Report of ship cruise SK –256 on

Satellite and in-situ studies on the bio-optical properties, carbon cycle, primary production, and phytoplankton functional type (PFT) of winter bloom in northern Arabian Sea

by

SK- 256 team

(February 9- 23, 2009)

Background

Ocean colour represents the spectral information of the oceanic constituents, which help to understand various physical and biological oceanographic phenomena. The series of ocean colour sensors available today like SeaWiFS, MOS, OCM, MODIS-Aqua, MODIS-Terra, OCTS, MERIS followed a path to explore the ocean ecosystem from space and attributed new dimensions to biological oceanography. They provide information on different biological parameter like concentrations of chlorophyll, suspended sediments and yellow Substance, diffuse attenuation coefficient (K), photosynthetically available radiation (PAR) etc., which form the basic components of the primary productivity model, study of bio-geo chemical cycles and other ocean colour applications. Since the launch of India's first ocean colour satellite Oceansat I in May 1999, several cruises have already been conducted by now for validation of satellite derived ocean products.

During winter monsoon (December-March), bloom concentrations of phytoplankton are observed in the entire northern Arabian Sea covering the coastal-shelf regions of Oman and Gujarat. Cruise SK186 during January 2003 was aimed at studying pre-bloom conditions. Time -series of satellite ocean colour images indicate that the bloom generally initiates by the end of January and persists till middle of March. Various studies suggest that bloom occurs due to convective mixing triggered by cooling of surface waters, which injects nutrients into the surface layers across thermocline region, triggering high primary production. Primary production resulting from the use of nutrients from below the mixed layer, typically nitrate is referred to as new (export) production. Rate of new production decides the rate at which atmospheric CO_2 will be drawn from the atmosphere into the sea due to the decreased partial pressure in seawater. Therefore study of new production can help to understand the carbon biogeochemistry and has implications for global warming and climate change.

Winter blooms had been monitored for five consecutive years 2000-2006 using IRS-P4 OCM data. Four cruises SK 186, FORV 212, FORV 222 and FORV 253 were specifically aimed to study the bio-optical state of the bloom area during this period. It has been observed that productivity and phytoplankton biomass starts increasing by January end, reaches a peak during the third or fourth week of February, and starts decaying by end of March and by second week of April typical oligotrophic conditions prevail in the northern Arabian Sea, characteristic of inter-monsoon phase. During the cruise FORV-212 in March 2003, the bloom species was identified as Noctiluca *miliaris*, a dinoflagellate. Subsequent cruise of FORV-222 during February-March 2004 confirmed the bloom species to be Noctiluca *miliaris*. The area covered during FORV-212 and FORV-222 was limited to the northeastern Arabian Sea within Indian EEZ. The cruise FORV-253 was extended

beyond Indian EEZ from 64° -67° E to study the spatial extent of the bloom beyond Indian EEZ. The present cruise SK-256 is specifically aimed to take a detailed set of in-situ measurements on the bio-optical properties, carbon cycle, primary production and pigment composition of Noctiluca *miliaris* in northern Arabian Sea

STATUS

Techniques to retrieve chlorophyll concentration using OCM data have been developed and validated. The technique has been operationalised and is now routinely used to generate chlorophyll fields using biomass data by various user agencies.
Mixed layer productivity using satellite and *in-situ* parameters have been developed using analytical model. However the same has to be validated in different areas and seasons in the Arabian Sea. Also, there is a requirement to measure photosynthetic parameters, which change for seasons and area. The magnitude of these parameters has to be incorporated in the mixed layer model to reduce the error in estimating mixed layer productivity in different areas.
F-ratios, nutrients, absorption measurements and optical light field have been measured during the previous bloom cruises within Indian EEZ. Similar measurements have to be taken in the northern Arabian Sea outside Indian EEZ.

OBSERVATIONS DURING JANUARY 2001, MARCH 2003,February -March 2004, March 2007

Ship cruises were carried out with Sagar Kanya during January 3-20, 2003 and Sagar Sampada during February 27 - March 07, 2003,February 21- March 11, 2004 and March 1-17, 2007. They were specifically aimed at studying primary productivity during the pre bloom and bloom phases. Chlorophyll was observed to be high at surface & all depths with a broader peak and vertical distribution of chlorophyll was more or less uniform in January 2003. During March 2003 very high values of chlorophyll (>2 mg/m3) was observed in the open ocean. The bloom species was identified as Noctiluca *miliaris*. The distribution of the bloom in the study area was uniform. High wind speed and low SST confirmed the theory of winter cooling and convective mixing. During February-March, 2004, Noctiluca bloom was confirmed in the open ocean waters of Northern Arabian Sea. Time series OCM/chlorophyll images revealed that distribution of the bloom was patchy and scattered unlike homogeneous distribution in 2003. During March 2007 Noctiluca cells were more in 66°-67° E compared to 64° -65°E. The cells were very large (>100 microns) and harbored the green flagellates. Bongo net samples showed very high concentration of zooplankton in the bloom areas. Displacement volume showed biomass equivalent to that found in phytoplankton rich coastal waters. In the areas having big size and large number of Noctiluca cells herbivore zooplanktons dominated the net samples whereas in stations having smaller size and less number of Noctiluca cells, carnivore zooplanktons dominated the net samples.

EXPERIMENTAL DESIGN

Locations of ship observations were pre-determined using weekly composite February 1-8, 2009 chlorophyll image generated from MODIS-Aqua data and were modified according to the latest information on the location of bloom that was obtained from SAC through e-mail during the cruise in near real time. This was repeated every day through out the cruise period. Optical data on parameters like spectral downwelling irradiance and upwelling radiance profile were taken using Satlantic under water radiometer. Water samples were collected for determining nutrients concentrations, chlorophyll-a from fluorometer and HPLC taxonomy, and study of absorption characteristics. C^{14} based primary production using deck incubations were carried out for all stations. Measurements for dissolved oxygen from the waters affected by winter bloom were taken during this cruise. PI parameters using an experimental setup were measured. In addition to this, sun photometer was used to measure aerosol characteristics to improve algorithms for chlorophyll retrieval in bloom waters. Auxiliary parameters like SST, wind speed, wind direction, sky conditions, and sea color were also taken.

