

Seasonality in sub-surface chlorophyll maxima in the Arabian Sea: Detection by IRS-P4/OCM and implication of it to primary productivity

S. G. Prabhu Matondkar*^a, Sushma Parab^a, R. M. Dwivedi^b

^aNational Institute of Oceanography, Goa, INDIA 403 004

^bSpace Application Centre, Ahmedabad, Gujarat, INDIA

ABSTRACT

Arabian Sea is highly influenced by monsoon systems like SW monsoon (June – September) and NE monsoon (December-February). This affects distribution pattern of phytoplankton, availability of nutrients and changing temperature specially during winter cooling period (February-March). These and other conditions like quality and quantity of light influence phytoplankton (type and concentration) in the Arabian Sea. In our study we have observed monsoon related peaks in phytoplankton and chlorophyll *a* in the Arabian Sea. These chlorophyll *a* (Chl *a*) concentrations detected by OCM sensor onboard IRS-P4 satellite is helping us to work out seasonality of phytoplankton in the Arabian Sea, which is of the great importance in the field of biology and biogeochemistry of this region. However, during these study subsurface chlorophyll *a* maxima (SCM) was observed as characteristics feature of chlorophyll *a* distribution in the Arabian Sea. The subsurface chlorophyll *a* maxima varies from 30m to 55m in the Arabian Sea during various seasons. During November at St. 1 surface chlorophyll *a* was 1.503 mgm⁻³ and subsurface chlorophyll maxima was 12.692 mgm⁻³. Similarly, at St. 13 surface chlorophyll *a* was 0.584 mgm⁻³ and surface chlorophyll maxima was 8.517 mgm⁻³. During upwelling, nutrients remained unused at sub surface due to shortage of light which may lead to subsurface blooms, detection of which is critical for precise estimation of chlorophyll *a* from ocean colour sensor. During our 5 year study (covering all the seasons) in northeastern (NE) Arabian Sea, we have observed more than 50 % stations were with subsurface chlorophyll *a* maxima where chlorophyll *a* was approximately 10 times higher compared to surface value. The high chlorophyll some time detected by OCM is mainly because of detection of subsurface chlorophyll maxima by the satellite but may not actually sampled during ship studies. The satellite penetration depth (ze), subsurface chlorophyll maxima depth, OCM derived chlorophyll *a* for different seasons in NE Arabian Sea is presented and discussed in this paper.

Keywords: Ocean colour monitor, Arabian Sea, primary productivity, blooms, chlorophyll maxima

1. INTRODUCTION

Sub-surface chlorophyll maxima (SCM) occur in a variety of environment from fresh water¹, brackish water², estuaries³, the coastal zone⁴, Shelf areas⁵ to open ocean⁶. There has been focus in recent years, on SCMs in general^{7,8} as well as their dynamics^{8,9}, and maintenance^{10,11}. Occurrence of SCMs has been explained as adaptation to low light levels¹², a decrease in phytoplankton cell settling velocity¹⁰, grazing⁸, or diapycnal nutrient fluxes¹¹, SCMs can also develop a intrusions of nutrient rich water into the photic zone¹³ or intrusion of phytoplankton-enriched waters, as with the toxic *Chrysochromolina polylepis*^{14,15} and the *Pseudo-nitzschia pseudodelicatissima*¹⁶. The importance of the SCMs as contributor to the primary production was recently demonstrated in the North Sea region¹³. The growth in the thermocline contribution to 20-30% of total primary production¹⁷. SCMs are by definition located below the sea surface and out of reach from satellites including the Sea-WiFs satellite¹⁸. These facts emphasize the importance of SCMs with respect to carbon production in the Arabian Sea and thereby studies of their bio-optical properties and the development of SCMs, where only few studies have focused on these properties. The present study is detailed multi-parameter description of SCM in the Arabian Sea.

*sgpm@nio.org; phone +91 (0832) 2450233; fax 91 (0832) 2450606.

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2. METHODOLOGY

Water samples were collected from water column from NE Arabian Sea covering coastal and offshore region from November to April months (Fig. 1). CTD was used for sampling as fluorescence profile to locate SCM in water column. PAR is recorded as the part of radiometric studies using SAT-Atlantic radiometer. water samples were assayed for Chl *a* and Primary productivity measurements.

