

Basin scale distribution of *Trichodesmium* spp. in the Arabian Sea using Oceansat I/ OCM

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ABSTRACT

Trichodesmium spp. is widely spread in the Arabian Sea. It form dense patches. During 2000-2005 (5 years period) extensive sampling was done in the Arabian Sea covering large area and different months starting from November to May. Three prominent sites are identified as *Trichodesmium* bloom sites in the Arabian Sea: 1) Lakshadweep waters 2) Off Goa and 3) Off Gujarat area. Bloom of around 100 km² area with 4 to 400737 filamentsL⁻¹ concentrations are recorded. Two species of *Trichodesmium* are encountered based upon seasonality and environmental conditions. OCM derived chlorophyll *a* during bloom was as high as 0.5 to 1 mgm⁻³, at time increased upto 5 mgm⁻³ and depends upon number of filaments in water. The *Trichodesmium* features were identified at 869, 670, 555nm in OCM data. *Trichodesmium* was detected as stripes and eddies in OCM images. The bloom patches appear darker which is taken as measurement of spread of the bloom in water. Total 133 stations are covered during 5 years period out of which 63 stations showed presence of *Trichodesmium* with discolouration of water. In offshore water *Trichodesmium* was detected as early as November and continued upto April month whereas in the coastal water *Trichodesmium* prevailed from February to May. The seasonality of these blooms was observed with respect to inshore/offshore and two species of *Trichodesmium* is discussed with the help of OCM data processed for chlorophyll *a* during *Trichodesmium* growth period, at 3 identified sites in the Arabian Sea.

Keywords : *Trichodesmium*, Ocean color monitor, filaments, chlorophyll *a*, Arabian Sea

1. INTRODUCTION

The *Trichodesmium*, filamentous cyanobacteria is the major group of N₂-fixing (and carbon producing) phytoplankton in the ocean¹. *Trichodesmium* occurs as patches and higher concentration (blooms) in tropical and subtropical oceans which can be detected by remote sensing^{2,3}. It has been estimated that N₂-fixed in ocean globally is ~ 80 TgN¹. However little is known about the contribution by *Trichodesmium* in the Arabian Sea. The large blooms of the *Trichodesmium* in the Lakshadweep Sea waters was reported⁴. *Trichodesmium* blooms were also reported in the coastal waters of Goa^{3,5}. The large patches of *Trichodesmium* are reported from NE Arabian Sea (Off Gujarat) during April month⁶. These accounts does not give the information about the *Trichodesmium* in Arabian Sea in time and space. Similarly most of the time *Trichodesmium* bloom reported are compose of *Trichodesmium erythraeum* as single species and of mostly surface phenomenon. Attempt is made here to collect information about *Trichodesmium* distribution of large area and different months and water column level. Distribution of *Trichodesmium* spp. is also supported by Chl *a* estimated using survey and OCM images as indicator of larger aggregation of *Trichodesmium* in the Arabian Sea.

2. METHODOLOGY

The *Trichodesmium* bloom is initially recorded by PUV-500 fluorescence profiling system *Trichodesmium* filaments were counted as the part of the standard phytoplankton cell counts. Total 6 cruises on coastal ship (Fig. 1) during 2000-2005 period.

Phytoplankton cells: Water samples were collected by CTD rosette, preserved using lugol's iodine. Settled material is counted for phytoplankton using Inverted microscope (Olympus XI 50). Phytoplankton samples were identified using standard reference material⁷.

Chlorophyll *a*: Water samples were filtered on GF/F filtered, Chl *a* extracted in 90 % acetone at low temperature overnight. Chl *a* was estimated using Turner fluorometer and sigma Chl *a* as external standard⁸. The Chl images were generated using OC-2 algorithm; ERDAS Imagine 2.5 software was used for image processing⁹.

3. RESULTS

The PUV-500 profiles of coastal and open ocean during *Trichodesmium* blooms are presented in Fig. 2A. The intensity of bloom was clearly seen by comparing fluorescence of filaments values specially is surface waters. Similarly, the surface maxima of Chl *a* observed was due to *Trichodesmium* bloom (Fig. 2B).

