1.1 Simulation of Tropical Precipitation Climatology from an Intermediate Model

Simulation of the tropical precipitation processes in general, and the monsoon precipitation process in particular, continues to be a major challenge in numerical weather prediction. An important question is regarding the relative roles of boundary forcing such as by sea surface temperature (SST) and internal (convective) dynamics. To examine and identify the role of convective internal dynamics, the tropical precipitation climatology was simulated using an intermediate model of tropical circulation. This model, which has been validated and successfully used to simulate the observed spectrum of tropical variabilities is an anomaly model with observed climatological annual cycles of SST and mean winds from Comprehensive Ocean Atmosphere Data Set (COADS). In the present version, the model simulates the total precipitation in response to internal dynamics generated by anomaly circulation. The highlight of the dynamical scenario is a convective relaxation time scale developed in earlier works. The simulated precipitation climatology was constructed from ten model simulations from 1979 to 1988 with initial conditions from COADS; the observed climatology for the corresponding period was obtained from Xie-Arkin precipitation data. It was found that convective internal dynamics with a convective relaxation time scale, can account for a large part of observed precipitation climatology. *Fig. 1.1.1*, for example, compares the observed summer (JJAS) precipitation with that from simulation. The corresponding results for winter (ONDJ) precipitation climatology are shown in *Fig. 1.1.2*. As can be seen from these figures, the simulated climatology successfully captures the major features of the observed climatology.

(P. Goswami and K. Rameshan)

1.2 A Coupled Physical-Biological-Chemical Model of the Indian Ocean

One of the primary aims of the Joint Global Ocean Flux Study (JGOFS) is the estimation of the carbon flux across the air-sea interface over the Arabian Sea and the Indian Ocean basin. The parameters that control this exchange are the partial pressure difference of carbon dioxide (pCO_2) between the atmosphere and the ocean surface and the wind speed. The pCO_2 content of the surface waters are controlled by the primary production which converts inorganic carbon to organic form and physical effects which transport inorganic carbon from deeper waters. It is well known that the Arabian Sea is one of the most productive regions biologically and the effects of biology and physics work in opposite directions in fixing the pCO_2 content of the sea water. In order to quantify all these effects, 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. The physical model is based on the Modular Ocean Model, Version 2 (MOM_2) and the biological model describes the nonlinear dynamics of a 3-component and

Fig. 1.1.1. Longitude-latitude structure of ten-year mean of seasonal precipitation (mm/day) from observation and model simulation for summer (June, July, August and September).

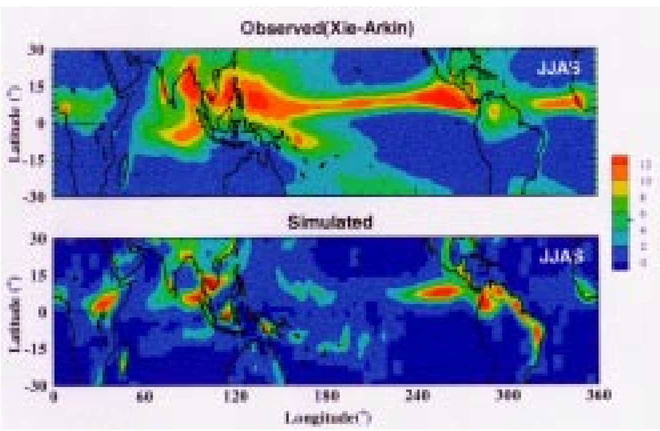
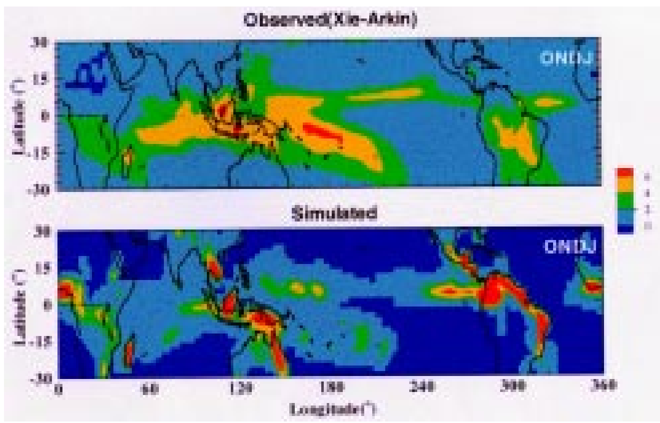


Fig. 1.1.2. Longitude-latitude structure of ten-year mean of seasonal precipitation (mm/day) from observation and model simulation for winter (October, November, December and January).



