

Remote sensing applications in oceanography with special reference to bio-physical coupling: A review

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A review of the work carried out by us so far in this field has been presented. The spatial and temporal distribution of phytoplankton pigment (with optimized and non optimized sensors) in relation to physical oceanographic parameters (satellite and climatological data) has been discussed and the need for region and season specific relationship between different parameters has been emphasized, which can provide input for bio-physical coupled models. This will lead to understanding and quantifying the processes that contribute to the spatial and temporal development of nutrient and plankton distributions. It is concluded that various oceanographic processes and their application can be studied using remote sensing techniques like algal bloom dynamics, use of sea surface temperature (SST) in forecasting fishery potential areas besides interrelationship between temperature profile, wind and mixed layer depth towards developing biophysical models which are region and season specific.

The physical dynamics of the ocean depends upon the local field of biological and chemical properties. Nutrient limitation interacting with changes in light intensity and temperature can lead to seasonality in primary and secondary production. Therefore, the processes that lead to nutrient enrichment play a key role in seasonality particularly in tropical regions. Recent concern about increased levels of atmospheric carbon dioxide and global warming have led to studies of the ocean's role in the Global Carbon Budget, Joint Global Ocean Flux Study (JGOFS) is one such example. Besides there has been increased interest in interannual and interdecadal oceanic variability. The Coastal Zone Colour Scanner (CZCS onboard Nimbus-7) data set for the first time, provided an opportunity to view the global distribution, in space and time of phytoplankton concentration in the upper ocean layer. If the long-term change in phytoplankton standing crop is significant, it is not known as to whether this change is a consequence of local or remote forcing, and if so what variables than controlling phytoplankton pigment concentration are being affected. The extent to predict production from pigment distribution

depends on connection between physics and biology. The ocean physics determines the global geographic pattern of primary production because of dominant role of climate. The Arabian Sea in particular is subjected to a very strong seasonally reversing atmospheric forcing. The circulation undergoes a unique semiannual reversal due to forcing by seasonally reversing winds. The reversal in winds induces a seasonal variation in the underlying oceanic currents and the characteristic of the mixed layer. The seasonal variation in mixed layer dynamics and upwelling is also an important determinant of annual cycle of primary productivity in the Arabian Sea¹. Entrainment of waters from the thermocline and upwelling are both sources of nutrient for photic zone. Investigations of the impact of long term changes in meteorological forcing on ocean physics and biology can be pursued using coupled models of physical and biological processes. It is likely that an important contribution to the biological and physical environment is random variability in the inputs to the system.

At present the CZCS data is the only source for remote-sensing observations to study the phytoplankton pigment distribution (optimized marine applications sensor) in space and time till the

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launch of SeaWiFS on 1 August 1997. CZCS sensor was launched in 1978 and remained operational till 1986. Besides Landsat Multi Spectral Scanner (MSS) that was originally meant for land applications could detect very high concentration of phytoplankton pigment i.e. bloom conditions^{2,3}. Largely, the data from CZCS on board Nimbus-7 has been used for estimating phytoplankton pigment. In recent years Landsat Thematic Mapper (TM) data has also been used to determine chlorophyll concentration^{4,5}. Similarly the Indian Remote Sensing Satellite (IRS) is meant for land applications but due to the presence of spectral band in the blue region the detection of pigment concentration above 1.0 mg/m³ and seasonal analysis for a part of Gujarat coast could be achieved^{6,7}. The details of these sensors are given in Table 1. A relationship between fish resource and presence of pigment concentration along with thermal features was also attempted.

Besides understanding the interaction between biological and physical oceanographic parameters the processes leading to enhanced production viz. internal wave phenomenon could also be studied. The characterization of initiation and/or maturation

phase of internal waves in the Andaman Sea using IRS LISS I data is one such example⁸. Distributional pattern of phytoplankton pigment/temperature for NW coast of India, off Bombay and further south has been studied using CZCS data⁹. The relationship between phytoplankton pigment and physical oceanographic parameters (temperature profile, mixed layer depth, wind speed etc.) were studied using processed CZCS data (DAAC,NASA) and climatological data respectively to evaluate and define the requirement of biophysical coupled models^{10,11}.

