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C-MMACS Environmental Modelling Programme

Highlights

- Formal Launching of CSIR Network Project on Development of Integrated Forecast Platform Sub Task II
- International Conference on Scale Interaction and Variability of Monsoon
- Launching of CSIR Non-Network Project on Long-Range High Resolution Forecasting of Monsoon
- Experimental Long-range Forecast of Monsoon Rainfall for 2004
- Simulation of WHOI Buoy Data with Modular Ocean Model
- Identification of Characteristic Scale of Organisation for Monsoon Intensity
- Long-range Forecasting and Simulation of Monsoon Variability with C-MMACS Coupled GCM (CM-CGCM)
- Development of the first Version of the Parallelized GCM under the NMITLI Project on Monsoon Related Meso-scale Forecasting
- Inversion of Tropospheric Delays Abstracted from GPS Data at Various Permanent Sites Yield Estimates of Total Precipitable Water Vapour Overhead, that Correlate Reasonably well with Local Meteorological Conditions of Humidity & Rainfall

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- Long- range, High-resolution Forecast for Monsoon 2004
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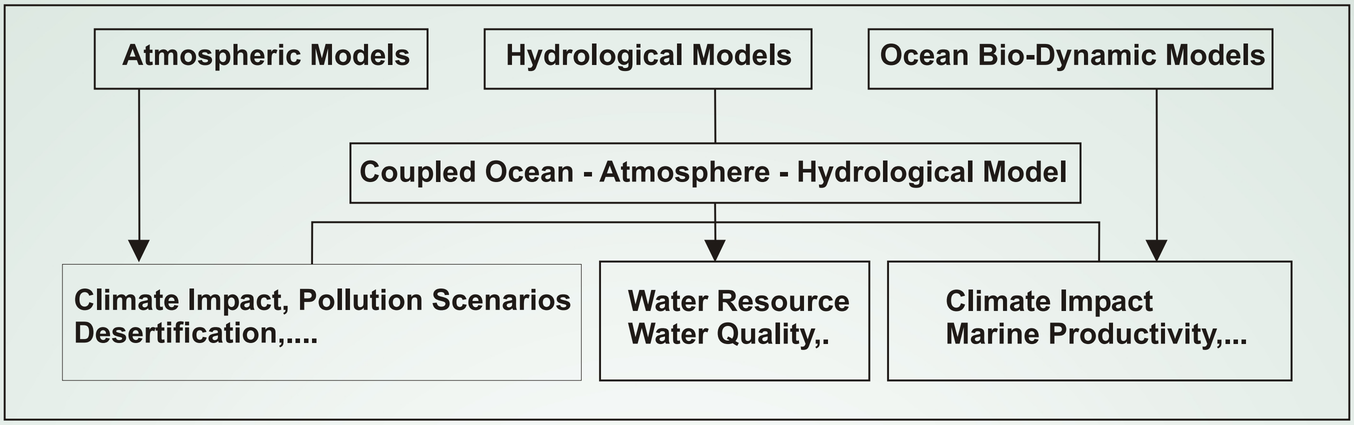
- Ocean Atmosphere Coupled Model: Monsoon Variabilty in C-MMACS CGCM
- Convective Organization and Monsoon Variability
- Modelling of Biogeochemical Cycles in the Indian Ocean
- Simulation of Upper Ocean Thermal Structure at the Arabian Sea Mooring Site
- Estimation of Global Sources and Sinks of Co_2 through Inversion

2005 Perspective

With the formal launching of the CSIR Network project on the development of a Multi-scale Modelling Platform for Environmental Systems, a large part of the effort will be on this. Similarly, considerable effort will be towards development of the Community Indian Ocean Model and the C-MMACS coupled General Circulation Model. A research project under the proposed Indo-French Centre for Environment and Climate (IFCEC) and funded by Indo-French Centre for Promotion of Advanced Research (IFCPAR) has been initiated to measure and model CO_2 concentrations at the Indian Astrophysical Laboratory at Hanle. C-MMACS has prepared a comprehensive, multi-institutional project for development of an Integrated Technology for Cloud Modification; the work is expected to begin in the coming year.

A Schematic Representation of CEMP



Some Milestones:

The Modular Ocean Model has been installed and evaluated; An Indian Ocean Community Model Is under development.

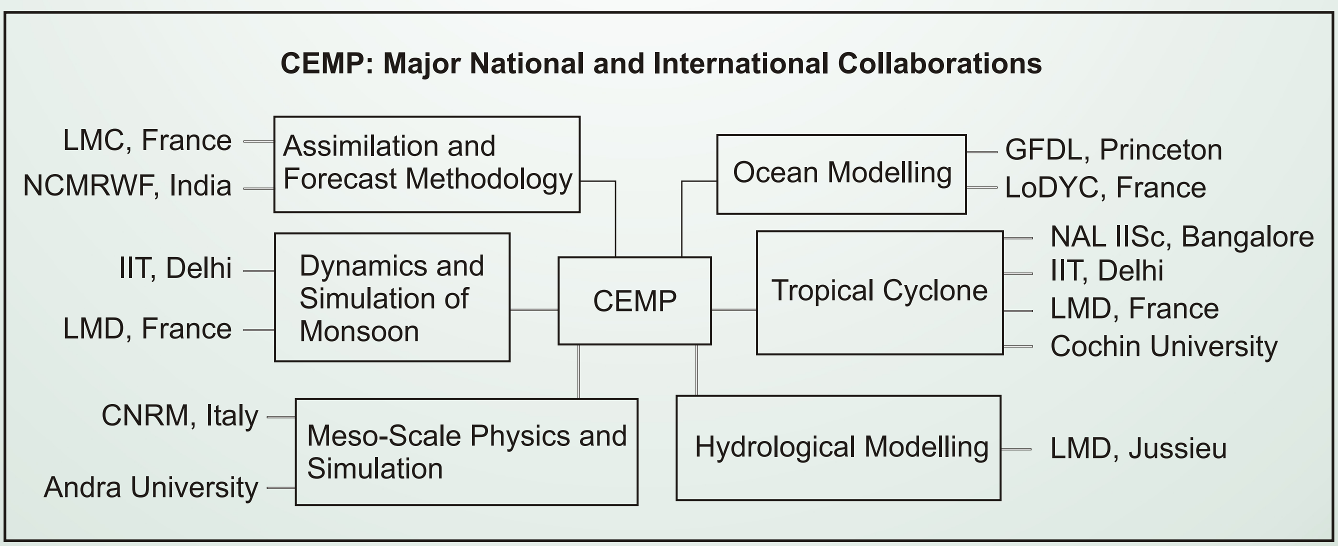
A comprehensive dynamical mechanism for the broad spectrum of tropical variabilities has been developed; this has direct implications for model improvement and model evaluation.

A new parameterization of convection in the tropics has been developed using the concept of convective time lag.

A preferred scale for intensification of tropical disturbances has been predicted using experiments; This has direct implications for early identification and early warning of tropical cyclones.

Process models for marine primary productivity have been developed and evaluated. This forms Basis for modelling higher trophic levels.

The Neural Network model developed at C-MMACS for long-range forecasting of monsoon rainfall has been successfully used to generate experimental forecasts for the past seven years.



1.1 Long-range, High-resolution Forecast for Monsoon, 2004

As in the past few years, the Atmospheric General Circulation Model was employed to generate experimental forecasts for 2004 with long range (3-6 months) and high resolution (~ 50 km). The simulations were carried out with initial conditions from daily averaged fields from NCEP on a 2.5°x 2.5° grid.

