Large Scale Atmospheric Circulation

Modelling of Large Scale Tropical Circulation: Convective Organization

A well-known problem in numerical modelling of atmospheric and oceanic processes is that of climate drift, which makes the model simulation drift away from the observed climatology. It is likely that both numerical and physical (process) modelling are responsible for the origin of climate drift in a numerical model. In order to investigate and identify the physical process that may play a role in climate drift, a simple numerical model of the tropical atmosphere was developed and used at C-MMACS. The emphasis has beeen on moist processes, especially on moist feedbacks (MF) in the form of evaporation-wind feedback (EWF) and convergence feedback (CF). In the first phase of this work reported earlier (C-MMACS Annual Report 1994-95), a linear version of the model was used to show that MF can organize a random initial field into a well structured one in space and time. The structure of the organized field, as expected, resembles that of an equatorial Kelvin wave, the most unstable wave in the spectrum. In the second phase of the work reported here, the role of nonlinear MF was considered to investigate convective organization in a more realistic framework. Fig. 1 shows the results for four versions of the model, UHLE (linear MF), UHNE (linear CF, nonlinear EWF), CHLE (nonlinear CF, linear EWF) and CHNE (nonlinear CF, nonlinear EWF).

The panels show the time-latitude structure of the model u (left panels) and v (right panels) fields for 60 days of model integration. The important point is that for nonlinear MF, the structure of the organized field is quite different from that of the tropical eigenfunctions. These results indicate that a random error field present in the initial field can organize itself into a characteristic structure causing the model simulation to drift into a state dominated by these structures. *(P. Goswami, B. Joseph and M. Naveen Kumar*, * Project Student)*

Effect of Land-Ocean Contrast on Tropical Circulation

Many parts of the tropics, especially the Indian Ocean region, are characterized by the presence of huge land masses which affect the regional as well as the global scale atmospheric circulation (for example, the monsoon system). The effect of land- ocean contrast (LOC) on the growth and structure of perturbations is investigated using the shallow-water model developed at C-MMACS (C-MMACS Annual Report 1994-95). In our model the primary effect of LOC is to introduce an inhomogeneity in the lower boundary forcing, which can modify the atmospheric heating through control of evaporative flux. The initial fields are generated by running the model for a certain amount of time starting from a random field. The em-

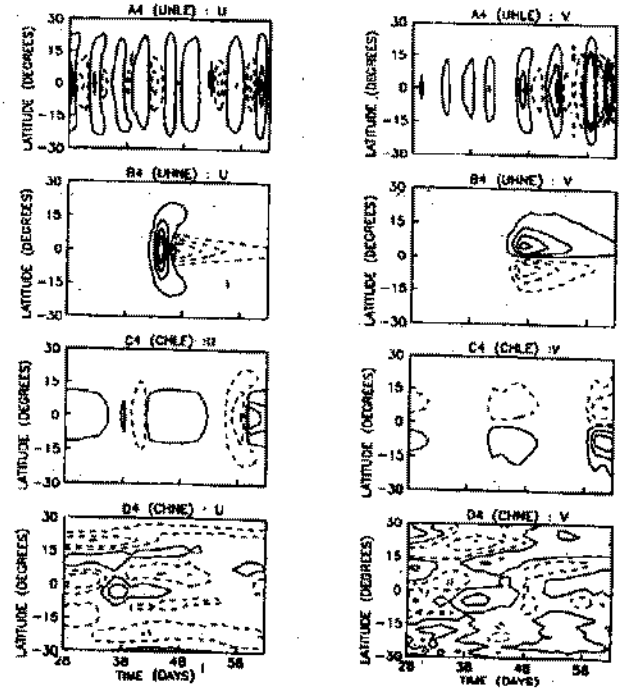


Fig. 1: Time-latitude structure of the model u (left panels) and v (right panels) fields for 60 days of integration for moderate strengths of EWF and CF. The results are shown for the four versions of the model UHLE, UHNE, CHLE and CHNE.

phasis is on latitudinal (in contrast to zonal) LOC and its effect on the internal dynamics of tropical circulation, which is more relevant to the Indian Ocean region.

