Biogeochemistry of the Arabian Sea: Synthesis & Modelling

18-20th January 1999,
Bangalore, India
ABSTRACTS

Poster: **Study of a common effluent treatment plant receiving tannery wastewater at Tamil Nadu**.
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Tanneries have been a source of water as well as soil pollution. Work has been carried out to improve the performance of a Common Effluent Treatment Plant (CETP) at Tamil Nadu, Indiaso as to bring the quality of water within the prescribed standards before releasing it into the natural environment. Qualitative and quantitative assessment of wastewater coming in and going out of the CETP was done and it was found that the effluent after treatment had high quantities of organics, dissolved and suspended solids, much above the prescribed limits. It also possessed a pale yellow colour. This so-called treated water was released into a fresh water body Palar River, thereby polluting it. After suggesting necessary improvement measures the quality of wastewater was brought within the prescribed limits but before this a lot of damage had already been done to the surrounding areas. Some bore wells contained stinking pale yellow water in which was present fresh drinking water once upon a time. The river too had been polluted to quiet an extent. It is known that Coastal Zone Colour Scanner (CZCS) and the Thematic Mapper (TM) yield good data on Ocean colour and by employing techniques of band ratioing we can estimate the concentrations of chlorophyll quite precisely. However, the estimation of Dissolved and Suspended particles is rather difficult specially if they do not impart colour. If the techniques of remote sensing (i.e. scanners of better resolution) can be applied for the detection and estimation of pollutants, it would be of great assistance in checking the pollution problems.

Poster: **Investigating the Oceanography of the North Arabian Sea: The NASEER Program (North Arabian Sea Environment and Ecosystem Research)**.
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The North Arabian Sea is distinguished by its many features that makes it an ideal place to study changes in physical parameters brought about by seasonally driven atmospheric forcing. The thermal structural response to momentum and heat flux as exhibited by changes in mixed layer depths produces associated changes in chemical and biological response which are key to understanding primary, secondary and tertiary production and hence particle flux. The chemical and biological data thus generated are of critical importance in building models for forecasting global carbon cycle and predicting climate changes. The NASEER program was launched with several goals in mind: 1) Develop a comprehensive understanding of the spatial and seasonal distributions of pigments, primary production and size-fractionated primary production between Pakistan and Oman coasts. 2) Develop knowledge of seasonal and spatial distributions of secondary and tertiary productivity and food chain dynamics. 3) Initiate survey of large zooplankton, larval fish and fish and their relationships to the oxygen minimum zone. 4) Develop an understanding of the physical and biological oceanographic features responsible for high fisheries yield typical of late summer, early fall off the coast of Pakistan. 5) Improve knowledge regarding the extent to which variations in recruitment of commercially important fish species along the coast of Pakistan and within its EEZ is related to the intensity and duration of monsoons. 6) Characterise unusual bioluminescent displays in the North Arabian Sea, especially the seasonality of displays and their relationships to plankton dynamics. So far, a total of five NASEER cruises have been conducted in collecting data on salinity, temperature, dissolved oxygen, fluorescence, nutrients, pigments, bacteria, phytoplankton, zooplankton and fish along a cruise track totalling 1,200 nautical miles. The track includes 62 ocean observation stations and strategically located, 24-hour time-series stations.

Oral: **On the paradox of high mesozooplankton biomass in the western Arabian Sea throughout the year: re-analysis of IIOE data and comparison with newer data.** M. A. Baars, Department Biological Oceanography, Netherlands Institute for Sea Research, P.O. Box 59, 1790 AB Den Burg, Texel, The Netherlands. baars@nioz.nl

The mesozooplankton data from the northwestern Indian Ocean collected during 1962-1965 by the International Indian Ocean Expedition (IIOE; displacement volumes from vertical net catches, 330 µm mesh, upper 200 m) showed highest biomass in the summer upwelling areas off Oman and Somalia but also suggested that zooplankton stocks were relatively large outside the SW monsoon. Catches by 200 µm nets off Oman (1963/64), Yemen (1984/85) and Somalia (1992/93) confirmed that mean biomass during winter is considerably above the level that is found in waters with the typical tropical structure. In the Gulf of Aden, the NE monsoon is even the richest zooplankton season. This is due to winter cooling, with entrainment of nutrients into the upper layer producing phytoplankton blooms. The relatively high zooplankton biomass outside the upwelling season seems less paradoxical since seasonal differences in phytoplankton production and stock are not as extreme than previously thought. On the one hand, the early ^{14}C data underestimated primary production outside the SW monsoon, and on the other hand, the CZCS images exaggerated the chlorophyll concentration during the SW monsoon. The productivity in the strong Somali Current upwelling is below potential due to large advection and mixing, and zooplankton stocks in July are probably much smaller than off Oman. Results from an Arabian Sea model (McCreary *et al.* 1996, Prog.Oceanog.37, p.193), including zooplankton biomass and grazing, support the observation that zooplankton development differs between subregions and that entrainment blooms produce zooplankton peaks during the NE monsoon as well. The IIOE data set seems still useful for comparison with existing and recently collected data from smaller-meshed nets, and for validation of JGOFS Arabian Sea modelling. Displacements from 330 and 230 µm catches were strikingly similar (*RV Discovery* 1963/64). In catches from hauls with a 50 µm net, the 50-300 µm fraction only added about 25% to the biomass >300 µm (samples without contamination by phytoplankton, *RV Baldrige* 1995).

Oral: **Offshore phytoplankton pigment for 1978-1986 in the Arabian Sea and for 1978 -1981 in the Laccadive Sea from the Coastal Zone Color Scanner.** K. Banse, School of Oceanography, Box 357940, University of Washington, Seattle, WA 98195-7940, USA. banse@u.washington.edu

For the open Arabian Sea north of 5°N, Coastal Zone Color Scanner (CZCS) observations for most available dates, re-processed using new cloud-screens will be presented as daily means for 13 subregions. Noting the two seasonal blooms in the north and one (SW monsoon) in the central and southern Arabian Sea, monthly averages of pigment will be correlated with wind strength, wind curl, and heat flux. Daily means from the CZCS Global Data Set for five subregions for the Laccadive Sea show that the seasonal cycle is hardly affected by the upwelling on the Indian shelf. Instead, it is quite similar to that in the Arabian Sea to the west of the Laccadive and Maledive islands chain. There is no bloom in the Laccadive Sea during the NE monsoon.

Poster: **Monsoonal influence on pigment chemotaxonomic distributions of phytoplankton in the Arabian Sea.** R.G. Barlow[1], R.F.C. Mantoura[2] & D.G. Cummings[2], [1]Sea Fisheries Research Institute, Private Bag X2, Rogge Bay 8012, Cape Town, RSA; [2]Plymouth Marine Laboratory, Prospect Place, West Hoe, Plymouth PL1 3DH, UK. rgbarlow@sfri.wcape.gov.za

Variations in the distribution of chemotaxonomic pigments were monitored in the Arabian Sea and the Gulf of Oman at the end of the SW monsoon in September 1994 and during the inter-monsoon period in November/December 1994 to determine the seasonal changes in phytoplankton composition. Pigment abundances and ratios were used to estimate the proportion of eucaryotes and procaryotes contributing the total chlorophyll *a*. The Gulf of Oman was characterised by sub-surface chlorophyll maxima at 20 to 40-m during both seasons, and low levels of divinyl chlorophyll *a*. This indicated that prochlorophytes did not contribute significantly to the total chlorophyll *a*. Prymnesiophytes (19'-hexanoyloxyfucoxanthin), diatoms (fucoxanthin) and chlorophyll *b* containing organisms accounted for most of the phytoplankton biomass in September, while prymnesiophytes dominated in November/December. In the Arabian Sea in September, high total chlorophyll *a* concentrations up to

1742 ng l^{-1} were measured in the coastal upwelling region and a progressive decline was monitored along the 1670 km offshore transect to oligotrophic waters at 8^0N. Divinyl chlorophyll *a* was not detected along this transect except at the two most southerly stations where prochlorophytes were estimated to contribute 25-30 % to the total chlorophyll *a*. Inshore, the dominance of fucoxanthin and/or hexanoyloxyfucoxanthin indicated that diatoms and prymnesiophytes generally dominated the patchy phytoplankton community, with zeaxanthin containing *Synechococcus* also being important, especially in surface waters. At the southern oligotrophic localities, *Synechococcus* and prochlorophytes dominated the upper 40-m and prymnesiophytes were the most prominent at the deep chlorophyll maximum. During the inter-monsoon season, total chlorophyll *a* concentrations were generally half those measured in September and highest levels were found on the shelf (1170 ng l^{-1}). Divinyl chlorophyll *a* was detected at all stations along the Arabian Sea transect and we estimated that prochlorophytes contributed between 3 and 28 % to the total chlorophyll *a*, while at the 2 oligotrophic stations this proportion increased to 51-52 %. While procaryotes were more important in November/December than September, eucaryotes still accounted for >50 % of the total chlorophyll *a*. Pigment/total chlorophyll *a* ratios indicated that 19'-hexanoyloxyfucoxanthin containing prymnesiophytes were the dominant group, although procaryotes accounted for 65 % at the two southerly oligotrophic stations.

Oral: **The Arabian Sea Carbon Cycle, a Vertical Flux Modelling Study**. J. C. Blackford & P. Burkill, Centre for Coastal and Marine Studies, Plymouth Marine Laboratory, Prospect Place, Plymouth, PL1 3DH, UK. jcb@pml.ac.uk
The objective of this study is to quantify the carbon cycle for three characteristic stations in the Arabian Sea and in so doing determine the relative influence of physical and ecological processes on carbon fluxes. The three positions chosen correspond to stations A1, A5 and A7 of the ARABESQUE Arabian Sea process study and may be considered to represent strong upwelling, downwelling and a-seasonal zones respectively. The modelling methodology used is a well tested synthesis of the Princeton Ocean Model (POM) and the European Regional Seas Ecosystem Model (ERSEM) which has been adapted for use in the Arabian Sea situation. This provides a vertically resolved process flux model including; detailed trophic dynamics, the carbonate cycle, atmospheric CO_2 exchange, multi-nutrient limitation and sedimentation losses within a dynamic simulation of the mixed layer. The influence of short-term physical forcing events on the response of the ecology indicates the importance of a well-coupled and parameterised physical model. Also shown is the complexity of light, nutrient and grazing interactions with respect to bloom formation and cessation, and the balance between classical and microbial type dynamics. The exchange of CO_2 between the water column and the biota seems to have little direct connection with the exchange of CO_2 between atmosphere and sea, the former having a high degree of variation compared with the latter in addition to the general lack of correspondence between these two signals. CO_2 exchange is instead primarily a function of the physical forcing. The a-seasonal oligotrophic regimes may periodically display influx or outflow of CO_2, but over an annual cycle the net exchange is small (~200 mmoles m^{-2} y^{-1} loss to the atmosphere). In the upwelling zone outgassing of CO_2 from the water is permanent and amounts to ~4000 mmoles m^{-2} y^{-1}.

Oral: **Modelling primary production in the subtropical North Atlantic.** H. A. Bouman[1], B.D. Irwin[2], S. Sathyendranath[3], T. Platt[2], M.R. Wernand[4], & G.W. Kraay[4], [1]Biology Department, Dalhousie University, Halifax, Nova Scotia, Canada, [2]Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada, [3]Oceanography Department, Dalhousie University, Halifax, Nova Scotia, Canada, [4]Netherlands Institute of Sea Research, Den Burg, Texel, The Netherlands. bowmanh@mar.dfo-mpo.gc.ca
Bioptical characteristics of subtropical phytoplankton were assessed at five time-series stations located in the central North Atlantic basin. At each of the stations, information on the vertical structure of algal biomass, photophysiological parameters and chlorophyll-specific absorption coefficients was obtained and incorporated into a spectral model of primary production. When profiles of instantaneous production generated by the model were compared with production profiles obtained by 12-hour *in situ*

incubations, a clear discrepancy was observed: estimates of production generated by the model were noticeably higher than measurements of in situ production at the same depth. One reason why modelled production might have been overestimated at depth is that the modelled irradiance was too high. To investigate whether the attenuation of underwater irradiance was misrepresented in the model, vertical profiles of spectral irradiance generated by the model were compared with profiles of spectral irradiance at specific wavebands measured using a spectral irradiance meter. Upon examining the two spectral irradiance profiles, a divergence was noted that below the mixed layer in the blue wavebands, where modelled irradiance values were markedly higher than the measured irradiance. In the green wavebands, however, the computed and measured irradiance profiles were in good agreement. To reconcile the two irradiance profiles, the assumed contribution of yellow substances to total absorption was increased below the mixed layer, since these substances are known to absorb blue light strongly. When the adjusted irradiance profiles were introduced into the model, the magnitude and shape of the computed production profiles corresponded very well with the *in situ* production profiles.

Oral: **Bio-optical modelling in the Arabian Sea.** W. Breves & R. Reuter, Carl von Ossietzky University, Physics Department, D-26111 Oldenburg, Germany. wiebke@las.physik.uni-oldenburg.de
As part of the German JGOFS Indian Ocean Programme, two cruises into the Arabian Sea took place in 1997 at the onset of the Southwest monsoon. New data on yellow substance, tryptophan and chlorophyll fluorescence were obtained. The examination of this data set together with other parameters like chlorophyll, dissolved organic carbon and dissolved inorganic carbon yields new hints for a better understanding of the biogeochemistry of the Arabian Sea. The findings indicate, that optical parameters like the fluorescence of tryptophan bound to pigments, yellow substance and proteins reflects upwelling processes as well as the routinely used hydrographic parameters. They can be used as additional information to describe and explain biochemical processes. To synthesise the findings first steps towards a bio-optical model have been made. The 0D- / 1D-model encloses optical variables like yellow substance and tryptophan fluorescence into the context of a biogeochemical model. This model is used to simulate and, if possible, to quantify observed processes. The incorporation into a 3D-model of the Arabian Sea is planned to overcome the lack of a 'realistic' description of hydrographic conditions, which is always connected with 1D-models.