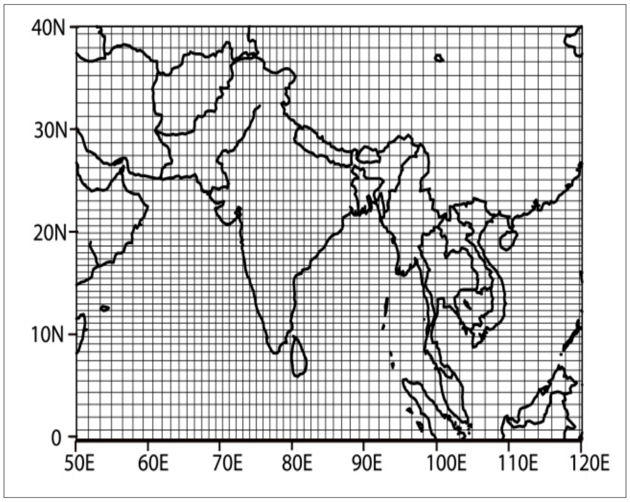


Fig 1.1 Part of the model horizontal grid with its zoom centered at 75°E and 15°N.

The results presented here (except for onset) are from 4-member multi-lead (May 7,15,21, June 1) ensemble average.

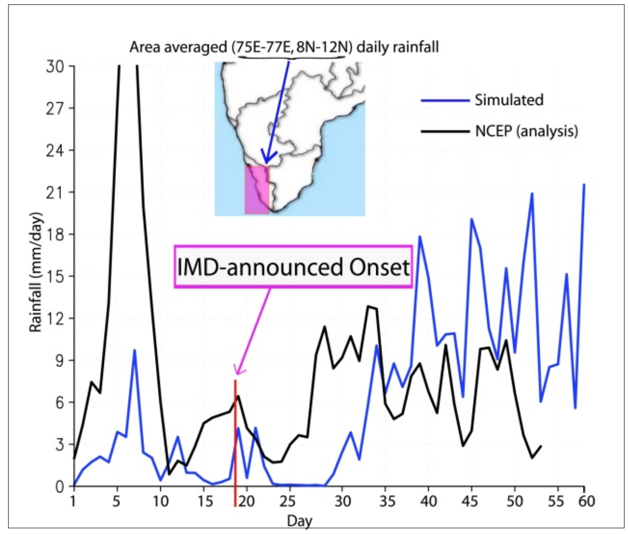


Fig 1.2 Time series of area-averaged (75-77E; 8-12N) daily rainfall over coastal Kerala. Day 1 corresponds to 1st May 2004.

All the simulation were carried out in a forecast setting with sea surface temperature prescribed from a monthly climatology from AMIP data set. An interesting feature of monsoon 2004 is its very early onset; large-scale persistent rain over the coast of Kerala has begun as early as the first week of May. Fig1.2 shows the time series of daily rainfall from NCEP (black) and model forecasts

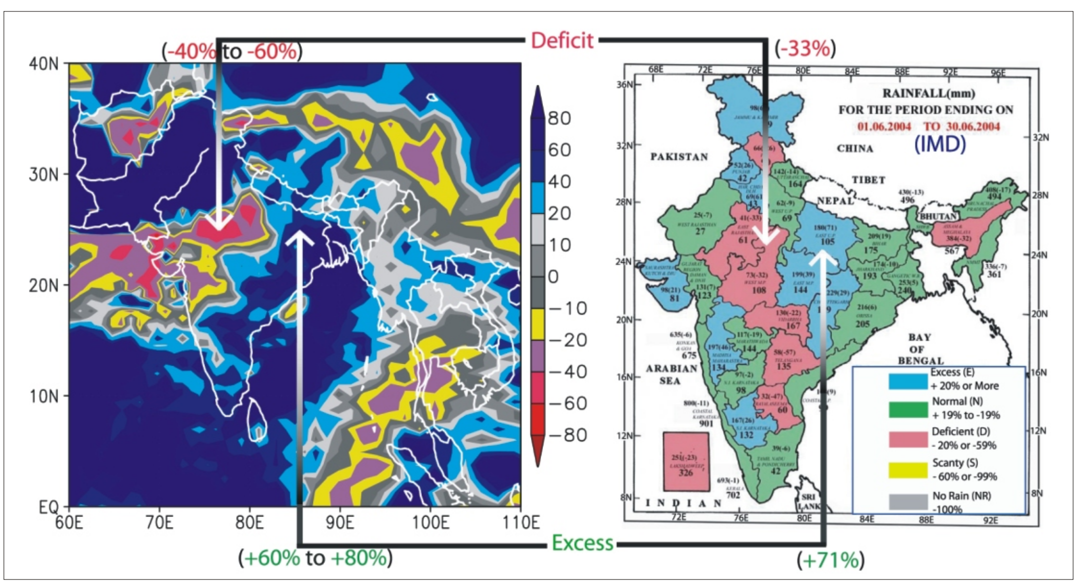


Fig 1.3 Longitude-latitude distribution of monthly rainfall from 4 member ensembled model forecasts as percentage deviation from model mean for June,2004. The corresponding observed distribution from IMD is shown on the right panel. Comparison of model forecasts and observations for a few extreme areas are indicated.

(blue) for the period May-June, 2004 over the coast of Kerala as indicated. The forecast for onset was created with the initial condition extracted from NCEP analysis for March 25, 2004. The simulated time series for 2004 shows persistant rain all throughout May, as observed with a peak around May 18, 2004, the date of onset as announced by IMD.

Fig 1.3 shows the distribution of normalized (with respect to 15-year model mean) rainfall anomalies for the month of June, 2004 (left panel). The corresponding observed distribution from IMD (www.imd.ernet.in) is shown on the right panel. It is clear that the forecast successfully captures most of the important features of observed distribution.

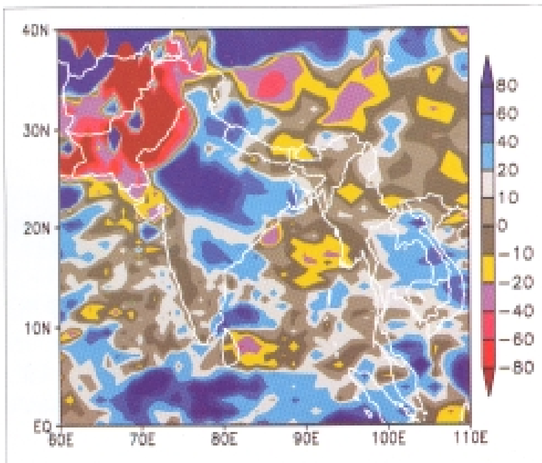


Fig 1.4 Longitude-latitude distribution of normalized rainfall anomaly (in % of mean) for the month of July,2004 from a 4-member ensemble average forecast

The forecast for month of July, 2004 is an overall normal monsoon with excess over central and north India and normal rainfall over southern and north-eastern India.