OBJECTIVES

i. To determine the spatial extent and optical characteristics of the bloom (underwater light field, absorption characteristic of optical constituents)

ii. To determine the rates of primary production.

iii. To validate existing remote sensing mixed -layer model of primary productivity developed for the bloom.

iv. To determine P-I parameters, absorption characteristics of the winter bloom and vertical chlorophyll profile during winter bloom.

v. To measure new (export) primary due to NO_3 according to pre-set domains.

vi. Comparison and validation of atmospheric correction model.

vii. environmental conditions facilitating *N.miliaris* blooms in the open ocean waters off the Arabian Sea and oceanographic and meteorological conditions contributing to their enhanced frequency and magnitude 3

STUDY AREA

Northern Arabian Sea covering open ocean waters in the range 20-22° N and 64-68° E was selected as the study area for sea truth data collection. The distance between the stations was decided during the cruise according to the ship speed and time taken for measurements at a particular station. Station locations and Cruise track are delineated in figure1.

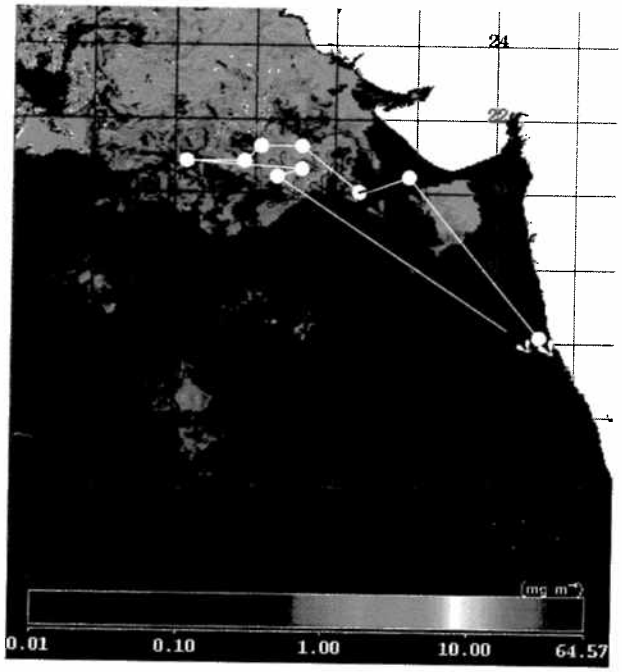


Figure 1. cruise track for SK-256

PARAMETERS MEASURED

During Sagar Kanya Cruise-256 following Biological, physical, chemical, optical and bio-optical parameters were measured (Table-1 and Table-2).

Biological Parameters:

Chlorophyll-a (surface and vertical profile)

Accessory pigments

Primary Productivity (C^{14})

Species identification

Zooplankton composition

Optical Parameters:

Upwelling radiance /irradiance

Upwelling radiance and upwelling irradiance

PAR (Profile)

Bio-optical parameters:

P-I parameters for surface

Absorption measurements of particulate and dissolved constituents.

Physical Parameters:

Temperature, salinity, density profile, dissolved oxygen, Wind speed and direction

OPERATIONAL SCHEDULE

Schedule of operation followed a pattern of water sample collection in the morning for CTD. Water samples were collected at 10:00 hrs for productivity measurements, sample filtration for chlorophyll, pigments, CDOM, particulate absorption and dissolved oxygen. Depths of water samples collection were decided after observing the par profile by getting the light levels from Satlantic hyperspectral radiometer. Samples were collected from seven different depths to enable integration of chlorophyll and productivity over euphotic depth. Surface sample at one station was also collected for PI parameter measurements. Continuous Plankton Recorder (CPR) was towed after each station while the ship was sailing to next hydrographic station to study the composition and distribution of zooplankton in the study area. Underwater radiometer operations were carried out around mid-noon. Aerosol optical depth and particle size was measured throughout the cruise period every three hours from sunrise to sun set.

DETAILS OF MEASUREMENTS

Table 1 and 2 summarizes over all performance of data collection during the period of cruise. Optical, biological and atmospheric parameters were measured in view of objectives of the mission.

METEREOLOGICAL PARAMETERS

Data on wind speed, wind direction, air pressure and air temperature for all stations were recorded on board Sagar Kanya.

Aerosol optical depth

Sun photometer (Micro tops)measurements were carried out every 30 minutes interval to provide AOD at 400, 500, 670, 870 and 936 nm on clear sky conditions. The basic principle is that solar radiation after undergoing multiple scattering in the atmosphere by aerosols and Rayleigh (air molecules) falls on the sun photometer filters and is converted into voltage value.

Aerosol Particle Sizer

The instrument provides the aerosol particle size distribution of particles from the range of 0.25 to 32 □m.(See Fig 5) The instrument was mounted on a clear site at a height on a B-deck.

Optical parameters

Water leaving radiance (L_W) describes apparent optical property of the water and it is the signal that contains information about water constituents. Therefore, most of the empirical approaches for retrieval of oceanic constituents from satellite data require this parameter. Reflectance (R_{rs}), which is essentially radiance/irradiance ratio, has become very popular lately amongst developers of empirical algorithms. Even for calculating reflectance, knowledge of L_W is required. L_W is also used to compute TOA radiance for sensor validation. Thus L_w is the basic and important parameter for any ship campaign to complement remote sensing technique development.
Satlantic under water radiometer measures surface incident spectral irradiance, Es (λ) = Ed (0+, λ), downwelled spectral irradiance, Ed (z, λ), and upwelled spectral radiance, Lu (z, λ).