The seasonal variations in *Trichodesmium* filaments are presented in Table 1. *Trichodesmium* season starts during November and continue well upto 19th of May upto first showers of monsoons in the Arabian Sea. The high values were reported during November and April compared to other seasons. The concentrations of filaments varies from 4-400737 nos. L⁻¹ throughout the growth period. High concentrations recorded in the coastal waters during March (Fig 3A) and May (Fig. 3B) where Chl *a* distribution pattern was decided by *Trichodesmium* distribution. In depth study in Lakshadweep has strengthened the idea that these concentrations were entirely depends upon the wind speed prevailed during sampling time (Fig. 4). The calm sea condition, high temperature and low nitrate and clear waters promote *Trichodesmium* growth which was also recorded as high Chl *a* concentrations in the ocean colour images presented in Fig. 5. The high concentrations in the ocean colour images presented in Fig. 5. The high concentration of *Trichodesmium* during April were clearly depicted in the April OCM Chl image from the Arabian Sea.

4. DISCUSSION

4.1 Distribution

Phytoplankton (including *Trichodesmium*) in the NE Arabian Sea vary on monthly basis since it was subjected to various seasons like Fall Inter-monsoon, NE monsoon and Spring Inter-monsoon. These seasons are related to monsoon systems like SW monsoon and NE monsoon.

4.1.1 *Trichodesmium* during Fall Inter-monsoon season (November) in the NE Arabian Sea

During fall Inter-monsoon season (November) high abundance of *Trichodesmium* filaments were recorded between the 18⁰N, 68 and 70⁰E which was offshore water in the NE Arabian Sea. *Trichodesmium thiebautii* was the only one dominant species found in this region during this season. It is worth mentioning that this is the first record in the Arabian Sea that *Trichodesmium thiebautii* was found to occur in the month of November, forming blooms. The highest (109570 filaments L⁻¹) abundance was found at surface with an average of 10815 filaments L⁻¹ (n=13; Table 1). During this time (November) filaments were free (solitary). These observed filament counts were high as compared to those reported¹⁰ from Atlantic ocean (2200 filaments L⁻¹).

Our observations have showed that the *Trichodesmium* bloom was at the surface as well as in sub-surface depth upto 50 m. The conditions like calm weather, bright light and low temperature supported the *Trichodesmium thiebautii* growth in the NE Arabian Sea. The Chl *a* during *T. thiebautii* bloom was comparatively high (0.1733 to 5.344 µg L⁻¹) considering deep part of the Arabian Sea basin. In the earliar study¹¹ indicated that *Trichodesmium* occurs in the Northern Arabian Sea during October-November however, no information on the details of species was available.

4.1.2 *Trichodesmium* during NE Monsoon (December to February) in the NE Arabian Sea

Trichodesmium bloom was found during December - February months in the NE Arabian Sea. During this period, both the species *T. erythraeum* and *T. thiebautii* formed blooms in the NE Arabian Sea. In December average *T. erythraeum* count was 30 ± 15 (n=14) and *T. thiebautii* was 46 ± 17 filaments L⁻¹ (n=14). At most of the stations, *Trichodesmium* filaments were distributed throughout the euphotic zone. The total average *Trichodesmium* spp. filaments were 71 filaments L⁻¹ (Table 1). The present study revealed that *T. erythraeum* and *T. thiebautii* grow almost 1:1 proportion during December.

In January, seven stations showed occurrence of *Trichodesmium* out of twenty five stations sampled in the NE Arabian Sea. *Trichodesmium* was observed at column at most time during January. The *Trichodesmium* concentration was 0 to 60 filaments L⁻¹ at seven stations studied during January. It was also observed that *T. erythraeum* was in higher proportion

compared to *T. thiebautii* concentrations in the column. Subsequently, in February, the high filament concentrations were observed at 12°N and 74°E (6160 filaments L⁻¹). The same bloom was distributed up to 13 to 17°N and 19 to 20°N. Another bloom of *Trichodesmium* in the same area was distributed in the region of 68 to 72°E except 71°E. The average *T. erythraeum* was in the concentration of 949 ± 435 filaments L⁻¹ and *T. thiebautii* count was 450 ± 401 filamentsL⁻¹. The total average *Trichodesmium* spp. filaments were 8 filamentsL⁻¹ (n=14; Table 1). These concentrations were much higher than earlier reported value of 100 filamentsL⁻¹ in the NE Arabian Sea during February¹².