A Mandal and P Goswami

1.2 Hydro-Biospheric Processes and Soil Moisture Variability

Amount and variability of soil moisture plays a critical role in the variability of local precipitation. The dynamics of soil moisture, however, is a

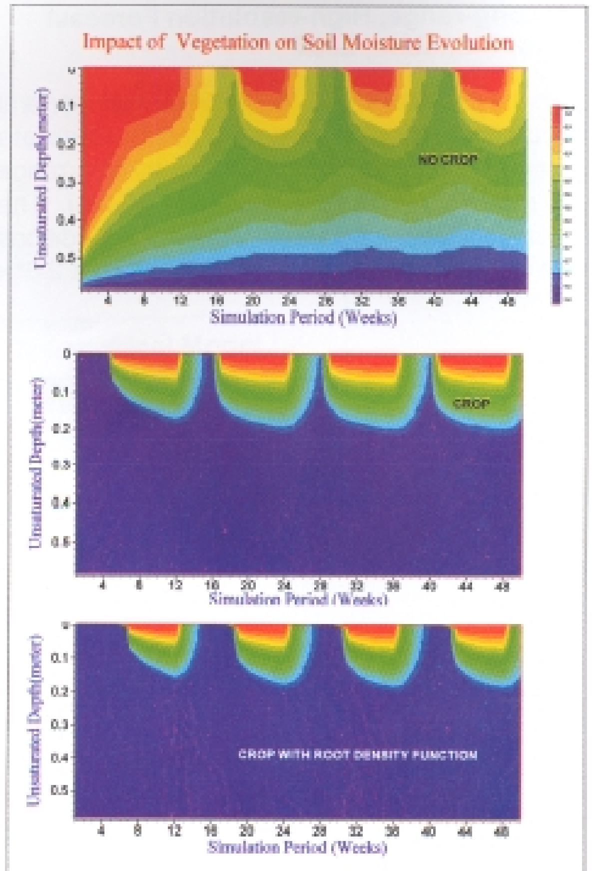


Fig 1.5 Effect of Vegetation on Soil Moisture Variability

strongly non-linear processes with a number of interacting scales. This necessitates the use of comprehensive numerical model to investigate issues like relative roles of various processes We have developed a one dimensional multi-level soil hydrology model to investigate and quantify the effects of some of the key vegetation and surface processes on soil moisture dynamics. The simulations clearly brought out the important role of parameters like root zone can play in the evolution of soil moisture.

The model is based on the numerical solution to highly nonlinear Richard's equation with exponential decrease type of hydraulic conductivity function. Series of numerical experiments are carried out by forcing the model with precipitation as surface boundary condition and zero pressure gradients as lower boundary condition. The initial vertical profile of soil moisture is extracted from a

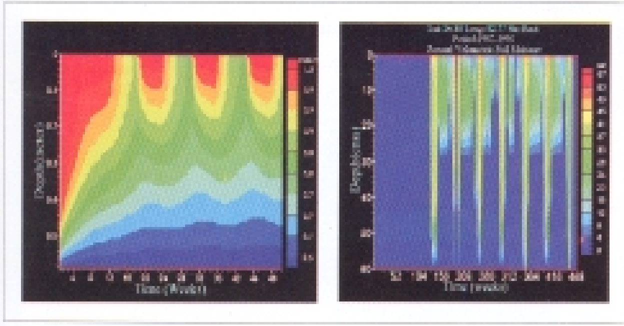


Fig 1.6 Observed Vs Simulated Soil Moisture

weekly-averaged data. Evaporation processes from vegetated land surface and plant root uptake have been incorporated as sink terms in the aforementioned Richard's equation. The calibration and evaluation of the model was carried out through a long-period (one year) simulation of soil moisture at select locations. Simulated results have shown significant effect of vegetation on soil moisture evolution as shown in Fig 1.5. Simulated and observed results are compared in Fig 1.6. Vertical structure and time variability of observed and simulated results are reasonably comparable. This effort , in addition to being an integral part of CEMP forms a part of the project on *Atmosphere-Biosphere* Interactions sponsored by ISRO under IGBP program.

S Himesh and P Goswami

1.3 Mesoscale Simulation: Effect of Convective Parameterization

An important step towards development of an integrated and comprehensive modelling platform was achieved with the incorporation of the MM5 mesoscale model into the CEMP modelling platform. The model has been configured for the Indian region for multi nest simulation. A series of simulations was carried out to access relative merits of different parameterisation schemes for monsoonal convective systems.

The simulations were carried out for a heavy rainfall event that occured along the west coast of India during monsoon on 13 June 1988. The model was set up with 4 nested domains 81 km, 27 km, 9 km and 3 km grid sapcing with 23 vertical levels. Fig 1.7 shows the domains of integrations, with the four nests with thier respecive resolution.

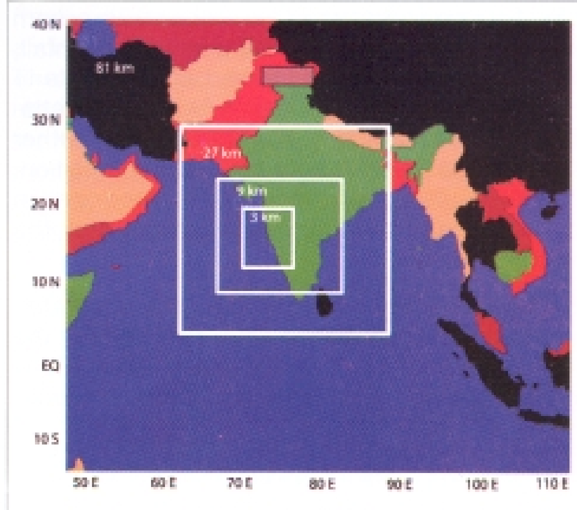


Fig 1.7 Domains of model integration with mutiple nests. The highest resolution(inner most nest) is 3Km

The model was initialised at 00z 11 June 1988 using the NCEP's 2.5 degree gridded analysis. We have carried out the simulation with different cumulus parametirisation schemes such as Anthes-Kuo, Betts-Miller, Grell and Kain-Fritch

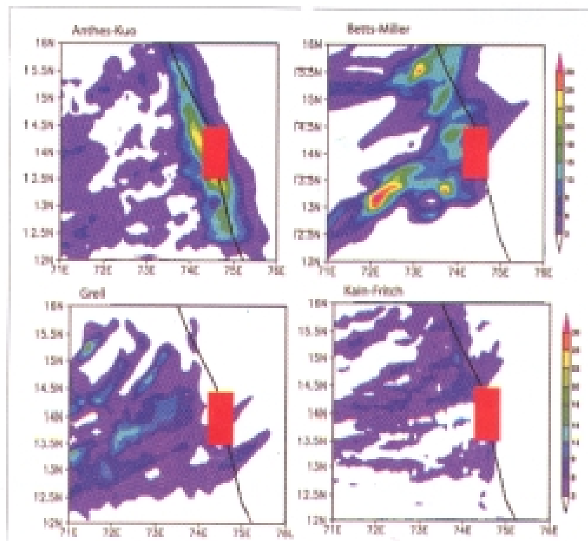


Fig 1.8 Simulated 24 hour rainfall for different parameterisation schemes. The area of observed heavy rainfall is marked with the red square.

schemes. We have kept the Eta boundary layer scheme and Simple Ice microphysiscs foe all simulations. The model was ran for 48 hours and last 24 hour rainfall is shown in Fig 1.8. A scruiny of Fig 1.8 reveals that while the Anthes–Kuo schem gives less error in amount and position of rainfall, the Betts-Miller scheme gives better results in terms of the amount of rainfall, however the Betts-Miller scheme failed to capture position. The other two schemes failed in both amonut and position. These simulations form a key component in calibrating and configuring the model for the monsoon region

The MM5 is a key component for the integrated modelling platform being developed under the CSIR Network Project on Development of Multi-scale Forecast Platform for Environmental Systems.