2.1 Biological studies

2.1.1 Chl *a* by Fluorometer

Phytoplankton Chl *a* concentration was determined by filtering 1000 ml of seawater first through a 105 µm mesh to remove zooplankton and then through GF/F filter at low pressure. The same was then placed in 10 ml of 90 % acetone, sonicated and held in the dark in a freezer overnight. Chl *a* concentration was determined with a Turner designs 10-000R fluorometer¹⁹. The fluorometer was periodically calibrated with a spectrophotometer¹⁹.

2.1.2 Primary Productivity

Water samples were collected depending upon the euphotic zone that was established using a Secchi Disc. For total phytoplankton measurement, the volume of water samples was transferred in triplicates to 250 ml capacity Nalgene Polycarbonate bottles. One ampoule of ¹⁴C (5µci) was injected to each three light and one dark bottles. These bottles were then incubated for 12 hrs on deck using appropriate light cutoff screens. At the end of the incubation period, water sample (250 ml) was filtered through GF/F filter. All the filters exposed to fuming HCL for 20 minutes in a desiccator in order to dissolve left over bicarbonates. Samples were then placed in a 7 ml mini scintillation vial with scintillation cocktail and activity was determined with a Wallac Scintillation counter (model no. 1409). All counts were quench corrected¹⁹.

Temperature and Salinity data was used to locate thermocline and mixed layer depth in water column. Chlorophyll *a* is also estimated using OCM data. Further primary productivity is computed using Chl *a*, PAR, MLD and P-I parameters.

2.2 OCM data

2.2.1 Estimation of chlorophyll from Oceansat I / OCM

As a part of processing of OCM data to generate chlorophyll images water leaving radiances were retrieved through removal of atmospheric effects from the satellite radiance values in the first step²⁰. The atmospheric correction scheme makes use of long wavelengths for estimating aerosol optical thickness. Subsequently, bio-optical algorithm was applied to the corrected water leaving radiance data^{21,22}. OC-2 algorithm was used for generating chlorophyll images from OCM data²³.

2.2.2 Modeling mixed layer primary production from remote sensing data

Oceansat I / OCM data have been used to estimate mixed layer primary production using photosynthesis-light relationship in Arabian Sea. In the present work, non-spectral analytical model²³ was implemented in the Arabian Sea. The model assumes biomass independent of depth, attenuation coefficient independent of depth and a sinusoidal variation of surface irradiance. The computations used inputs like chlorophyll, diffuse attenuation coefficient, P-I (photosynthesis-light) parameter and day length. The mixed layer column production is given by an expression with depth and time integrals,

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

An analytical solution based on dimensional analysis was used for estimation of mixed layer primary production²⁴.

3. RESULTS AND DISCUSSION

One of the constant feature of Chl *a* profiles in the Arabian Sea (Fig. 2A and Fig. 2B) is subsurface SCM associated with a density discontinuity and low light. The SCM was first described as a global feature who showed that it might be

a continuous feature across ocean basins²⁵. During present study the productivity maxima and Chl *a* were noticed at 40-60m during various seasons. These features are found mainly related to temperature profile (Fig. 3). At station 1, high Chl *a* ~ 12mgm⁻³ was associated with bottom of the thermocline. At station 16 in absence of well developed thermocline prominent SCM was not recorded (Fig. 3). Seasonality of in-situ measurement is presented in Table 1 and productivity in Table 2. The high column primary productivity during December, January and April was not matching with low Chl *a* values estimated during same period. It was further noticed that Chl *a* by fluorometer is much higher than OCM retrieved Chl *a* (Fig. 4). This has happened mainly because of avoidance of SCM by satellite largely during December, January and April months (Table 3). The OCM derived Chl *a* during various months is depicted in Fig. 5A and primary productivity in Fig. 5B. The results extracted from these images were compared with in-situ primary productivity and presented in Table 4. The variable results were largely due to seasonality in deep Chl *a* maxima which is avoided by satellite and mismatch arise in productivity estimates.

4. CONCLUSIONS

SCM was the permanent feature of algal profiles in the Arabian Sea. SCM was shallow during March and deep during April months. Most of the time Chl *a* retrieval was lower than actual and hence primary productivity modelled was lower side considered to in-situ estimates.