Oral: **Southwest monsoon in the Western Arabian Sea: phytoplankton dynamics.** Klaus von Bröckel & Claudia Sellmer, Institute for Marine Research, University of Kiel, Düsternbrooker Weg 20, 24105 Kiel, Germany. broeckel@ifm.uni-kiel.de
Monsoons are a determining feature of the Western Arabian Sea, reversing the general current directions twice a year. During the SW-monsoon (June to September), a region of intense upwelling occurs along the coast of Oman. From these events, long filaments of relatively cold and nutrient rich water develop and finally do stretch for several hundred kilometres into the open ocean. Naturally, with changing monsoons, conditions for phytoplankton populations are changing too. Thereby three major regions within the Western Arabian Sea can be distinguished physicochemically: (1) the central part with stable oligotrophic conditions: SST above 27 °C, a deep thermocline (about 80-m) and nutrient concentrations below detection limit down to about 90-m; (2) the highly variable "Findlater Jet region" with conditions ranging from oligotrophic to eutrophic from the outside to the inside of filaments: SST between 24 and 27 °C, NO_3: between 0 and 10 µM/l in surface water and (3) the coastal upwelling with typical upwelling features of low SST (<24 °C) combined with relatively high nutrients in surface water (NO_3 between 5 and 18 µmoles l^{-1}). Concerning phytoplankton dynamics these regions can easily be described and characterised with general parameters like surface Chl *a* and POC concentrations as well as primary production. The central part contains ca. 0.4 mg Chl *a* m^{-3}, 85 mg POC m^{-3} and 10-14 mg C; Findlater Jet region contains between 0.4 and 0.5 mg Chl *a* m^{-3}, 120 mg POC m^{-3} and 80 mg C m^{-3} d^{-1}; coastal upwelling contains 0.9 mg Chl *a* m^{-3}, 150 mg POC m^{-3} and about 190 mg C m^{-3} d^{-1}. But, intense analysis reveal the possibility of unexpected severe silicate limitations in the coastal upwelling as well as a huge variety of different phytoplankton populations within the Findlater Jet region as well as the coastal upwelling. Conceptional models of the different regions are presented which demonstrate the necessity of intense measurements for the understanding of a pelagic

system, although for a general overview and/or modelling purposes generalising parameters might be sufficient.

Oral: **What controls enhanced production during upwelling in the Arabian Sea?** P. Burkill[1], E. Edwards[1], & SONNE 120 Cruise Team[2], [1]CCMS Plymouth Marine Laboratory, Plymouth PL1 3DH, UK, [2]Plankton Group, Institut fuer Meereskunde, Kiel D 24105, Germany. p.burkill@pml.ac.uk.
The conventional view on biological response to upwelling is that diatoms out compete other phytoplankton groups and come to dominate the phytoplankton. During the German JGOFS programme in the Arabian Sea in 1997, we ran a 17-day drift experiment during the upswing of the summer monsoon. We were surprised to find few diatoms in surface waters and those present, particularly Dactyliosolen phukensis and Lauderia annulata, declined. At the same time photosynthetic and heterotrophic bacteria, including Synechococcus, increased. Such a response is more characteristic of a 'recycling' community rather than one fueled by 'new' production considered more typical of upwelling zones. During the drift experiment, upwelling was vigorous and surface nitrate concentrations raised from 8 to 14 µmoles l^{-1}. Microzooplankton populations were low, and their herbivory decreased in parallel with the loss of diatoms and did not increase with the rise in picoplankton. This might be a key to what is forcing the system. The paper will elaborate on this and conclude that we now need to reappraise our views on biological response to upwelling and the factors that control production in such systems.

Oral: **The oceanic nitrogen cycle and global change: an idea whose time has come?** L.A. Codispoti, Old Dominion University, Norfolk, VA 23529, USA. lou@ccpo.odu.edu
It might be fair to say that, until recently, a majority of investigators concerned with global change have discounted the idea that the oceanic nitrogen cycle could be a major factor in considerations of global climate change. This is no longer the case because of the following factors: 1) The recognition that iron limitation is important in the ocean and that primary production supported by nitrogen fixation requires much more iron than "normal" primary production. 2) Upward revisions of the major source and sink terms for oceanic fixed nitrogen suggest a residence time for oceanic fixed nitrogen about 3,000 years vs. the "canonical" 10,000-year residence time. 3) Evidence that suggests that the oceanic source term for nitrous oxide is stronger than previously thought and very unevenly distributed in time and space. Because the Arabian Sea has enhanced rates of nitrous oxide turnover, denitrification, iron supply, and nitrogen fixation, it represents an excellent natural laboratory for furthering our understanding of those aspects of oceanic nitrogen cycling that are most relevant to considerations of global climate change. The adjacent Red Sea could also prove to be an excellent natural laboratory because of high nitrogen fixation rates, inflows and outflows that are relatively easy to quantify and the possibility of high sedimentary denitrification rates.

Oral**: Sedimentary organic matter distribution and preservation controls in the Arabian Sea: Pakistan margin.** G.L. Cowie[1], S.E. Calvert[2], T.F. Pedersen[2], R.Keil[3], H. Schulz[4] & U. von Rad[4], [1]Marine and Environmental Geosciences Group, Geology and Geophysics Department, University of Edinburgh, [2]Oceanography Department, University of British Columbia, [3]School of Oceanography, University of Washington, [4]Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, Germany. glcowie@glg.ed.ac.uk
Organic-rich sediments that line the margins of the Arabian Sea are generally attributed to high primary production, in turn linked to monsoon-related upwelling, or to the intense mid-water oxygen minimum zone (OMZ) that impinges on the continental slope. Recently, adsorption of organic material onto mineral surfaces has been identified as a further important control on the organic matter content of marine sediments. We report on textural, organic, inorganic and stable isotopic studies of surficial sediments from stations spanning the OMZ on the Pakistan margin. The results show a general predominance of marine organic material and a clear mid-slope organic matter concentration maximum, roughly coincident (as elsewhere) with the OMZ. Despite this factor of 2-4 enrichment in concentration, bulk and molecular-level organic compositions are either uniform or only subtly variable across the OMZ, and some homogeneous sediments below the OMZ are as or more organic-

rich than laminated sediments within it. Moreover, trace metal distributions indicate that depositional redox conditions within the OMZ are only moderately reducing. These observations clearly indicate that oxygen depletion is not the sole or even the primary control on sedimentary organic content on this margin. Nonetheless, organic carbon loadings relative to available mineral surface area resemble those previously observed in fully anoxic regimes, and these decline sharply below the OMZ. Consequently, exposure to oxygen may play an important role in controlling the lower boundary of the belt of organic-rich sediments observed on Arabian Sea margins.

Oral: **Radiative transfer model for ocean-atmosphere system: Application to PAR computation**. E. Devred, Universite du Littoral, Maison de la Recherche, Laboratoire Interdisciplinaire en Sciences de l'Environnement, 28 Avenue Foch, BP 59 62930 Wimereux, France. devred@loalit.univ-littoral.fr
Radiative transfer models are powerful tools to understand the light behaviour in atmosphere and ocean. We have developed a model ("OS AIR/EAU") to compute the vertical distribution of the PAR (Photosynthetically Active Radiation, 0.4 to 0.7 5m) in the ocean under different conditions of the atmosphere and the ocean. This work deals with a presentation of the "OS AIR/EAU" code and a sensitivity study of the PAR to atmospheric and oceanic parameters. The "OS AIR/EAU" code is based on the resolution of Radiatif Transfer Equation with the method of Successive Orders of Scattering (Deuzi et al. 1987, Chami 1997 and Dilligeard 1997). This model allowed us to simulate different sky conditions (11 types of clouds and 4 types of aerosols) in a multilayer atmosphere (the number of layer depends on the accuracy and the optical thickness). The oceanic part is calculated in a similar way. The different parameters are the depth, the concentration and the optical properties of suspended matter, the chlorophyll and yellow substances. The atmospheric part of this model was validated with the code GAME (Global Atmospheric ModEl, Dubuisson 1996) and the oceanic part with in situ measurements. A sensitivity study of the PAR to different atmospheric and oceanic conditions was performed. The main parameters in the atmosphere are the clouds because of their important optical thick, the solar angles and the aerosol optical characteristics. In the ocean, we study the decreasing of PAR at different concentrations of chlorophyll and suspended matter, keeping the concentration of yellow substances as constant. This model is useful to determine the euphotic zone and has good estimation of PAR in different water cases (case 1 and case 2, Morel and Prieur 1977). Both parameters could be integrated in primary production model.

Oral: **Formulation of plankton models--how can a dynamical-systems approach help us?** A. M. Edwards**,** Biological Oceanography Division, Bedford Institute of Oceanography, B240, P.O. Box 1006, Dartmouth, Nova Scotia, B2Y 4A2. andy@caligo.bio.dfo.ca
The formulation of plankton population models is fraught with uncertainties. These include determining how many biological entities should be modelled, which mathematical functions should be used to represent ecological processes, and what values should be ascribed to the parameters of these functions. These problems were addressed by investigating the dynamics of four seasonally forced plankton population models. Two are NPZ models, explicitly simulating concentrations of nutrient (N); phytoplankton (P) and zooplankton (Z) in the oceanic mixed layer. The models differ only in the functional form of zooplankton mortality (the so-called closure term). The other two models are NPZD models, which additionally include detritus (D). The detritus can be consumed by zooplankton in one NPZD model, but not in the other. Annual simulations of the models are presented. Features of the simulations include the presence of a spring bloom, persistence of zooplankton through the winter and occurrence of short-term oscillations of the populations in the summer. Any of these features may or may not occur depending on the differences between the structures of the models and the parameter values used. The occurrence or absence of the features is explained by computing bifurcations for the four unforced models, using the mathematical theory of dynamical systems. The resulting bifurcation diagrams indicate how the differences in the simulations are due to the alternative model formulations and parameter values. Such information provides modellers with an improved understanding of the dynamics of plankton models.

Oral: **Functions used in Biological model and their influences on simulations**. H. Gao & W. Sun, Institute of Physical Oceanography, Ocean University of Qingdao, 266003, Peoples Republic of China. wxsun@lib.ouqd.edu.cn

The processes taking into account in biological modelling is getting more complete and more complex, but the photosynthesis, respiration, grazing of zooplankton on phytoplankton, natural mortality are the most important. There are just a few kinds of descriptions of respiration and natural mortality, whereas the functions used to describe the photosynthesis-light relationship, the nutrient limitation and grazing are quite different in different biological models. Several types of functions showing radiation and nutrient limitation on photosynthesis and zooplankton grazing on phytoplankton generally used in biological and physical-chemical-biological coupled models are presented and analysed. Based on a simple NPZD (Nutrient (N), Phytoplankton (P), Zooplankton (Z), and Detritus (D)) biological model, the influences of different function types on model results are shown. It is indicated that function types may exert a great influence on model results. Therefore, it is very important to find functions to fit a specific marine ecosystem.

Poster: **On the variability of oceanic air-sea dissolved oxygen fluxes to the atmosphere**. H. E. Garcia & Ralph F. Keeling, Scripps Institution of Oceanography, University of California-San Diego, La Jolla, CA 92093-0236, USA. hegarcia@ucsd.edu

The distribution of oxygen concentration in the atmosphere depends on the spatial and temporal pattern of land and oceanic sources and sinks. We examine the effect of global oceanic air-sea dissolved oxygen flux variability. Specifically, we evaluate the large-scale effect of seasonal sea-surface heat flux and seasonal to inter-annual sea-surface temperature variability on the net oxygen air-sea input to the atmosphere. The oceanic oxygen flux to the atmosphere is derived from climatological sea-surface dissolved oxygen data and gas-exchange coefficient using ECMWF winds. The effect of seasonal to inter-annual (1982-1998) sea-surface temperature (SST) changes on oxygen fluxes is investigated. We derive least-squares relations between net oxygen air-sea flux and heat flux, sea-surface temperature, and satellite derived primary production estimates. The oceanic net oxygen flux to the atmosphere is examined using a coarse atmospheric transport model. The modelled atmospheric results are compared to time-series of atmospheric oxygen data collected along an array of sea-level monitoring stations. Our ultimate goal is to define empirical algorithms that relate satellite and physical data to estimate regional to basin-scale oxygen gas fluxes on seasonal to inter-annual time scales. Our results show a strong correlation between oxygen flux and heat flux poleward of about 30° in both hemispheres. Weaker correlation values are mostly restricted to the tropical region. A similar correlation is found between sea-surface oxygen flux, satellite derived primary production data, which suggest regional differences between physical, and biological source sinks of oceanic fluxes to the atmosphere. The regional distribution of heat flux and SST in the tropics is dominated by stronger subsurface advection than in the subtropical band. Weaker correlations found in the tropics might be due to poorer spatial and temporal coverage of sea-surface oxygen data.

Poster: **Using high quality phosphate data to help estimate nitrate deficits in the Arabian Sea.** S.E. Gaurin[1], L.A. Codispoti[1], S.W.A. Naqvi[2] & A.H. Devol[3], [1]Center for Coastal Physical Oceanography Old Dominion University, Norfolk, VA 23529, USA; [2] National Institute of Oceanography, Dona Paula, Goa -403 004, India; [3]School of Oceanography, WB-10, University of Washington, Seattle, WA 98195, USA. gaurin@ccpo.odu.edu

The northern Arabian Sea contains one of the three major sites of the suboxic portion of the global oceanic water column. Although these regions comprise only ~0.1 percent of the total oceanic volume, the denitrification that occurs in them represents a globally significant sink for fixed nitrogen. In investigations of these regions, various methods have been employed to estimate the amount of nitrate that has been converted to free nitrogen gas. Recent studies of the Arabian Sea have emphasised the use of inorganic nitrogen and oxygen data along with physical oceanographic properties to estimate nitrate deficits in its suboxic waters. These methods have given results that are moderately different, largely because of differing assumptions but probably also because of the complicated water mass structure in the Northern Arabian Sea. In recent years, phosphate data have not been employed to

estimate nitrate deficits in the Arabian Sea, in part because many historical data sets do not contain oxygen, nitrate, nitrite, and phosphate data of uniformly high quality. In this work, we re-examine the utility of employing phosphate data for helping to refine estimates of the nitrate deficits in the Arabian Sea, using high quality data obtained during the U.S. JGOFS Arabian Sea Process Study. We will show that with such data, phosphate concentrations can be useful in estimating nitrate deficits.

