated PP along the central BOB transect was the least during summer monsoon though nutrients were available in the northernmost BOB by way of river input and eddy-pumping. The fall intermonsoon also showed the lowest column integrated PP in the northern BOB. The highest PP of all the seasons in the north was in the spring intermonsoon. Along the western boundary of the BOB also, the highest PP in the north did not occur either in summer or fall intermonsoon, but occurred during spring intermonsoon when there was presumably no nutrient input from rivers. An examination of the vertical profiles of PP (Figure 5) showed that along the central BOB transect during summer and fall intermonsoon, the PP below 20 m depth in the north (at 20°N) was small and below 40 m it was negligible (Figure 5, left panels). In contrast, in the south during both the seasons substantial amount of PP was seen below 20 m depth which extended up to 60 m. Similarly along the western boundary also, the PP in the north (at 19°N) during summer below 20 m depth reduced drastically and below 40 m it was negligible (Figure 5, right panels). However, in the south similar to that in the central BOB, substantial amount of PP was seen below 20 m (17°N and 12°N). Interestingly, during spring intermonsoon, the rate of decrease of PP with depth in the upper 80 m water column in the north was slower compared to both summer and fall intermonsoon when the highest column integrated PP of all seasons occurred in the north. It is well recognized that the strong stratification that exists during summer due to fresh water influx could curtail the vertical transfer of nutrients across the nitracline into the mixed layer[9] thereby reducing the primary production[6,9]. What we notice from the vertical profiles of PP is a drastic reduction in PP with depth in the upper 20 m water column in the north compared to south during summer and fall intermonsoon and below 20 m (and up to 40 m) there is very little PP in the north while PP is substantial in the south. Note that the nutrient concentration increases with depth both in the north as well as south. The question then is why the northern BOB showed less productivity in summer and fall intermonsoon, when there is nutrient input to the upper ocean by way of river influx in addition to eddy-pumping? The obvious reason is the light limitation, as speculated by earlier researchers[1,2,6].

To explore the possible influence of the river flux in curtailing the downward penetration of solar radiation, the satellite derived spectral diffuse attenuation coefficient, $K_d$(490), a standard ocean colour satellite product of SeaWiFS was analysed. Diffuse attenuation represents the rate at which light at 490 nm is attenuated with depth. The monthly mean climatology of the freshwater discharge from rivers bordering BOB showed dominant discharge during July to October[14], which encompasses the summer and fall intermonsoon. Accordingly, the associated sediment load also will be high during this period[15]. Hence the $K_d$(490) during 10 June to 15 October was averaged during 2001 and 2002 (Figure 6) for analysis. Note that *in situ* measurements for summer were in 2001 and that for fall intermonsoon was in 2002. The main reason why we use $K_d$(490) is because it is sensitive to all constituents (SPM, CDOM and chlorophyll) of the water and is also strongly correlated to $K_d$(PAR) and hence the depth of the photic zone[16,17]. The $K_d$ values are extensively validated with global *in situ* data[18] and have standard uncertainties and mean biases of 0.020 and 0.000 $m^{-1}$ with measured $K_d(490) < 0.25\ m^{-1}$ and 0.196 and –0.085 $m^{-1}$ with measured $K_d(490) > 0.25\ m^{-1}$. The dynamic ranges of $K_d$(490) distribution during 10 June to 15 October 2001 (Figure 5, top) showed values varying between 0.2 and 0.1 $m^{-1}$ (shades of green) in the northern region of BOB. Given the relation for euphotic zone depth[19] $(Z_{eu}) = 4.6/K_d$, we get the range of values in the northern BOB to be between 23 and 46 m respectively, where the light field decreases to 1% of that just below the surface. Similarly, given the relation between the midpoint of the euphotic zone $(Z_{eum})$[19], the depth at which the light field reduces to 10% of that below the surface, to be $2.3/K_d$, we get values from ~ 11 to 23 m respectively. Compared to the northern regions of BOB, the central regions showed $K_d$(490) values that are nearly half (0.02–0.04 $m^{-1}$, shades of blue). Thus, the values of $Z_{eu}$ and $Z_{eum}$ increased 4–5 times in the central region compared to northern BOB. A similar pattern was seen during the same period in 2002 (Figure 6, bottom). Available Secchi disc data collected during spring intermonsoon 2003 cruise showed a strong inverse relationship with $K_d$(490) values. The Secchi disc values ranged from 22 to 35 m that corresponds to $K_d$(490) values between 0.02 and 0.04 $m^{-1}$. This demonstrates that during the summer and fall intermonsoon months, the increased river flux (including turbidity) in the northern regions of BOB considerably reduced the depth of light penetration and restricts productivity even if nutrients were abundant in the upper water column by way of river influx and eddy-pumping.