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Table 1 Chlorophyll *a* at surface and column in the Arabian Sea during different months

Months	Surface Chl <i>a</i> (mgm ⁻³)			Column Chl <i>a</i> (mgm ⁻²)		
	Min	Max	Aver	Min	Max	Aver
Nov (n=13)	0.173	5.344	0.726	8.621	146.426	43.812
Dec (n=14)	0.190	0.510	0.340	18.39	27.24	22.140
Jan (n=25)	0.173	2.6	0.723	1.743	322.525	44.529
Feb (n=10)	0.132	0.960	0.344	3.292	49.383	17.366
March (n=13)	0.169	2.741	0.963	1.605	338.975	62.842
April (n=35)	0.074	5.905	0.665	3.337	64.126	14.001

Table 2 Primary productivity at surface and column in the Arabian Sea during different months

Months	Surface PP (mgCm ⁻³ d ⁻¹)			Column PP (mgCm ⁻² d ⁻¹)		
	Min	Max	Aver	Min	Max	Aver
Nov (n=13)	0.953	20.457	8.460	7.808	42.267	21.139
Dec (n=12)	55.85	706.66	314.68	1299	15442.57	7343.33
Jan (n=13)	0.907	2572.194	226.098	182.195	26906.72	3356.701
Feb (n=6)	1.724	12.528	5.406	93.168	389.543	219.096
March (n=10)	1.056	19.775	9.093	93.033	872.025	436.578
April (n=24)	5.441	3489.104	367.982	100.131	17414.98	2711.610

Table 3 Comparative account of avoidance of sub-surface chlorophyll maxima (SCM) by OCM imageries

Months	Stations detected by OCM (SCM)	Stations not detected by OCM (SCM)
Nov (n=23)	8	15
Dec (n=14)	2	12
Jan (n=19)	9	10
Feb (n=10)	4	6
March (n=13)	11	2
April (n=35)	3	32

Table 4 Comparison of the modelled primary productivity with in-situ primary productivity in the Arabian Sea

In-situ Primary productivity (mgCm ⁻² d ⁻¹)	Modelled (mgCm ⁻² d ⁻¹)
294.506	847.379
1068.38	906.491
2599.09	526.721
1435.67	571.646
993.89	515.348
893.432	682.598
355.625	965.18
901.178	842.315