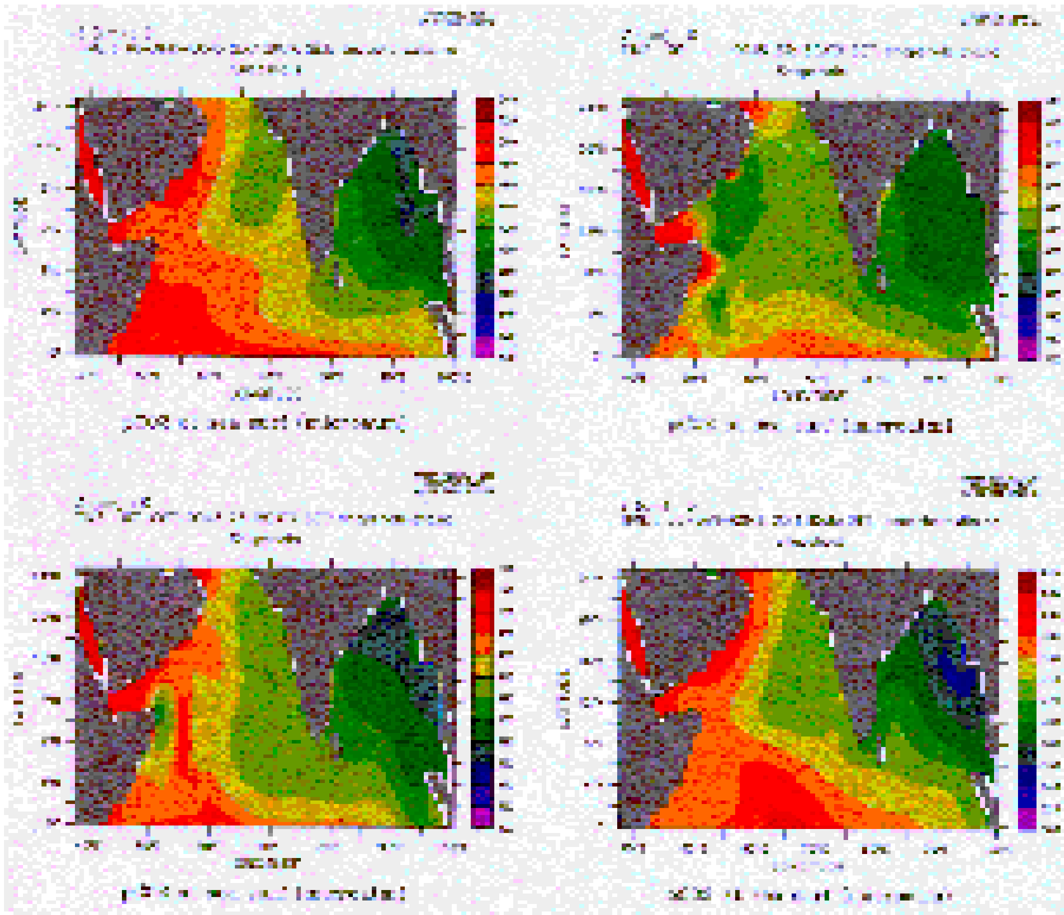


Fig. 1.2.1. Partial pressure difference of CO_2 (pCO_2) at sea surface in the Indian Ocean at four typical times, premonsoon (April), monsoon (July), postmonsoon (October) and NW monsoon (January).

a 7-component system. The chemical model includes dynamical equations for the evolution of dissolved inorganic carbon (DIC) and total alkalinity. The interaction between the biological and chemical model is through the Redfield ratio. The pCO_2 content of the surface layer is obtained from chemical equilibrium equations. 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 4 forms and bacteria with appropriate production, grazing and mortality laws. The biological model is embedded within MOM_2 in the form of additional tracer equations. The fully coupled model has 11 tracers in all- 7 biological and 2 chemical constituents along with temperature and salinity. 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 time series data for the whole ocean, we assume a constant value of 345 ppm. For the momentum transfer, we employ Hellerman's climatology of monthly mean winds. Restoring conditions with a time scale of 50 days and a space scale of 10 m are 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 20^0S to 30^0N in latitude and from 30^0E to 110^0E 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 100m 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