Figure 2: The Satlantic hyperspectral profiling radiometer (HYPR OCR) during operation

Radiometer was deployed at all stations during the noon period when the solar zenith angle was low. The data measured would thus find application in ocean color satellite applications.

- The reference sensor was mounted at a clear site avoiding any ship shadow and a height above 4 meters from the deck.
- The instrument was always deployed up to 1 % of light level.
- The instrument deployed at the port side far away from the ship shadow. This was achieved by allowing the wind to blow on the port side allowing the ship to drift away from the radiometer.

- The radiometer sensors measured simultaneously the spectral values at 1 nm interval beginning from 400 nm the upwelling radiance and the downwelling irradiance.
- Apart from these it also measured using other sensors chlorophyll fluorescence, CDOM, backscattering coefficient, temperature and conductivity.

Secchi depth

Secchi disk of 30 cm diameter with alternate sectors of black and white was used.

PHYSICAL PARAMETERS
Temperature, Salinity and density from CTD sensor

The CTD system consists of an underwater unit and a Deck unit (for real-time readout using conductive wire). The Sea-Bird underwater hardware consists as a main pressure housing comprising power supplies, acquisition electronics, telemetry circuitry and a suite of a modular sensors all mounted within a stainless steel guard cage (SBE 9 plus CTD Underwater unit). It features high-resolution sampling (24 Hz), up to 6800 m depth capability, auxiliary sensor flexibility, and modem channel for water sample control.

The temperature sensor (model SBE 3 plus) is a compact module containing a pressure- protected high-speed thermistor and 'Wein bridge oscillator' interface electronics, which can be operated at -5°C and +35°C. The conductivity sensor (model SBE 4C) is similar in operation and configuration to the temperature sensor except that the Wein bridge element is the cell resistance. The measurement range of this sensor is 0 - 70 mho cm^{-1}. The pressure sensor also provides a variable frequency output. The sensor frequencies are measured using a high-speed parallel counters and the resulting digital data in the form of count totals to numeric representations of the original frequencies. The equivalent measurable depth ranges from 0 to 10 500m (as per configuration selected).

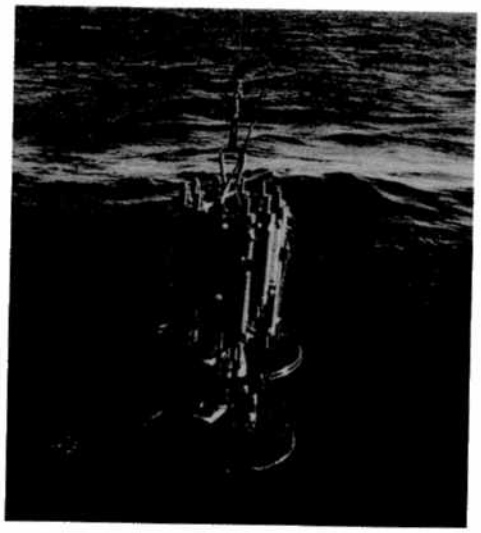


Figure 3: CTD-water sample collection in operation during the cruise SK -256

CHEMICAL PARAMETERS

Dissolved Oxygen

Samples for dissolved oxygen [from different light levels from radiometer] were immediately fixed with Winkler A and Winkler B reagents and subsequently analyzed onboard using titration method [*Dosimat model 665*) after calibration.

BIOLOGICAL PARAMETERS

Water samples were collected to measure chlorophyll-a, primary productivity, dissolved and particulate absorption coefficients etc. at six to seven different depths. Vertical profile of chlorophyll will be used to integrate surface chlorophyll up to euphotic depth. Integrated chlorophyll is an important input for primary productivity model.

ESTIMATION OF EUPHOTIC ZONE PRODUCTION USING C^{14} TECHNIQUE

Photosynhtetically available radiation (PAR) from hyperspectral radiometer instrument was used to provide the light information of each hydrographic station, which was taken as a reference to collect the water sample. Primary productivity samples for C^{14} based measurements were prepared with **deck incubation.** This simulated incubation method uses ambient light with neutral density filters. The samples were incubated for a period of 4 hours. Later they were filtered through GF/F filters (0.7 microns pore size) and stored in scintillation vials for further analysis. JGOFS protocol was followed for all the experiments. Chlorophyll and primary productivity deck samples will be analyzed at NIO, as this requires further analysis in laboratory with Scintillation counter.

DETERMINATION OF P-I PARAMETERS

The Oceans play an important role in bio-geo-chemical cycling of carbon, functioning primary sink of the element as is reflected from its huge carbon reserves. Satellite remote sensing of ocean colour offers opportunity to extend the estimation of biological carbon fixation over the entire ocean. The models which allow calculation of carbon fixation, or primary productivity, requires information on the light available at the sea surface, biomass at the surface, the vertical structure of the phytoplankton biomass, estimates of the parameter of photosynthesis-light model and the light transmission under water. Satellite can provide all the information needed except the biomass profile and the values of the parameters of photosynthesis-light model, or P-I parameters.

The photosynthetic response of phytoplankton, and in general the plant, is not linear; it is on light-dependent at the lower light intensities and becomes independent (saturated) at higher light intensities, producing a curve which is described by its slope (α) and the maximum photosynthesis (P_{max}). While the value of α is largely dependent on the photosynthetic efficiency of the phytoplankton, or in other words, it is species specific, the P_{max} value is dependent largely on the environmental factors, such as temperature, etc. The distribution of species (phytoplankton) is itself dependent on the geographical location of the water. Therefore, the values of α and P_{max} can be used to partition the ocean the world over into some distinct bio-geo-chemical provinces, and then use these values for the calculation of column productivity of the concerned provinces.