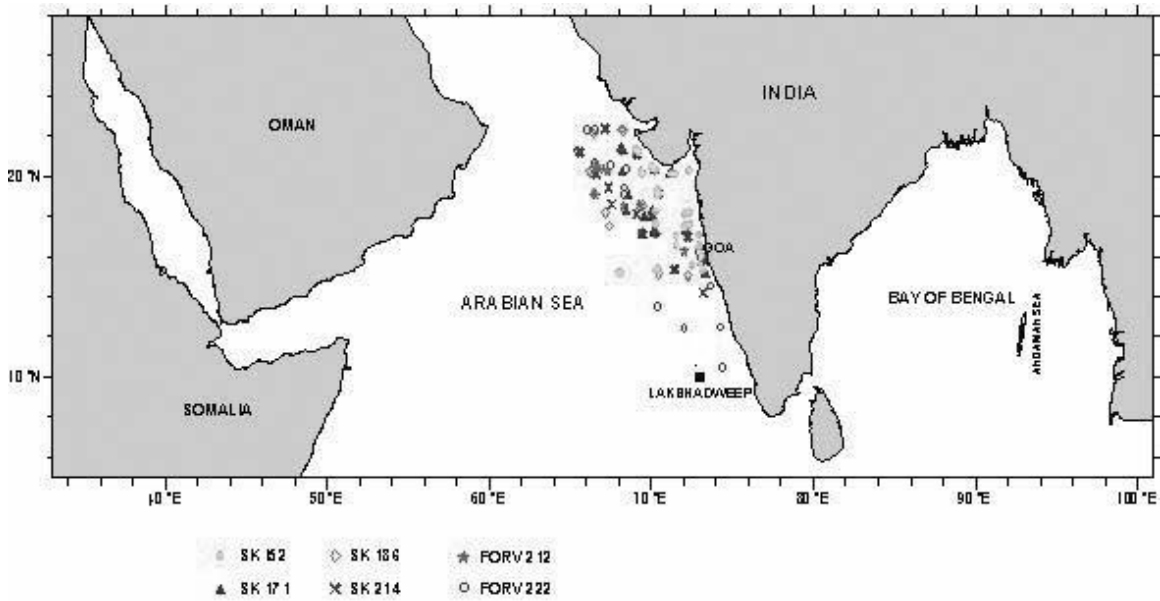


Fig. 1 Sampling stations in the Arabian Sea

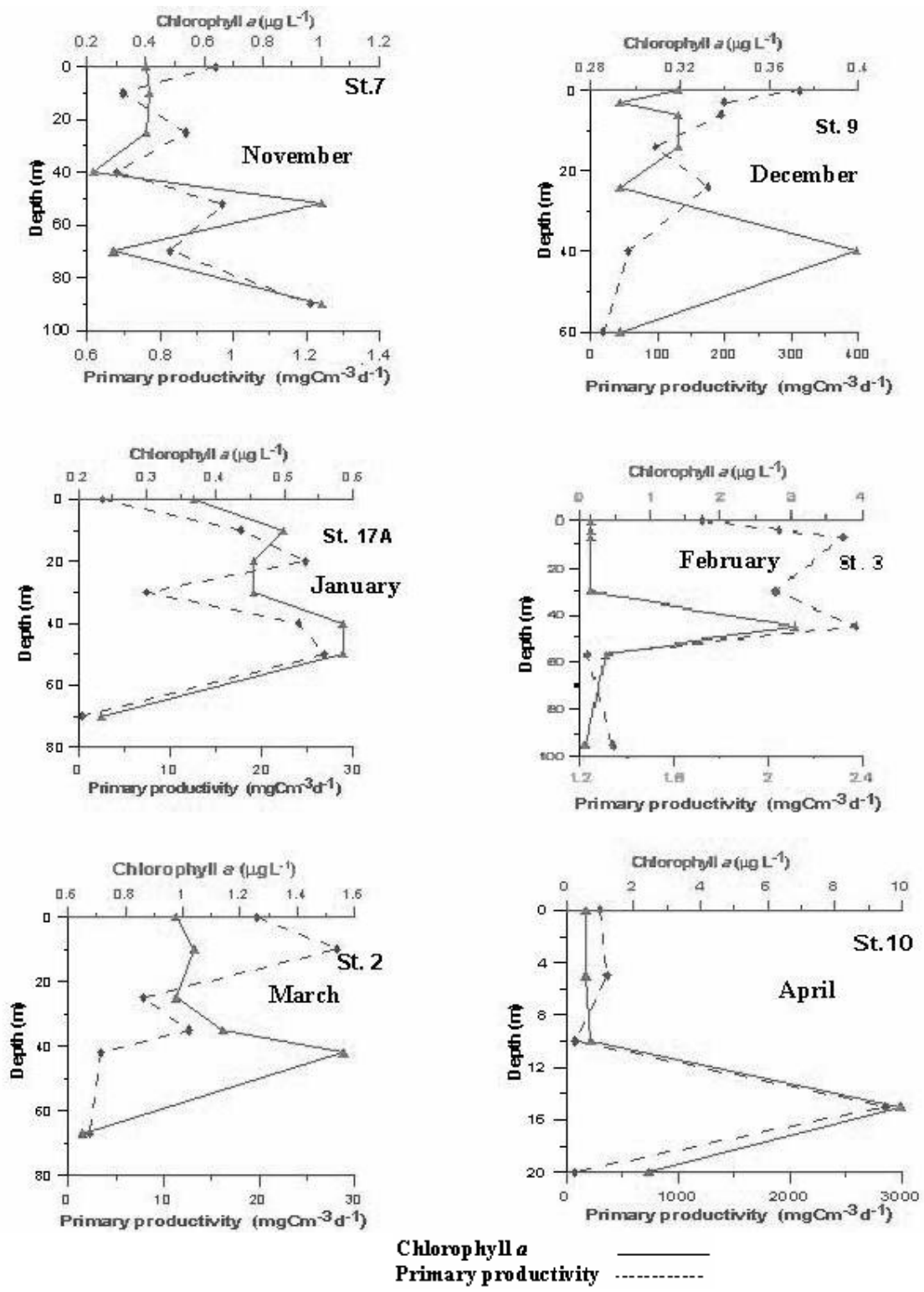


Fig. 2A SCM below satellite detection (peaks of primary productivity are noticed during November, January, February and April)