The studies performed were towards mapping very high concentration of chlorophyll *a* localized phenomenon, seasonal change of chlorophyll at the north west coast of India, relationship of thermal features with fish catch and chlorophyll. Besides interrelationships of biological along with physical oceanographic parameters have been presented in brief, which will be an input for developing biophysical coupled models.

Data and Discussion

The following is the theme wise details of the

Table 1—ZCS, TM and IRS LISS I performance parameters relevant to water sensing

Parameters	CZCS	TM	IRS LISS I
Spectral bands (in nm/ μ m)	433-453 (443)	452-518 (485)	0.45-0.52 (0.485)
	510-530 (520)	529-611 (570)	0.52-0.59 (0.555)
	540-560 (550)	627-693 (660)	0.62-0.68 (0.650)
	660-680 (670)	774-902 (838)	0.77-0.86 (0.815)
Band width (in nm)	20	66	70
	20	82	70
	20	67	60
	20	128	90
Signal to noise ratio	200	50-140	128
	150	60-280	
	150	50-250	
	100	35-342	
Reflective band gain counts	22-47	15.55	
	32-67	7.85	
	40-85	10.20	
	88-187	10.82	
Resolution (meters)	800	30	72.5
Swath (km)	1625	188	148
Radiometric resolution (bits)	8	8	7

techniques developed or studies undertaken in the field of biological oceanography including attempts at defining the requirement of biophysical coupled models. The themes are: (a) algal bloom mapping, (b) phytoplankton pigment mapping, (c) seasonal pattern of phytoplankton pigment, (d) monitoring thermal features, phytoplankton pigment and fish resource relationship, (e) characterization of internal waves in the Andaman Sea, (f) distributional pattern of phytoplankton pigment/temperature, (g) region specific evaluation of interrelationship between biological and physical oceanographic parameters as an input for bio-physical coupled modelling. This experience is confined to the Arabian Sea and Bay of Bengal of the Indian Ocean.

(a) Algal bloom mapping

The algal bloom due to *Trichodesmium erythraeum* (a blue green algae) has been reported every year from February to May in the nearshore waters off Goa and remains mainly confined to the surface¹². Satellite images from US satellite Landsat were used for the bloom period during the year 1975 to develop technique for its mapping. A comparative study was performed between the non bloom images and those falling at the reported start and peak period of algal bloom. Landsat scenes of March 1 and 19 for the year 1975 covering coastal waters off Goa and approximately corresponding to reported start and peak bloom period were used. An image of December 2, 1972 for the study area was used to assess the situation during non bloom period. The study area lies between latitude 15° 15' to 15° 35' N and longitude 73° 40' to 73° 55' E. A comparative study of MSS band 4 and 5 as diapositives could lead to map the area under algal bloom along with the suspended sediments. The comparative evaluation of images is as follows:

(i) Normal FCC: This was prepared using spectral bands 4, 5 and 6 which showed areal extent of suspended sediments but, however, did not yield the desired details on bloom.

(ii) Enhanced FCC: Bands 4, 5 and 6 were linear stretched and FCC generated showed a better contrast in the distribution of clear water, suspended sediments and algal bloom. However, it was difficult to distinguish between area under algal bloom and suspended sediments.

(iii) Enhanced FCC with a ratio: A ratio of band 4/5 could further improve upon the contrast of areas under suspended sediments. An enhanced FCC using a combination of band 4 (red), 6 (green) and ratio of 4/5 (blue) was found most useful in distinguishing area under algal bloom and suspended sediments. The bloom was approximately confined to 10 m depth on March 1 and up to 20m depth on March 19 which closely matches the reported nature and occurrence of bloom by Devassy *et al.*¹² i.e. started on February 27 and reaching a peak around March 10 during the year 1975. The chlorophyll concentration is reported to be of the order of 600 mg/m³ during the peak bloom conditions. The occurrence of algal bloom has a significant contribution in acting as carbon dioxide sink. In addition it plays an important role in the enrichment of water by fixing atmospheric nitrogen. The role played by the sudden appearance of bloom is significant from the point of view of biological productivity, carbon dioxide flux (acting as sink) and nutrient enrichment (nitrogen fixation). The mapping and monitoring can be done on a regular basis with the help of satellite data.