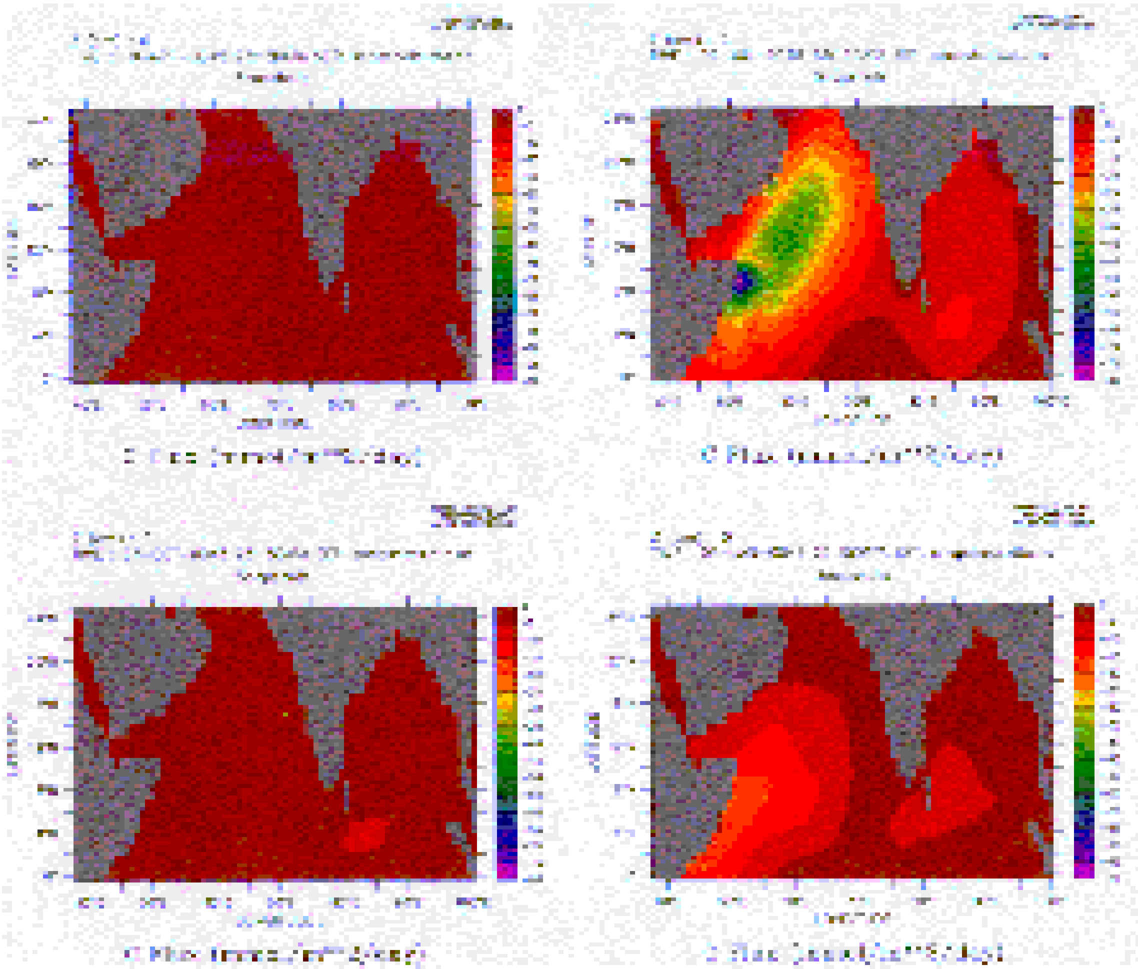


Fig. 1.2.2. Air-sea flux of carbon at the same four typical times, as in Fig. 1.2.1, in the Indian Ocean; negative values indicate transfer from ocean to atmosphere.

is integrated for 35 years after which the additional tracers are introduced.