4.1.3 *Trichodesmium* during spring inter-monsoon (March to April) in the NE Arabian Sea

In March, the proportion of *T. erythraeum* counts increased as compared to *T. thiebautii*. The average concentration of *T. erythraeum* was 115 ± 43 (n= 3) and that *T. thiebautii* was 40 ± 38 filamentsL⁻¹. The total average *Trichodesmium* spp. filaments were 158 filamentsL⁻¹ (n=3; Table 1). However, in April it was observed that offshore concentrations of *Trichodesmium* decreased to nil due to impact of convective mixing during winter cooling. The blooms of the *T. erythraeum* were observed in coastal waters. The total average *Trichodesmium* sp. filaments were 26250 filamentsL⁻¹ (n=24; Table 1). The signature of these blooms was noticed in OCM data presented in Fig. 6.

4.2 Ecological factors

It is evident from the present study that *Trichodesmium* appear in the coastal and offshore region of Arabian Sea covering a period of 5 – 6 months imply that, environmental factors supporting these different species and forming bloom is of great ecological importance. Such nature of observations further made it imperative to understand and provide appropriate answers as to why *Trichodesmium* density is high in the open ocean during fall inter-monsoon and intense in coastal water during spring inter-monsoon season? The environmental determinant of *Trichodesmium* success or failure in competition with other phytoplankton is not well established (Hood, et al., 2000). Here, an attempt has been made to elucidate the abundance of *Trichodesmium* filaments and the ecological conditions those mark the success of the bloom.

4.2.1 Wind speed

During present study, a direct relationship of low wind and high concentration of *Trichodesmium* was observed (Fig. 4). Wind stress at the surface affects the qualitative distribution of *Trichodesmium*. It was earlier known that at calm sea condition the *Trichodesmium* bloom occurs^{5,13,14,15}. In our study, it was found that when the wind speed was low (< 4 ms⁻¹), thick bloom of *Trichodesmium* was observed. However, more wind speed resulted in mixing of water column thus, triggering *Noctiluca* bloom in the Arabian Sea in March, replacing *Trichodesmium* bloom. Earlier studies¹⁶ reported that water temperature as one of the important factor regulating *Trichodesmium* abundance. In the Arabian Sea, during major period (other than monsoons) the upper layers of the waters are devoid of nutrients. In such situation, *Trichodesmium* had advantage over other phytoplankton, as it can fix nitrogen and dive deeper depths for phosphate and take up vertical migration to well lighted zone¹⁷.

Stratification of water column during low wind condition (as seen during January, February and March) was the most critical ecological factor for *Trichodesmium* blooms occurrence in the Arabian Sea. Association between *Trichodesmium* abundance and vertical stratification have been reported in the North Pacific sub-tropical gyre¹⁴ and stated that the mixed layer depth may play an important role in the occurrence and abundance of *Trichodesmium*. Average mixed layer depth was 10-40 m in the Arabian Sea supporting *Trichodesmium* blooms.

4.2.2 Temperature

During the present study, in the NE Arabian Sea, temperature varied from 28 to 30 °C for the period of November-April. It was observed that in November (Fall Inter-monsoon) the temperature was < 28°C wherein, only *Trichodesmium thiebautii* was present. However, in December the temperature increased to 29°C, and *Trichodesmium thiebautii* was found to occur in addition to this few filaments of *Trichodesmium erythraeum*. The observations made in January also revealed similar trend of occurrence and distribution of these species. In February and March, the temperature showed slight increase and *Trichodesmium* bloom was dominated by *T. erythraeum* filaments. In some locations, *Trichodesmium* was totally replaced by the *Noctiluca miliaris* supplemented by low temperature due to convective mixing triggered by high wind speed.

4.2.3 Salinity

During the present study period salinity was high (> 35 psu) during the *Trichodesmium* bloom occurrence. There was no much effect of minor salinity variation on *Trichodesmium*. However, lower salinity does not support growth of *Trichodesmium* as seen at station A in the coastal waters of Goa. It was also noticed that at station B salinity decrease during monsoon was associated with absence of *Trichodesmium*. An elevated level of atmospheric temperature lead to increase salinity, creating conducive ecological conditions for *Trichodesmium* to establish.