(b) Phytoplankton pigment mapping

The variability in phytoplankton abundance is due to geographic variations (e.g. rich in coastal, upwelling and reef regions due to availability of high nutrient concentration) and that it shows a temporal variability. Nutrient enrichment is one of the factor responsible for high plankton concentration besides other oceanographic parameters. The likely processes responsible for nutrient enrichment are land run off, and other wind forced circulation pattern viz. coastal upwelling.

Indian Remote Sensing Satellite (IRS) LISS I data (4 spectral bands viz. 0.45-0.52, 0.52-0.59, 0.61-0.68, 0.77-0.86 μ m; spatial resolution 72.5 m) has been used to generate phytoplankton pigment map⁶. A bio-optical algorithm developed for coastal waters of the western coast of India was used⁵. Density sliced colour -coded hard copy was generated using an in-house developed image processing system ISROVISION. In general a range between 1.0 to 1.5 mg/m³ was obtained throughout the year. Due to broad spectral bands

lower concentration of pigment that is $< 1 \text{ mg/m}^3$ could not be detected.

The signal received at the satellite sensor particularly from clear oceanic water is less than 10% in blue, green, and red wavelengths and almost negligible in near infrared wavelength. The rest of the signal is due to contribution resulting from the absorption and scattering by various atmospheric constituents. An atmospheric correction model-ATMRAD of radiation transfer in the earth's hazy atmosphere based on simplistic solution of radiation transfer equation and tropical model atmosphere was used¹³ to estimate the path radiance in selected spectral bands of IRS 1A LISS I data for the retrieval of phytoplankton pigment. For the given solar coordinates of the scenes analyzed, the ATMRAD model calculations⁷ were carried out for visibility ranges from 25 km to 10 km. Radiance in band 4 (near infrared band) was used to fix the visibility by assuming that the path radiance in band 4 is nearly equal to the clear water radiance. Parameters derived from ATMRAD model calculations⁷ are given in the Table 2.

A bio-optical algorithm developed for the waters off the west coast of India using seasonal data on chlorophyll concentration and synchronous radiance measurement in TM band 1 and band 2 was used to generate the chlorophyll map⁵. It was assumed that the TM derived coefficients will not seriously affect the pigment retrieval from IRS LISS I which has slightly different spectral response and bandwidths. The equation used is as follows,

$$C = 1.62 \left(\frac{L_{485}}{L_{589}} \right)^{-0.63}$$

where C, is the phytoplankton pigment (chlorophyll-*a* + phaeophytin) in mg/m^3 and L is

the water leaving radiance. Density sliced and colour-coded pigment maps in steps of 0.10 mg/m^3 were generated.

The CZCS data¹⁴ could retrieve a chlorophyll concentration from 0.2 to 2 mg/m^3 while Landsat TM could provide 0.5 to 2.0 mg/m^3 range^{4,5}. The IRS LISS I data⁶ could give only a range of 1.0 to 1.5 mg/m^3 .

(c) Seasonal pattern of phytoplankton pigment

An attempt has been made to study the temporal variations in phytoplankton pigment concentration for a part of the NW. coast of India. It was observed that there is no significant difference in the range (1.0 to 1.5 mg/m^3) of the phytoplankton pigment map (= chlorophyll map) generated from atmospherically corrected or uncorrected IRS LISS I data⁷. This may be due to broad spectral bands and low radiometric resolution. Therefore, the chlorophyll maps (C-maps) for rest of the scenes were generated without applying atmospheric correction i.e. the radiance in band 1 (blue) and band 2 (green) were directly substituted in the bio-optical algorithm as discussed earlier. Multitemporal data was used to study the seasonal variability for which, a number of scenes were mosaiced and registered using the ground control points (GCP's). The pigment map was finally registered digitally with reference image by image-to-image registration while using the common GCP's.