Poster: **The Seasonality of phytoplankton Regime in the Bay of Bengal.** H.R.Gomes[1], J.I.Goes[1, 2] & T.Saino[1]. [1]Institute for Hydrospheric-Atmospheric Sciences, Nagoya University, 464-8601 Japan, [2]National Institute of Oceanography, Dona Paula, Goa, 403004, India. helga@ihas.nagoya-u.ac.jp
We have examined the seasonality of phytoplankton in the western and northern Bay of Bengal using shipboard data collected during three seasons as well as ocean color imagery from OCTS and SeaWiFS. Seasonal changes in the hydrography of the bay that were observed during these seasons gave rise to striking differences in biomass and primary productivity. The influx of heavy fresh water from rivers and the resulting stratification impeded vertical transfer of nutrients. Although such a nutrient regime resulted in an oligotrophic environment, physical processes that could erode the strong halocline substantially enhanced chlorophyll a and primary production. In March-April (pre-southwest monsoon) the poleward flowing East India Coastal Current brought to the surface, nutrient laden cooler waters that enriched the coastal region, but highest biomass (Chl a, 53 mg m^{-2}) and productivity (4.5 g C m^{-2} d^{-1}) were in the region of an eddy like structure along the coast and in the region between 130° and 160°N. Its appearance in satellite images of two consecutive years suggests the structure to be an annual feature. Wind driven coastal upwelling and increased river runoff during the following season, the southwest monsoon (July-August), increased phytoplankton biomass dramatically (92 mg m^{-2}) but productivity averaged only 0.3 g C m^{-2} d^{-1} suggesting light limitation due to intense cloud cover. With a reduction in cloud cover and enhanced irradiance during the following season, the northeast monsoon (January-February), primary production increased especially in the northern part of the bay where phytoplankton appeared to benefit from both improved light conditions and nutrient inputs from estuarine mechanisms and river runoff.

Poster: **JGOFS-India - CD ROM.** A. Ghosh Kolli, NODC (INDO), National Institute of Oceanography, Dona Paula, Goa 403 004, India. garvind@csnio.ren.nic.in ‘
The JGOFS-India programme, which was conceived in 1991, had completed its field programme. This was done during the years 1992-97 although the main programme was carried out in five cruises during 1994-97. A host of oceanographic parameters was collected during these cruises. In this CD ROM, an attempt is made to put together all the data measured along with the details on each of the investigations, measurements, protocols, participating organisations with a link to the people involved. There is a separate section on new scientific insights, which have emerged in JGOFS-India programme apart from a section on important scientific results. All the papers published in reviewed journals and presented in seminars/symposia/meetings are also incorporated in the publication section. A user friendly graphical software package has been developed which would help the user to easily access and visualise the data with various options such as latitude vs. depth, longitude vs. depth vertical sections, plots of individual or cluster of profiles with their mean. The numerical data could also be accessed on a variety of options such as cruises, stations, monthly, seasonally and yearly.

Poster: **Phytoplankton ecology in coastal waters off Gopalpur, notheastern Bay of Bengal.** R. Gouda, S.K.Tripathy & R.C. Panigrahy, Department of Marine Sciences, Berhampur University, Orissa, India.
Seasonal and spatial variation in species composition, population density and photosynthetic pigments of phytoplankton in relation to various environmental factors were studied during January-December 1992. During the course of investigation, 129 species of phytoplankters were encountered. Floristically, diatoms were predominant over dinoflagellate. Number of centric and pennate diatoms remained almost parallel. During the period of observation, Biddulphiaceae, Coscinodiscaceae and Chaetoceraceae among centrales and Naviculaceae among Pennales emerged as floristically rich families. Marked variations were also found in the floral composition during pre-monsoon, monsoon

and post monsoon seasons. Blooming of *Asterionella glacialis* followed by *Peridinium* sp. are striking features of this study. Termination of the bloom is due to depletion of silicate and nitrate in the water column. Changes in salinity and nutrient concentration played major roles in controlling the distribution of phytoplankton. Pigment concentrations in general followed the phytoplankton density and there exists good correlation between chlorophyll-a and phytoplankton density.

Oral: **Comparison of anthropogenic CO_2 concentration in seawater across the Arabian Sea and the Bay of Bengal.** C. Goyet, C. Coatanoan, & G. Eischeid, Woods Hole Oceanographic Institution, 360 Woods Hole Road, MS #25, Woods Hole, MA 02543, USA. cgoyet@whoi.edu
Using a novel approach for the calculation of anthropogenic CO_2 concentration in the ocean based upon the fundamentals of water-sources mixing (Goyet et al., 1999), we compare the anthropogenic CO_2 fields along WOCE sections across the Arabian Sea and the Bay of Bengal. As part of a co-operative effort of the JGOFS and WOCE programs, we have measured total CO_2 (TCO_2) and total alkalinity (TA) along these sections in September-October 1995. We describe the observations and mixing of water-sources and the quantification of anthropogenic CO_2 concentrations in these waters. The data show large spatial variations in surface seawater of both TCO_2 (up to 50 μmol kg^{-1}) and TA (up to 40 μmol kg^{-1}). The contrasts between the sections across the Arabian Sea and the Bay of Bengal emphasise the large property differences between the two ocean basins. Multiparametric analyses on the data clearly show the relative contributions of different water-sources in each of the ocean sections. The mixing coefficients calculated from the multiparametric analyses are further used to quantify anthropogenic CO_2 concentrations in each water-source. The results indicate that in the surface waters there is more anthropogenic CO_2 across the Bay of Bengal (50.4 μmol kg^{-1} in the water-source) than across the Arabian Sea (42.1 μmol kg^{-1} in the water-source). In contrast, anthropogenic CO_2 has penetrated deeper in the Arabian Sea than in the Bay of Bengal. We will present the spatial variations of the anthropogenic CO_2 concentrations as well as the total inventory of anthropogenic CO_2 along these two sections.

Poster: **Primary production in the Arabian Sea during 1995: historical comparisons, filaments, and the iron story.** M.R. Hiscock & R.T. Barber, Nicholas School of the Environment, Division of Earth and Ocean Science, 135 Duke Marine Lab Road, Beaufort, NC 28516, USA. hiscock@duke.edu
Primary productivity has been measured in the highly variable Arabian Sea off the coast of Oman on six cruises in 1995 as part of the US-JGOFS Arabian Sea Process Study. Cruises have sampled the winter northeast monsoon (two cruises), spring intermonsoon, summer southwest monsoon (two cruises), and fall intermonsoon. *In Situ* and on deck productivity was determined according to JGOFS protocols on a section that ran offshore in a south-easterly direction for 1000 km to 14.5°N and 65°E. This section was intended to sample the coastal upwelling and offshore upwelling regions of the Arabian Sea. The lowest value observed during the six cruises was about 60 mmol C $m^{-2}d^{-1}$ at the 14.5°N, 65°E station. The highest values were about 150 mmol C $m^{-2}d^{-1}$ at offshore stations 500 km to 700 km from the coast. During the first SW monsoon cruise in July/August productivity was relatively high across the entire 1000-km section (140 mmol C $m^{-2}d^{-1}$). The mean productivity value for the section during the two SW monsoon cruises was 125±8 mmol C $m^{-2}d^{-1}$ (similar to mean values of 127±14 and 115±21 reported by comparable cruises on the Arabesque 1994 and the Anton Bruun 1963 respectively). The annual mean productivity along the section was 97±10 mmol C $m^{-2}d^{-1}$. More frequent "short" stations, which measured productivity with on deck incubations, suggested that widely spaced "long" stations did not capture the variability of productivity and the existence of filaments. Mean annual Arabian Sea productivity is about twice that in the equatorial Pacific and is coupled on the scale of hundreds of kilometres to seasonal wind variability. The productivity vs. chlorophyll signature of SW monsoon upwelling stations and filament sites is similar to productivity vs. chlorophyll signatures for iron enrichment experiments in the equatorial Pacific Ocean.

Oral: **Bacterial Utilisation of Primary Production-C in the Indian Ocean: Results and Principles**. H.-G. Hoppe & S. Ullrich, Institute of Marine Science, Department of Marine Microbiology, Duesternbrookerweg 20, D24105 Kiel, Germany. hhoppe@ifm.uni-kiel.de

Results from two German JGOFS Indian Ocean expeditions during SW-monsoon periods are reported. Horizontal and vertical profiles of bacterial C-demand were measured together with autotrophic C-production from the equator towards the upwelling regions off the coast of the Arabic peninsula. The relationship between both variables showed a strong dependency from the prevailing climatic and hydrographic regime. Most of bacterial biomass and secondary production was concentrated in the mixed layer. Vertical distributions of bacteria and their activities were clearly different in the oligotrophic and eutrophic parts of the ocean. In addition, the relationships between bacterial growth, abundance and different hydrolytic decomposition processes changed with depth. Strict C-limitation of bacterial growth led obviously to the induction of C-recruiting enzymes. This suggests that not only the intensities but also the mechanisms of bacterial OM utilisation as well as remineralization were different in the vertical compartments of the ocean. Possible effects of the suboxic intermediate layer on the decomposition of sedimenting OM are discussed.

Poster: **Boundary retention effects upon contaminant dispersion in secondary flows**. G. Jayaraman, Centre for Atmospheric sciences, Indian Institute of Technology, New Delhi.110016, India. jgirija@cas.iitd.ernet.in
The studies concerning the longitudinal dispersion processes in fluid flows are motivated by the demand for understanding the pollutant mixing in coastal environment, canals and lakes. To begin with, it is important to characterise the longitudinal mixing by a dispersion coefficient and relate that coefficient to bulk flow and channel geometry parameters. Later, this knowledge is to be used to find the rate at which a stream is capable of transporting and dispersing a pollutant. The information will be useful not only to control contamination of a stream or predict levels of pollution but also to determine the dosage of herbicides to be released into canals to kill weeds. The combined effect of secondary flows and irreversible boundary reaction on the dispersion process is analysed based on the generalised dispersion model. The study describes the development of dispersive transport following the injection of a tracer in terms of the three effective transport coefficients, viz. the exchange, the convection and the dispersion coefficients. Unlike the corresponding straight tube analysis where the exchange coefficient was found independent of the velocity distribution, the present analysis shows its dependence on cross-stream velocity distribution. In the absence of interface transport, the exchange coefficient approaches zero and the other two coefficients attain their proper values. At the other extreme, it is shown that for rapid wall reaction mechanism and in the presence of mild secondary flows, the exchange coefficient is enhanced while the convection and the dispersion coefficients are reduced. For large values of the retention parameters, the retention effects are found to be rate determining processes and the secondary flows have negligible effect.

Poster: **Principal Component Analysis of Physical Variables in the Western Arabian Sea During the Southwest Monsoon, 1995**. E. Key, Division of Meteorology and Physical Oceanography, Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL 33149. elka@playin.rsmas.miami.edu.
After the onset of the 1995 southwest monsoon in the Arabian Sea, several mesoscale eddies and upwelling zones formed along the Somali and Omani coasts. During this time, many international projects monitored the salinity and temperature with CTDs and XBTs in an effort to better understand the spatial and temporal extent of these mesoscale features. Using data collected from JGOFS, U.S. and German WOCE, GLOBEC, and ships-of-opportunity, a detailed study of the formation and propagation of the eddies and upwelling areas was performed. Through principal component analysis, variability associated with these mesoscale features was compartmentalised and quantified, giving a good statistical estimate of their spatial and temporal scales. In a preliminary run, the salinity signal associated with the first mode oscillated on a weekly time scale whereas temperature fluctuated on a time scale of 4 days. Principal component modes described a warm Arabian Basin punctuated by four areas of very cool water and increasing salinity with increasing latitude. In an analysis of EOF amplitudes in the upper 300-m, the thermocline appeared at 100-150 m but the 200-m halocline did not. With increased data density and quality control, resolution of the temperature and salinity variability along the coastlines improved.

Poster: **Organic carbon losses measured by heterotrophic activity of mesozooplankton and bacteria in the bathypelagic zone of the Arabian Sea.** Rolf Koppelmann, University of Hamburg, Institute of Hydrobiology and Fishery Research, Zeiseweg 9, 22765 Hamburg, Germany. koppelmann@uni-hamburg.de
Organic carbon requirements for metabolisms of bacteria and mesozooplankton in the bathypelagic zone (i.e. below 1000 m) were calculated for two stations (WAST, 16°N 60°E and CAST, 14°N 64°E) and two different inter-monsoonal periods (October 1995 and April 1997) in the Arabian Sea. These requirements were compared with inputs of particulate organic carbon (POC) measured by sediment traps. Secondary production of bacteria was determined by measuring the rate of ^{3}H-thymidine and ^{3}H-leucine incorporation. The potential oxygen requirements of mesozooplankton were measured by the electron transport system activity and converted into "real" respiration by applying conversion factors from literature. Uptake rates of ^{3}H-thymidine and ^{3}H-leucine by bacteria were below the detection level in the bathypelagic zone. The mesozooplankton demands in the zone between 1050 to 3000 m differed locally and seasonally. At WAST, the mesozooplankton required 1778 µg C m^{-2} d^{-1} in October and only 484 µg C m^{-2} d^{-1} in April. At CAST, the respective values were 997 µg C m^{-2} d^{-1} and 211 µg C m^{-2} d^{-1}. No differences between the stations and time periods were discernible for the zone between 3000 to 3900 m at CAST and 3000 to 4000 m at WAST; the values ranged between 73 and 98 µg C m^{-2} d^{-1}. The input measured by sediment traps seemed sufficient to cover the requirements of the mesozooplankton. However, carbon needed for somatic growth and for losses due to excretion is not considered in this paper. In addition, the requirements of gelatinous organisms are not included.