In this cruise, at one station (bloom station) experiment was carried out to estimate PI parameters for the surface samples using C^{14} tracer Samples were collected in 20 different scintillation vials and inoculated with C^{13} tracer. Each bottle was, then, exposed to variant light intensities in the PI box using different filters. Samples were incubated for 2hrs, then filtered and preserved for later analysis. Relationship between biomass normalized C^{14} measured productivity and light will analysed to estimate values of α and P_{max}.

PHYTOPLANKTON TAXONOMIC ANALYSIS

I liter each of water sample at each depth was filtered through 5 µ, 20µ and 100µ bolting silk and the filtrate preserved in 4% Lugol's Iodine solution.

ZOOPLANKTON STUDIES:

A continuous plankton recorder was towed behind the ship after the completion of work at every hydrographic station. The CPR collects various zooplankton along the ship track.

Figure 4: Continuous Plankton Recorder (CPR) operation during the cruise

Measurements for the calibration of Fluorometer sensors.

Recently procured two fluorometric sensors for the measurements of Chlorophyll, FLNTUS (Wetlabs) and Trilux (Chelesea) were used to observe the fluorescence counts in the lab using waters obtained at discrete depths. These values will thereafter be used to compare with the actual chlorophyll measured from the water samples.

BIO-OPTICAL PARAMETERS

Absorption Measurements of particulate and dissolved substances

Measurement and analysis of spectral absorption coefficients of marine particulate and dissolved substances are important for modelling submarine light field for estimating primary production from space and development of regional bio-optical algorithms. Techniques for operational determination of absorption coefficients for particulate and soluble matter in water samples are based on the protocols for satellite ocean color sensor validation outlined during NASA- sponsored workshop. These protocols are described under "Ocean Optics Protocols for Satellite Ocean Colour Sensor Validation", Volume 2. Typically, the methodology for particulate absorption consists of filtering on to (27mm 0.7 μ pore size) GF/F filters 1-2 liters of waters sample from each depth using a filtration unit. The filter pad is then place flat in a petridish and stored in cryocans for further analysis in laboratory.
For measurement of soluble absorption, 250ml of water from each depth was drawn directly into brown bottles (washed with Milli-q and dried). The samples were filtered onboard through 0.2 μm membrane filter into a conical flask. The sample is then preserved in refrigerator at around 4^0C if measurements are to be taken after 3-4 hours otherwise the optical depth (OD) of the filtrate is determined using a UV-VIS dual-beam Spectrophotometer. Deionised Milli-Q water is used as reference.

The absorbance due to yellow substance is calculated as follows (Mitchell et al, 2000)

$$a_y(\lambda) = 2.303 * [(OD_s(\lambda) - OD_b(\lambda)) / L] \quad m^{-1}$$

Where,

$a_y(\lambda)$	absorption due to yellow substance
$OD_s(\lambda)$	optical depth of the sample
$OD_b(\lambda)$	optical depth of the blank
L	path length (m) which is usually 10cm.

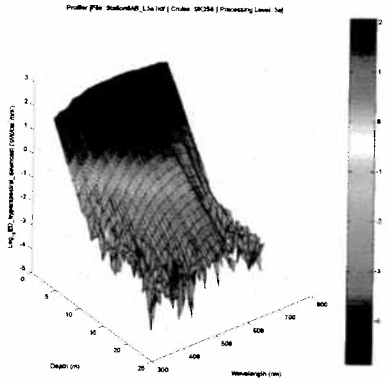
HIGHLIGHTS AT A GLANCE

- Mesotrophic to eutrophic conditions prevailed in deep open ocean waters of Northern Arabian Sea.

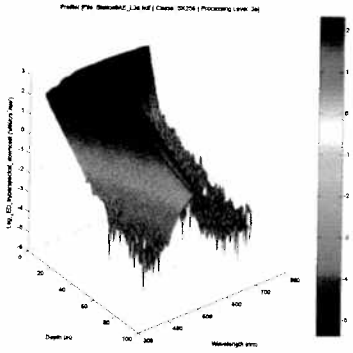
- Sea Surface temperature ranging from 24-26 deg C was observed in the study area.
- Hydrographic profiles revealed mixed-layer depth to be in the range of 60-80 m for all stations.
- Noctiluca bloom were observed in all open ocean stations except The cells were very large (>150 microns) and harbored the green flagellates
- Absorption measurements of CDOM were taken on board using a Shimadzu UV-VIS spectrophotometer.

OPTICAL CHARACTERISTICS

The normalized water leaving radiance and diffuse attenuation coefficient in all bands of hyperspectral radiometer was calculated for all the stations during the SK 256 cruise.

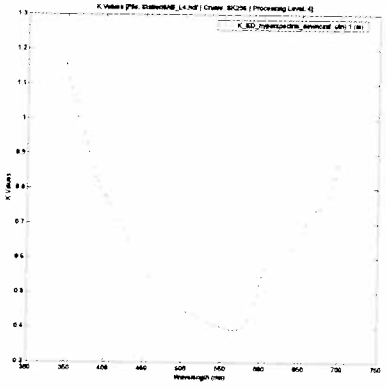


Coastal waters

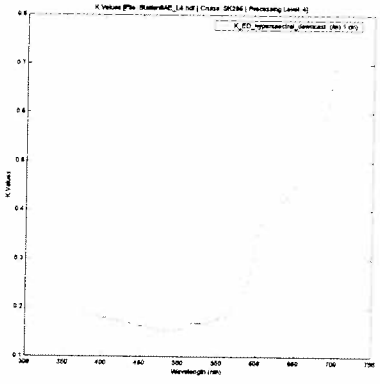


Open Ocean

Ed(z,λ)