The main conclusion that emerges from this study is that the structure of the flow in the presence of LOC can be qualitatively different from that in the absence of LOC. In particular, the structure of the evolved fields in the absence of LOC is essentially similar to the most unstable tropical eigenfunctions (for the linear case). LOC, however, introduces dramatic changes in the structure of the tropical eigenfunctions. In particular, the model v-field clearly becomes asymmetric about the equator and is centered at the latitude of land-ocean boundary (Fig. 2a).

The effect of shifting the land-ocean boundary further north has been found to revive the equator centered v-field structure which is expected in the case with no LOC (Fig. 2(b)). This behavior is attributed to the trapped na-

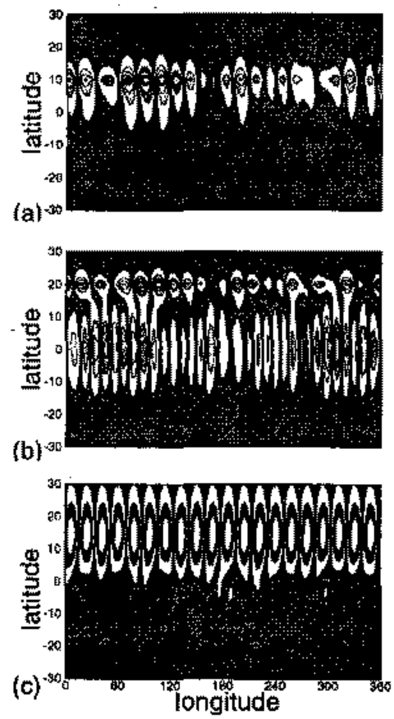


Fig. 2: Structure of model v-fields on day 30 (a) with LOC at 10° N and (b) with LOC at 20° N, and (c) with no LOC, but with a localised heating.

ture of tropical eigenmodes. It is also shown that LOC in our model can be represented in terms of a dynamical analogue in the form of a prescribed and localized heating along the transition latitude of LOC (Fig. 2c).

Due to the simple parameterization of LOC used, the present study can only be considered as a preliminary one for the understanding of the effect of LOC on the tropical atmospheric dynamics. A future study should take into account more realistic coastline configurations to define the land-ocean boundaries. More realistic parametrization of land surface should also take into account the important role played by the sensible heat flux and possible improvements in modelling moist feedbacks. *(P. Goswami and B. Joseph)*

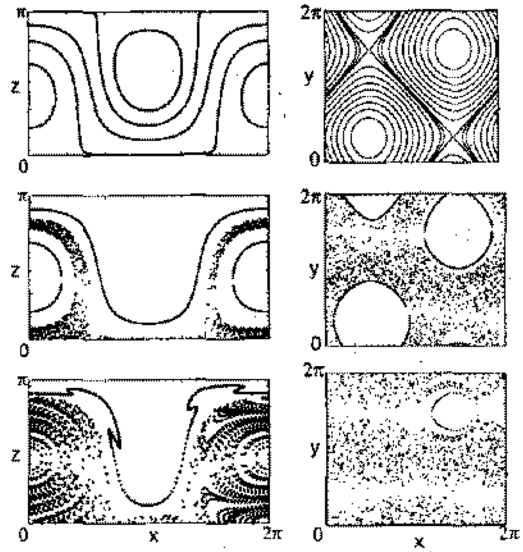


Fig. 3: Behavior of particle paths for vertically trapped waves (left panels) and for waves propagating in a three-dimensional space (right panels). The top panels are projections of the trajectories and the middle and bottom panels are Poincare maps.

Recent analyses reveal that even when the Eulerian flow is simple (for example, periodic in time or space), the Lagrangian motion of fluid particles in such flows can be chaotic. This phenomenon, known as chaotic advection or Lagrangian turbulence, arises purely through deterministic chaos and considerably enhances the mixing of tracers in fluid flows. Chaotic mixing of 'passive' fluid particles by certain superpositions of internal gravity waves (IGWs) is of relevance to atmospheric and oceanic flows. Mixing by IGWs is of fundamental importance also to stratospheric chemistry and dynamics, entrainment across the oceanic thermocline etc.