4.2.4 Nutrients

The uptake of NO_3 or NH_4 molecules is energetically cheaper, and the respective enzymes are not deactivated by exposure to oxygen, as is nitrogenase. In the laboratory under different conditions, even N_2 -fixers have been found to obtain most of their N from NH_4 and NO_3 when they are available, rather than from N_2 ¹⁸. Although N_2 -fixers such as *Trichodesmium* are not obliged to fix N_2 if other nitrogen sources are present, the constraints of being adapted to a N_2 -fixation lifestyle probably mean that they can compete successfully with other phytoplankton only in condition favouring N_2 -fixation. This implies that they will be competitively excluded in the presence of high nitrate or ammonium concentration¹⁵. The high abundance of *Trichodesmium* indeed occur in nitrate-depleted surface waters. It can be inferred that the most favourable place for N_2 -fixers is likely to be one in which N is present only as N_2 but yet other needs such as light and phosphate are abundantly satisfied. In our study, it was found that nitrate was depleted soon after diatom bloom was triggered by monsoon upwelling. Initially, it happened in offshore waters (November) and subsequently in the coastal water during January.

Trichodesmium appearance in the Arabian Sea was well associated to nutrient supply and availability as observed in our study. It was also observed that the area where there is prevalence of oligotrophic conditions, the *Trichodesmium* was found to occur. As it could be highlighted from our data that during *Trichodesmium* bloom nitrate was completely exhausted hence, the exudation by *Trichodesmium* can form excellent source of nutrients for other phytoplankton.

4.3 Succession of phytoplankton

The decomposition of surface blooms is likely to favour the fate for the other phytoplankton to occur (succession). The succession occurs when the environmental conditions become exceptionally favorable for certain organisms to appear in abundance. Thus, fairly rapid or abrupt changes occurring in the environment are associated with one or other type of phytoplankton blooms. In the present study, it was found that following the *Trichodesmium* bloom in the coastal water, diatoms and dinoflagellates were supporting the prevailing food chain. During NE monsoon (December) dinoflagellates were as high as diatoms and *Trichodesmium* was low, at the mid of NE monsoon (January). During spring Inter-monsoon (March-April), *Noctiluca miliaris* and diatoms were found to be followed by *Trichodesmium* bloom which show the intense bloom of *Trichodesmium* in the Goa water.

In Lakshadweep, during April, the *Trichodesmium* was associated with dinoflagellates such as *Scrpsiella* sp., *Gymnodinium spirale*, *Gymnodinium gracile*, *Gonyaulax pacifica* and *Gymnodinium* sp. Earlier¹⁹ it was reported that the *Trichodesmium* was associated with *Nitzschia* sp. In the Sargasso Sea it was reported the occurrence of *Rhizosolenia alata*, *Thalassiothrix* sp., *Nitzschia closterium*, *Gonyaulax* sp. alongwith *Trichodesmium* spp.²⁰ and stated that these species appears to be ecologically important. However, published literature²¹ suggests that *Trichodesmium* blooms are toxic. This has been demonstrated for *Trichodesmium erythraeum* and *Trichodesmium thiebautii*. Fish deaths have been reported to occur in many areas during *Trichodesmium* blooms with some mass mortalities of fish, holothurians, crabs, sea urchins and mollusks along Cylon waters²². In Brazil, 'Tamandare fever' has been reported in the human population during the presence of *Trichodesmium*²³. Residents experience respiratory problems and coughing. In the Caribbean, Hawser, et al., (1991) have reported highly neuro-toxic metabolites from mixed species of *Trichodesmium thiebautii* and *Trichodesmium erythraeum*. In the present study, we have not experienced any of the above effect in the Arabian Sea. In fact, we have done experimental fishing off Goa waters during April, 2006. The fish catch was moderately high. The echogram during this study indicated the bloom in high concentrations during fishing activity. Such observations of abundance of fish catch during occurrence of *Trichodesmium erythraeum*, supports little evidence that these blooms affect fish catch. Further, it also indicates that such effects on fish population may be largely influenced by the prevailing physico-chemical parameters and geographical scale. The oligotrophic condition (especially low nutrients) triggers the development of *Trichodesmium* being a diazotroph. The carbon production and nitrogen fixed by these organisms via bloom formation enters in marine environment through exudation, grazing, sinking and decomposition. Thus,

Trichodesmium play an important role of nutrient cycling and energy transfer during oligotrophic conditions. This happens in between two monsoon systems and just after occurrence and abundance of other phytoplankton in the Arabian Sea. The Chl *a* images of OCM developed of this period also support the growth of *Trichodesmium* in the Arabian Sea elevating Chl *a* level from low Chl *a* values.