Coastal waters



Open Ocean

. Kd(0,λ)

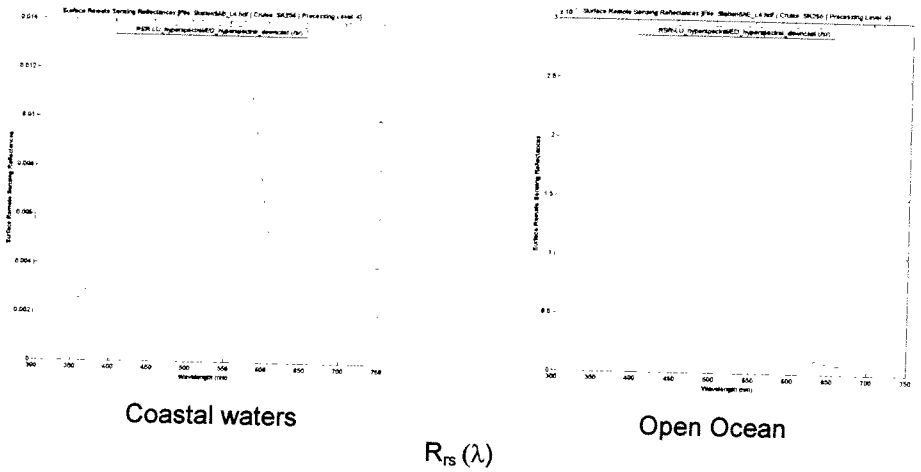


Figure 5: Ed(z,□), Kd(0,□) R_{rs} □□) for open and coastal waters.

Secchi depth

Secchi disk of 30 cm diameter with alternate sectors of black and white was used. The Secchi depth varied from a low value of 2.46 m (Station 6 & 9) in the coastal water to a high value of 21.22 (Station 8) in the open ocean.

Aerosol optical depth

AOD was found to be low at stations in the Northern Arabian Sea and it was found to increase while moving towards coastal regions of Mumbai. (See figure below)

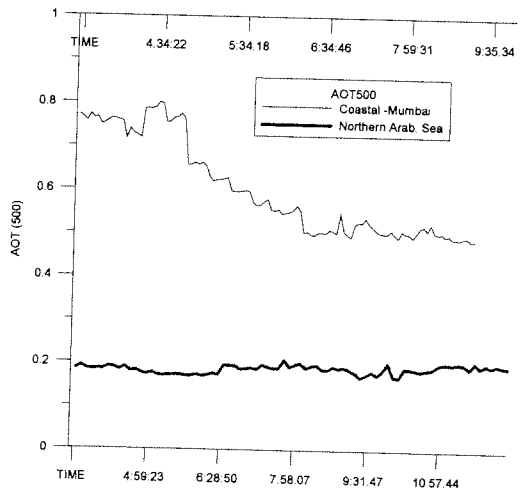


Figure 6: AOT for Coastal and Open Ocean

Aerosol Particle Sizer

The instrument provides the aerosol particle size distribution of particles from the range of 0.25 to 32 □m.(See Fig 5) The instrument was mounted on a clear site at a height on a B-deck.

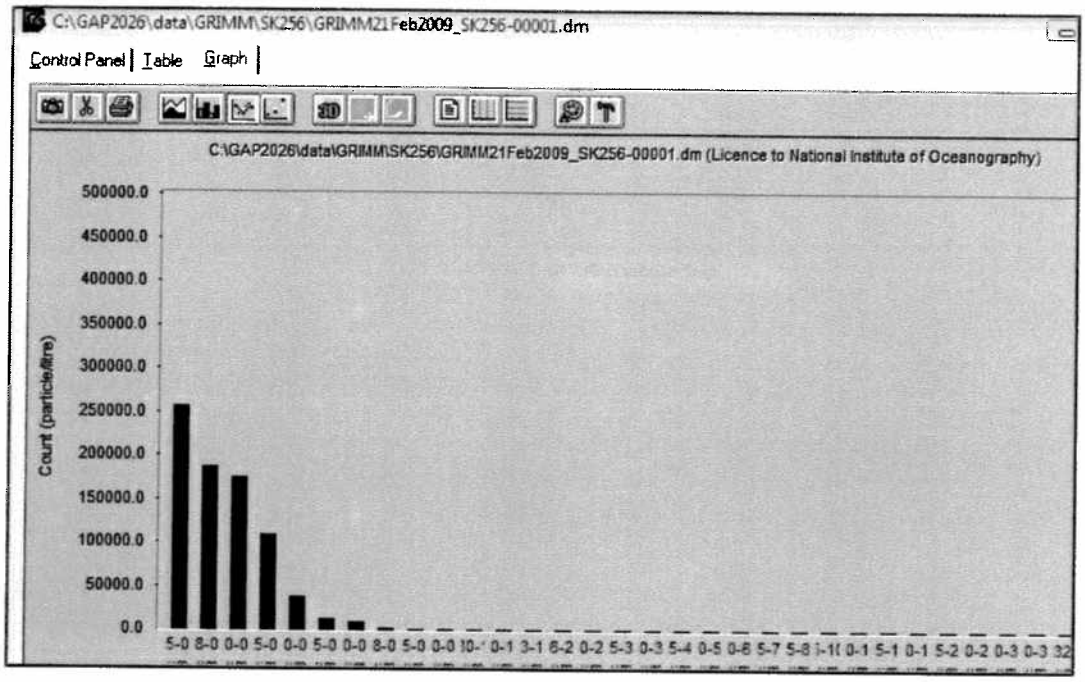


Figure: 7. Histogram of Particle Size Distribution

PHYSICAL OCEANOGRAPHY

During the cruise 256, tent stations were sampled covering, the area between 17°-22°N & 64°-72°E). CTD data of temperature, salinity and dissolved oxygen at 1 m bin intervals were recorded in all stations. Surface meteorological parameters were also recorded

Weather conditions during the cruise period were characterized by NE winds with speed ranging 6.7 knots to 13 knots. Average wind speed for the area was around 9 knots. Air temperature ranged between 26.0° to 27°C for the northern stations and for the non-bloom station the air temperature was around 28°C. Sea surface temperature (SST) averaged around 26°C for bloom stations and for non-bloom station SST was warmer at 27°C. Preliminary analysis of salinity structure showed surface salinity to be around 36 psu. MLD (60-80m) was found in the study area during the cruise period.