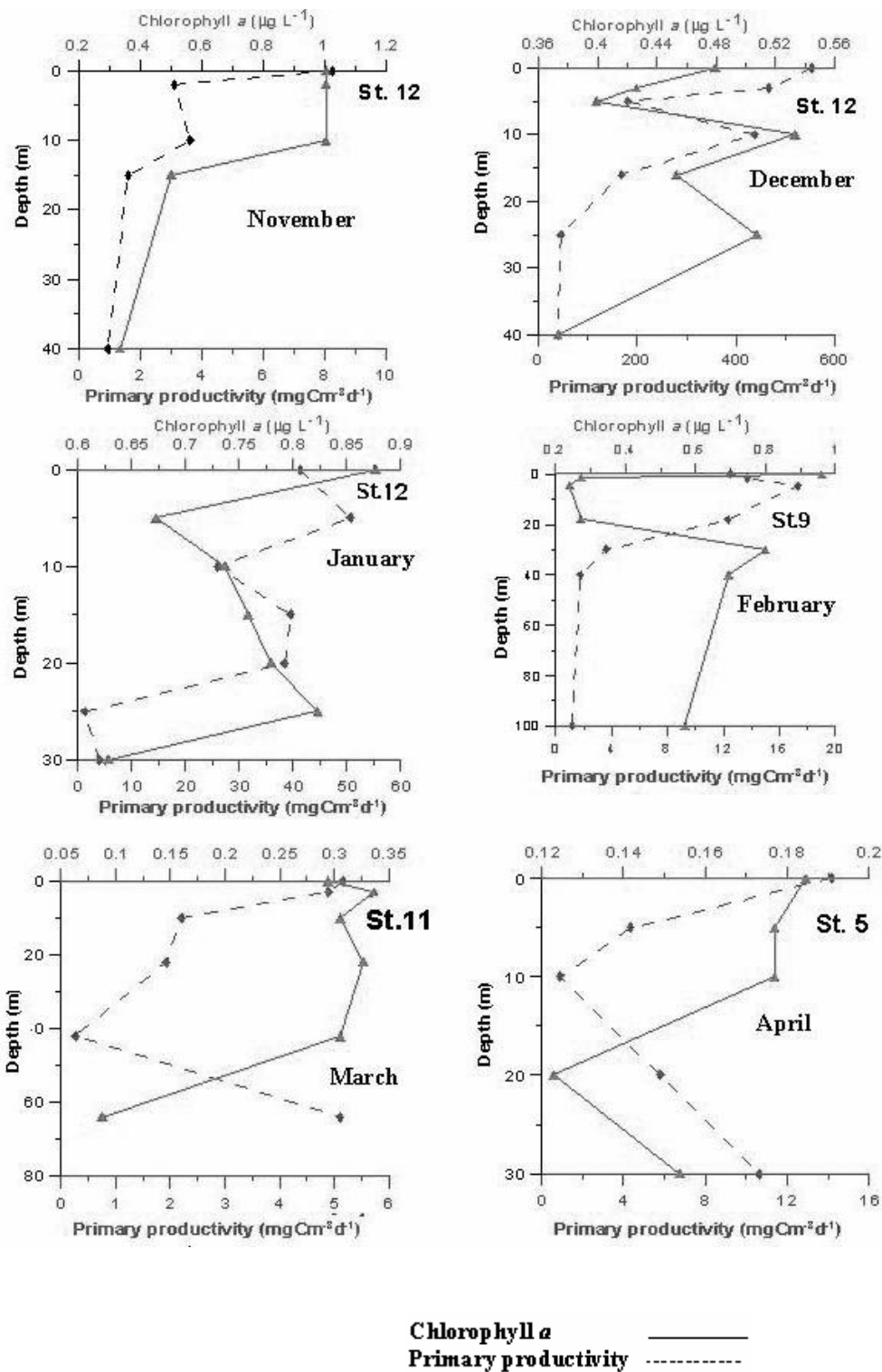


Fig. 2B SCM which could be detected by satellite (Primary productivity peaks are noticed during December and January)