Oral: **A model for phytoplankton aggregation**. I. Kriest & G. T. Evans, Institut fuer Meereskunde, Kiel, Germany; Department of Fisheries and Oceans, St. John`s, Canada. ikriest@ifm.uni-kiel.de
The formation and subsequent sedimentation of particulate organic matter is governed by many biological and physical processes, including faecal pellet production by zooplankton, and production and aggregation of phytoplankton cells. In nearshore environments, amorphous aggregates 0.5-mm or greater in diameter are important (Alldredge & Gotschalk, 1989). They consist largely of living, photosynthetically active phytoplankton, for example of the genera Chaetoceros and Nitzschia. The sinking rate of these aggregates increases as a power of their diameter (Alldredge & Gotschalk, 1988), leading to a removal of phytoplankton carbon from the upper mixed layer. To check for the influence of such processes as phytoplankton growth, aggregation and sedimentation on carbon removal from the upper mixed layer, a module for the aggregation of phytoplankton cells has been incorporated into a vertically resolved nitrogen-based model simulating the biology of the upper 400-m of the water column of the open ocean. Runs with the model have been compared with the same model representing single phytoplankton cells having a constant sinking rate. The aggregation model shows a higher, more distinct and more rapidly settling peak of the phytoplankton bloom than the model representing single phytoplankton cells with a constant sinking rate. Sensitivity experiments show a strong influence of aggregation, cell size and colony formation on the export production. Especially when simulating colony formation (break-up probability <1) rapidly settling aggregates are produced. Model simulations for locations in the western and central Arabian Sea show the importance of aggregation for flux to the ocean interior.

Oral: **Physical forcing and biological productivity in the Arabian Sea.** S.P. Kumar, M. Madhupratap, P.M. Muraleedharan & M. Gauns, National Institute of Oceanography, Dona Paula, Goa-403 004, India. prasanna@csnio.ren.nic.in
Conventional understanding of the Arabian Sea productivity largely based on the International Indian Ocean expedition (IIOE, 1960-65) and Indian Ocean Expedition (INDEX, 1979) is that upwelling occurring along continental margins during summer (southwest) monsoon (June to September) leads to high primary production along the coastal regions of Somalia, Arabia and along the southwest coast of India. These studies, however, indicate that the open ocean waters of the Arabian Sea largely remain oligotrophic throughout the year. Contrary to this earlier belief, the recent ship board measurements under the Indian programme of Joint Global Ocean Flux Study (JGOFS) indicate high production in

the central Arabian Sea during summer (1995,96) and in the northern Arabian Sea (north of 15^{o} N) during winter (1995) monsoon (November to February). During summer, the physical forcing that makes the open ocean waters of the Arabian Sea productive (ca. 1700 mg C m^{-2} d^{-1}) is through a combination of lateral advection of nutrient rich upwelled waters from Somalia and Arabia and open ocean upwelling. The southwestern coast of India also showed equally high production through coastal upwelling. In winter the physical forcing that brings about the high production (more than 800 mg C m^{-2} d^{-1}) all over the northern (both open and coastal) Arabian Sea is the surface cooling due to reduced solar insolation and evaporation which initiates convection. In contrast, however, the transition periods between monsoons show very low values of production.

Poster: **A data assimilation system for coupled primitive equation ocean circulation and marine biological models**. J.-m. Lellouche, JRC-EC, SAI/Marine Environment Unit, TP 690, I-21020 Ispra (VA), Italy. Jean-michel.lellouche@jrc.it
The main objective of my research activity is to develop a data assimilation system for coupled primitive equation ocean circulation and marine biological models. The system is based on an existing data assimilation tool, available at the Space Applications Institute / Marine Environment Unit of the Joint Research Centre, and based on the Ocean Circulation Model Ispramix and its Adjoint. A specific objective of this project is to list and select relevant biological models for coupling with the ocean model, and to develop, implement, and validate data assimilation techniques for these models. The system will be designed to assimilate a variety of satellite observations such as: Sea-Surface Temperatures derived from AVHRR-NOAA observations, Sea-surface Height Anomalies from TOPEX/POSEIDON and ERS-radar altimeter, and CZCS and SeaWiFS Ocean Color observations.

Poster: **Tidal propagation, water exchange and sediment transport in a mangrove-dominated estuary, Mtwapa Creek, Kenya.** C. Magori, Kenya Marine & Fisheries Research Institute, P.O. Box 81651, Mombassa, Kenya. cmagori@reciscix.com
Mtwapa creek is a tropical, tidal water system surrounded by mangrove dominated mudflats. It is located along the Kenyan coast in the Western Indian Ocean region. In this study, time series of tide, current, temperature and salinity data is used to describe the salient hydrographic features of the system. Harmonic and spectral analysis showed that the tide is typically semi-diurnal (F=0.2). A 30% decrease in the semi-diurnal tidal range including appearance of shallow water tides towards the inner end of the creek indicate a choking caused by channel friction. Maximum currents lag high tide by 3.45 hours and there is a phase lag of 15 - 20 minutes in maximum sea level between the creek and the entrance. The currents show an asymmetry of ebb-dominance. Water exchange was calculated from salinity measurements. The residence time for water was 12 days. The exchange is totally dominated by tides. An implicit one-dimensional numerical model developed by Wolanski (1980) was successfully used to simulate water circulation and sediment transport in the creek. The sediment accumulation in the creek is 80 % inorganic, and based on ^{210}Pb dating is accreting at a rate of 0.098 grams per square cm per year equal to a 2.7 mm per year vertical sedimentation rate. One year of inorganic suspended sediment flux through the inlet is calculated to be a net import of 1.76 kg sec^{-1}.

Poster: **Meridional variability in low light adaptation of Antarctic phytoplankton**. K. Mahapatra, Y. Senga, Y. Okada, & S. Matsumura, School of Marine Science and Technology, Tokai University, 3-20-1 Orido, Shimizu-shi, Shizuoka, 424-8610 Japan; National Research Institute of Far Seas Fisheries, 7-1, Orido 5 chome, Shimizu-shi, Shizuoka, 424-0902 Japan. kedar@scc.u-tokai.ac.jp
Bio-optical data collected from three summer cruises in the south-west Atlantic sector of the Antarctic Ocean were analysed to assess the interrelationship between the beam and diffuse attenuation properties of biological particulates. The covariance between optical depth at 488nm, K(488nm)Z, and pigment-specific beam attenuation coefficient Cp* (660nm) was identified to be a stable parameter to spatially delineate distribution of low light adaptability of phytoplankton. Large variation in Cp* with almost no change in K(488)Z along one meridional transect (45^{o}W), extending from 50^{o}S to 62^{o}S was analysed to assess meridional extent of magnitude of low light adaptability of Antarctic phytoplankton. An examination of horizontal as well as vertical distribution of temperature and sigma-t along 45^{o}W

transect further revealed lower Cp* values to be characteristic of waters with low temperature and high density and vice versa. Cp* was also found to have strong inverse relationship with meridional distribution of silicate. Lower Cp* values were detected in waters with high dissolved silicate concentration at the southern end of the transect, gradually decreasing northwards with depletion of silicate. Such observations clearly established the bearing of water mass on distribution of low light adapted phytoplankton in Antarctic waters. The trend is supportive of the hypothesis that the diatoms and silicoflagellates known to be typical of silicate-rich continental shelf waters close to Antarctic Peninsula, are adapted to low light environment, however, towards the Antarctic Convergence in the north, these groups sink out of the euphotic zone, leaving behind the phytoplankton groups with low silicate requirement. This underlines the importance of silicate distribution in deciphering foot print of low light adapted phytoplankton in Antarctic Ocean. Results from the present study point at the need of incorporating the latitudinal extent of the unique regional photo-biological phenomena in Antarctic Ocean while attempting any future remote sensing models to estimate phytoplankton biomass and primary production in Southern Ocean.

Poster: **Interannual variability of air-sea O_2 fluxes**. G. McKinley, M. Follows & J. Marshall, Climate Physics and Chemistry, Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, 77 Massachusetts Avenue, 54-1517, Cambridge MA 02139 USA. galen@plume.mit.edu
Atmospheric concentrations of O_2 are controlled by rates of photosynthesis and respiration on land and in the ocean, and by fossil fuel combustion. Atmospheric O_2 is consumed in fixed proportion to the amount of CO_2 produced and so is linked directly to the global carbon cycle. Joint time-series measurements of atmospheric CO_2 and O_2/N_2 can be used to infer the fate of fossil fuel carbon dioxide because they allow the separation of ocean and terrestrial components of the CO_2 cycle, and have been used to identify Northern Hemisphere terrestrial biota as a sink for approximately 30% of anthropogenically produced atmospheric CO_2 (Keeling et al. 1996). To arrive at this result, the authors found it necessary to assume that seasonal air-sea O_2 fluxes average to zero over each annual cycle, although this assumption is not supported by data. The balance of O_2 influx and efflux from the ocean may be altered by variability in primary productivity, local wintertime convection or high latitude ventilation rates. In this study, we investigate the magnitude of interannual variability in air-sea O_2 fluxes, and test and quantify the assumption that it can be neglected. We examine the air-sea O_2 flux using a global ocean general circulation model with parameterised biogeochemical processes. We model the global ocean/atmosphere oxygen system using ocean circulation state estimates from the MIT Ocean General Circulation Model, driven by realistic winds and heat fluxes, and with biogeochemical processes parameterised as simplified nutrient cycling. Our future aim is to use ocean circulation state estimates constrained by TOPEX/POSEIDON altimetry and a marine ecosystem model calibrated with SeaWiFS remotely sensed ocean color data (Dutkiewicz et al. 1998). The preliminary global calculations presented here allow an estimation of interannual variability in air - sea O_2 fluxes. Regions and mechanisms of significant influence on air-sea O_2 fluxes are identified.

Poster: **Retrieval of chlorophyll concentrations from coastal case -2 waters using Landsat-5 Thematic Mapper data.** A.K. Mishra, Marine Science Division, Indian Institute of Remote Sensing, Dehradun, India. mishra@hotmail.com
The Landsat -5 TM data covering the coastal waters off Visakhapatnam and off Paradip, Bay of Bengal East Coast of India have been taken to retrieve the surface chlorophyll concentration distribution. The subsurface reflectance R(0_) for band -1 and band-2 were retrieved after applying the atmospheric correction algorithm. A semi-empirical algorithm for retrieval of chlorophyll and suspended sediment concentrations developed from in situ measurements has been applied to the Landsat -5 TM bands. The satellite derived and in situ measured chlorophyll concentrations were compared. The above study indicates that the chlorophyll concentration can be retrieved from Landsat -5 TM data with a difference of ± 33% from optically complex coastal waters.

Oral: **Seasonal variation of hydrographic and nutrient fields during the U.S. JGOFS Arabian Sea Process Study.** J. Morrison[1], L.A. Codispoti[2], S. Gaurin[2], B. Jones[3], V. Manghnani[1] and Z. Zheng[3], 1Department of Marine, Earth and Atmospheric Sciences, North Carolina State University, Raleigh, NC 28695-8208, U.S.A; [2]Center for Coastal Physical Oceanography, Crittenton Hall, Old Dominion University, Norfolk, VA 23529, U. S. A; [3]Department of Biological Sciences, Allen Hancock Foundation, University of Southern California, Los Angeles, CA 90089, USA. lou@ccpo.odu.edu
Between September 1994 and December 1995, the U.S. JGOFS Arabian Sea Process Experiment collected extensive, high quality hydrographic data during all seasons in the northern Arabian Sea. These data suggest the presence of many features described in the canonical literature. Some of the new insights from the data include: 1) Temperature-salinity (TS) distributions are extremely variable in the upper 1000 db, and 2) The densest water reaching the sea surface during coastal upwelling appear to have come from ~150 m and sigma-theta's close to the core value (~25) for Arabian Sea Water (ASW). The densest water found at the sea surface during late NE Monsoon conditions had sigma-theta's >24.8 and relatively high salinities suggesting that they are a source for the ASW salinity maximum. 3) The salinity maximum associated with Red Sea Water (RSW, sigma-theta = 27.2) is only found at the southernmost JGOFS sampling site. 4) Inorganic nitrogen to phosphate ratios are lower than the standard Redfield ratio of 15/1-16/1 (by atoms), suggesting that inorganic nitrogen is more important than phosphate as a limiting nutrient for phytoplankton growth, and that denitrification dominated nitrogen fixation. 5) The waters upwelling off the Omani coast during the SW Monsoon have inorganic nitrogen to silicate ratios higher (~2/1) than the ~1/1 ratio often assumed as the ratio of uptake during diatom growth. 6) The temporal evolution of inorganic nitrogen to silicate ratios suggests major alteration by diatom uptake only during the late SW Monsoon. 7) Widespread moderate surface layer nutrient concentrations occur during the late NE Monsoon.

Oral: **The oxygen minimum zone in the Arabian Sea during 1995**. J. M. Morrison[1], L. A. Codispoti[2], S. L. Smith[3], K. Wishner[4], C. Flagg[5], W. D. Gardner[6], S. Gaurin[2], S. W. A. Naqvi[7], V. Manghnani[1], L. Prosperiey[2] and J. S. Gundersen[6], [1]Department of Marine, Earth and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695-8208, USA, [2]Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, VA 23529, U.S.A; [3]Rosentiel School of Marine and Atmospheric Science, University of Miami, Miami, FL 33149, U.S.A; [4]Graduate School of Oceanography, University of Rhode Island, Narragansett, RI 02882, U.S.A; [5]Oceanographic and Atmospheric Science Division, Brookhaven National Laboratory, Upton, NY 11973, U.S.A; [6]Department of Oceanography, Texas A&M University, College Station, TX; 77843-3146, U.S.A; [7]National Institute of Oceanography, Dona-Paula, Goa 403 004, India. john_morrison@ncsu.edu
This paper focuses on the characteristics of the oxygen minimum zone (OMZ) as observed in the Arabian Sea over the complete monsoon cycle of 1995. Dissolved oxygen, nitrite, nitrate and density values are used to delineate the OMZ, as well as identify regions where denitrification is observed. The suboxic conditions within the northern Arabian Sea are documented, as well as biological and chemical consequences of this phenomenon. Overall, the conditions found in the suboxic portion of the water column in the Arabian Sea are not greatly different from those reported in the literature. Within the main thermocline, portions of the OMZ are suboxic (oxygen less than ~4.5 μM) and contain secondary nitrite maxima that sometimes exceed 6.0 μM, suggesting active nitrate reduction and denitrification. Organism distributions show strong relationships to the oxygen profiles, especially where the OMZ was pronounced, but the biological responses to the OMZ vary with type of organism. ADCP acoustic backscatter measurements show diel vertical migration of plankton and movement into the OMZ. Daytime acoustic returns from depth are strong, and the dawn sinking and dusk rise of the fauna are obvious. However at night, the remaining biomass in the suboxic zone is so low that no ADCP signal is detectable at these depths. There are at least two groups of zooplankton (used loosely), one that stays in the upper mixed layer and another that makes the daily excursions. A subsurface zooplankton peak in the lower OMZ (near the lower 4.5 μM oxycline) is also typically present; these animals occurred day and night and do not vertically migrate.