In addition to turbidity-driven reduction in the light penetration in the northern BOB, cloud cover could also reduce the availability of light for photosynthesis. Since the BOB comes under the summer monsoon regime, it experiences strong seasonality in the extent of cloud cover with highest during summer (June–August) and least in spring intermonsoon (March–May). Hence, the spatial distribution of cloud cover over the BOB was

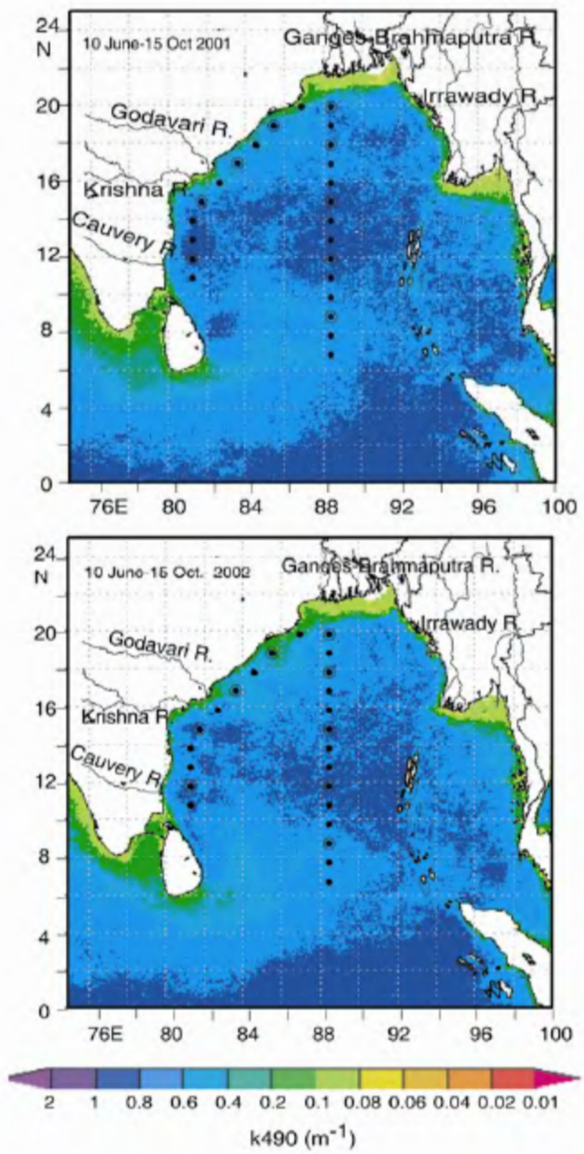


**Figure 6.** Monthly mean climatology (1998–2006) of photosynthetically active radiation (PAR) (Einstein $m^{-2}$ $day^{-1}$).