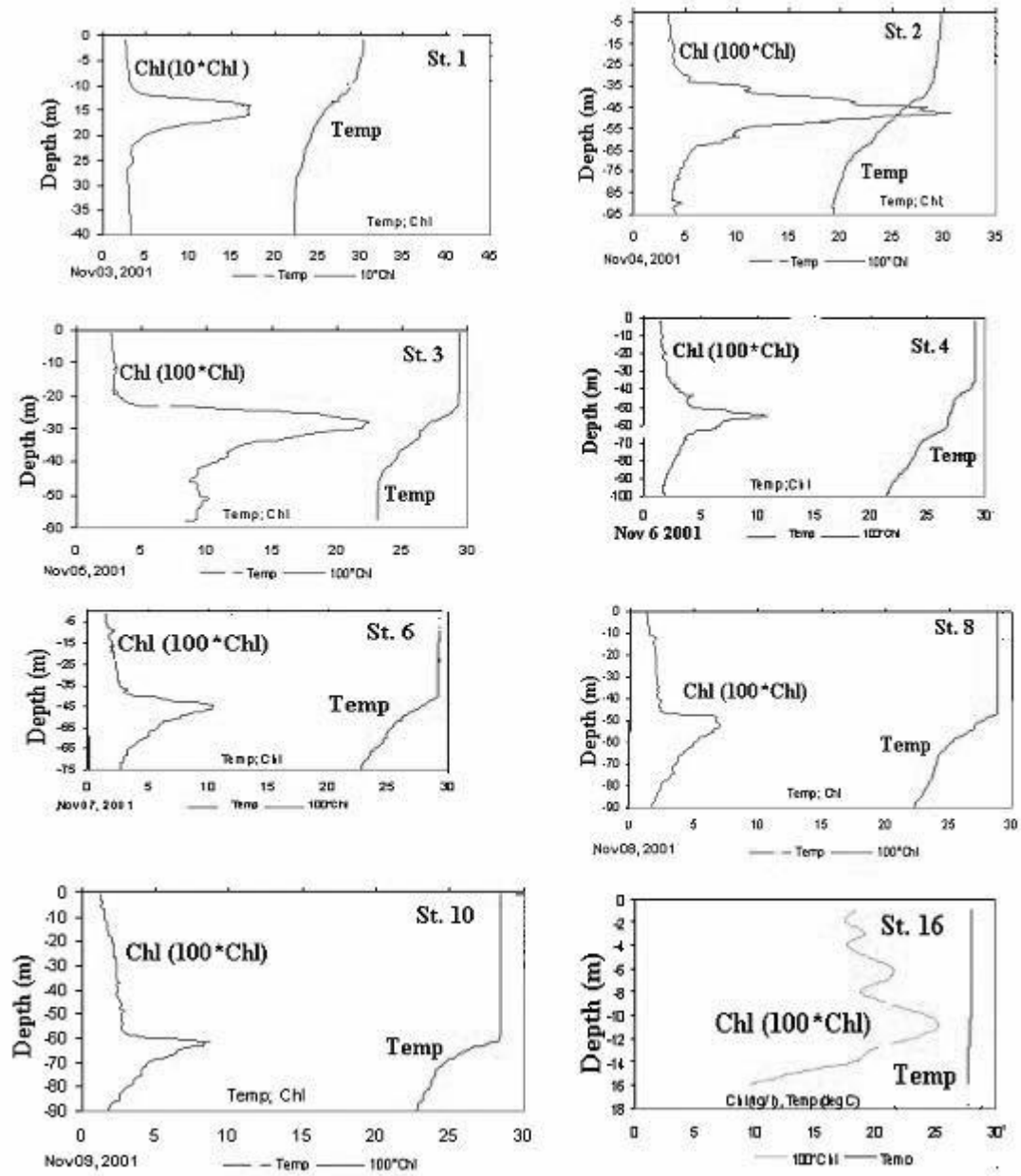


Fig. 3 Sub-surface Chl maxima and Temperature profiles during November 2001 in the Arabian Sea