Poster: **300 ka organic $d^{13}C$ record of monsoon variability on the Oman continental margin, Arabian Sea**. A. N. N. Muzuka, University of Dar es Salaam, Institute of Marine Sciences, P.O. Box 668, Zanzibar, Tanzania. muzuka@zims.udsm.ac.tz
The stable isotope compositions of sedimentary organic carbon and content of organic carbon for sediment cores recovered at two sites (sites 724C and 725C) during Ocean Drilling Program (ODP) Leg 117 on the Oman continental margin are used to document variability of monsoon winds for the past 300 ka. The $d^{13}C$ values range from -18 to -25 per mill with an average value of -21 per mill at Site 724C, while at site 725C the values range from -18 to -26 per mill and average -21.5 per mill. The contents of residue organic carbon (ROC) for the two sites range from 1 to 10%. Both sites are characterised by three low d13C values events (event 1 at 50 ka; event 2 at 200 ka; and event 3 between 250 and 300 ka). Lowest isotope values of organic carbon at these two sites are observable during event 3, and are as low as -25 per mill. These three events are associated with low contents of ROC. These three events, which fall within the oxygen isotope stages 4, 8 and 10 (glacial periods), may represent periods of enhanced input of terrestrial organic matter in response to the monsoon winds variability. The allochthonous organic materials could have been derived from the eastern and northeastern side of the Arabian Sea, suggesting stronger northwest monsoon winds. The isotopic compositions for other isotope stages are not very different from each other (-20 per mill) suggesting dominance of marine phytoplankton production and near constant strength of the monsoon winds.

Poster: **Spatial and temporal distribution of dissolved inorganic nutrients in Mida Creek, Kenya.** B. Mwashote, Kenya Marine and Fisheries Research Institute, PO Box 40874, Mombassa, Kenya. bmwashote@recoscix.com
The spatial and temporal distribution of dissolved inorganic nutrients were investigated between May 1996 and April 1997 in Mida creek, a creek found within the richness of biodiversity of flora and fauna in the north-eastern part of the Kenya coast. The nutrient levels of boreholes/wells found within the surrounding area of the creek were also investigated for comparison purposes. Measurements carried out within the creek revealed that the mean concentration ranges for NH_4^+-N, $(NO_2^-+NO_3^-)$-N, PO_4^{3-} and SiO_3^{2-} were 0.002-5.45; 0.12-5.63; 0.10-0.58 and 1.31-81.36 µmoles l^{-1}, respectively. For the case of boreholes/wells found in the surrounding area, their respective levels were found to lie in the ranges 0.4-907.0; 16.7-4897.0; 1.09-22.39 and 83.9-596.0 µmoles l^{-1}. The highest nutrient concentrations within the creek were experienced during the wet season as compared to dry season although no significant variations ($p>0.05$) were found with respect to the tidal cycles. In contrast, diurnal nutrient concentrations especially in areas with high residence time (>12h) were found to be highest during dry season as opposed to wet season for all nutrients except SiO_3^{2-}. The relatively high nutrient concentrations in boreholes/wells found around Mida creek and the probable outflow of ground water into the creek waters are associated with the elevated nutrient incidents in the creek waters. Other sources that contribute significantly to the nutrient distribution in Mida creek include benthic nutrient fluxes and occasional surface runoff events during wet seasons.

Poster: **The trophic spectrum and associated physic-chemical factors in the central and eastern Arabian Sea**. K. K. C. Nair[1], M. Madhupratap[2], T. C. Gopalakrishnan[1], P. Haridas[1] & M. Gauns[2], [1]National Institute of Oceanography, Regional Centre, P.B. No.1913, Cochin-682 018, India; [2]National Institute of Oceanography, Dona Paula, Goa - 403 004, India. niopc@giasmd01.vsnl.net.in
The Arabian Sea is a unique geographic area known for its seasonally oscillating biological productivity resulting from monsoon driven circulation. Its northern region experiences high biological productivity in winter, which results from convective overturning, associated with winter cooling. Open ocean areas also continue to be productive during summer monsoon due to open ocean upwelling. Thus, the recent understandings are contrary to the earlier belief that the coastal regions of the Arabian Sea alone are productive regions resulting from boundary and circulation related upwelling. Though there are considerable temporal and spatial variations in primary productivity, the merozooplankton abundance in the Arabian Sea is high in the mixed layer all through the year. This may be partly resolved by explaining the microbial loop. This is because most of the herbivorous forms are either small filter feeders like copepods or large mucous filter feeders like salps, which are

able to feed on very small particles. The maintenance of high biomass of mesozooplankton in the northern Arabian Sea apparently sustain a huge stock of mesopelagic fish, mostly belonging to Myctophidae, whose estimated potential is about 100 million tonnes. They are metabolically adapted to low ambient oxygen levels and mostly live in the core of the oxygen minimum layer. They migrate to the surface layers during night to feed on zooplankton.

Oral: **Nitrogen isotopic studies in the suboxic Arabian Sea.** S. W. A. Naqvi[1], T Yoshinari[2], J. A. Brandes[3, 4], A. H. Devol[3], D. A. Jayakumar[1], P. V. Narvekar[1], M. A. Altabet[5] & L. A. Codispoti[6], [1]National Institute of Oceanography, Dona Paula, Goa 403 004, India; [2]Wadsworth Center, New York State Department of Health, and School of Public Health, State University of New York at Albany, P.O. Box 509, Albany, NY 12201, USA; [3]School of Oceanography, University of Washington, Seattle, WA 98195, USA; [4]Present Address: Geophysical Laboratory, Carnegie Institution of Washington, Washington, DC 20015, USA; [5]Department of Chemistry and Biochemistry and Center for Marine Science and Technology, University of Massachusetts, Dartmouth, North Dartmouth, MA 02747, USA; [6]Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, VA 23529, USA. naqvi@csnio.ren.nic.in
Measurements of $^{15}N/^{14}N$ in dissolved molecular nitrogen (N_2), nitrate (NO^{3-}) and nitrous oxide (N_2O) and $^{18}O/^{16}O$ in N_2O [expressed as $d^{15}N$ and $d^{18}O$, relative to atmospheric N_2 and oxygen (O_2), respectively] have been made in water column at several locations in the Arabian Sea, a region with one of the thickest and most intense O_2 minima observed in the open ocean. Microbially-mediated reduction of NO^{3-} to N_2 (denitrification) in the oxygen minimum zone (OMZ) appears to greatly affect the natural isotopic abundances. The $d^{15}N$ of NO^{3-} increases from 6 o/oo in deep waters (2500 m) to 15 o/oo within the core of the denitrifying layer (250-350 m); the $d^{15}N$ of N_2 concurrently decreases from 0.6 o/oo to 0.25o/oo. Values of the isotopic fractionation factor (E) during denitrification estimated using simple advection-reaction and diffusion-reaction models are 22 o/oo and 25 o/oo, respectively. A strong decrease in $d^{15}N$ of NO^{3-} is observed from ~200 m (>11 o/oo) to 80 m (~6 o/oo); this is attributed to the input of isotopically light nitrogen through nitrogen fixation. Isotopic analysis of N_2O reveals extremely large enrichments of both ^{15}N and ^{18}O within the OMZ, presumably due to the preferential reduction of lighter N_2O to N_2. However, isotopically light N_2O is observed to accumulate in high concentrations above the OMZ indicating that the N_2O emitted to the atmosphere from this region cannot be very heavy. The isotope data from the intense upwelling zone off the southwest coast of India, where some of the highest concentrations of N_2O ever found at the sea surface are observed, show moderate depletion of ^{15}N, but slight enrichment of ^{18}O relative to air. These results suggest that the ocean-atmosphere exchange cannot counter inputs of heavier isotopes (particularly ^{18}O) associated with the stratospheric back flux, as proposed by previous workers. This calls for additional sources and/or sinks of N_2O in the atmosphere. In addition, the N_2O isotope data cannot be explained by production through either nitrification or denitrification, suggesting a possible coupling between the two processes as an important mechanism of N_2O production.

Poster: **Baseline data for biogeochemical modelling of coastal resources management in West Africa.** S. Oni, Department of Geography, University of Lagos, Lagos, Nigeria. library@rcl.nig.com.
A systematic appraisal of the interactions between ecosystems, biogeochemical parameters and the status of coastal resources management in the West African sub-region has been undertaken. In particular, use is made of an application specific framework designed for the acquisition of data on biogeochemical and coastal resources use in the study area. This data acquisition technique is designed to fit into a computer-aided analysis, based on the use of Geographic Information System models. Apart from providing hitherto unavailable baseline data for use in other similar studies, results obtained effectively characterise prevailing coastal resources management practices in West Africa. Based on these results, an optimum coastal resources management strategy is proposed; the model developed, which is particularly suited to the West African sub-region accommodates the effects of such important parameters as demography, land use and degradation, patterns, pollution, socio-economic indices and status of technological development among others.

Poster: **Phytoplankton composition** and **Productivity in the Arabian Sea: JGOFS (India).** A. Pant, Biochemical Sciences, National Chemical Laboratory, Homi Bhabha Road, Pune 411 008, India. aditi@ems.ncl.res.in
An overview of primary productivity, chlorophyll a and cell count data from the Arabian Sea during 3 JGOFS cruises from 1994 to 95 are presented. Low production during the intermonsoon was followed by higher production in winter and summer monsoons. Winter production in the order of 200 to 800 m C m^{-2} day^{-1} with the high values in the NE Arabian Sea are discussed as a consequence of winter cooling and convective sinking resulting in a deepened mixed layer. Summer monsoon highs in the order of 400 to 1700 mg C m^{-2} day^{-1} are a result of upwelling off the Indian coast and advective processes. There is a subsurface chlorophyll a maximum and mostly diatoms and dinoflagellates with pronounced population maxima are recorded in the preserved samples.

Poster: **Study of marine environment of the Bay of Bengal using satellite data (Bangladesh Perspective).** Md. O. Quader, Bangladesh Space Research and Remote Sensing Organization (SPARRSO), Agargaon, Dhaka-1207, Bangladesh. sparrso2@bangla.net
This paper reports on sea surface temperature, chlorophyll concentration, sedimentation and cyclones in the Bay of Bengal using satellite data at SPARRSO. The Bay of Bengal is a breeding ground of cyclones and some devastating cyclones occurred in 1970,1985,1991 and 1998. Sea surface temperatures of the Bay of Bengal from NOAA AVHRR satellite and associated fisheries data were analysed using VAX-11/750 computer and I2S software. The difference between the MCSST data and sea surface temperatures ranged between 0.8-1.5 ^{o}C. It was also found that coastal water is cooler than deep-sea water. However, the temperature difference was not great, 1-30 ^{o}C. Although a few images of the monsoon season were not analysed because of cloud disturbances, some eddies, vortices and circulation patterns were observed in the winter MCSST data. The temperature varied from 23-30 ^{o}C in different seasons. Some of these data were verified from the sea surface temperature observations in the Bay of Bengal. Interrelationship of sea surface temperature on genesis of cyclones and potential fishing ground identifications will be discussed. The studies on chlorophyll content in the Bay of Bengal as determined by Nimbus-7 (CZCS) satellite data were conducted at the NASA Goddard Space Flight Center and partly at SPARRSO using VAX-11/750 computers and SEAPAK software. The results showed that the Bay of Bengal has 0.1 to 10 mg m^{-3} chlorophyll content from coast to deep sea. This was verified with ocean data from the International Indian Ocean Expedition. These types of data are useful for surveying potential fishing zones as observed from CZCS and AVHRR data. The marine environmental study of the Bay of Bengal used multi-temporal Advanced Earth Observation Satellite (ADEOS) Ocean Colour Temperature (OCTS) data to monitor the marine environment over the coastal areas. Specifically, the study was conducted (i) to understand the dynamic process of sediment transportation related to erosion and accretion; (ii) to characterise the chlorophyll distribution pattern over these areas as a function of bottom topography, tidal condition and seasonal variabilities: and, (iii) to understand their spatial and temporal variation in the light of the simulated current vector that prevailed at the time of satellite data acquisition.

Poster: **Overview of the ecology and fishery resources of Dhofar coast, Oman.** A. Rajan, A. A. Mashikhi & A. A. Shanfari, P.O.Box-308, Raysut Marine Research Laboratory, Ministry of Agriculture and Fisheries, Salalah-211, Salalah Sultanate of Oman. rama7@gto.net.om
The Dhofar area of Oman has been identified as one of the outstanding interest for marine ecological studies, both in terms of species diversity and their ecology. The poster presents the distribution of physical, chemical and biological characteristics of Dhofar coast. Upwelling due to the trade wind is the most significant process, which enhances the productivity of the area. Many floral and faunal communities recorded are unusual for a tropical area as this and some cases are unique. Among the various fishery resources in this area, some of which depend directly on the rocky shore algal communities and all of which depend indirectly on the upwelling of cold, nutrient rich waters generated by the south-westerly monsoon. Along with other commercially important finfishs, abalone (Haliotis mariae) and lobsters (Panulirus homarus) form the most valuable shell fish resources in the Dhofar coastal fisheries. Khawrs (Lagoons) and mangroves are other interesting and valuable natural

habitats found associated with this Arabian Sea coast. This study has also shown the animal populations of intertidal and subtidal regions. The nature of the area and its significance to the fishery potential are also discussed.