examined during April (peak of spring intermonsoon) and July (peak of summer monsoon) by analysing the PAR product derived from SeaWIFS. PAR is the downwelling flux of photons just below the sea surface integrated over the wavelength range of 400–700 nm which is strongly affected by the presence of water vapour/cloud. Unlike the $K_d(490)$ we choose to use monthly mean climatology of PAR for April, July and October because of small interannual variability as seen from its standard deviation (Figure 7 *d–f*). The monthly mean climatology of PAR in April showed very small spatial variation between 45 and 55 Einstein $m^{-2} d^{-1}$ with most part of the BOB showing a value within a range of 50–55 Einstein $m^{-2} d^{-1}$ (Figure 7 *a*). In contrast, July PAR in the northern BOB varied from 30 to 40 Einstein $m^{-2} d^{-1}$ and towards the central and southern BOB it increased to 40–50 Einstein $m^{-2} d^{-1}$ (Figure 7 *b*). In October, however, PAR showed low values (~ 40–45 Einstein $m^{-2} d^{-1}$) in most part of the BOB (Figure 7 *c*). The least PAR values were noticed along the western and northern BOB in addition to the Sumatra region. In general, the northern BOB had more cloud cover during summer and fall intermonsoon than the central and southern BOB as could be seen from the distribution of OLR (outgoing longwave radiation) climatology in BOB during June–September[20]. In the northern bay, $K_d(490)$ showed a factor of 10-increase compared to the southern parts, whereas PAR showed 20% decrease. From this, it is clear that during summer monsoon, the role of river influx in the northern bay overwhelms that of cloud-cover in curtailing the availability of light for photosynthesis.

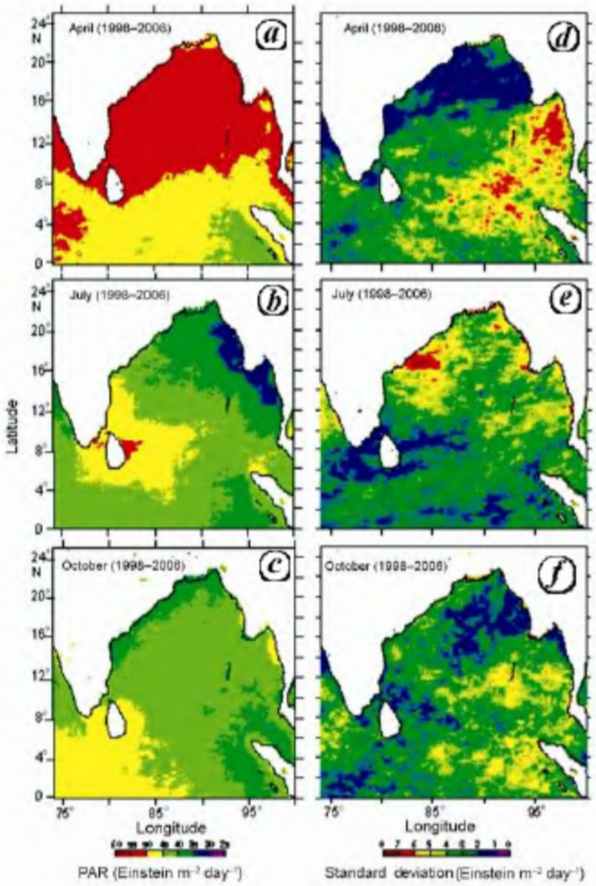


**Figure 7.** Monthly mean climatology (1998–2006) of photosynthetically active radiation (PAR) (Einstein $m^{-2} day^{-1}$) during April (***a***), July (***b***), and October (***c***) and its standard deviation during April (***d***), July (***e***) and October (***f***).

## Summary and conclusions

The BOB is traditionally considered to be biologically a less productive basin compared to its western counterpart, the Arabian Sea. The chlorophyll pigment concentrations derived from satellite remote sensing data also support this notion. The reasons for this have been variedly attributed to narrow shelf, cloud cover, sediment load, stratification, etc. Being situated in the tropical region sunlight, in general, should not be a limiting factor for primary production. A recent *in situ* data collected from the central and western BOB during summer, fall and spring intermonsoons were used to address the role of light in curtailing the biological productivity in the northern BOB. The analysis showed that in spite of the availability of nutrients in the upper water column by the river input and eddy-pumping, the primary productivity in the northern BOB was least during summer compared to all other seasons. During summer the input of fresh water and sediment from rivers was dominant. The highest PP occurred during spring intermonsoon when there was practically very little river input of fresh water or sediment to BOB. The analysis of the diffuse attenuation coefficient showed that during summer and fall intermonsoon months, the increased river flux in the northern BOB considerably reduced the depth of light penetration and restricts primary productivity in spite of availability of nutrients. Though the cloud cover over BOB during summer and fall intermonsoon also contributed towards the reduction of light penetration in the northern bay, the effect of river influx overwhelmed.

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