Fig. 1.2.1 shows the pCO_2 at the surface at four typical times in the Indian Ocean: premonsoon (April), monsoon (July), postmonsoon (October) and the NW monsoon (January) periods. The higher values of pCO_2 seen in April in the Arabian Sea are considerably reduced in July due to biological activity which accompanies the high upwelling of nutrients, but the values are still higher than 345 ppm, the atmospheric pCO_2 value, indicating that it is an outgassing region. In October, with the retreat of the monsoon, the productivity is reduced and pCO_2 levels increase further. The effect of salinity on pCO_2 can be clearly seen in the Bay of Bengal; the pCO_2 values are much lower than that seen in the Arabian Sea and in some regions quite close to the atmospheric pCO_2.

Air-sea flux of carbon is shown in *Fig. 1.2.2.* Negative values indicate that the transfer is from the ocean to the atmosphere. In April and October, when the winds are relatively weak, there is very little CO_2 exchange. However, during the monsoon, the air-sea exchange is very vigorous reaching nearly 80 m-mol of C per square meter per day. This is mainly on account of the strong winds. Similarly during the NW monsoon region, we see outgassing but of a lesser magnitude. Comparison with some measured values of pCO_2 fluxes show that there is reasonable agreement between simulation and data. However, experimental data due to its sparsity cannot yield a basin-wide picture as the model does. The results show that the Arabian Sea is an outgassing region of CO_2 over the entire year.

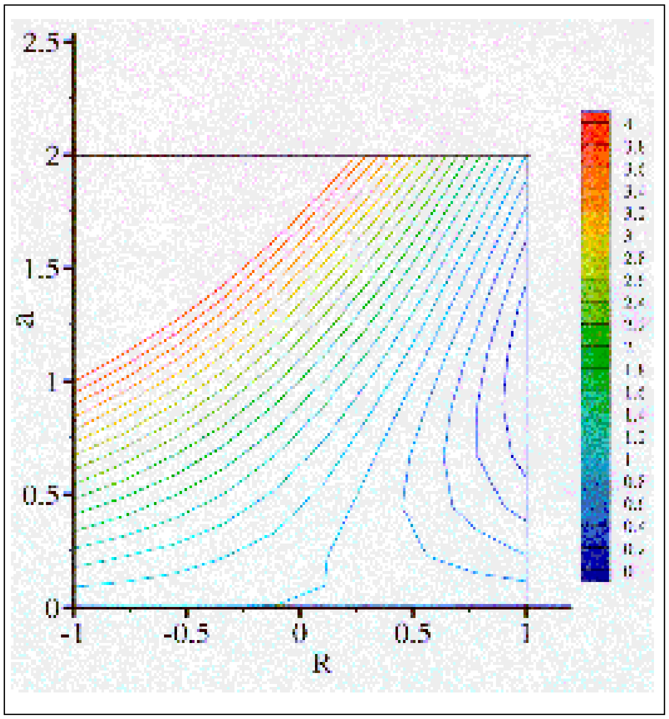
(P.S. Swathi and M.K. Sharada)

1.3 Comparisons of Simulations of a Marine Ecosystem Model with Coastal Zone Color Scanner (CZCS) Data of the Arabian Sea

The development of realistic models of biogeochemical cycles depends critically on evolving a methodology for objective comparison of results of model simulations with observations. Such comparisons can be used for parameter estimation, validation, data assimilation and, more generally as a guide in model refinement. The first task of these models is to capture the essential features of seasonal variation of chlorophyll and work out monthly averages which can be compared with data obtained for vast regions over relatively long time intervals by satellite observations.