Oral: **Bacterial Relationship with Organic Carbon in the Arabian Sea**. N. Ramaiah, V.V.S. Sarma, M. Gauns, M. Dileep Kumar & M. Madhupratap, National Institute of Oceanography, Dona Paula 403 004, Goa, India. ramaiah@csnio.ren.nic.in
The biogeochemical cycles in the Arabian Sea are of interest to the oceanographers since this part of the world ocean is known for subsurface low oxygen and intense denitrification resulting in a nitrate deficit of 10 µmoles in the north. As a part of the Joint Global Ocean Flux Study, we measured, among other parameters, the concentrations of DOC, transparent exopolymer particles (TEPs) and bacterial abundance during the summer monsoon of 1996. This was done in order to understand the role of bacteria in utilisation and assimilation of organic carbon and their influence on carbon turnover in the Arabian Sea. Vertical and horizontal distribution of DOC suggested a high regional variability. TEPs, formed probably from dissolved extracellular polysaccharides, were generally high in surface waters at 18-20^{o} N along 64^{o} E with their concentrations well over 25 mg equivalents of alginic acid l^{-1}due to upwelling induced productivity. Their concentrations were generally low between 200 and 500-meters suggesting the bacterial preference to extracellularly formed labile forms of organic substrates. The bacterial numbers were in the range of 1x 10^{8} cells l^{-1} in the surface waters and, decreased by an order at depths below 500m. A direct relationship appears to exist between bacterial abundance and the concentrations of TEPs than between the former and DOC. This indicates that the bacterial metabolism is fuelled by the availability of labile fractions of organic carbon, particularly the TEPs. The particulate and certain dissolved organic fractions are assimilated by water column bacteria, which in turn are important in sustaining moderate to higher numbers of microzooplankton (10 to 265 l^{-1}) in waters immediately below thermocline (200-300-meters). Comparison between concentrations of DOC and bacterial abundance suggests that the deep layer DOC is recalcitrant and, unlike TEPs, is of not a greater consequence to bacteria. Assuming either 33% or 20% efficiencies for bacterial growth rates, their carbon demand is in the range of 0.04 to 3.6 or 0.06 to 5.0 µg C l^{-1} h^{-1} in the surface waters.

Poster: **Protozoan abundance, biomass and size distribution in the western Arabian Sea and southern Red Sea during the SW monsoon 1992 and NE monsoon 1993.** M. Reckermann, Research and Technology Centre Westcoast, University of Kiel, Hafentoern, D-25461 Buesum, Germany. recker@ftz-west.uni-kiel.de
Abundance, biomass and size distributions of three protozoan groups (heterotrophic nanoflagellates - HNF, heterotrophic dinoflagellates and ciliates) were estimated during two cruises to the Somali Current area, the Gulf of Aden and the southern Red Sea during summer and winter, in the SW monsoon (July 12 - August 8, 1992) and in the NE monsoon (January 11 - February 6, 1993) respectively. The cruises were part of the JGOFS pilot study 'Monsoons and pelagic systems', within the framework of the Netherlands Indian Ocean Programme 1992-1993 (NIOP). HNF cell concentrations in the summer ranged between 304 - 1,243 cm^{-3} (carbon biomass: 0.94 - 7.25 µg dm^{-3}). During the winter monsoon, HNF numbers and carbon biomasses were slightly higher (812 cm^{-3} to 4,268 cm^{-3}, carbon: 1.79 µg dm^{-3} to 6.28 µg dm^{-3}). Cell concentrations of heterotrophic dinoflagellates in summer ranged from 8 - 29 cm^{-3} (carbon biomass: 0.57 µg dm^{-3} to 15.46 µg dm^{-3}). In winter, dinoflagellate cell concentrations ranged from 13 - 60 cm^{-3} (carbon biomass: 1.07 - 6.74 µg dm^{-3}). Ciliate cell concentrations in summer ranged from 657 dm^{-3} to 7,839 dm^{-3} (carbon biomass: 0.27 - 16.72 µg dm^{-3}); during the NE monsoon, ciliate concentrations ranged between 108 - 8,748 dm^{-3} (carbon biomass: 0.17 - 6.21 µg dm^{-3}). HNF numbers and biomasses appeared to be more conservative across all provinces than heterotrophic dinoflagellate and especially ciliate concentrations. This was evident at the most eutrophic stations encountered: an upwelling plume off the Somali coast in summer, and the southern Red Sea in winter. During both monsoons, HNF numbers were clearly dominated (60 - 90% of cells) by very small individuals (<3µm). This trend of smaller individuals at more oligotrophic stations and larger ones at more eutrophic stations applied to both monsoons for all protozoan groups. Ciliates were dominated by oligotrich forms (over 90% of both numbers and

biomass). Only in the upwelling water, a higher diversity (scuticociliates, didiniids, hypotrichs) was observed. Almost all-heterotrophic dinoflagellates were small (i.e. <20µm) members of the genus Gymnodinium, with larger individuals again occurring at the eutrophic stations during both monsoons.

Oral: **Multidisciplinary observations in the NW Indian Ocean, Strait of Hormuz and Arabian Sea.** H.S.J. Roe, J.T. Allen, N. Crisp, G. Griffiths, P. Herring, A. Mustard, R. Pascal & D. Smeed, Southampton Oceanography Centre, Empress Dock, Southampton SO14 3ZH, UK. howard.s.j.roe@soc.soton.ac.uk
During February and March 1997, we carried out a multidisciplinary programme of research in the Gulf of Oman, Strait of Hormuz and Arabian Sea. Intensive hydrographic observations with CTDs and SeaSoar allowed us to follow the outflow of Arabian Sea water through the Strait into the Gulf of Oman where it forms a tongue of warm, high salinity water following the Oman continental slope and mixing with water above and below it by a variety of processes including double diffusion. Coupled with the hydrography is the oxygen minimum layer which extends from the Gulf of Oman up into the southern end of the Strait and which has a dramatic effect on the distributions, behaviour and physiology of the animals within the water column. Intense spatial and temporal variability in biological distributions correlated with the Arabian Sea outflow, the oxygen minimum layer and topography were observed with a variety of bioacoustic, optical and net samplers. Surface meteorology linked *in situ* observations with the atmosphere, allowing us to couple local Shamal winds with internal waves and consequent variations in hydrography and acoustic backscatter in the Strait of Hormuz.

Oral: **Seasonal dynamics and biological productivity in the Arabian Sea as simulated by a 3-D ecosystem model.** V. A. Ryabchenko, St. Petersburg Branch, P.P. Shirshov Institute of Oceanography, Russian Academy of Sciences, 30 Pervaya Liniya, 199053 St. Petersburg, Russia.
A nitrogen-based, seven component ecosystem model of Fasham [1993] type is coupled to a 3-D quasi-geostrophic ocean general circulation model of Gorchakov and Ryabchenko [1992] and applied to a simulation of the seasonal variability of physical and ecosystem variables in the northwestern Indian Ocean. The comparison of the solution with available data (seasonal changes in surface chlorophyll at certain key positions from the climatological CZCS database, satellite-derived annual primary production, and data from cruises) has highlighted many agreements but also some disagreements between the model and observations. In particular, the model produces an entrainment bloom in May-June in the central Arabian Sea for which there is no evidence in the CZCS data and does not reproduces the observed August-September bloom in the northern Arabian Sea. In the latter case, an analysis showed that zooplankton-grazing control prevents the development of the model bloom. A comparison of our solution with the results obtained by McCreary et al. [1996] using a 2.5-layer physical-ecosystem model showed that, despite numerous distinctions between the models, the period and location for the most of blooms in these solutions coincide closely. The model reproduced the differences in primary productivity between the northeast and southwest monsoon periods and showed that the model phytoplankton in the main upwelling areas were only seriously nutrient limited during the spring inter-monsoon period. For large parts of the year the model predicts that phytoplankton production is closely coupled to zooplankton grazing with blooms only occurring when there are rapid changes in phytoplankton growth rate, due either to the entrainment of nitrate into the mixed layer or decreased light limitation when the mixed layer is shallowing, thereby allowing the phytoplankton to escape from grazing control.

Poster: **Phytoplankton biogeography of Indian Ocean.** R. Santhanam, Fisheries College and Research Institute, Tamilnadu Veterinary and Animal Sciences University, Tuticorin 628 008, India.
Phytoplankton distribution patterns and their biogeography are known to indicate the distinctive regional characteristic and the geographical history of water types in different seas and oceans. The present account deals with the diversity and biogeographical status of the phytoplankton of the Gulf of Manar, which is contiguous with the Bay of Bengal and is influenced by monsoon-based seasonal currents. Sixty two species of diatoms and 40 species of dinoflagellates have been found to occur

commonly in the sea and majority of them is allochthonous, as they are known to occur in other latitudes. A biogeographical analysis of these species showed that 26 species have cosmopolitan distribution, 11 species are known to occur between war waters and temperate waters, 10 species between cold waters and temperate waters, 10 species in warm waters and 4 species in cold waters. The corresponding numbers of species of dinoflagellates distributed in the above biogeographical areas are 21, 9, 1, 1 and 1 respectively. The occurrences of allochthonous species in the sea could possibly be due to the incursion of seawaters and the sources are about the same as for the Arabian Sea. A tongue of the Antarctic waters which is also known to extend into the Arabian Sea and Bay of Bengal could also bring cold water species into these sea. The chief hydrographical parameters recorded during the occurrences of allochthonous species of phytoplankton in the area are also discussed.

Oral: **NO_3 and ^{210}Pb distribution in aerosols and their deposition fluxes to the surface Arabian Sea.** M. M. Sarin, R. Rengarajan & S.Krishnaswami, Physical Research Laboratory, Ahmedabad - 380 009, India. sarin@prl.ernet.in.
The concentrations of NO_3 and ^{210}Pb have been measured in the aerosols over the central-eastern Arabian Sea in order to investigate the atmospheric deposition of NO_3 and to assess its role in contributing to Primary Productivity. Bulk aerosol samples were collected during April-May (inter-monsoon) 1994, July-Aug. (monsoon) 1995, 1996 and Feb-March (winter) 1995,1997. Our approach is to use natural ^{210}Pb as a tracer to assess the deposition fluxes of aerosols over the sea-surface. The NO_3 concentrations during the inter-monsoon and winter ranged from 0.4 to 4.1 μ g m^{-3}, with systematically higher concentrations during winter. During monsoon, NO_3 concentrations were the lowest, 0.2 to 0.8 μ g m^{-3}. The seasonal and spatial distributions of NO_3 and ^{210}Pb in the aerosols show an overall positive correlation, with $NO_3/^{210}$Pb ratio centring on 50 μ g dpm^{-1}. Using this ratio and a measured ^{210}Pb deposition flux of 0.75 dpm cm^{-2} yr^{-1} at ~100-m below the sea-surface, the atmospheric deposition of NO_3 is estimated to be 1 mg m^{-2} d^{-1}. These results suggest that the atmospheric N-NO_3 flux to the mixed layer is insignificant compared to that fixed by Primary Production, 320 - 1150 mg C m^{-2} d^{-1}, in this region.

Oral: **^{234}Th scavenging and particle export from the upper Arabian Sea.** M. M. Sarin[1], R. Rengarajan[1] & V. Ramaswamy[2], [1]Physical Research Laboratory, Ahmedabad-380 009, India & [2]National Institute of Oceanography, Dona Paula, Goa-403 004, India. sarin@prl.ernet.in
The removal of dissolved ^{234}Th by adsorption onto sinking particulate matter is an important mechanism controlling its distribution as a tracer in the surface ocean. In this study, the dissolved and particulate ^{234}Th activities have been measured in the central-eastern Arabian Sea during the winter (Feb.-March), the inter-monsoon (April-May) and the SW Monsoon (July-Aug.) on five cruises between April 1994 to Feb. 1997. The data allows us to quantify the vertical ^{234}Th fluxes via sinking particles on a seasonal and spatial scale. In addition, the measured C/^{234}Th ratios in the particulate matter collected by free-floating traps (deployed at 100 to 130-m) are used to constrain the particle and carbon export fluxes from the upper 100-m. The ^{234}Th: ^{238U} activity ratios in the mixed layer vary from 0.4 - 0.8 indicating intense scavenging of ^{234}Th onto settling particles and its downward export. Using the mass balance approach, ^{234}Th export fluxes computed for the upper 100-m ranged from ~1100 to 2750 dpm m^{-2} d^{-1} with an enhanced export at coastal stations during the SW Monsoon. During winter sampling, export fluxes at open ocean sites vary with the column productivity. However, the measured ^{234}Th fluxes in the floating traps are considerably lower than those computed from the water column deficiency of ^{234}Th. Based on the specific activity of ^{234}Th in the trap material, the calculated particulate and carbon export fluxes range from ~700 to 3300 mg m^{-2} d^{-1} and 320 -1150 mg C m^{-2} d^{-1}, respectively. These results also suggest that the calculated POC fluxes at 100m are systematically higher than the column productivity thereby raising the question of differential cycling of the components of settling particles and ^{234}Th in the upper Arabian Sea.