S Sijikumar and P Goswami

1.4 Ocean Atmosphere Coupled Model : Monsoon Variability in C-MMACS CGCM

It is generally believed that ocean atmosphere coupled models (CGCM) can significantly enhance our skill in long-range forecasting of monsoon. Development of CGCM with adequate skill, especially over the Indian Summer Monsoon (ISM) region, however, remains a major challenge. While many factors, often interacting, determine the skill of a CGCM, it has been shown that the atmospheric component often plays the major role in deciding the performance of the CGCM. A carefully chosen atmospheric component, with good validity over the monsoon region, could result in a CGCM of significant skill for monsoon forecasting.

A CGCM configuration (C-MMACS CGCM) was therefore developed which exhibits significant skill in simulating the variability at different scales. The oceanic component of the CGCM is the MOM developed at GFDL, Princeton while the atmospheric component is the grid point variable resolution AGCM, developed at LMD, Paris. In addition, we use a semi-empirical SST module that constructs the SST field from the simulated sub-surface temperature and surface winds. The model interface essentially controls the exchange of the information between the two component GCMs and the SST module. The interface also prescribes the frequency at which the coupling is to be invoked. We analyze 20 one-year integrations to examine the variability at intra-seasonal, seasonal, and inter-annual scales.

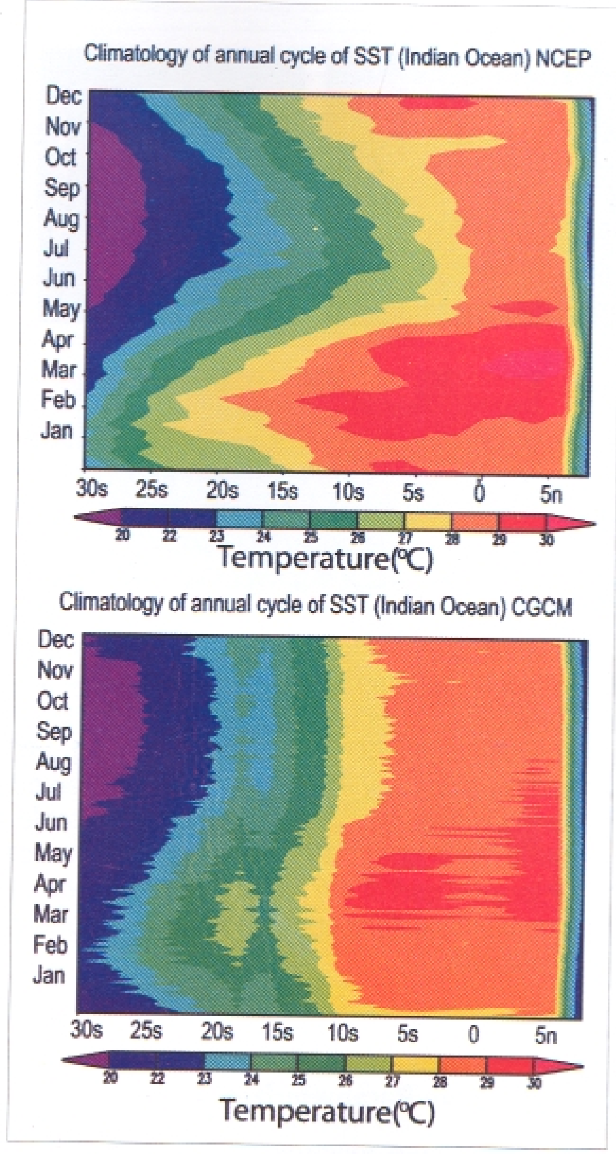


Fig 1.9 Latitude-Time diagram of longitudinally averaged (45°E-95°E) SST from 20-year mean daily values of NCEP (top panel) and CGCM (bottom panel) for the Indian ocean basin (30°S-8°N).

The grid pattern selected for MOM is 182X92X13 (2°Square grid) and 192X96X11 (1.875° Square grid).

The MOM is initialized with the respective monthly Levitus- climatology of SST and salinity. The SBC for MOM is the interpolated surface wind field of GCM simulation at the end of each day. For the initial spin-up, NCEP data of the particular year is used. GCM has initial conditions prepared from NCEP data of the particular day of the year. SBC of GCM is interpolated SST of MOM, constructed

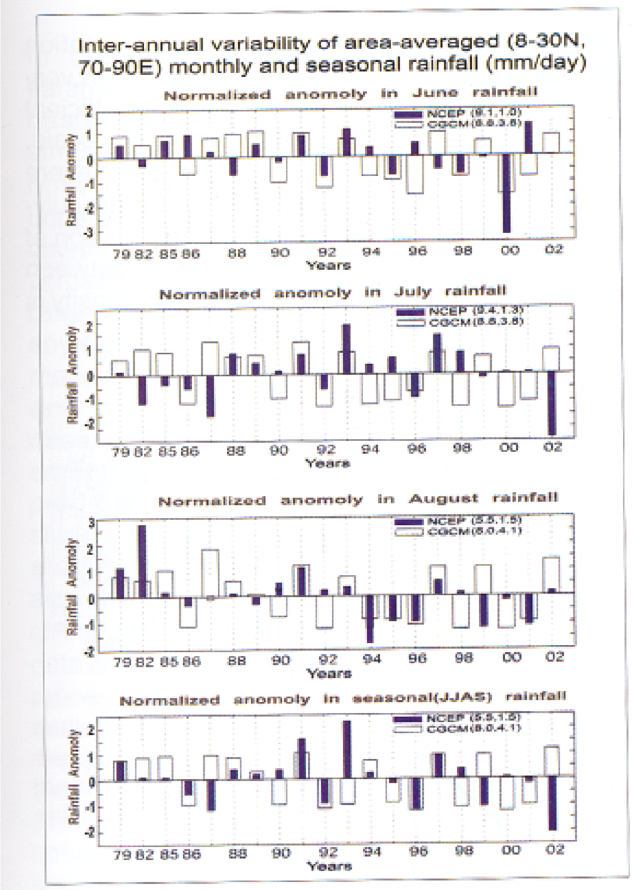


Fig 1.10 Inter annual variability of area averaged rainfall over the ISM region from CGCM (hollow bar) and NCEP (solid bars). Numbers in the censored brackets show the mean and standard deviation respectively.

by an SST module, using top layer MOM temperature simulated each day. The OGCM is restored with monthly climatology of SST from AMIP wit a restoring time scale of 30 days.

Fig 1.9 compares the annual cycles, in the form of latitude-time structure of longitudinally averaged SST over the equatorial Indian Ocean basin (70°-90°E, 8°-30°N), from a 20-year climatology of model simulation and NCEP reanalysis data. The two climatologies compare well, although the simulated temperatures south of 10°S are somewhat colder (by about a degree) than the corresponding NCEP value.

One of the primary goals of our work is to achieve acceptable skill in long-range forecasting of monsoon with CGCM. The model's ability in capturing the inter-annual variability is shown in Fig 1.10 which compares normalized departures (from respective means) in area-averaged monthly and seasonal rainfall over India for 20 hindcasts. The numbers in brackets in each panel show the mean and standard deviation respectively. Thus the model exhibits considerable skill in forecasting monsoon intensity with 6-9 months lead. Further calibration exercises to improve the model's performance are in progress.

P Rajeevan and P Goswami

1.5 Convective Organization and Monsoon Variability

For a large fraction of the world's population that depends on the monsoon rainfall, it is the variability of ISM which is a deciding factor in areas such as crop planning, sowing schedule and fodder banking. However, the spectrum of monsoon variability, covering intra-seasonal to inter-annual time scales, has remained elusive to both our understanding and model simulation. In the complex interaction of scales and processes that characterize the ISM, it is not easy to identify mechanisms and processes for a given feature. An important issue that needs to be examined is organization of dynamics, and hence induced heating, at different scales.