The chlorophyll concentration range was observed from 1.05 to 1.45 mg/m^3 throughout the year. In the month of October and November the range is from 1.15 to 1.45 mg/m^3 while in the month of March the concentration is relatively higher i.e. 1.25 to 1.45 mg/m^3 . April shows a pattern similar to that of March with slightly lower concentration in offshore waters. The month of

Table 2—Details of the model (ATMRAD) calculations for IRS LISS I scene (January 1990): (Solar Zenith angle: 50° and Visibility range: 18 km)

Spectral band (C in μm)	Path radiance ($\text{mW/cm}^2/\text{sr}/\mu\text{m}$)	Spectral transmittance	Solar irradiance ($\text{mW/cm}^2/\text{sr}/\mu\text{m}$)	Total optical depth
1. (0.49)	2.01	0.758	0.138	0.259
2. (0.55)	1.62	0.809	0.138	0.217
3. (0.65)	0.96	0.852	0.117	0.116
4. (0.82)	0.04	0.691	0.616	0.424

January shows a range of 1.05 to 1.45 mg/m³. It appears that the concentration declines during winter (January) and increases with approaching summer (March). In general it has been shown that the chlorophyll concentration varies between 0.6 to 1.61 mg/m³ in this region¹⁵. Similarly Radhakrishna *et al.*¹⁶ observed the values from almost nil to 1.5 mg/m³. This indicates that higher concentration of chlorophyll (>1 mg/m³) can be successfully retrieved from non-optimized sensor like IRS LISS I data.

(d) Monitoring thermal-features, phytoplankton pigment and fish resources

In the early 1989 attempts have been made for the first time in the country to map the thermal features from NOAA AVHRR to locate the fishing grounds for west coast of India by Narain *et al.*^{17,18}. The information on potential fishing zones (PFZ) generated in the form of direction, distance from the fishing harbour and compass bearing of the ground with respect to the light house was communicated through FAX and the telecasts were made through TV network. An attempt has been made to compare the ocean colour from Indian Remote Sensing Satellite's (IRS) linear Imaging Self Scanning Sensor (LISS I) data (with four bands similar to first four of Landsat TM) with the sea surface temperature (SST) from NOAA AVHRR and near synchronous data on fish catch in waters off Gujarat on the west coast of India^{6,7}. The near synchronous ocean colour and SST showed a high fish catch in waters with large temperature gradient (2°C) and moderately high phytoplankton pigment concentration (1.25-1.35 mg/m³).

(e) Characterization of internal waves in the Andaman Sea

Internal waves are known to be present in Indian seas and its characterization using SIR-A data has been studied in the Andaman Sea¹⁹. Internal waves are reported to enrich the water²⁰. In the Bay of Biscay²¹ where level of nitrate is considered to be a major factor regulating the standing stock of phytoplankton the nutrient mixing takes place by large soliton like internal waves. Two IRS LISS I scenes of 31 August, 1989

and 2 May, 1992 covering parts of the Andaman Sea have been used to generate phytoplankton pigment map representing the initiation and maturation phases respectively¹¹.

The chlorophyll map of 2 May, 1992 shows distinct internal wave signatures. A high phytoplankton pigment concentration was observed along the crests. A distinct signature of the internal wave was seen in the optical region (Band 1 of IRS LISS I). However, the chlorophyll map of 31 August, 1989 did not show any distinct variability in the pigment concentration. This apparently means that this image represents the initiation phase, i.e., triggering of nutrient cycling and 2 May, 1992 image is of the maturation phase. It is known that there is a time lapse in phytoplankton growth from the time the nutrients become available. Thus it appears that the presence of phytoplankton pigment modulates the spectral behavior of the internal wave signatures which can readily be observed by satellite data in the optical region.

(f) Distributional pattern of phytoplankton pigment/temperature

The spatial and temporal distribution pattern of phytoplankton pigment depends on several physical oceanographic parameters viz. temperature, wind, current, mixed layer depth, etc. which affect nutrient availability and direction of transport. Based on biomass/temperature relationship the water masses can be classified into mixed/stratified/frontal waters²². A single date CZCS image of north west coast of India covering the area off Bombay and further south for March showed distinct patterns of pigment distribution. The single channel thermal data, when density sliced, show close similarity of features as that seen on the pigment image particularly in the offshore waters.