A general method of comparing two sets of monthly averages, obtained from observations and from results of a simulation using Fasham, Ducklow and McKelvie (FDM) model was considered and was applied to an ensemble of simulations at a set of eight stations on two transects in Arabian Sea. The choice of two transects was based on the view that model simulations should perform well at least on these transects if they are to succeed in capturing blooms in the Arabian Sea, a major zone of primary productivity. It was readily seen that the least square measure of error can be expressed in terms of the error in the annual mean, the variance of observed seasonal (monthly) anomaly, the ratio of simulated to observed variance in seasonal anomalies and the correlation between the observed and simulated monthly anomalies. This relation provides a systematic basis for comparison when one deals with simulations at several stations. Two points are worth noting. First, the variance of observed seasonal anomaly provides a natural scaling of the RMS error associated with the seasonal anomaly, and the second, the non-dimensional relative RMS error of seasonal anomaly depends not only on the correlation coefficient (*R*) but also on the ratio (*a*) of the variances of simulated and observed seasonal anomalies *(Fig. 1.3.1)*. It can be seen from the figure that RMS error of seasonal anomaly will be minimum when *R* and *a* are close to one. Since our interest is in predicting the seasonal blooms, the distribution of relative RMS errors of seasonal anomaly for an ensemble of simulations at a set of stations were considered. Then, the ensemble was partitioned by a criteria such as the model used was of a switching type or a non-switching type or by the value of a parameter used. If the error distribution was significantly better for one subset, the corresponding model variation or the value of the parameter can be said to give more realistic simulations. It was noticed with this method of comparisons that the number of really good simulations was very small. This general method of comparison can be used to establish objectively whether certain modelling options result in more realistic simulations of seasonal variability or not. It was not clear whether some major modifications were needed in the model or its application or whether some tuning would significantly reduce the relative errors.

Fig. 1.3.1. Contour plot of relative RMS error of seasonal anomalies of Chlorophyll.



In order to get more realistic simulations, some modifications were introduced in the phytoplankton growth term of FDM model. Seasonal variation of daylength and diurnal variation of solar radiation were considered to model the growth of phytoplankton due to solar radiation. Seasonal variation of daylength at different locations in Arabian Sea was calculated as a function of solar declination and latitude. Also, seasonal variation of solar radiation available for the growth of phytoplankton was calculated by including losses due to clouds and atmosphere, vertical attenuation coefficient, and phosynthetically useful waveband of short-wave radiation. Diurnal variation of solar radiation was considered to be triangular and sinusoidal. With these modifications in the FDM model, an ensemble of simulation results were obtained at different locations in Arabian Sea like in earlier studies and the comparisons with CZCS data was carried