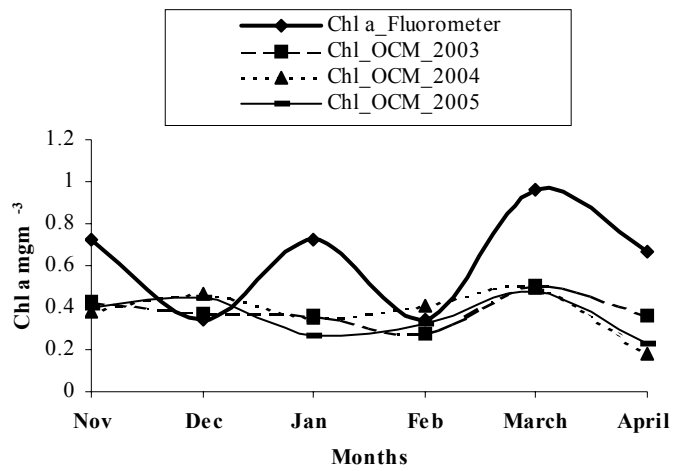


Fig.4 Chlorophyll *a* by fluorometer and OCM during different months and year

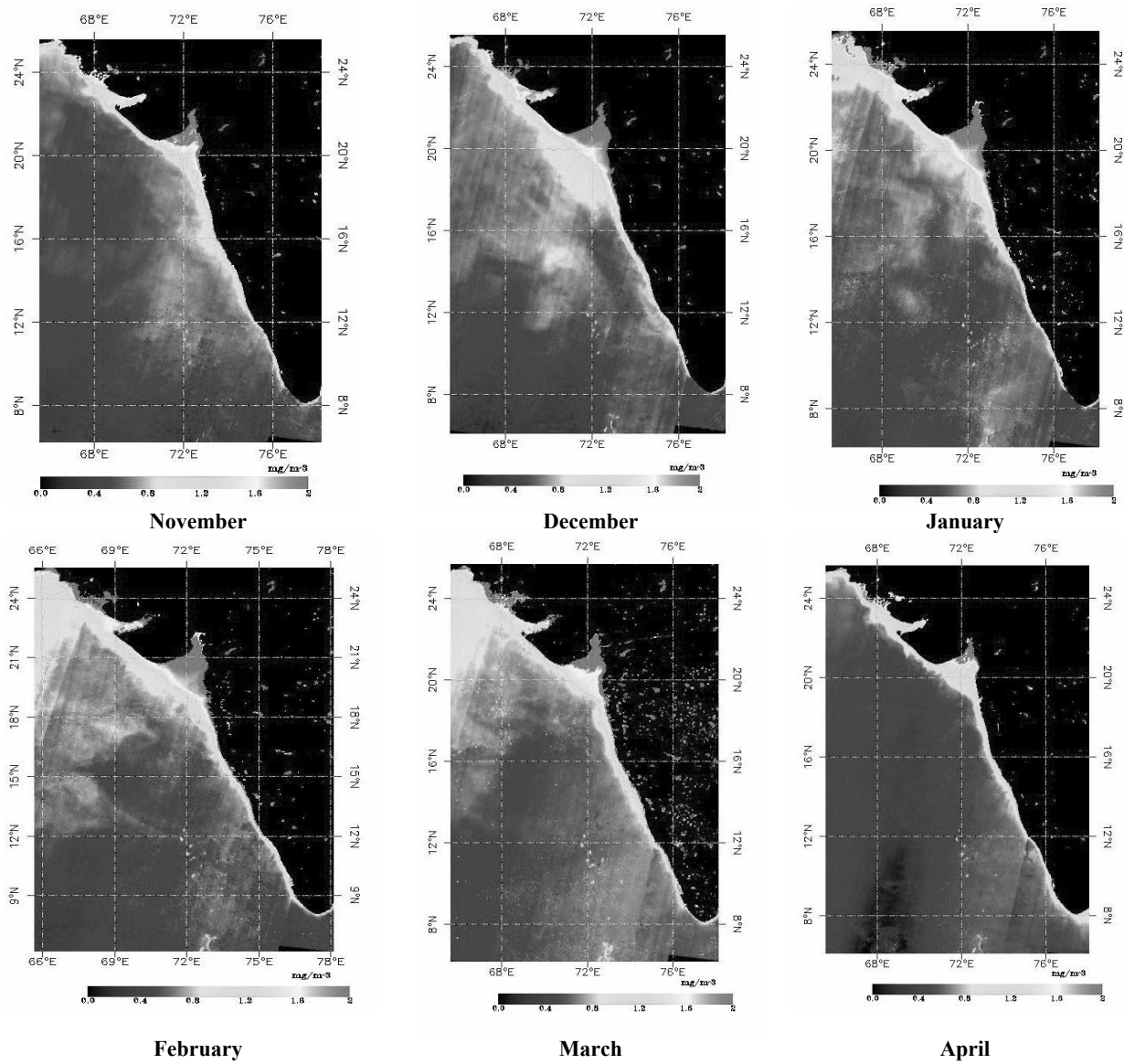


