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Short communication

Possible Future Directions for Oceanographic Research in India

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Introduction

Human activities during that past two centuries have altered our environmental significantly. While much of the observed change in the mean annual global surface temperature during the last century could be explained by variations in the solar activity, the record after the seventies could be explained by climate models only if the anthropogenic perturbation of the atmosphere by fossil fuel combustion is taken into account (IPCC AR$, 2007). The anticipated changes in the next decade include not only increasing terrestrial and ocean surface temperatures, but also ocean acidification and stratification of the Ocean. Therefore it is quite likely that most research in Oceanography in the next decade would be broadly in the area of Global Change and its consequences for humans, flora and fauna.

Most oceanographic research to date pertains to the surface ocean which is well lit by the Sun or to benthic organisms that have been seen by dredging and coring the sea floor. We are just beginning to know about the organisms in the deep ocean after the developments of remotely operated vehicles and underwater instruments.

Research related to Global Change

There are several anticipated effects of Global Change (IPCC AR4, 2007). These include (i) Sea Level rise, both due to the thermal expansion of the oceans and due to the melting of sea ice (e.g. Arctic), (ii) Ocean Acidification, due to increased absorption of carbon dioxide from the atmosphere, (iii) Extreme events such as cyclones and tsunamis, (iv) Ocean productivity and nitrogen balance, (v) exploitation of marine living and non-living resources and (vi) Geoengineering.

Sea level monitoring is important for determining how much land is lost from the continents. Tropical corals and ptreopods, made of aragonite, and foraminifera and coccoliths made of calcite may start dissolving with ocean acidification. This may worsen the efficiency of oceanic uptake of carbon.ge scale experiments such as iron fertilization of the oceans that come under geo-engineering, have adverse consequences for oceanic biota.

Satellites are useful in providing data about sea ice extent, sea level, river discharge, coastal erosion, sea surface temperature, winds, chlorophyll and thus productivity. Satellite data are in general not as precise as sea-truth data, but they provide global coverage. Sometimes secular trends seen in satellite data could be an artifact of changes in the sensitivity of sensors, therefore self-calibrating sensors are being developed.

Ocean warming, productivity and the nitrogen balance

The contrast in the observed biological productivities in the Arabian Sea and the Bay of Bengal, two neighbouring basins located at the same latitude (Prasanna Kumar et al., 2010) is illustrative when we wish to understand the anticipated effect of global warming and consequent ocean stratification on the biological productivity. It is well known that productivity (typically ~1 g C m^{-2} day^{-1}) in the Arabian Sea is many fold relative to that in the Bay, mainly because of clear skies, upwelling and convective mixing respectively, during summer and winter monsoons, and absence of significant fresh water discharge from rivers [1]. Cloudy skies, absence of significant vertical mixing and high runoff from rivers debauching in to the Bay [2] make it well stratified and therefore low to moderately productive (typically ~200 mg C m^{-2} day^{-1}). With Global warming, the tropical oceans would warm and get thermally stratified, and thus we may expect the Arabian Sea to resemble the Bay of Bengal as far as biological productivity s concerned. However Goes et al reported an increasing trend in the productivity of the Arabian Sea, and also attributed to increased vertical mixing induced by stronger monsoons. This was independently checked by Satya Prakash and Ramesh (2007) and Prasanna Kumar et al., (2010) who found that the increasing chlorophyll trend was unrelated to enhanced winds. Global trends in ocean chlorophyll for the period 1998-2003 are shown in Table 1 (source: Gregg et al., 2005).

Over the past decade we have used stable isotopes of Nitrogen (^{15}N) and Carbon (^{13}C) as tracers to quantify carbon and nitrogen fluxes over different parts of the Indian Ocean.

1) *Primary productivity using ^{13}C:* Carbon has two stable isotopes – ^{12}C and ^{13}C. ^{12}C is abundant while natural abundance of ^{13}C is 1.11%. This isotope in enriched (99% ^{13}C) form is used to quantify primary productivity (inorganic carbon uptake rate during photosynthesis by phytoplankton is the surface ocean).
2) *Quantifying new and regenerated production using ^{15}N:* Nitrogen is the most important nutrient controlling primary productivity. On the basis of nitrogen uptake rate, under steady state conditions, primary productivity

is divided into two parts – 1. 'New productivity' - supported by nitrate and 2. 'Regenerated productivity' - supported by ammonium and urea. Only stable isotopes of nitrogen can separate these two parts of productivity. Like carbon, nitrogen also has two stable isotopes – ^{14}N and ^{15}N. ^{15}N (natural abundance 0.37%) is used in 99% enriched form to estimate new and regenerated production [6].

3) *Quantifying N_2 fixation using $^{15}N_2$ gas tracer:* Nitrogen is lost from the oceans as a result of denitrification. This loss is made up by direct nitrogen (i.e. N_2 from the atmosphere) fixers. Diazotrophs (e.g. *Trichodesmium*, as shown in Fig. 1, were observed in April 2009) present in the ocean surface are able to fix N_2. Recently it is concluded that this process (N_2 fixation) is an important input of nitrogen to the ocean. Technique to measure N_2 fixation is developed recently in which nitrogen gas is used in the form of 99% enriched $^{15}N_2$.

We have shown using a new data on N uptake rates and *f*-ratios in the north-eastern (NE) Arabian Sea, where significant amounts of *Trichodesmium* were present in spring-2006, that the measured total nitrogen uptake rates may vary from 0.34 to 1.58 mmol N m^{-2} d^{-1}. N_2 fixation associated with *Trichodesmium* varied from 0.002 to 0.54 mmol N $m^{-2}d^{-1}$ estimated from the abundance of *Trichodesmium* and specific N_2 fixation rates of 1.5 pmol N $trichome^{-1}$ h^{-1}. Inclusion of N_2 fixation rates significantly changes *f*-ratios particularly in the coastal stations. Nitrogen isotopic data of surface suspended particles suggest that recently fixed nitrogen contributes as high as ~79% of the nitrogen in surface suspended particles. In addition, water column gained ~30 mmol N m^{-2} in the form of nitrate, likely due to nitrification of ammonium released by *Trichodesmium*. For better estimations, direct measurement of N_2 fixation is recommended (Gandhi et al., 2010). Also the importance of anammox, a recently discovered process by which nitrogen is lost from the ocean by the oxidation of ammonia is yet to be assessed.

Some questions that need addressing in the coming decade are:

- Can we identify marine phytoplankton species that can fix carbon faster?
- What is the effect of acidification of the photosynthetic rate of different marine organisms?
- How does monsoonal runoff affect ocean stratification with Global warming?
- What is the effect of Harmful Algal Blooms and anammox on the marine nitrogen budget?
- How much is the Fe fertilization in tropical regions?

Both culture experiments and mesocosm experiments are needed to answer these questions.

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Table 1: Global trends in Ocean Chlorophyll between 1998 and 2003 based on satellite data

Ocean region	Maximum no. of values in a year	Percentage trend over 6 years
Coastal	530579	10.4
Open ocean	1979	0.9*
Global	560247	4.1

- Not significant at 95% confidence level.

Figure 1: ***Trichodesmium*** **bloom observed in the spring-2009 in the eastern Arabian Sea.**