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Table 1. Distribution of *Trichodesmium* filaments (nos. L⁻¹) in the Arabian Sea

Months	Min	Max	Average	N
Nov	42	109570	10815	13
Dec	22	216	71	14
Jan	4	60	8	14
Feb	77	6160	1400	7
March	138	176	158	3
April	63	400737	26250	24
May	990	1170	729	12

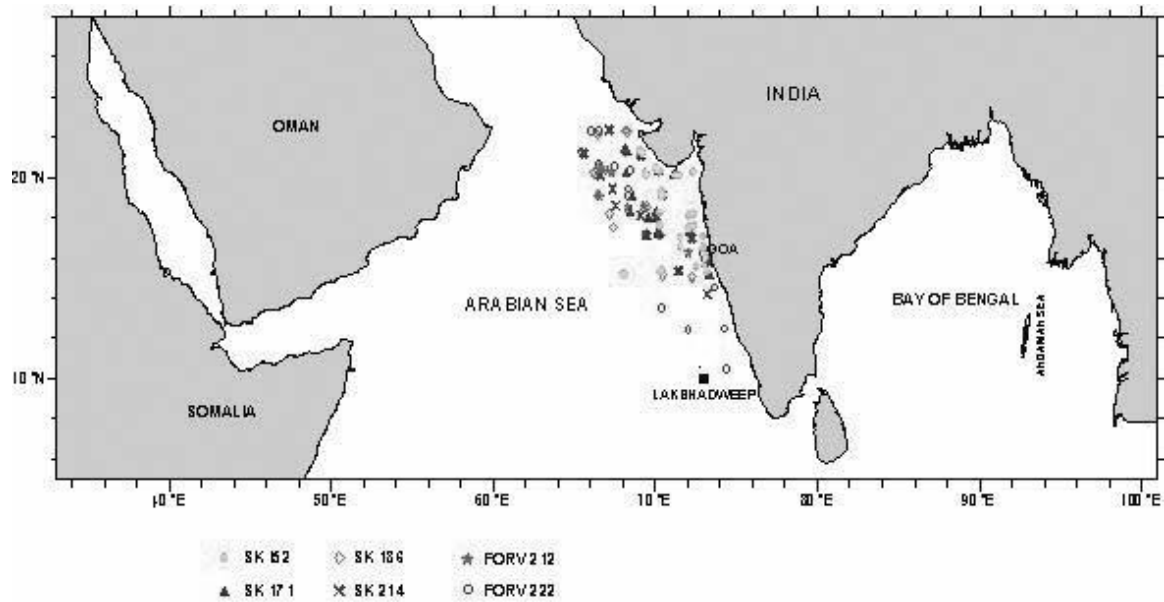