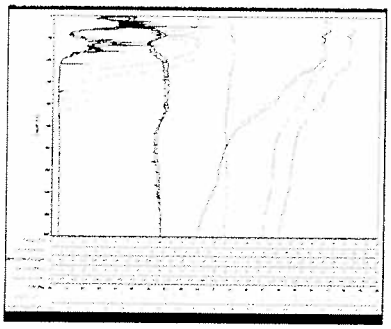


Figure 8: The temperature profile and depth of MLD during the cruise SK-256.

DISSOLVED OXYGEN

The DO at 1 m depth varied between 2.5 ml/L in bloom patches of *Noctiluca miliaris* at station 6 to 5.1 ml/L at reference station 1. In intense bloom areas, the DO varied from 2.84 ml/L at 1 m to 1.25 ml/L at 45m in Station 4 and 2.5 ml/L at 1m to 2.27 ml/L at 33m in station 6 and were lower in comparison to other stations. This possibly is due to the respiration of grazing zooplanktons, bacteria and the bloom itself. The DO profiles from stations 4 and 6 harboring intense bloom patches and station 1 in the non-bloom area are as below:

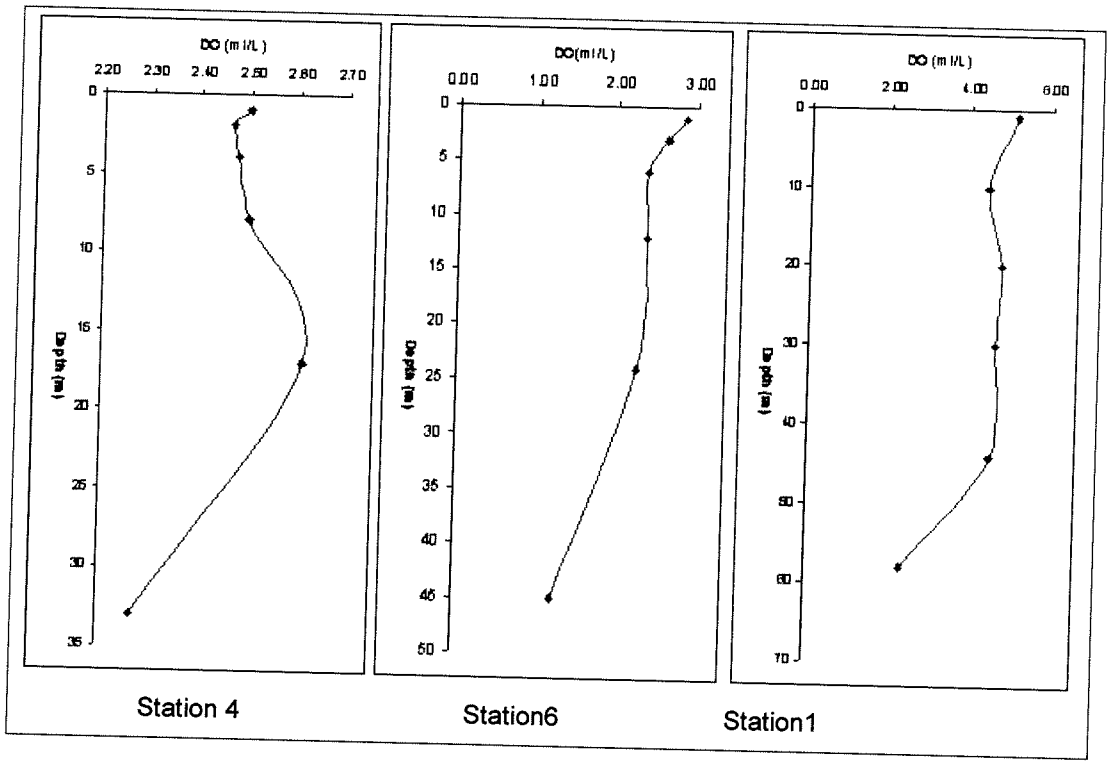


Figure 9: Dissolved Oxygen in bloom and non-bloom areas.

ALGAL BLOOM SPECIES IDENTIFICATION

Bloom of *Noctiluca miliaris* was observed at all stations. Between 64° and 66°E, thick blooms patches having brilliant lime-green colour were observed. Massive numbers of positively buoyant cells accumulated at the sea surface, and appeared clustered. However stations located at 65° and 66° had larger and bigger Noctiluca cells. These cells are known to harbour the green flagellate *Pedionomonas noctilucae* longing to the family prasinophyceae.