A mechanism that can play a critical role in this process is convective feedback, leading to scale selection. Dynamically, the situation is akin to a conditional instability of second kind (CISK), where a weak perturbation (low-pressure system) can amplify by inducing convergence over a wide domain. Although CISK as originally proposed was unsuccessful to account for selective excitation at observed scales, the basic physical scenario implied by CISK is likely to be operative in some form. Organization is a characteristic feature of atmospheric circulation at all scales; the important role of organization in convective forcing has been emphasized in a number of studies. Our studies have helped identify and quantify such a scale for monsoon dynamics.

We characterize and quantify convective organization through the following quantity: The vertical integral essentially represents up-ward motion through the continuity equation; H_1 and H_2 are taken to be 1000 and 500 mb, respectively.

Here S represents the domain, corresponding to a scale s, over which the convective organization is considered. Numerically, C_{LS} is computed by considering appropriate longitudes and latitudes to represent a domain of size S. As the NCEP Reanalysis used here has a resolution of 2.5°x2.5° in longitude and latitude, the smallest step by which s can change is about 250 kms. C_{LS} as calculated above can be both positive and negative. However, only convergence can lead to upward transport of moisture and hence precipitation. On the other hand, divergence does not imply negative precipitation. Unless otherwise specified, therefore, we shall only consider convergence values (considered positive for ease of discussion) in our subsequent analysis.

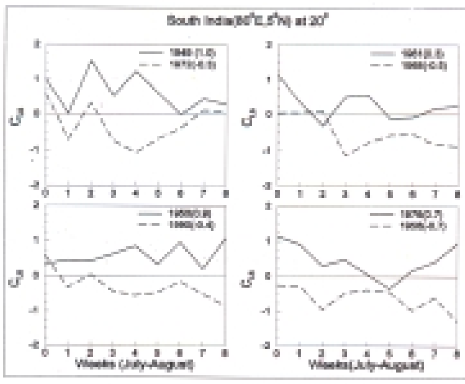


Fig 1.11 Organized convergence (considered positive at 20° scale over south India for a few selected excess (solid line) and deficit years (dash line) as indicated.

Fig 1.11 illustrates the contrast in C_{LS} for excess and deficit years by considering a few selected years, chosen at random over the analysis period, as indicated. For ease of comparison, in this figure, we show both convergence (considered positive) and divergence. The strong contrast in organized convergence for excess and the deficit years is quite striking; a pre-dominance of divergence in the deficit years is clear against a pre-dominance of convergence in the excess years. The numbers in the bracket show values of R_N (calculated for July-August period).

$$C_{LS} = \frac{1}{s}\int_{S} \int_{z=H_1}^{H_2} -\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}\right) dz\, ds \qquad (1)$$

The specific case of 2002 is considered in Fig 1.12. The solid line shows the values of C_{LS} at s=20° while the dash line shows precipitation anomaly (Equation 1) beginning with July 1. A very clear association, with a co-relation co-efficient close to 0.7 (0.4) at lag 0 at weekly (daily) scale, is evident. The figure clearly shows the severe suppression of organized convergence in the July-August period and the associated suppression of rainfall. In other words, the association between organized convergence and monsoon intensity is significant even in daily scale.

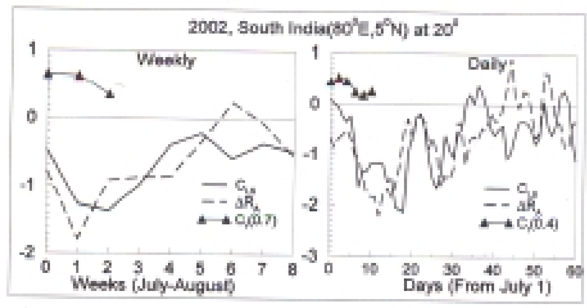


Fig 1.12 Daily and weekly averaged values of low-level convergence (considered positive) organized at 20° scale over south Indian (rectangular) region (solid line) and corresponding precipitation anomaly from NCEP averaged over India for 2002. The solid line with triangles represents lagged correlation.

Our analysis thus brings out organized dynamics as another important factor in monsoon intensity, in addition to known processes like sea-surface. The important role played by dynamics (convergence) in determining monsoon intensity underlines the necessity for model capability to simulate high-frequency dynamics accurately for reliable prediction of even quantities like area-averaged seasonal rainfall.

G K Patra and P Goswami

1.6 Mathematical Modelling of Biogeochemical Cycles in the Indian Ocean

Marine biogeochemical cycles play a significant role in key environmental issues like oceanic response to climate change, coastal pollution etc. The major challenges in modelling of marine biogeochemical process are the identification of the ecosystem compartments and the underlying biogeochemical processes and their parametrizations, model-data comparisons and data assimilation. Since most of the present models do not include many of the key processes in ocean biogeochemistry or the model parameters are not defined on a clear mechanistic basis, their results from global or regional simulations often do not compare well with observations. Such a situation limits the understanding of coupled interaction of physical, chemical and biological processes in the ocean across relevant space and time scales. At present biogeochemical modelling is inherently data driven, any significant progress in developing numerical models can be attained only if modelling efforts are integrated with the growing body of observations and the conceptual paradigms emerging from large-scale field and satellite programs. The main objectives in modelling studies are identification of key biogeochemical elements/compartments and processes, estimation of the model parameters and evaluation of the integrated system models through model-data comparison at different temporal scales. The process of nutrient uptake by phytoplankton in a multinutrient environment, is one such process in marine biogeochemical cycle studies. An error in the representation of nutrient kinetics can lead to overestimation or underestimation of nutrient uptake and hence of primary productivity, which is the major controlling factor in the carbon cycle and is also a major factor in the food web.

As a part of these studies, 3D simulations based on biological model and the chemical model were coupled to a physical oceanographic model (Sarmiento et al., 1993) were performed at C-MMACS. We report here the results of the effect of biology on the carbon flux across air-sea interface in Arabian Sea (AS) and Bay of Bengal (BOB) and compare them with observations. Arabian Sea and Bay of Bengal are the adjoining seas of Indian Subcontinent, having similar terrains. They are relatively small ocean basins located in the tropical region and are influenced by the reversing monsoon winds. The physical, chemical and biological features of Bay of Bengal are much different from Arabian Sea because of (i) enormous supply of fresh water and the associated sediment load from large rivers of Indian peninsula, (ii) Bay of Bengal is partially connected to Pacific. The fresh water input reduces the surface salinity but bring in new nutrients which forms a strong stratified layer hampering exchange processes between atmosphere, surface and deep waters. The available data also shows that Bay of Bengal is less productive though there is large riverine import of nutrients. The cyclones during May and October in Bay of Bengal are expected to offset the heat and buoyancy fluxes dramatically over very short span of time, triggering associated changes (which are not yet quantified) in the water column chemistry and biology. Bay of Bengal is under-sampled and least understood. Precipitation is more than evaporation in Bay of Bengal which influences the chemistry and biology. The effects of all these processes on the carbon cycle needs to be studied.