Fig 5A OCM derived Chlorophyll *a* in the Arabian Sea during different months

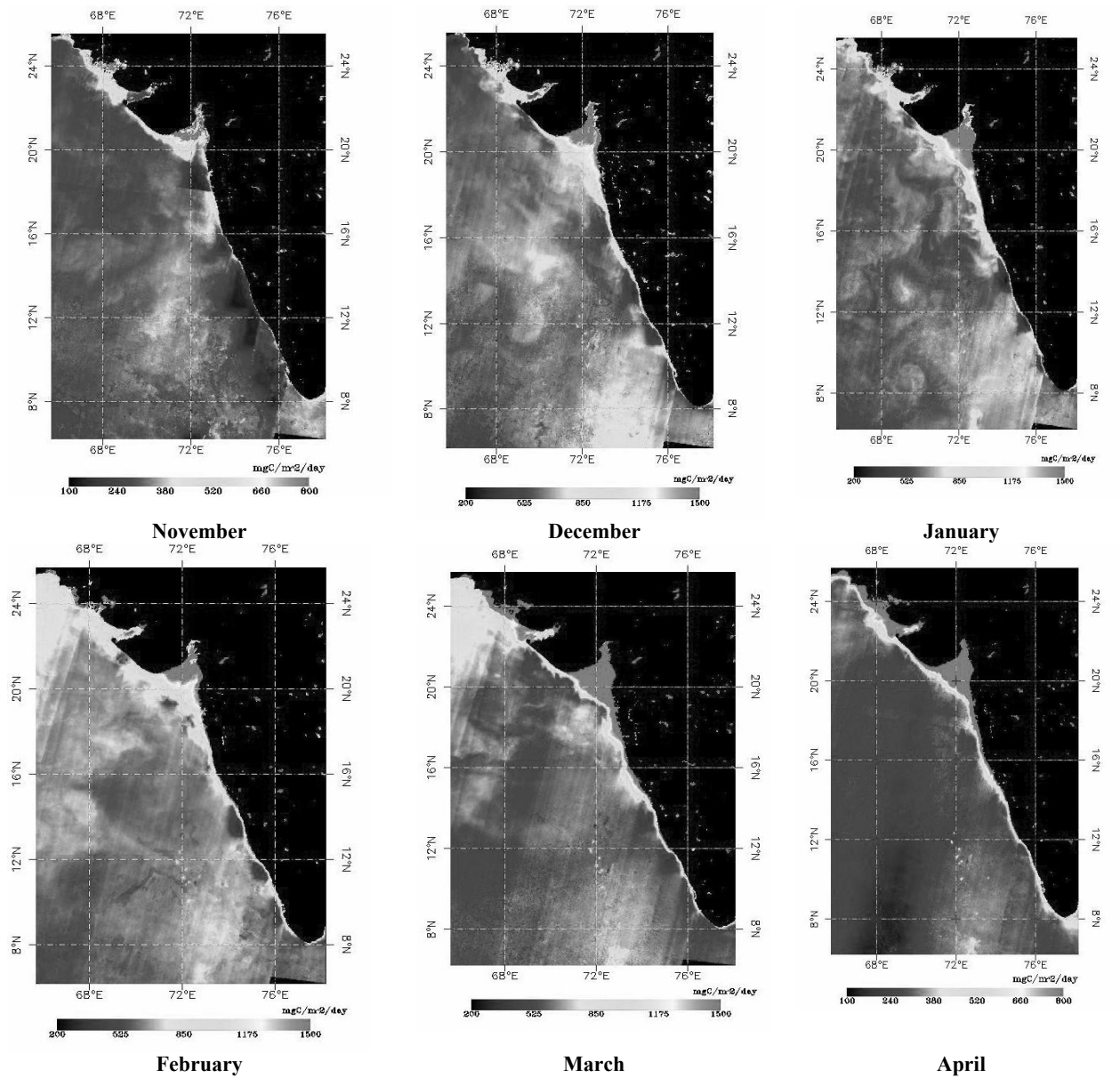


Fig 5B OCM derived Primary productivity in the Arabian Sea during different months