The mean monthly pigment map derived from CZCS data showed seasonal change both qualitative as well as quantitative. The climatological temperature data shows variation with season and different patterns at different depths. However, when compared with the pigment distribution pattern the temperature contour at 50 m depth closely matches the pigment

concentration contours of 0.2 mg/m^3 and 0.6 mg/m^3 particularly during March, September and October. The contour of 0.2 mg/m^3 and 0.6 mg/m^3 correlate with the temperature contours of 26°C and 24°C respectively. However, for other months no specific correlation is seen. It is observed that during these months which represent transition phase between northeast (March) and southwest (September, October) monsoon, the MLD tends to be shallower. In the Arabian Sea the pigment distribution reflects the introduction of nutrients into the photic zone. The maximum annual pigment biomass in the Arabian Sea occurs when the mixed layer is relatively shallow²³. Therefore, at the time of sufficiently shallow MLD and less turbulent conditions, the pigment and temperature pattern show covariation. For any modelling activity such an understanding is crucial when interrelationship of physical and biological oceanographic parameters are involved. This provides a useful input for modelling the coupling between these parameters.

The satellite derived ocean colour information pertains to the value at one attenuation length, which may vary from less than 1 meter in high turbid (pigment rich) area to 25-30 m in low pigment ($<0.1 \text{ mg/m}^3$) area²⁴. The climatological atlas²⁵ shows temperature distribution at sea surface and at various depths viz. 50 m, 100 m, etc. The phytoplankton pigment map derived from CZCS data is compared with satellite derived SST map of the same day/same season. Apart from this the CZCS derived phytoplankton pigment maps for each month generated from using all cloud free data from 1979 to 1986 have been used. This data was acquired from DAAC, NASA, USA. These monthly phytoplankton pigment maps were compared with the climatological temperature for each month/season.

Data: CZCS (chlorophyll image), NOAA, AVHRR (sea surface temperature), and subsurface temperature (climatological atlas)

Study area: Northwestern Arabian Sea ($50^\circ\text{-}80^\circ\text{E}$ and $05^\circ\text{-}25^\circ\text{N}$).

An inverse relationship between pigment concentration and temperature may be due to the negative correlation between temperature and nutrient²⁶ which ultimately affects phytoplankton growth. Since the satellite derived information

comes from one attenuation length rather than skin depth, the pigment concentration correlates better with temperature pattern at 50 m depth rather than at the surface.

During the months which represent transition phase between northeast and southwest monsoon i.e. March, September and October comparison of monthly analysed chlorophyll vs climatological temperature, a close correlation is seen between the pigment and temperature at 50 m depth. The physical forcing is the primary factor influencing the spatial pattern of mixed layer depth and pigment biomass during the monsoon seasons in the Arabian Sea²⁷.

In order to develop any model for bio-physical coupling, the study of relationship of parameters at temporal and spatial basis is a pre-requisite. New production is defined as the production of phytoplankton resulting from nitrogen supplied from outside the euphotic zone whereas regenerated production is that production associated with nitrogen regenerated within the euphotic zone. Synoptic mapping of new production is an important requirement of global biogeochemical studies. Oceanic production can be estimated from remotely sensed data on ocean colour and temperature²². The present study shows the variation in relationship when a single parameter is considered on monthly basis. Therefore, more related parameters have to be considered and spatial variation have also to be observed before making any conclusive statement. But one point comes out very clearly that the satellite derived pigment concentration cannot be directly compared with the satellite derived sea surface temperature unless one is sure as to how the temperature is distributed at different depths.

Muller-Karger *et al.*²⁸ used CZCS derived pigment maps and AVHRR derived SST maps of the Gulf of Mexico region on monthly basis and found that the algal biomass is not directly related to the temperature of the water. This may be true if only skin depth temperature is considered.

(g) *Region specific evaluation of interrelationship between biological and physical oceanographic parameters as input for biophysical coupled modelling*

At few locations reasonably good correlation

was observed between phytoplankton pigment and subsurface temperature ($r^2 = 0.56, 0.72$) in the nearshore waters while no significant correlation was observed with surface temperature (Fig. 1A, B).