In this study chaotic mixing of 'passive' fluid particiles has been investigated. Two classes of IGWs are considered viz., trapped, horizontally propagating waves and those propagating in a three-dimensional space. It has been shown that in the former case two waves are sufficient to produce Lagrangian turbulence (chaos) whereas in the latter case at least three waves are necessary for chaotic particle paths. In Fig. 3 we present the behavior of trajectories in integrable and nonintegrable (or chaotic) flows, for vertically trapped case on the x-z plane (left panels) and for the case of waves propagating in 3D on the x-y plane (right panels). The top panels correspond to the integrable cases. The middle and bottom panels, respectively, present Poincare maps of the nonintegrable flows for a small and a larger value of the perturbation parameter. Evidently, chaos occupies a larger region as the perturbation forcing increases.

The error doubling times obtained from Liapounov exponents are of the order of a few hours. The diffusion process is found to be, generally, of the shear-flow dominated type or a bit faster in a few cases. Correlation dimensions of dispersing particle clouds indicate that at first the cloud stretches more like a filament, then proceeds on to surface filling, and finally to a space filling nature. *(B. Joseph)*

Because of the growing realization that land surface processes play an important role in atmospheric dynamics, considerable effort is now being made by the scientific community to represent these processes accurately in numerical weather prediction (NWP) models. Many of the land surface parameters are also crucial for designing agricultural strategies. This is particularly true for India whose economy depends strongly on the country's agricultural prospects. However, lack of an appropriate data set based on observations for the Indian region has been a major bottleneck in this direction.

To fill this gap between modelling and observation, the Department of Science and Technology (DST) has planned to carry out a major field experiment on land surface processes. The main site of the experiment has been selected at Anand, Gujarat. Although the main experiment is scheduled for 1996, a pilot experiment has already been completed for the period April to July 1995 at Anand, Gujarat by the scientists of Indian Institute of Tropical Meteorology, Pune and their collaborators. This data set provided an excellent opportunity to validate a dynamical model for inccorporating land surface processes. Such an effort has now been initiated. In the first phase, a one-dimensional, multi-layer model for predicting soil temperature profiles has been developed and its performance has been evaluated with the Anand data set.

Figs. 4a and 4b show four sample simulations with the model, two for the day of 12th July and the other two for the night of 24th July. In each of these figures, we show the soil temperature profiles after 6 hours (upper) and 9 hours (lower) of model integration. The solid lines represent simulated values with the top boundary condition (BC) given in terms of surface heat flux while the dashed line repre-

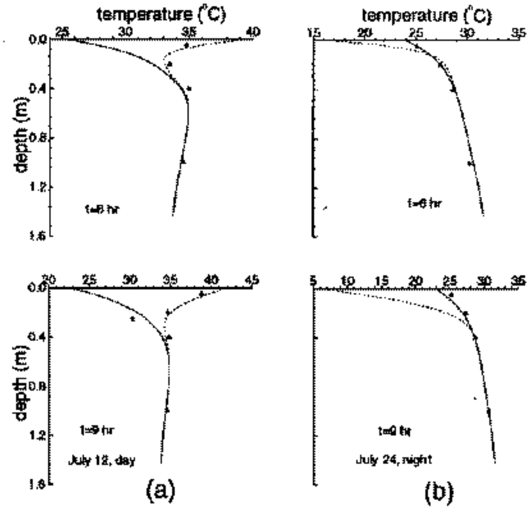


Fig. 4: (a) Model simulation for the day of 12th July. The time integration starts at 0531 hr IST, (b) Model simulation for the night of 24th July. The time integration starts at 1731 hr IST.

sents simulation with the top BC determined by surface temperature. The observed values at the depths at which they are available are represented by traingles. As can be seen from Fig. 4a, the prescription of the top BC in terms of temperature seems to provide a much better daytime simulation on 12th July. However, the night-time simulation on 24th July (Fig. 4b) shows that it is the prescription of flux as the upper BC which provides a better simulation. Further examination of the observations revealed that the period of simulation for which flux BC provided better simulations were preceded by a substantial amount of rainfall. Preliminary experiments with the model indicate that the flux BC gives better simulations during night and the temperature BC gives better simulation during day. However, these simulations need to be subjected to a more rigorous statistical evaluation before assessing the generality of the results.