Fig. 1 Sampling stations in the Arabian Sea

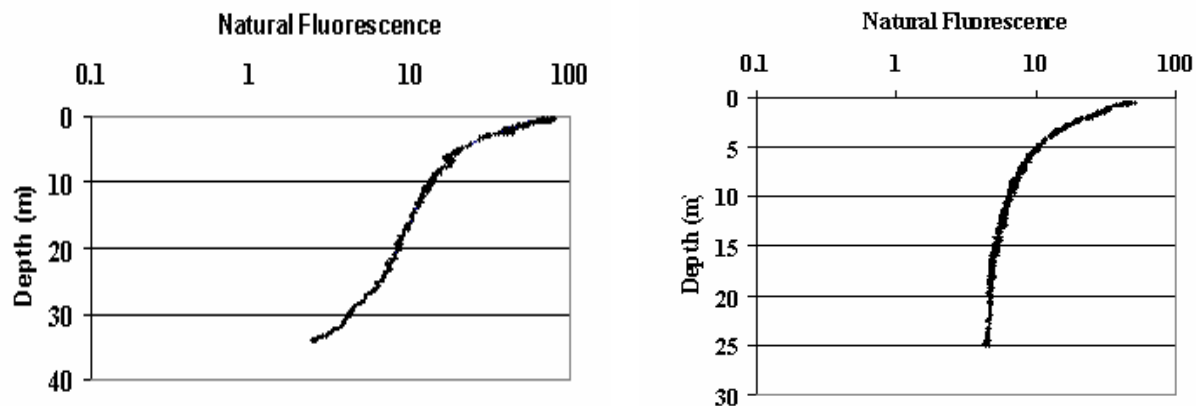


Fig. 2A PUV profiles during *Trichodesmium* bloom in the Arabian Sea

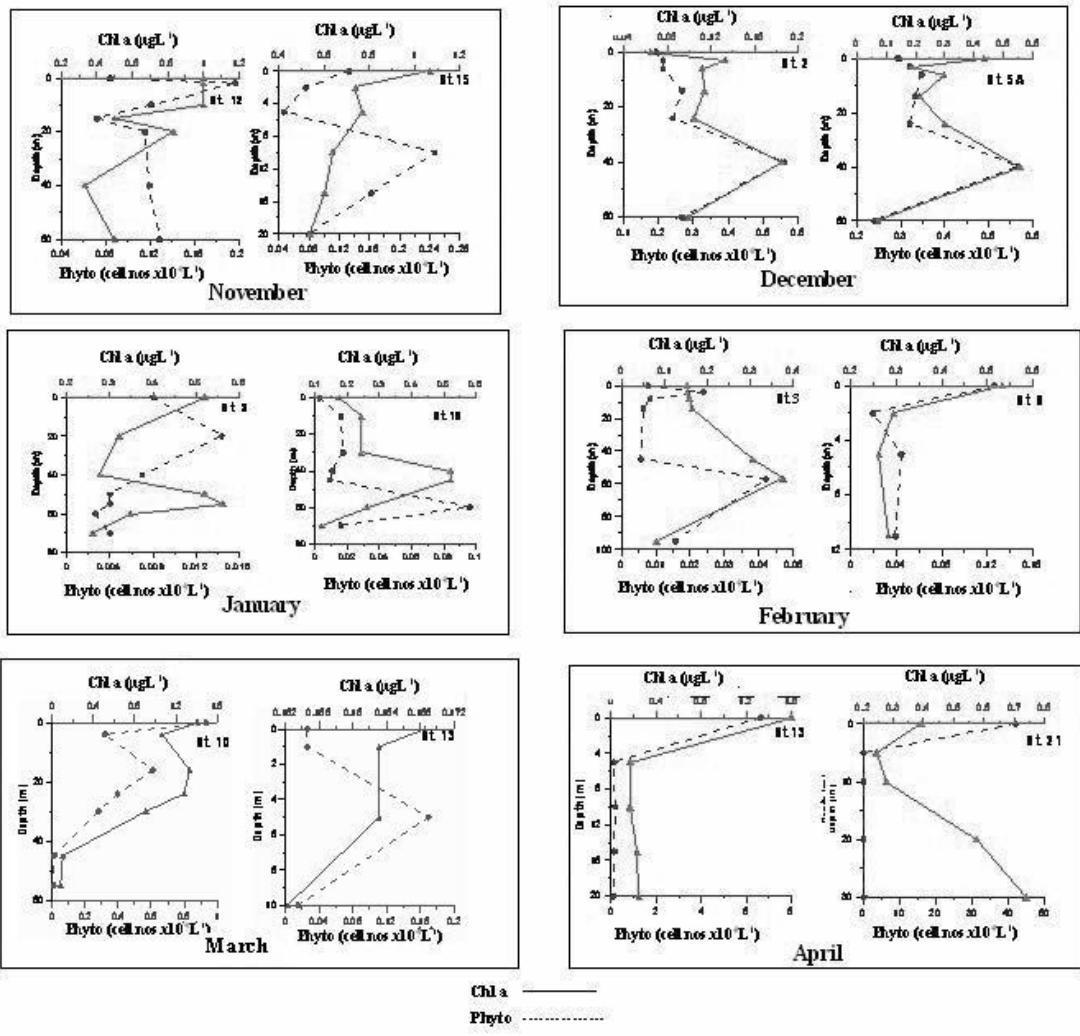


Fig. 2B Chlorophyll a (Chl a) and total phytoplankton (including *Trichodesmium*) in the Arabian Sea during various months