The spatial and temporal characteristics of the depth distribution of temperature and plant nutrients combine to yield latitudinal specific relationship in plant nutrients vs temperature. The presence of phytoplankton is also known to affect the sea surface temperature by interception of short-wavelength radiation and thereby rise in the SST values²⁹.

Mixed layer depth (MLD) and wind speed showed a positive correlation [$r^2 = 0.63$ ($Y = 25.69 + 8.39X - 0.35X^2$)] in the offshore waters at one of

the location (Fig.1C). The sub-surface temperature and wind speed gave a good correlation [$r^2 = 0.60$ ($Y = 23.46 + 0.68X - 0.16X^2 + 0.01X^3$)] at one of the location in the nearshore waters (Fig.1D). Locational differences in the relationship between different parameters are obvious. It appears that besides season, location plays an important role in determining the relationship between various parameters. The maximum pigment biomass is seen when MLD is shallow²³. The physical forcing is the primary factor influencing the spatial pattern of mixed layer depth and pigment biomass during the monsoon seasons in the Arabian Sea²⁷. The phytoplankton pigment and temperature do not covary across the season. Surface and subsurface temperature may or may not covary depending

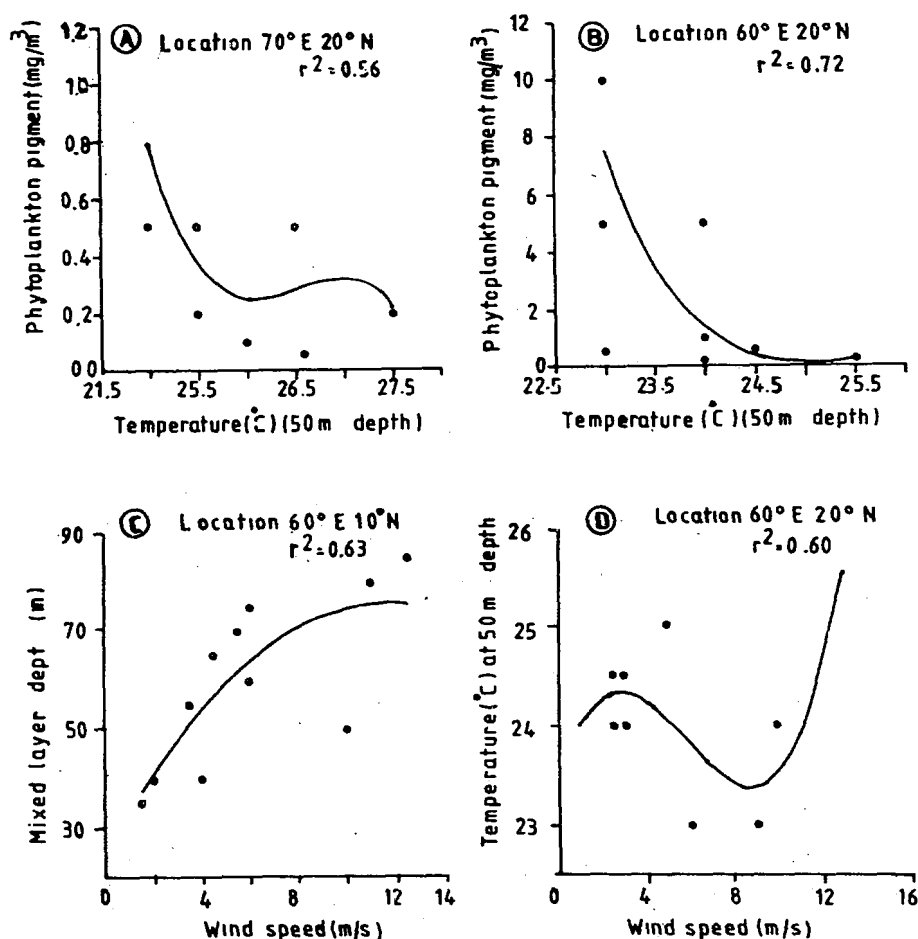


Fig. 1—Interrelationship between different oceanographic parameters at specific locations i.e. phytoplankton pigment and subsurface temperature (A and B), between mixed layer depth and wind speed (C), and between subsurface temperature and wind speed (D). (Source: climatological atlas and CZCS data)

upon the location and at times when sea surface temperature remains constant the subsurface temperature and phytoplankton pigment concentration show large variation¹⁰. Because of strong horizontal gradients of properties and appreciable current in the upwelling region, vertical and horizontal processes need to be considered for an understanding of nutrient supply at a given locality. In contrast, the nutrient supply to the upper layers of eastern and southern Arabian Sea seems to be little affected by the southwest monsoon (hence, oligotrophic conditions) and that the chlorophyll concentration as well as rate of primary production tends to stay low²⁷.