Oral: **Controls of pCO_2 and its air-water exchange in the Arabian Sea.** V. V. S. S. Sarma & M. Dileep Kumar, National Institute of Oceanography, Dona Paula, Goa, India. dileep@csnio.ren.nic.in

Extensive data sets on total inorganic carbon dioxide (TCO_2) and pH were collected in the eastern and central Arabian Sea, together with other hydrographic and nutrient parameters under the JGOFS Programme of India. $TCO_2$was measured by coulometry and the pH by multiwavelength spectrophotometry. The pCO_2 were computed from the TCO_2 and pH data sets with a precision of 4 matm. The pCO_2 varied between 351 and 478 matm in all seasons with generally higher values in intermonsoon season (April-May 1995) but southwestern coastal waters exhibited the extreme range observed (266-685 matm) because of freshwater influx and upwelling. The pCO_2 showed significant variability in the top 60 meters. Relationships with physical and biological variables indicated that physical processes predominantly regulate its distribution during winter and southwest monsoons while both physics and biology are important in intermonsoon when microbial populations are extremely high. The pCO_2 is generally higher in surface waters than in the atmosphere, except in a few small areas affected by continental run-off. Thus this region seems to act as a perennial source with an average rate of ~6.4 mmoles m^{-2} d^{-1}. The pCO_2 in the intermediate and deep Arabian Sea is controlled by regeneration of organic matter and denitrification processes. However, utilisation of 10 mM of nitrate (the near maximum nitrate deficit evaluated) as oxidant under suboxic conditions would result in only a marginal increase of 11 matm of pCO_2 since its value is two orders of magnitude higher (>1000 matm) in intermediate waters of the Arabian Sea. Our results further suggest that the transparent exopolymer particles are more labile than dissolved organic carbon, and therefore microbial activity in the intermediate waters of the Arabian Sea is perhaps largely sustained by this pool of organic matter. Moreover, the regenerated pCO_2 in the intermediate layers seems to be due to the decomposition of transparent exopolymer particles in addition to the sinking particulates (since the latter is insufficient to support the subsurface respiration demands) than from dissolved organic carbon in the Arabian Sea.

Poster: **Remote sensing data from the Persian Gulf and the Gulf of Oman, North West Indian Ocean**. A. Savari, Faculty of Oceanography, Biological Oceanography Department, University of Shahid Chamran, Ahvaz, Iran. alizadeh@neda.net
Estimates of chlorophyll concentrations in the Persian Gulf and the Gulf of Oman have been computed from CZCS images for the period of 1978-1986. In addition, the biomass of the area have been computed from monthly mean near-surface chlorophyll fields for September 1997-March 1998 by the SeaWiFS radiometer. A synoptic thermal coverage of the area was obtained from AVHRR Sea Surface Temperature (SST) data for the same period. Information regarding field distribution of chlorophyll and the parameters of the photosynthesis-light relationship were collected from field works. The area was divided into three provinces and nine horizons based on differences in physical conditions. The net primary production was calculated. Using CZCS and field data it was found that the primary production was higher for the Western horizon and the Strait of Hormuz. Bloom conditions were observed in these two parts especially during autumn and wintertime. Mean primary production was greater than 1.5 gr. cm^{-2} d^{-1} except for the central parts of the Persian Gulf and the Gulf of Oman, which displayed lower values. With SeaWiFS and AVHRR data, spatial and temporal variabilities in biomass and primary production were observed similar to those observed by CZCS. The relationships between photosynthesis and environmental variables were also studied. The depth-temperature (r^{-2} = 0.73) and nitrate-temperature (r^{-2} = 0.79) related significantly while the relationship between alpha B and depth, alpha B and temperature and alpha B and nutrients was not significant. This work has been carried out at Bedford Institute of Oceanography, Canada under the supervision of Prof. Platt for the first time over the whole area of the Persian Gulf and the Gulf of Oman for the period of 1978-1998.

Poster: **Southwest monsoon in the western Arabian Sea: production and fate of calcium carbonate.** C. Sellmer & K. von Bröckel, Institute for Marine Research, University of Kiel, Düsternbrooker Weg 20, 24105 Kiel, Germany. csellmer@ifm.uni-kiel.de
The peculiarities that differentiate the Arabian Sea from other oceanic areas essentially arise from its unusual geographical setting, which has tremendous impact on its climate. The dramatic seasonally varying monsoon-related physical forcing seems to predominantly determine the mixed layer dynamics and upper ocean circulation. This lead to the largest variability in many surface water

properties observed anywhere. The resulting diverse biogeochemical regimes in the Western Arabian Sea provides perhaps the best sites for investigating various pathways of carbon transformation. The coastal upwellings as well as the filaments are regions of high primary production as well as high amounts of particulate organic carbon and inorganic carbon in the form of calcium carbonate. Coccolithophores are the main primary producers, which produce organic and inorganic carbon. Mainly their body scales build the calcareous sediments in the ocean and therefore influence global biogeochemical cycles. However, analysis of phytoplankton populations from those regions revealed unexpected low occurrences of coccolithophores (highest portion found about 20% of phytoplankton biomass as organic carbon). On the other hand, sediment traps, deployed directly below the euphotic zone, recorded high amounts of sedimenting calcium carbonate (up to 80% of total dry weight). The only other carbonate source could be pelagic foraminiferas. As these protozooplankter are feeding mainly on other zooplankton organisms, the composition of the phytoplankton population is of unexpected importance. But the production, downward transport and consumption of organic and inorganic matter through the biological pump out of the pelagic regime is of considerable relevance to JGOFS. A conceptional model will be represented describing the implications for the pelagic environment.

Oral: **Evaluation of Marine Ecosystem Model simulations using Satellite Chlorophyll data.** M. K. Sharada[1] & K. S. Yajnik[2], [1]CSIR Centre for Mathematical Modelling and Computer Simulation, Belur Campus, Bangalore 560037, India; [2]Regal Manor, 2/1 Bride Street, Langford Town, Bangalore 560025, India. sharada@cmmacs.ernet.in

A rather general method is developed for comparing the results of several simulations with observations describing seasonal variations (climatological averages) by considering measures that quantify the difference between the result of a particular simulation and observations. If xi and y_i are observations and simulation results ($i = 1,..,12$) of seasonal variation, the mean square error E^2 is given by

The above methodology is applied to the results of 64x8 simulations at eight stations in the Arabian Sea (four on 65^0 E transect and 4 normal to Oman coast) and (14.5^0 N, 65^0 E)). The chlorophyll data is taken from the CZCS data after averaging over a 5x5 square centred at the stations. (Cloudy parts are excluded, outliers are not, and no corrections have been applied.) The simulations are based on a seven-component model of FDM type with several variations like switching and non-switching version etc. These are based on our earlier sensitivity studies. The comparisons using the above measures show overwhelming evidence of better performance by models that use switching type of grazing formulation.

Oral: **Features of the Upwelling and Open Ocean Circulation in the Arabian Sea Observed During 1993-1995.** W. Shi, J. M. Morrison, E. Bohm & V. Manghnani, Department of Marine, Earth and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695-8208, USA. john_morrison@ncsu.edu

Satellite-derived sea-surface-temperature, TOPEX/POSEIDON altimeter data, model wind data and hydrographic data are used to characterise interannual variability in the Oman upwelling zone and mean circulation of the northern Arabian Sea for the period 1993 - 1995. JGOFS Arabian Sea Process Study (ASPS) hydrographic data are used to depict the typical geostrophic shear in the upper 500-meter layer within the northern Arabian Sea during 1995. This is used with TOPEX/POSEIDON altimeter data for 1993 through 1995 to estimate the upper layer geostrophic transport. The wind-driven component of the upper ocean flow is estimated using Ekman transports, derived from Navy Operational Global Atmosphere Prediction System (NOGAPS) modelled wind data. Contrary to what might be expected at these latitudes where, during the summer, sea level would be expected to rise because of the increase in steric height due to the seasonal warming, a significant decrease in steric height associated with the "Arabian Sea Cooling" process occurs during the SW Monsoon. The upwelling "front" moves offshore with the development of SW Monsoon with most of the offshore flow of cold upwelled water occurring in filaments. Cold upwelling water persists for nearly a month after the end of the SW monsoon within the bays along the Oman coast. The strong upwelling along

the coast leads to a compensating along-shore, northeastward flowing geostrophic current (East Arabian Current) during the SW Monsoon. Estimates of the magnitude of the transports within the upwelling zone and for the mean circulation, as well as an estimate of their seasonal variability will also be presented.

Poster: **Hydrography and characteristics of phytoplankton in shelf and oceanic waters of the Southern Brazilian Coast**. A. G. Silvera, Universidade do Rio Grande (FURG), Department de Fisica, C.P. 474, 96201-900, Rio Grande, RS, Brazil. adriana@calvin.ocfis.furg.br
The present study discusses the role of water masses distribution on phytoplankton biomass and primary production along the Southern Brazilian coast. This region presents a complex oceanographic structure due to interaction of nutrient-poor tropical waters (TW) of the Brazil Current and nutrient-rich subantartic waters (SAW) originated from the coastal branch of the Falkland/Malvinas Current. This system is part of the Sub-tropical Convergence, whose northern limit shows strong seasonal migration, moving from about 46^{o} S in summer to as far north as 35-30^{o} S in winter. The continental shelf has also influence from the freshwater discharge from both the La Plata River and the Patos lagoon, originating a low salinity and nutrient rich water mass near the coast, called Coastal Water (CW). In summer, associated to Ekman transport, shelfbreak upwelling occurrences have been observed, bringing subtropical waters from the South Atlantic Central Water (SACW) to surface layers, which is an important source of phosphate and nitrate. In shelf waters levels of chlorophyll-a and primary production are directly related to nutrients supplied by these water masses, whose influence depends mainly on the seasonal Subtropical Convergence displacement and meteorological conditions (rainfall and prevailing winds). The amount of chlorophyll *a* vary from 0.5 mg m^{-3} to values greater than 4 mg m^{-3}, and primary production rates from 12 mg C m^{-2} h^{-1} to 120 mg C m^{-2} h^{-1}. Higher values of chlorophyll *a* and primary production rates have been observed in spring related to nutrient input from SAW and CW. During winter, despite the influence of CW and SAW over the continental shelf, production rates and chlorophyll a concentration may be limited by light. TW and deeper layers dominate offshore, surface layers (upper 100m) by subtropical waters from the (SACW). Cold core rings are associated to the TW bringing up SACW to surface layers and influencing nutrient conditions and phytoplankton biomass in the euphotic zone. Under these conditions, most measured values of chlorophyll-a concentration are below 0.3 mg m^{-3} and primary production rates range between 8 and 57 mg m^{-2} h^{-1}. These results indicate the importance of water masses distribution on phytoplankton biomass and primary production levels over the Southern Brazilian Coast.

Oral: **Effect of Southwest Monsoon on Brightness Temperature of Arabian Sea and Neighbouring Region.** R.P. Singh & N. C. Mishra, Department of Civil Engineering, Indian Institute of Technology, Kanpur - 208 016, India; & H.N. Srivastava, B1/52, Paschim Vihar, New Delhi - 110 063, India. ramesh@iitk.ac.in
The seasonal variations of brightness temperature measured by SSM/I satellite over Arabian Sea during the years 1987 to 1991 show characteristic behaviour over the Arabian Sea during the southwest monsoon (June to September). The characteristic behaviour is interpreted in relation to interannual variability of southwest monsoons. The brightness temperature variations have been interpreted in relation to mean sea surface temperature anomalies, atmospheric temperatures over the Arabian sea and Indian subcontinent. The results have provided greater insight into the interannual variations of southwest monsoons performance over the country.

Oral: **The 1994-1996 U.S. Arabian Sea Expedition: an integrated, interdisciplinary investigation of the response of the northwestern Indian Ocean to monsoonal forcing**. S. L. Smith[1], L.A. Codispoti[2], J. M. Morrison[3], R. T. Barber[4], [1]University of Miami, Miami, FL 33149, [2]Old Dominion University, Norfolk, VA 23529, [3]North Carolina State University, Raleigh, NC 27695, [4]Duke University, Beaufort, NC 28516, USA. ssmith@rsmas.miami.edu
The strategy for studying the Arabian Sea included 1) multiple, interdisciplinary cruises for the experimental investigation of processes, 2) long term deployment of moorings containing the best available instrumentation for measuring physical forcing and chemical, biological, and optical

properties, 3) intense satellite data acquisition, and 4) continually improving models emphasizing the unique physical and biogeochemical variables of the Arabian Sea. The U.S. JGOFS Arabian Sea Process Study was designed to provide a seasonally and spatially resolved carbon budget for a basin exhibiting some of the highest and lowest concentrations of plant biomass observed anywhere in the world's ocean. Strong physical forcing known to have varied enormously during past glacial and interglacial periods drives the carbon cycle in the Arabian Sea. The regular, intense forcing and vigorous response at all levels of the food web allow us to gain insight into the extremes of the oceanic carbon cycle in one year in this location that we could not gain in several years of study at any other location. The goals of the Forced Upper Ocean Dynamics program were 1) to understand the extremes in the linkages between large scale, pulsed atmospheric forcing, oceanic circulation patterns and episodic biological displays (e.g., particle production, species composition, bioluminescence) which control the optical and acoustic signatures of the water column and 2) to test hypotheses in a region where insolation is nearly constant year-round but winds and nutrients vary. The strategy for achieving these goals was: 1) to develop predictive models of the coupled bio-physical system, 2) to quantify the roles of wind mixing, summer cooling, Ekman pumping and advection on mixed-layer dynamics, 3) to determine how variation in physical forcing controls biomass, speciation, and rate processes, and 4) to measure heat and momentum fluxes and their effects on sea surface temperature variability.

Poster: **The Primary Production and Chlorophyll distribution in the Yellow Sea and East China Sea.** S.-H. Son[1], S. Yoo[1] & J. Park[1,2], [1]Biological Division, Korea Ocean Research & Development Institute, Korea; [2]Department of Marine Science, Inha university, Korea. shson@sari.kordi.re.kr or shson@bada.ocean.pusan.ac.kr
The Yellow Sea and the East China Sea are shallow waters (< 200m) and have a typical feature of Case2 water affected by suspended sediments due to a strong tidal mixing. The study area is affected by fresh waters inflowed from the Changjiang River, and the southern region especially is occupied by warm water mass branched from the Kuroshio warm current. CTD, chlorophyll concentration, and primary production were investigated during the Coastal Ocean Process Experiment (COPEX) cruise for the East China Sea in 1993 to 1997 and the Large Marine Ecosystem (LME) cruise for the Yellow Sea in 1996 to 1998. Mixed Layer Depth (MLD) from sigma-t and Deep Chlorophyll Maximum (DCM) from fluorescence were calculated. In addition, in order to find out the possibility of estimating marine primary production from satellite Ocean Color Sensor, averaged primary production and chlorophyll concentration per unit volume were compared with surface chlorophyll concentration. Spring bloom appeared in March near the frontal area where warm waters meet fresh waters from the Changjiang River and then it spread to overall of the Yellow Sea in April. Chlorophyll concentration was high in tidal front near the Changjiang river estuary and western coast of Korea. DCM appeared near the thermocline in central part of the middle Yellow Sea. In terms of the geographical variations of primary productivity, southern part of the Yellow Sea and tidal front area near the Changjiang River and the western coast of Korea usually had high primary production while primary production was low in the Kuroshio warm waters.