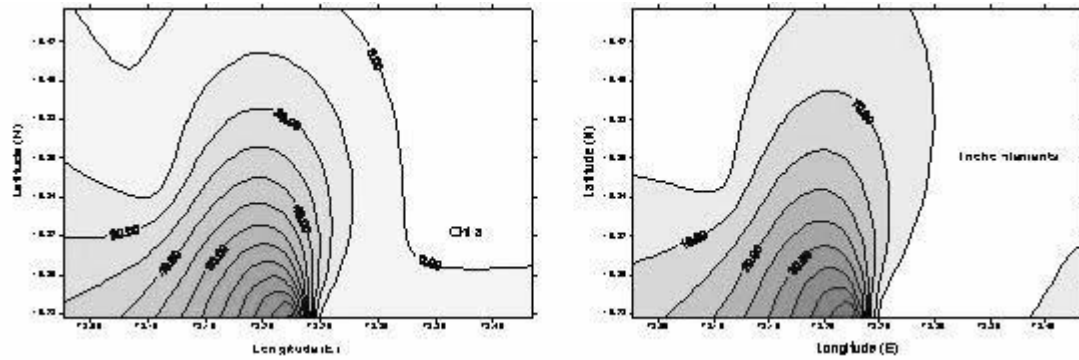


Fig. 3A Chl *a* (μgL^{-1}) and *Trichodesmium* filaments (nos. $\times 10^4\text{L}^{-1}$) in the coastal waters of Goa during March 2002

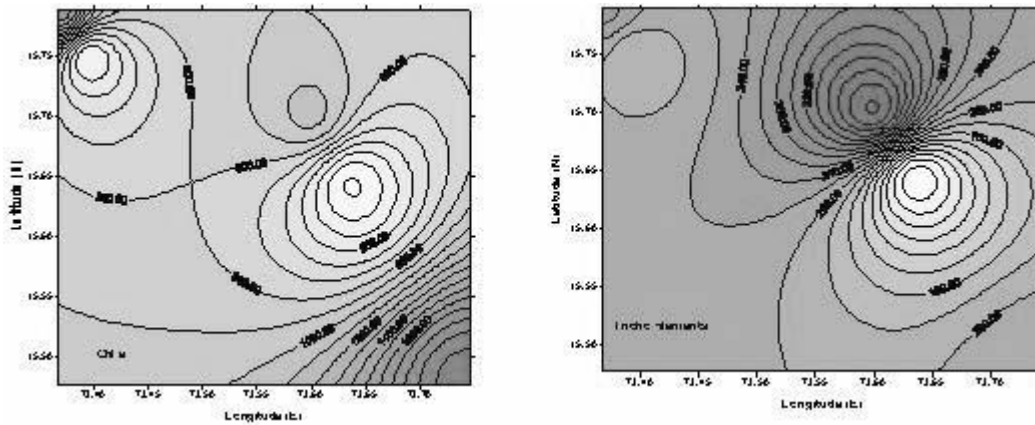


Fig. 3B Chl *a* (μgL^{-1}) and *Trichodesmium* filaments (nos. $\times 10^4\text{L}^{-1}$) in the coastal waters of Goa during May 2003