Nutrient entrainment into the mixed layer in response to a constant wind stress is periodic and is mainly determined by the wind stress - surface current interaction with a time lag of less than one half of the Coriolis period. Moreover the influence of initial physical and chemical structures on the favourable wind conditions required for nutrient entrainment is highly determinant³⁰. Nutrient

entrainment is associated with strong current shear and strong temperature and nitrate gradient at the base of the mixed layer. In order to develop any model for biophysical coupling, the study of relationship of parameters at temporal and spatial basis along with their subsurface profile is a prerequisite. In future ample opportunities will be available as far as ocean colour is concerned like Japanese System ADEOS (unfortunately satellite met with an accident and stopped functioning), the Indian Satellite Systems i.e. OCEANSAT I (to be launched by mid 1998) and II and US SeaWiFS (launched on 1 August 1997). The colour sensor onboard these have large number of narrow spectral bands in the visible and infrared regions of the electromagnetic spectrum for ocean colour retrieval in presence of the yellow substances besides atmospheric correction (see Table 3).

Based on the above review, it can be concluded that:

(1) The genesis of algal bloom phenomenon can be readily mapped and studied with the sensors

Table 3—Lists performance specifications for some of the ocean colour sensors planned for future missions

Sensor parameter	SeaWiFS (US)	MODIS (US)	OCTS* (Japan)	OCM (India)
GIFOV (km)	1.1 lac 4.5 gac	1.0	0.7	0.25
Swath (km)	2801 lac 1502 gac	1780	1400	1500
Repeativity	2 days	2 days	2 days	2 days
Local time (hrs)	1200	1300		1200
Scan plane tilt (deg)	±20	±50	±20	±20
Spectral, bands, (nm/μm)	402-422 (136.3)		402-422 (145)	402-422 (125)
(sat. radiance in w/sq.m-sr- μm)	433-453 (132.5)	430-440	433-453 (150)	433-453 (117)
	480-500 (105)	485-495	480-500 (130)	490-510 (103)
	500-520 (90.8)	515-525	510-530 (120)	500-520 (101)
	545-565 (74.4)	560-570	555-575 (90)	545-565 (91)
	660-680 (42)	615-625	655-675 (60)	660-680 (77)
	745-785 (30)	660-670	745-785 (40)	745-785 (52)
	845-885 (21.3)	680-690	845-885 (20)	845-885 (63)
		760-770	3.55-3.85 μm	
		860-870		
		+31 NIR & IR bands	8.25-8.75 μm	
			10.5-11.5 μm	
			11.5-12.5 μm	
Dynamic range	10 bits 4 gains	12 bits	10 bits	12 bits
Absolute accuracy	<5%	<2%	<10%	<10%
Polarization sensitivity (%)	<2%	<2%	2-5%	<2%

*Not functioning

with broad spectral bands.

(2) IRS LISS I data could be used to map chlorophyll concentration 1.0 mg/m^3 to 1.5 mg/m^3 which indicates that seasonal change in this range can be studied even from IRS LISS I data which is as such optimized for land applications.

(3) The internal waves which play an important role in nutrient enrichment could be mapped and initiation and/or maturation phase could be identified by mapping phytoplankton pigment using IRS LISS I data.

(4) The inverse relationship between phytoplankton pigment and temperature is observed.

(5) When monthly composites of chlorophyll derived from CZCS data were compared with the monthly temperature profile obtained from climatological atlas the correlation is better with temperature at 50 m depth rather than skin /surface temperature.

(6) The locational specificity observed in the relationship of different parameters indicates the need for developing region and season specific models.

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