The physical model (Modular Ocean Model) was forced with monthly climatological forcings. The two nutrient interaction laws currently in use, and a new general formulation based on the properties of similarity and hyperbolicity, have been introduced into the seven component marine ecosystem model, to study the effect of this formulation on the behaviour of the biogeochemical variables in the mixed layer. The consequences of selection of these kinetic relations on 3D simulations based on the biological model coupled to a physical oceanographic model of marine ecosystem were examined. Chemical tracers (dissolved inorganic carbon (DIC) and alkalinity), were introduced in the coupled physical-biological model to understand the influence of biology on chemistry on a basin-wide scale. Phytoplankton is the only carbon fixing component in the whole system. The formation of biogenic calcium carbonate was introduced. The flux of organic matter at the base of the euphotic zone was computed by summing the vertically advective and diffusive fluxes of phytoplankton, zooplankton and detrital matter, and a part of this flux was redistributed below the euphotic zone in an exponentially decreasing manner with an e-folding depth of 400m. To convert the ecosystem variables from nitrogen to carbon units, the Redfield ratio was used. The DIC and alkalinity fields were initialized using the objectively interpolated atlas of Myrmehl and Drange.

To determine the transfer of CO_2 across the air-sea interface, DIC was partitioned into three species, namely, the dissolved CO_2 component (pCO_2), HCO_3^- and CO_3^{2-}. Boric acid which is proportional to the salinity was considered, but phosphoric acid and silicic acid were not included.

An equilibrium model was used with some modifications to compute pCO_2. Since the chemical model calculations are computer intensive, they were made only for surface grid points. The flux of CO_2 across the air-sea interface (F) was computed using the equation (2)

$$F = k_l \alpha_s \left(pCO_2^{air} - pCO_2^{sea} \right) \qquad (2)$$

where kl is the piston or transfer velocity and α_s is the solubility of CO_2 in sea water. pCO_2 for air has been adjusted for 100% relative humidity and piston velocity (regulated by the turbulence at the air-sea interface and chemical reactions in the liquid phase) is calculated using the Wanninkhof (1992) formulation. In contrast to other biological and chemical species, the flux F is added only to the top grid box while solving the DIC equation.

The three dimensional coupled physical-chemical-biological model results showed that temperature, salinity and mixed layer depth for the Indian Ocean generally match well with the climatological data. It was also found from the simulations that the spatial variation of annual average primary productivity, especially in the regions of high primary productivity in the northern Indian Ocean, agree most favourably with SeaWiFS data for the relation based on similarity and hyperbolicity. Comparison of cruise profiles of nitrate, chlorophyll and primary productivity at a JGOFS station in Arabian Sea also shows that the our formulation give values closer to observations than other relations. Model results were compared with the cruise data available for Bay of Bengal. The contour plots of nitrate and chlorophyll for four months (Jul-Oct) obtained from model results show that there are no significant spatial and seasonal variations on the open ocean transect (88° E) in Bay of Bengal. Temperature profiles match well with observations at certain locations. However, salinity profiles do not match as well with the cruise data (July-August 2001, in Bay of Bengal) at certain locations. Temperature and salinity contours given by simulations using 6-hourly NCEP data compare better than the simulation results obtained using climatological forcings, with observations as given in BOBPS reports for 2002 and 2003. Nitrate (monthly average) profiles have a sharper nitracline than that in the cruise (snapshot) data. Modelling of biological and chemical processes below the euphotic zone need to be further examined. Monthly average values of chlorophyll for July at four stations on 88° E transect are significantly greater than the cruise (snapshot for July-August, 2001) data. Mild subsurface chlorophyll maxima are seen at some locations in the simulation. Chlorophyll values in the simulations are larger in the central parts of Bay of Bengal.

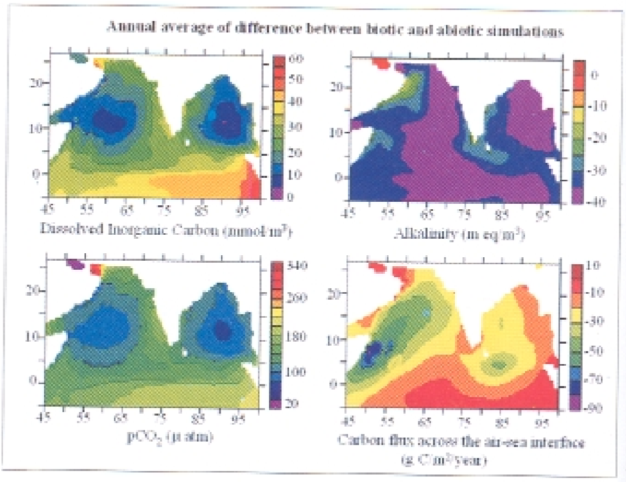


Fig 1.13 The effect of biology on the annual averages of DIC, alkalinity, pCO_2 and carbon flux across the air-sea interface in the Indian Ocean

Two types of simulations were carried out – abiotic and biotic. In the abiotic simulations, only physical and chemical models were coupled and biological tracers were not considered. In the biotic case, the simulations were carried out for the coupled physical-biological-chemical model. In both the simulations, spatial and temporal variations of DIC, alkalinity, pCO_2 and carbon flux across the air-sea interface were examined in detail for a few locations in the Arabian Sea and the Bay of Bengal. Fig 1.13 shows that annual average of DIC, pCO_2 and carbon flux from the ocean to atmosphere are more and annual average alkalinity is less for the biotic case compared to abiotic case everywhere in the Indian Ocean. Fig 1.14 compares DIC profiles obtained from the simulation with the US JGOFS data at a station in the central Arabian Sea.

Comparison of SeaWiFS data on annual primary productivity and US JGOFS data on the profiles of nitrate and chlorophyll at a station in Central Arabian Sea shows that the choice of the kinetic

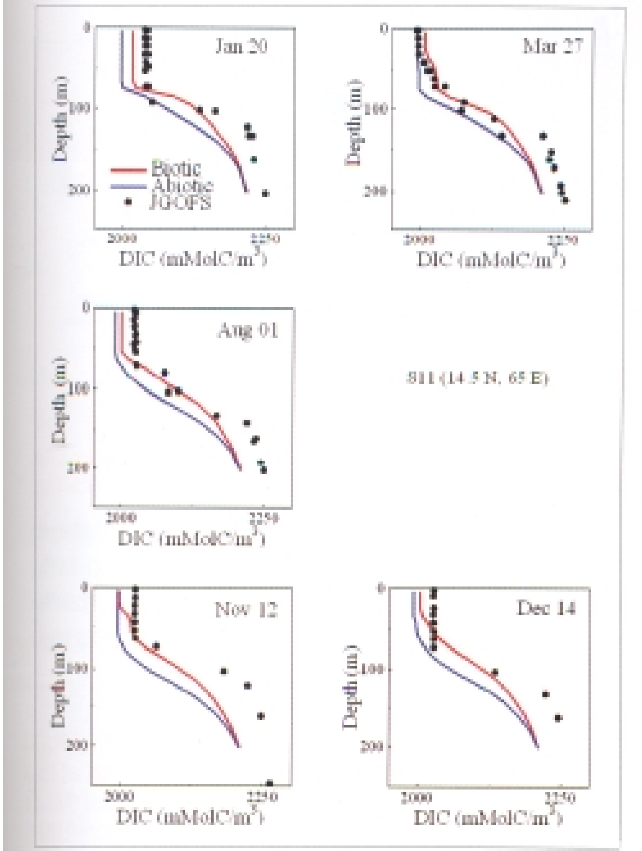


Fig 1.14 Seasonal variation of DIC profiles at 14.5°N, 65°E: Comparison of biotic and abiotic simulations with US JGOFS data.

relation has a significant effect on the dynamics of the ecosystem. Oceanic pCO_2 is more in AS than in BOB. In biotic and abiotic simulations, pCO_2 at the surface of the ocean is greater than the atmospheric pCO_2 everywhere in the Indian Ocean. Carbon flux from the ocean to the atmosphere in the biotic case exceeds that in the abiotic case, both in BOB and AS. Transfer of Carbon is maximum during August in AS. Biological and Physical pumps make comparable contributions to carbon flux in BOB as well as AS. Simulated DIC profiles obtained match fairly well with the US JGOFS data at a station in the Central Arabian Sea.