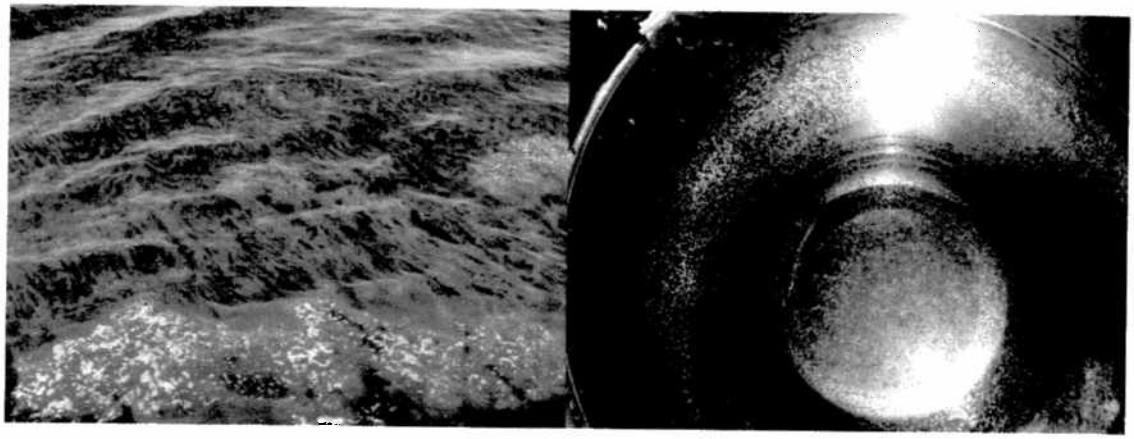


Figure 10: Patches of Noctiluca bloom observed from ship and Noctiluca cells collected in a bucket.

CDOM ABSORPTION

Figure 11 shows the typical absorption spectra of CDOM measured using a spectrophotometer. The CDOM absorption was higher in bloom waters (0.09 OD units) as compared to the non-bloom waters (0.013 OD units). DOM absorption is higher in the surface waters in bloom areas compared to waters at 1% light levels. Strong absorption due to amino acid (MAA) in the UV region (peak around 337 nm) is observed in surface where noctiluca occurs in patches. Absorption of CDOM is also strong in the UV region (250-350 nm) as compared to the visible region. Beyond 500nm CDOM has negligible absorbance.

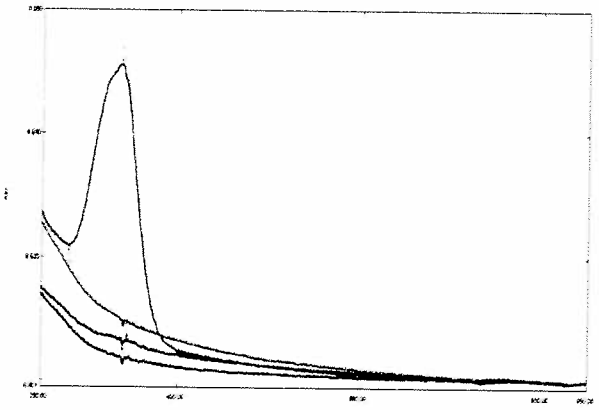


Figure 11: Absorption spectra of Coloured Dissolved Organic Matter (CDOM)

ACKNOWLEDGEMENT

Participants of this cruise are thankful to the National Center for Antartic and Ocean Research DOD for making Sagar Kanya available for the remote sensing cruise. Coordination provided by Dr. M.Sudhakar and by Shri M.M. Subramaniam is gratefully acknowledged. All the members of ship crew were cooperative and extended support for all technical as well as non-technical matters. Officers and all members of ship crew were cooperative and extended support for all technical as well as non-technical matters. Interest and concern shown by Master of the ship, Capt. K. Pandian, in the over all scientific programme is appreciable. Thanks are also due to engineers from Norinco Group, for working with us and extending their full cooperation. Reception of near real time chlorophyll images during the cruise was possible with sincere efforts of our colleagues at SAC. Everybody worked like one team and we are sincerely thankful to all of them.

Table 1: Measurements of C^{14}, CDOM, Particulate absorption, and Chlorophyll for varying light levels and the corresponding depths

Station Number	Latitude	Longitude	Light %	Depth (m)
1 10/02/2009	17^0 05.7'N	72^0 07..31'E	100	Surface
			80	1.5
			64	3
			50	7.2
			20	11
			5	21
			1	32
2 13/02/2009	21^0 09..93'N	066^0 37.22'E	100	Surface
			81	1
			62	4
			34	8
			17	15
			1	38
			1	45
3 14/02/2009	21^0 44.39'N	065^0 29.29'E	100	Surface
				2
				6
				12
				15
				24
				45
4 15/02/2009	21^0 49.038'N	064^0 05.00'E	100	Surface
			73	1
			66	3
			33	6
			16	12
			5	25
			1	45
5 16/03/2009	21^0 50.64'N	065^0 00.60'E	100	Surface
			83	1
			66	4
			33	8
			16	14
			5	23
			1	42
6 17/02/2009	20^0 53.98'N	066^0 10.18'E	100	Surface
			83	1
			66	2
			33	4
			16	8
			5	17
			1	33
7 18/02/2009	21^0 02.59'N	067^0 02.48'E	100	Surface
			80	1
			66	3
			33	7
			16	13
			5	23
			1	37
8 19/02/2009	20^0 25.78'N	068^0 59.73'E	100	Surface
			84	1
			68	3
			33	9
			16	13
			5	28
			1	48
9 20/02/2009	20^0 54.70'N	070^0 10..01'E	100	Surface
			70	1

			33	2
			16	3
			5	6
			1	7
10 22/02/2009	17. °00.70'	73°05.35'	100	surface
			84	11
			66	2
			33	3
			15	7
			5	21
			1	28

Table 2: Stations Covered, The Instruments Operated and the Parameters Measured during the Sagar Kanya - 256 Cruise from 09-02-09 to 23-02-09