Oral: **A coupled physical-biological-chemical model for the Indian Ocean.** P. S. Swathi, M. K. Sharada & K. S. Yajnik, CSIR Centre for Mathematical Modelling and Computer Simulation, NAL Belur Campus, Bangalore 560 037, India. swathi@cmmacs.ernet.in
A coupled physical-biological-chemical model for studying the time variation of primary productivity and air-sea carbon-dioxide exchange in the Indian Ocean is being developed at C-MMACS. The physical model is based on the Modular Ocean Model, Version 2 (MOM) and the biological model describes the non-linear dynamics of a 3-component and a 7-component system. The chemical model includes dynamical equation for the evolution of dissolved inorganic carbon and total alkalinity. The interaction between the biological and chemical model is through the Redfield ratio. The CO_2 content of the surface layer is obtained from the chemical equilibrium equations of Peng et al., 1987. Transfer coefficients for air-sea exchange of CO_2 are computed dynamically based on the wind speeds. The biological component consists of phytoplankton, zooplankton, nitrogen in four forms and bacteria with appropriate production, grazing and mortality laws based on the work of Fasham. The biological

model is embedded within MOM in the form of additional tracer equations. The fully coupled model had 11 tracers in all (temperature, salinity, 7 biological and 2 chemical constituents). From the numerical point of view, simple upwinding is applied for all the tracers to damp out unphysical oscillations. Solar radiation is prescribed on the top surface from Oberhuber's monthly mean Atlas. The model interpolates the monthly means to obtain solar fluxes at any time. In the absence of reliable atmospheric CO_2 data time-series data for the whole ocean, we assume a constant value. For the momentum transfer, we employ weekly winds from NMC for the period 1991-1995. Restoring conditions with a time scale of 50 days and a space scale of 10 m is applied for heat and salt. The coupled model is integrated synchronously with MOM integration with a time step of 1 hour. The model domain is from 20°S to 30°N in latitude and from 30°E to 110°E in longitude with a 0.5-degree resolution in both latitude and longitude. Sponge boundaries are applied at the southern edge. There are 20 levels in the vertical with ten levels in the top 100-m in order to capture the evolution of the ecosystem model in the mixed layer. Solar radiation attenuation by both water and biomass are accounted for. Vertical mixing is based on Pacanowski and Philander's Richardson-number based scheme. The physical model without biology and chemistry is integrated for 25 years after which the additional tracers are introduced. The results from the last 4 years of model simulation with biology and chemistry will be presented.

Poster: **Study of Aquifer (groundwater) hydrochemistry around the salt pans northwest of Chilka Lake, East Coast of India.** J.K. Tripathy, S.K.Tripathy & R.C. Panigrahy, Department of Marine Sciences, Berhampur University, Orissa, India.
After identifying the salt-water logged areas by remote sensing an attempt was made to assess the quality of groundwater samples in and around the salt pans located northwest of Chilka Lake. In addition to TDS (total dissolved solids), the concentration of major ions such as Na^+, K^+, Ca^{+2}, Mg^{+2}, HCO_3^-, SO_4^{-2} and Cl^- were determined. It was found that the groundwater was contaminated by salt water as indicated by some well-established ratios such as Cl^-/ $HCO_3^-$and Mg^{+2}/Ca^{+2}. It was also established that concentrations of several parameters such as TDS, Na^+ and Cl^- exceeded the maximum permissible limit set by WHO for drinking water purpose.

Poster: **Vertical distribution of nitrate and phosphate in relation to dissolved oxygen in the Arabian Sea, west coast of India.** S.K. Tripathy, J.K. Tripathy, R. Gouda & R.C. Panigrahy, Department of Marine Sciences, Berhampur University, Orissa, India.
Vertical distribution of temperature, dissolved oxygen, nitrate and phosphate in offshore region of Arabian Sea during January 1987 revealed some interesting and unique features. The water column above the thermocline remained well mixed and was characterised by uniformly high oxygen and low nutrient values. The oxygen concentration decreased sharply, i.e., to < 1 ml per litre in the thermocline layer where the nutrient values showed a rapid increase. The minimum oxygen layer was always associated with high nutrient concentration indicating thereby that oxidation of organic matter in the bottom layer is primarily responsible for oxygen depletion.

Poster: **Biological and physical processes off Cape Comorin.** C. S. Walter, CSIR-SRF, PB No. 1609, Department of Aquatic Biology and Fisheries, Beach post, Trivandrum, 695007, Kerala, India. elim@md3.vsnl.net.in.
Cape Comorin (8° 4'44" N; 77° 34' E) on the south West Coast of India is a shallow rocky coast where Arabian sea, Indian ocean and Gulf of Mannar mixes. This area supports a vast assemblage of flora and fauna where in this typical ecosystem the primary production, energy transfer, secondary production and allelopathy play a major role. The distribution, growth and abundance of organisms of this coast are greatly influenced by various constantly changing physico-chemical factors of the ocean. The physico-chemical properties of the study site and the influence of the physical factors on the nutrient dynamics were analysed. The occurrence, abundance and the production of both phytoplankton as well as zooplankton, and the influence of the physico-chemical factors on them were studied. Plankton productivity reflected significant seasonal fluctuation according to the climatic variations. The data were analysed statistically to get a better understanding over the relations between

the abiotic and biotic factors and the relations even between the biotic factors. Species diversity and abundance were drastically influenced by environmental parameters. From the results, the optimum ranges of the physico-chemical factors were found and experimentally confirmed to developed suitable artificial growth conditions for culturing microalgae. The metabolic by-products produced by certain marine organisms for its defence purpose could be used to create new tools for Biomedical research and Pharmaceutical products. An extensive study has been undertaken for the isolation of biologically active metabolites of selected marine microalgae, which were cultured individually. The extracts of diatoms were tested against various bacterial and fungal pathogens and some of the tested diatoms showed positive results. The next step is to isolate from such diatoms the bioactive principles.

Oral: **Modelling new production in the northwest Indian Ocean region.** L.J. Watts[1], S. Sathyendranath[2,] C. Caverhill[2], H. Maass[2], T. Platt[2] & N.J.P. Owens[1], [1]Department of Marine Sciences and Coastal Management, Ridley Building, University of Newcastle Upon Tyne, Newcastle Upon Tyne NE1 7RU, UK; and [2]Biological Oceanography Division, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, B2Y 4A2, Canada. l.j.watts@ncl.ac.uk
Oceanic new production is a potential avenue for the removal of atmospheric carbon dioxide to the deep abyss. The ability to estimate new production on large, ocean-basin scales has important implications for studies of the greenhouse effect. This paper describes the development of a method, which will allow real-time estimates of new production on ocean basin scales, given real-time data on ocean-colour and sea-surface temperature from satellites. This study has concentrated on the northwest Indian Ocean region but the protocol developed is geographically transportable. Results from a biogeochemical study carried out in the Northwest Indian Ocean during a monsoon and an intermonsoon period in 1994 indicate that this region can be partitioned into six distinct provinces based on bathymetry, sea-surface temperature and chlorophyll measurements. Parameters that define the vertical structure in the biomass profile and the photosynthesis-light curve have been established for each province and these, in combination with archived satellite data are used to compute the primary production for each province using an established light-dependent model. From our empirically derived relationship between the *f*-ratio (Eppley and Petersen 1979) and primary production, new production for the northwest Indian Ocean over these two different seasons is computed.

Poster: **Carbon dynamics in the Arabian Sea at the onset and maximum of upwelling off Somalia and off Oman (May and August 1995).** C. J. Wiebinga, M. A. Baars & H. J. W. de Baar, Netherlands Institute for Sea Research, P.O. Box 59, 1790 AB Den Burg, The Netherlands. cas@nioz.nl
During the two cruises of the U.S. GLOBEC Arabian Sea study, in May and August 1995 (NOAA *RV Malcolm Baldrige*), we have sampled both the Somali upwelling and the Oman upwelling, including the JGOFS time-series station (16°N, 62°E), for phytoplankton composition, bacterial enumeration and production, dissolved and particulate organic carbon. In May we observed typical oligotrophic conditions at most stations, with chlorophyll concentrations of about 0.05 micrograms per litre (µg/l) and low bacterial production of about 50 pM leucine/h. However, temperature and chlorophyll profiles indicated that upwelling had already started in early May at 10°N (Ras Hafun) and along the coast of Oman. XBT-sections (100 nmiles) showed the 25°C isotherm sloping up towards the coasts of Somalia and Oman. Associated with the starting phytoplankton blooms, reaching surface chlorophyll maxima of about 1 µg l^{-1}, we observed almost one order of magnitude higher bacterial production in the upwelling areas. During August, at the maximum of the SW-monsoon, chlorophyll concentrations exceeded 3 µg l^{-1} in both upwelling areas. Only in the Oman upwelling the particulate organic carbon was appreciably higher than we had encountered earlier. Apparently, strong advection in the Somali Current reduced the potentially high productivity of the Somali upwelling. Enhanced bacterial production only co-occurred with increased phytoplankton biomass, adding evidence for the direct supply of labile organic matter by phytoplankton to sustain the bacterial carbon demand, rather than a carbon supply by a semi-refractory DOC pool accumulated in an earlier stage.

Oral: **The northeast monsoon's impact on mixing, phytoplankton biomass and nutrient cycling in the Arabian Sea.** J. Wiggert[1], B. H. Jones[2], T. D. Dickey[3], K. Brink[4], R. A. Weller[4], J. Marra[5], & L. Codispoti[6], [1]Universities Space Research Association, NASA/GSFC Code 970.2, Greenbelt, MD 20771, [2]Department of Biological Sciences, University of Southern California, Los Angeles, CA 90089-0371, [3]ICESS, UC Santa Barbara, Santa Barbara, CA 93106-3060, [4]Woods Hole Oceanographic Institution, Woods Hole, MA, 02543, [5]Lamont-Doherty Earth Observatory, Palisades, NY 10964, [6]CCPO, Old Dominion University, Norfolk, VA 23529, USA. jerry@ardbeg.gsfc.nasa.gov
In the northern Arabian Sea, atmospheric conditions associated with the northeast (winter) monsoon lead to deep convective mixing. Due to the proximity of the permanent pycnocline to the sea surface, this mixing is unable to penetrate below 125 meters. However, a strong nitracline is also present and the deep convection results in significant nitrate flux into the surface waters. This leads to nitrate concentrations over the upper 100 meters, which exceed 4 μM toward the end of the monsoon. During the 1994/1995 JGOFS/Arabian Sea expedition, measured areal gross primary production was 1176 g C m^{-2} d^{-1} during the NE monsoon. Thus, despite the deep mixing which is evident throughout this portion of the monsoon, high rates of primary productivity were maintained. In order to understand these processes better, an interdisciplinary model was developed which consisted of a 1-D mixed layer model coupled to a basic ecosystem model. The latter contained terms for phytoplankton and the two major nutrients (nitrate and ammonium). Zooplankton grazing was parameterised by a rate constant determined by shipboard experiments. Model boundary conditions consist of meteorological time series measured from a surface buoy attached to the ONR Arabian Sea Experiment's central mooring. Sensitivity studies that focused on the choice of applied boundary conditions revealed that the frequency and penetration depth of convective mixing is significantly altered by salinisation resulting from surface evaporation. Enhanced mixing results in cooler surface temperatures, reduced water column stratification and lower near surface chlorophyll concentrations. The model also showed that phytoplankton growth during the NE monsoon is principally dependent on regenerated nitrogen. Finally, sensitivity studies based on altering pycnocline depth indicate that this feature's vertical position significantly contributes to predicted near surface chlorophyll concentration. We hypothesise that interannual variations observed in previous in-situ measurements of this region's primary production and surface chlorophyll concentration may result from such shifts in pycnocline depth.

Oral: **Analysis of ocean colour data of waters around Sri Lanka obtained from the Coastal Zone Colour Scanner (CZCS).** K.K.A.S. Yapa, Department of Physics, University of Ruhuna, Matara, Sri Lanka. kanthi@phy.ruh.ac.lk
Remotely sensed data on ocean colour of waters that surround Sri Lanka received from the Coastal Zone Colour Scanner (CZCS) obtained through NASA data archive centre, are analysed. An algorithm developed at NASA (SEAPAK) is used here to retrieve sea surface chlorophyll concentrations. Raw data on relatively cloud free days during 1978-1986 are processed to produce chlorophyll maps. A region in the Indian Ocean between latitudes 4.5°N-11°N and longitudes 78°E-85 °E is chosen as the study area. The processed data include about 150 chlorophyll maps. Composite averages of surface chlorophyll for each month are also made. The months of July, August and September are omitted in the calculation of averages due to insufficient data during those months. The waters between Gulf of Mannar and Palk Strait (region between north of Sri Lanka and south east of India) show high chlorophyll concentrations throughout the year. However, these high values may represent other suspended particles and dissolved organic matter besides chlorophyll, as this region is shallow (<100 m). Analysis show that there are upwelling regions with high chlorophyll concentrations (>0.5 mg Chl. m^{-3}) along the coastal waters and in the western ocean region in the months of October and November. High Chl. concentrations may indicate high productivity. Therefore, these regions need extensive studies of measurements of primary production and continuos monitoring of fish catches during these months.