P S Swathi, M K Sharada, K S Yajinik and C Kalyani Devasena

1.7 Simulation of upper ocean thermal structure at the Arabian Sea mooring site

The importance of the tropical ocean in influencing global climate is well understood. The Indian Ocean, especially, the Arabian Sea is unique for many reasons. It is the only ocean basin which is bounded in the north. Further, the monsoons reversals and the resulting currents make it quite unlike other ocean basins. It is a region of intense air-sea interaction and plays a very significant role in climate variability.

In connection with the JGOFS campaign, the Woods Hole Oceanographic Institute (WHOI) established a time series at 61.5°E and 15.5°N which operated from October 1994-October 1995. For the first time at the buoy site an accurate and continuous record of near-surface meteorology were collected. From the collected observations like surface parameters (wind velocities, short and long wave fluxes) and sub-surface parameters (temperature, salinity and velocities) a time series of latent and sensible heat fluxes, net shortwave radiation, net longwave radiation were determined. The recording interval was 7.5 minutes.

In this study we try to model the buoy observations using Modular Ocean Model (MOM-4), a contemporary OGCM. The domain of the model is 38°E-100°E (with 0.4° resolution), 15°S-27°N (with 0.4° resolution) and 35 levels in the vertical (10 m in the top 100m and 17m in the top 200m). The domain is closed in all the sides with a sponge of 3 degree width and 30 day restoring applied at the northern and southern boundaries.

The physics of the model is neutral physics for tracer diffusion and KPP physics for vertical mixing. The quicker scheme is used for tracer advection. The time steps are 2700 sec for tracer, baroclinic and the "large"eta time steps and 60 sec for the free surface. A "weak" surface restoring of 30 days was imposed but as the results will show the restoring amount is very small and the thermodynamics is essentially under imposed flux control.

We have used the diagnostic monthly fluxes from a 50 year run as input to our model. The surface buoy data which is at a high temporal resolution was blended with other gridded data sets at a coarser temporal resolution by blending the two. While the model forcing for all fields is daily, we have allowed a diurnal variation of solar radiation by applying a cosine variation between 6 and 18 hours and zeroing it outside this time interval.

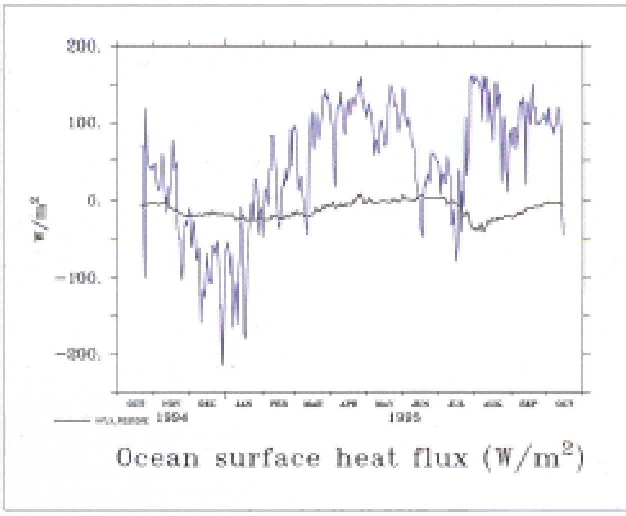


Fig1.15 Net ocean surface heat flux derived from the model at the WHOI buoy site for the period 1994-October 1995 October along with the restoring term in W/m^2

The model is spun up with climatological data for 15 years and with daily NCEP data from January 1 1994-October 20 1994. At this date, forcing is switched to the blended data described above. No adjustment of temperature and salinity profile data is made in the model at the starting date.

Fig 1.15 shows the net ocean surface heat flux for the years 1994 and 1995 at the buoy location. The northeast (NE) monsoon (November-January) was marked by a negative surface heat flux, while the SW monsoon (June-August) had a positive heat flux except for brief episodes in June and July.

It is expected that the model would require a few months to adjust to the new high frequency forcing and we examine the results from January 1995 onwards.

Fig 1.16 shows the mixed layer depth which has been computed using the following definition: Mixed layer depth is the depth at which the temperature differs by 0.1°C from the surface temperature. Notice that model has picked up the diurnal deepening and shallowing in the NE and SW monsoons quite well though there are other qualitative differences. During the south-west monsoon season, the mixed layer depth deepens with the onset of strong southwest monsoon, whereas during January to March mixed layer deepening is an account of negative buoyancy flux. We have compared our model derived MLD which

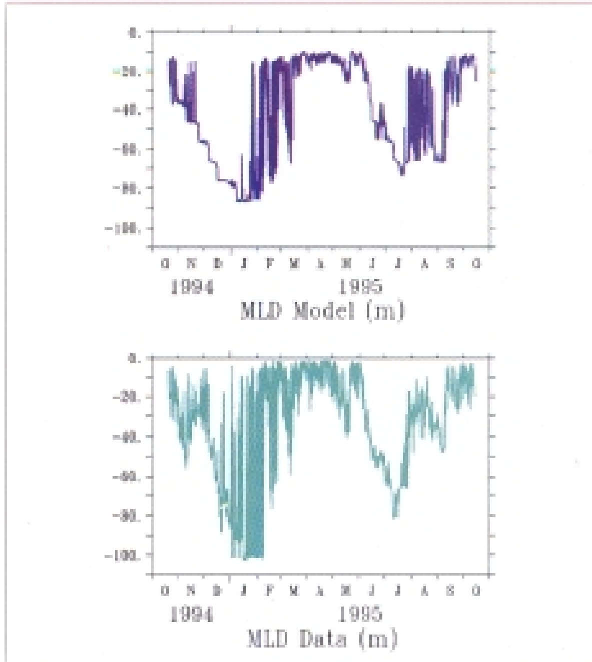


Fig 1.16 Comparison of Mixed Layer Depth (MLD) computed from the model derived temperature at the WHOI buoy site (top panel) with the observed MLD (bottom panel) for the period 1994 October-1995 October

were saved at every six hourly intervals with buoy observations. The deepening and cooling of the mixed layer during NE monsoon is attributed to local forcing and primarily by the negative heat flux and the changes observed during SW monsoon were mainly due to wind stress.