Station Number / Date	Latitude	Longitude	Instruments Operated	Parameters measured	Depth (m)	Remarks
1 10/02/2009	17^0 05.71'N	72^0 07..31'E	Hyperspectral under water radio meter, CTD, UV Spectrophotometer, Millipore	Lw, Ed, Lu, Es, Chlorophyll-*a*, , DO ,PAR, Absorption, CDOM, C^{14}	94	Clear sky, shelf waters, green colour
2 13/02/2009	21^0 09..93'N	066^0 37.22'E	Satlantic Radiometer, PNF, CTD, UV Spectrophotometer, Millipore	L_w, Ed, Lu, Es, Light levels,, C^{14}, Chlorophyll-*a*, PAR, Absorption, CDOM, DO	2331	Clear Sky, Calm Sea, Green waters, Noctiluca Bloom observed
3 14/02/2009	21^0 44.39'N	065^0 29.29'E	Satlantic Radiometer, PNF, CTD, UV Spectrophotometer, Millipore,CPR	L_w, Ed, Lu, Es, Light levels, C^{14}, Chlorophyll-*a*, PAR, Absorption, CDOM, DO	3335	Clear sky, Calm Sea, Green waters, Noctiluca Bloom observed
4 15/02/2009	21^0 49.038'N	064^0 05.00'E	Satlantic Radiometer, PNF, CTD, UV Spectrophotometer, Millipore, CPR	L_w, Ed, Lu, Es, Light levels, , C^{14}, Chlorophyll-*a*, PAR, Absorption, CDOM	2897	Noctiluca cells were present b
5 16/03/2009	21^0 50.64'N	065^0 00.60'E	Satlantic Radiometer, PNF, CTD, UV Spectrophotometer, Millipore, CPR	L_w, Ed, Lu, Es, Light levels, C^{14}, Chlorophyll-*a*, PAR, Absorption, CDOM, DO	2926	clear, partially cloudy, Noctiluca bloom observed
6 17/02/2009	20^0 53.98'N	066^0 10.18'E	Satlantic Radiometer, PNF, CTD, UV Spectrophotometer, Millipore, CPR	L_w, Ed, Lu, Es, Light levels, C^{14}, Chlorophyll-*a*, PAR, Absorption, CDOM, DO	2378	Clear sky, thick bloom of noctiluca
7 18/02/2009	21^0 02.59'N	067^0 02.48'E	Satlantic Radiometer, PNF, CTD, UV Spectrophotometer, Millipore, CPR	L_w, Ed, Lu, Es, Light levels, ^{5}, C^{14}, Chlorophyll-*a*, PAR, Absorption, CDOM, DO	2389	, very few cells of Noctiluca compared to stn:6
8 19/02/2009	20^0 25.78'N	068^0 59.73'E	Satlantic Radiometer, PNF, CTD, UV Spectrophotometer, Millipore, CPR	L_w, Ed, Lu, Es, Light levels, , C^{14}, Chlorophyll-*a*, PAR, Absorption, CDOM, DO	1852	Clear sky, only 3 cells in 30 liters of water
9 20/02/2009	20^0 54.70'N	070^0 10..01'E	Satlantic Radiometer, PNF, CTD, UV Spectrophotometer, Millipore, CPR	L_w, Ed, Lu, Es, Light levels, , C^{14}, Chlorophyll-*a*, PAR, Absorption, CDOM, DO	26	Clear sky, coastal waters, off Saurashtra
10 22/02/2009	17. °00.70'	73°05.35'	Satlantic Radiometer CTD, UV Spectrophotometer, Millipore, sun photometer	L_w, Ed, Lu, Es, Light levels C^{14}, Absorption, CDOM, DO	41	Hazy sky, coastal waters off Ratnagiri

Table 3: Location of CPR deployment and retrieval during the Sagar Kanya - 256 Cruise from 09-02-09 to 23-02-09

CPR track No.	Deployment			Retrieval		
	Date	Latitude	Longitude	Date	Latitude	Longitude
1	11/02/09	18° 43′ N	69° 36′ E	12/02/09	21° 11′ N	66° 36′ E
2	14/02/09	21° 46′ N	65°23′ E	15/02/09	21° 44′ N	64° 05′ E
3.	15/02/09	21° 47′ N	63° 59′ E	16/02/09	21° 57′ N	65° 02′ E
4.	16/02/09	21° 51′ N	64° 59′ E	17/02/09	20° 58′ N	66° 10 'E
5.	17/02/09	20° 57′ N	66° 10′ E	18/02/09	21° 2′ E	67° 3′ E
6.	18/02/09	20° 57′ N	67° 11′ E	19/02/09	20° 27′ N	68° 59′ E
7.	19/02/09	20° 22′ N	68 °59′ E	19/02/09	20° 50′ N	69° 13′ E
8.	20/02/09	19° 58′ N	70° 15′ E	22	17° 0.85′ N	73° 05′E

Annexure -2

PARTICIPANTS OF THE CRUISE

SAC, Ahmedabad

Ms. Mini Raman	DEPUTY Chief Scientist
Dr.. H.U.Solanki	Scientist

NIO

Dr. S. G. Prabhu Matondkar	Chief Scientist
Mr. T. Suresh	Scientist
Mr. V. Subramaniam	Scientist
Ms.Suraksha Pednekar	PAIII
Mr. Subhajit Basu	PAII
Ms. Sarita N. Kudtharkar	PAII
Mr. Praveen Singh	PAII
Ms. Shet Talaulikar Madhubala Vinayak	PAII
Mr. Pise Prashant	PAII
Mr. Shaikh Bilaloddin	
PAII	
Ms. Fernandez Alitia Maria	PAII

Mangalore University

Deepthi Thimmaiah	JRF
Ms. Keerthi Laxmi	Student

Gujarat University

Gunjan Motwani	JRF

M/s Norinco

Shri. Kalasadan Madhusudan	Service Engineer
Shri. M.K.R.Perumal	Service Engineer
Shri. Yarramilli Krishna Chaitanya	Service Engineer
Shri. Paul Ragain	Service Engineer
Shri. Thachezhathu Baiju	Service Engineer

NCOAR

Sameer Shaikh	Ship Assistant

Participants of Sagar Kanya Cruise SK-256