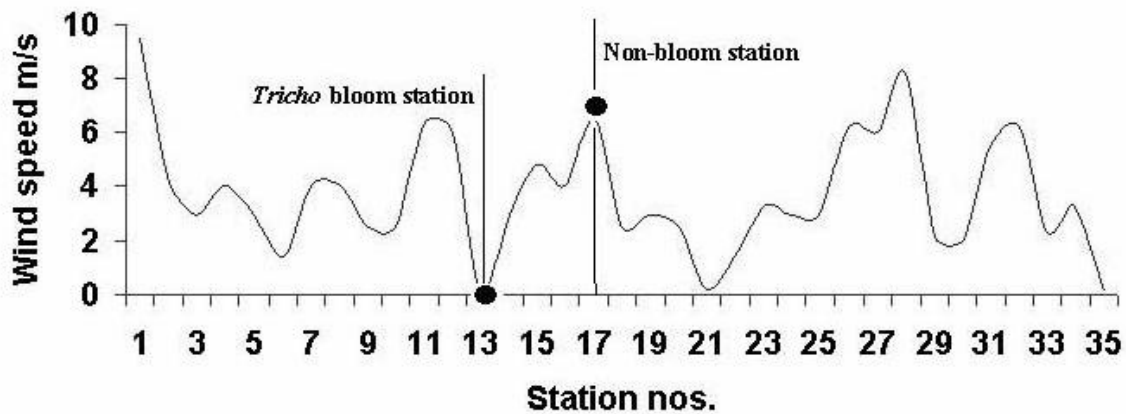


Fig. 4 Effect of wind on *Trichodesmium* bloom

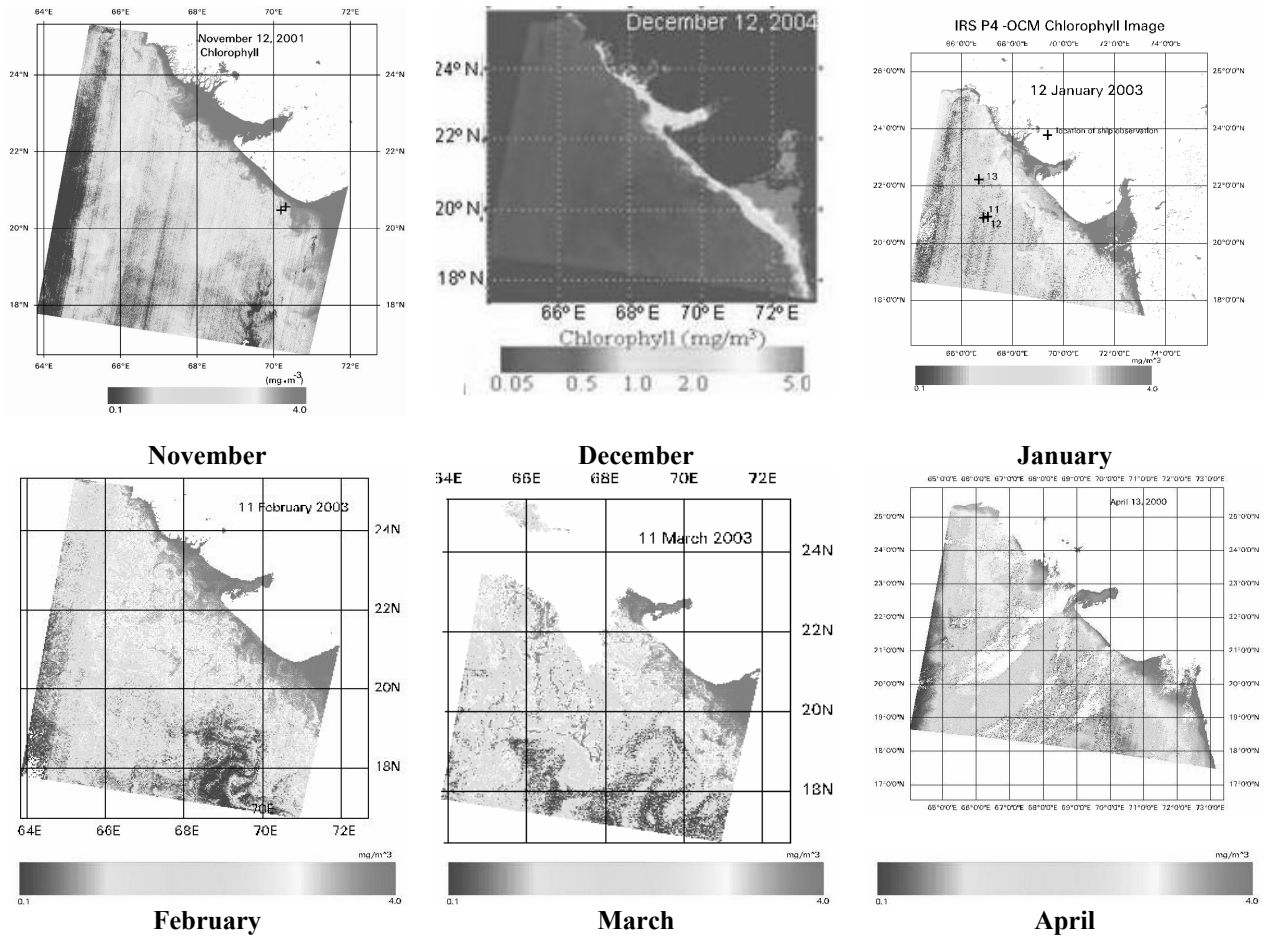


Fig. 5 Chlorophyll *a* from OCM in the Arabian Sea during different months