Fig 1.17 shows the difference between the model and buoy temperature profiles in the top 200 m. Note that they match within a degree at most depth until mid-July. Between July-October there are major differences between the two especially between the depths of 40-120 m. This is a region of intense cooling in the buoy data under a positive heat flux regime at the surface. We examine the terms in the energy equation to locate the source of this cooling. Fig 1.18 shows the various terms of the energy equation, for the two monsoon seasons separately. Under the influence of the positive buoyancy flux, the two mechanisms capable of removing heat are (a) enhanced mixing due to velocity shear at high winds and (b) advection. Of the two it appears that the latter is underestimated by a significant amount in the

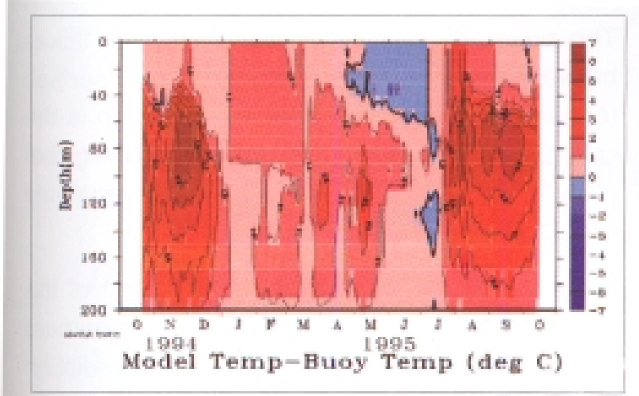


Fig 1.17 Difference between model derived and observed WHOI buoy temperature in deg C for the period 1994 October-1995 October.

model at depths. This difference is attributed to offshore advection of cool coastal water filaments which the model is unable to capture with the current resolution.

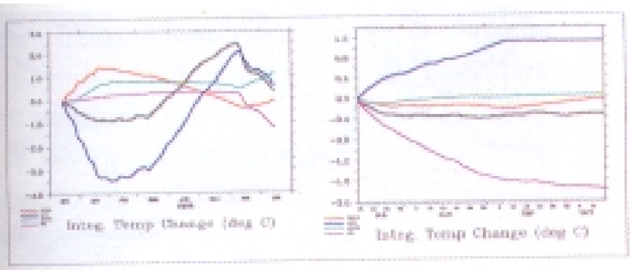


Figure1.18 Term balances of the temperature equation at the buoy site for NE monsoon (left Panel) and monsoon (right panel) seasons for the period December 1994-1995 October

1.8 Indian Ocean Community Model : Bay of Bengal Process Studies (BOBPS)

The full release of the Modular Ocean Model (MOM4) was installed on the origin 3000 and a global model (1° resolution in the longitude, 1/3° in the latitude in the tropics and 50 vertical levels) was run on multiprocessors with daily forcing from the Ocean Modelling Intercomparison Project (OMIP) data developed by the Max Plank Institute. The ocean/ice model is coupled to a simple atmospheric representation with bulk formulae. There is no restoring to SST for heat flux at the surface. The simulation from a 5 year run show good agreement between model and data in the Indian Ocean.

Under this programme one of the component is to study the physical process of the Bay of Bengal. As a part of this we have compared the thermal structure and salinity of the Bay of Bengal for summer monsoon of 2001 using model simulations and observations taken as a part of the BOBPS project by NIO Goa. Fig 1.19 shows the comparison of the vertical section of temperature (deg C) observations (Fig 1.19a) with model simulations (Fig 1.19b) for the 2001 summer monsoon. The sea surface temperature observed from the model simulations is around 29°C along the 88°E longitude and 7-20°N latitude transect. In the thermocline region we see oscillations in the top 300m of thermal structure, and upheaval of isotherms is noticed between 7-10°N. We can see shoaling towards 20°N. In the present simulations we have used NCEP 6-hourly winds and the forcing is able to capture eddy like features which are seen in the observations.

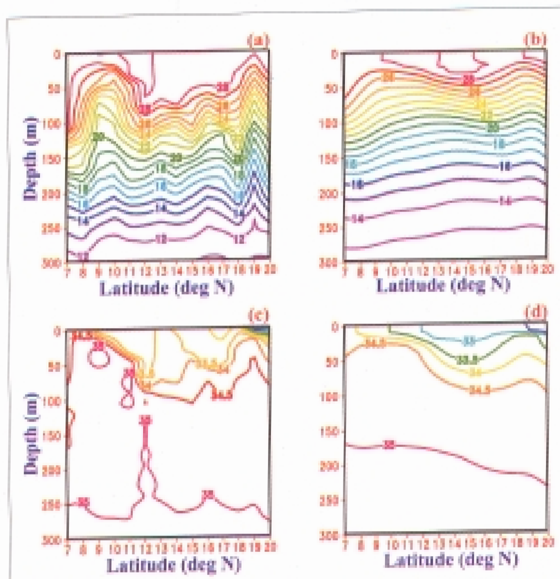


Fig 1.19 Comparison of vertical section of temperature (deg C) from observations (a) with model simulations (b) in the top panel and in the bottom panel vertical sections of salinity (c) from observations and model simulations (d) for 2001summer monsoon (July-August) under BOBPS programme along the open ocean track-88°E.

Salinity structure simulated from the model (Fig 1.19d) is not able to capture the sharp gradient as is seen in the observations (Fig 1.19c). At the surface we can observe salinity variations in the top 75 m and salinity decreases towards north. Below 75 m we can see homogeneous waters which are indicated by uniform salinity. To simulate the salinity structure better in the Bay of Bengal we have to include freshwater flux as one of the forcing This will be done in the new simulations which we plan to conduct as part of the community model development.

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1.19 Estimation of global sources and sinks of CO_2 through inversion

This work is under a collaborative project CaFICA (Carbon Fluxes in India and Central Asia) with LSCE France. It involves i) installation of an ultra high precision (100 ppb) CO_2 analyzer at the Indian Astronomical Observatory in Hanle, Ladakh and ii) the development of forward and inverse models for CO_2 transport and design of experiments to simulate observations at new measurement sites.

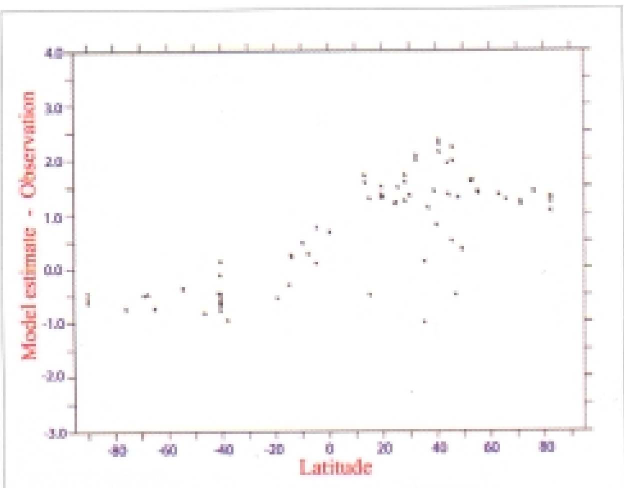

Fig 1.20 The points plotted here represents the prediction errors obtained through inversion at 76 stations over the globe using concentration data and estimates from Atmospheric Transport Model-TM2

The project is aimed at quantifying CO_2 fluxes between the atmosphere and the earth's surface (oceans and terrestrial biosphere), which is the critical outstanding question in modeling the global carbon cycle that shows significant variability (IPCC Report 2001).

As a first study, we attempted a re-run of the internationally coordinated Transcom experiment designed to compare model outputs of prediction errors in atmospheric carbon dioxide concentrations obtained from inverted estimates of sources and sinks using different atmospheric transport models. The Fig 1.20 below shows the model error in respect of one of the 16 re-runs carried out at C-MMACS. This figure corresponds to the TM2 model showing that, whilst the estimates are fairly well constrained by the observations in the southern hemisphere, there is considerable mismatch in the northern hemisphere. Further, the residuals indicate the presence of sinks in the northern hemisphere. We aim to quantify the location and strength of these sinks, particularly in Asia, once the additional concentration data from Hanle becomes available.

Further work planned for the future, is the implementation of inverse atmospheric transport models in respect of both the LMDZ model used by our collaborators in France and the CCM2 model developed by NCAR, to strengthen our expertise in refining assessment of CO_2 flux estimates.

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