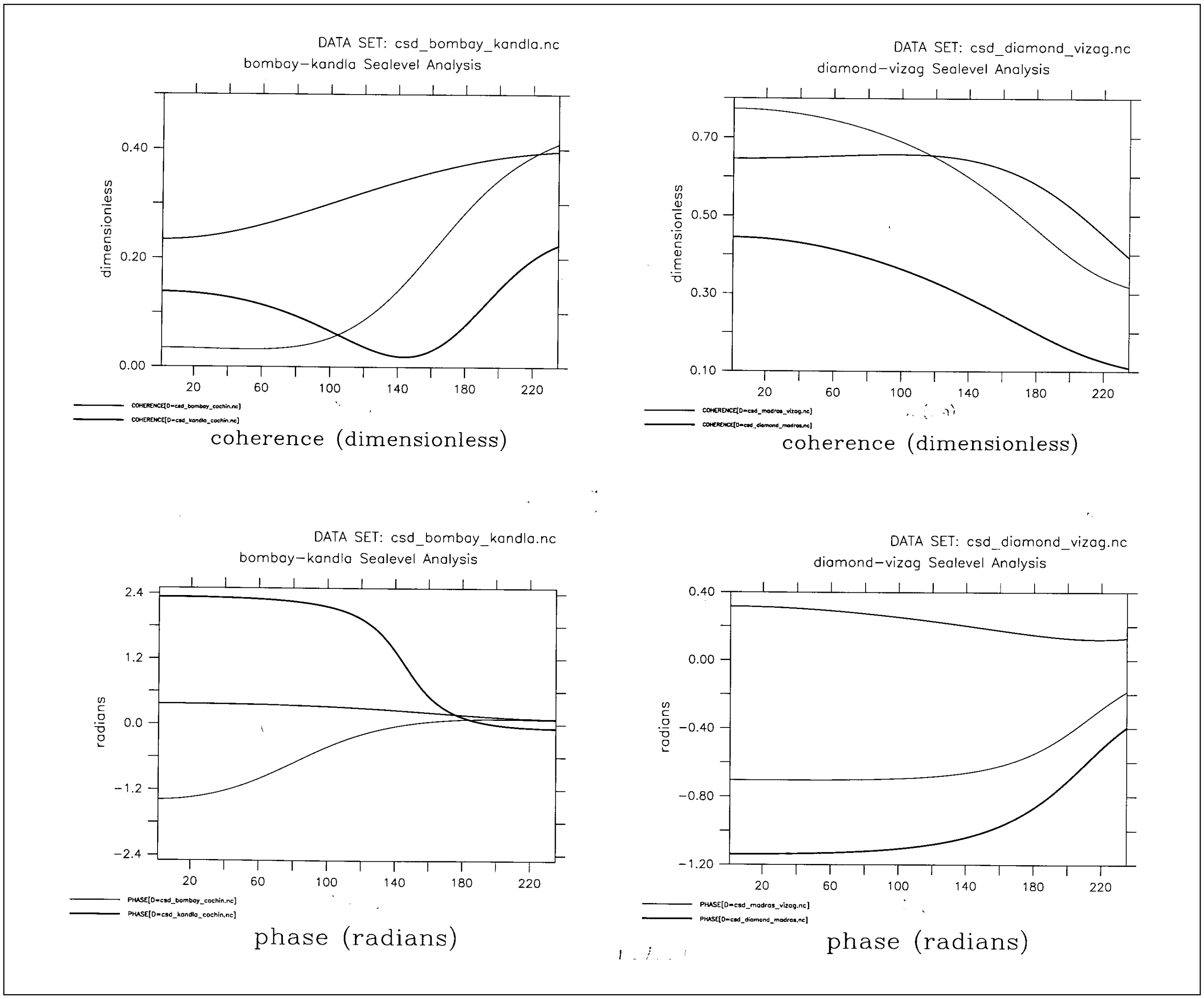


Fig. 1.4.1. Cross spectral density analysis of sea level data on Indian coasts. The three lines, in increasing thickness order, in each figure, show the results of the analysis, respectively, between the pair of stations Diamond Harbour-Vizag, Vizag-Madras, Madras-Diamond Harbour on the east coast (shown on the right), and Kandla-Bombay, Bombay-Cochin, Cochin-Kandla on the west coast (shown on the left). The x-axis of all the plots denotes the frequencies of the spectrum.

out. The results obtained from the simulations with triangular diurnal variation gave better comparisons with the observations. Some more model refinements and parameter tuning are being tried to get more realistic simulations.

(M.K. Sharada)

1.4 Sea Level Variations

It is well known that sea level variations are known to occur at various time scales. In the past, various linear and non-linear techniques have been used to analyse tide gauge data where annual averages of the daily mean sea level were employed. In this study, the monthly averages of the daily mean sea level are analysed to study the periodicity in the Fourier Transforms domain. It is noted that the Fourier Transforms show a peak at the same frequencies for the coastal stations in the east coast as well as in the west coast. The interesting thing will be to find out the relation between the Fourier Transforms of the data obtained for the same coast. The cross spectral density analysis is done over these data for this purpose. The cross spectrum of a pair of stations are taken and the coherence and cross phase are computed and compared. Coherence corresponds to the cross correlation between two signals at a particular frequency and the numerical values lie between 0 and 1, with 0 indicating no correlation and 1 indicating perfect correlation. In addition, the cross-phase indicates how much one signal is leading or lagging the other. If the underlying process, which controls the sea level variation at two points separated by some distance, is a linear wave, we expect a high coherence between the signals with a phase difference corresponding to the distance between them.

In this study we take three stations (Madras, Vishakhapatnam and Diamond Harbour) on the east coast and three (Kandla, Bombay and Cochin) on the west coast. Pairs of stations are taken on both the coasts and the spectral density computed and coherence measure obtained. As shown in *Fig.1.4.1*, the coherence is reasonably high at lower frequencies and falls down for the higher frequencies on the east coast. On the other hand, on the west coast, there is very small coherence at low frequencies and surprisingly it increases at larger frequencies. The cross phase analysis does not show any clear lag or lead in any of the cases. The cross phase analysis of Bombay and Cochin show approximately a constant value close to zero.

(N.K. Indira)