As the heat conductivity of the soil depends crucially on the soil moisture content, there is an urgent need to incorporate soil moisture into the present model. Also, it is plausible that an atmospheric boundary layer model with an interactive land surface component will perform better and thus be more useful in practical applications, such as in agrometeorological forecasts. *(P. Goswami and B. Joseph)*

Air-Sea Interaction and Coupled Models: Convective Coupling

It is well-known that parameterization of air-sea interaction plays a crucial role in the performance of coupled models. In the conventional formulation of ocean-atmosphere coupling (OAC), which we call direct or thermal coupling, the ocean directly heats the (lower) atmosphere through sea surface temperature (SST). However, such a scenario is unlikely to be applicable in highly convective situations like over the Indian Ocean. Besides, recent observational analyses reveal close relationships between SST and deep convection. The concept and the formulation of convective coupling was developed to incorporate the convective process directly into OAC. In convective coupling, the entire lower (convective) column of the atmosphere is coupled to the ocean and SST can only affect the evaporation into the column which controls the column precipitation. The modified convective heating changes the low-level atmospheric circulation which in turn affects the oceanic fields, thus closing the circle. The formulation of convective coupling has been applied to both analytical studies and to model development.

(a) A unified dynamical framework for coupled intraseasonal (ISO) and interannual oscillations

Recent investigations reveal that interannual oscillations almost in phase with El Nino-Southern Oscillation (ENSO) over the Pacific also appear over the equatorial Indian ocean. However, the conventional delayed oscillator mechanism used to explain ENSO, which requires an ocean basin of large zonal extent, can not be applied to the Indian ocean. Recent obsevational analysis also reveal the importance of OAC at other (e.g. intraseasonal) time scale. The principle of convective coupling was applied to investigate the dynamics of coupled Kelvin waves to explore a unified dynamical framework for coupled interannual and intraseasonal oscillations. For this purpose two representations of SST dynamics, (SST Model I and Model II) were considered. Further, for the same dynamical model two scenarios, one representative of the interannual time scale and the other representative of the intraseasonal were considered. These scenarios are characterized by parameters that depend on the mean quantities and hence on the time scales. In particular, we have chosen strength of EWF (Λ), east-west gradient of mean SST (G) and the strength of convergence feedback (Γ) to characterize the scenarios. The spectrum of coupled oscillations for various nondimensional strengths of these parameters for SST models I and II are shown in Table 1a and 1b respectively. It was found that the same dynamical mechanism gives rise to ENSO type interannual oscillation and ISO of 60-90 day time scale depending on the scenario. The values of time period, wavelength, etc. of the selectively destabilized waves for the two SST models and for the two scenarios are show in Table 1 for a standard set of parameters. An interesting result is that the interannual variabilities over a upwelling dominated ocean basin have relatively shorter zonal scales. *(P. Gowami and K. Rameshan*, * Dept of Physics, IIT, Kanpur)*

Time Scales	Scenario Parameters Λ (10^{-1})	G (10^{-2})	Γ	λ (Days)	T ($10^3 km$)
Intraseasonal	5.7	-12.5	1.35	107	18
	4.9	-10.5	1.35	93	19
Seasonal	5.0	-8.4	1.35	175	38
	4.0	-10.5	1.35	150	34
Annual	2.3	-10.5	1.10	331	10
	1.9	-8.4	1.10	337	10
Interannual	2.0	-6.3	1.00	1527	1.6
	2.6	-8.4	1.00	1493	17

Table 1a: Spectrum of convectively coupled oscillations for SST model I

Time Scales	Scenario Parameters Λ (10^{-1})	G (10^{-2})	Γ	T (Days)	λ ($10^3 km$)
Intraseasonal	4.9	6.3	1.4	89	26
	6.5	8.4	1.4	98	34
Seasonal	3.2	-12.5	1.3	202	15
	2.9	-21	1.5	206	33
Annual	3.2	-8.4	1.3	336	20
	2.5	-10.5	1.3	386	27
Interannual	2.5	-5.2	1.2	2310	23
	2.5	-7.3	1.2	1172	20

Table 1b: Spectrum of convectively coupled oscillations in SST model II

(b) Intermediate Coupled Model with Convective Coupling

Encouraged by the results of the analytical investigations, a numerical model of intermediate complexity is now being developed to investigate convective coupling in more complex situations. Thus an atmospheric model with convective time lag has been developed and tested. This atmospheric component has been coupled to a two dimensional reduced gravity ocean model. Preliminary investigations with this coupled model reveal that it can support a number of variabilities. This is expected to pave the way for the development of a new type of coupled model which can be used to address a variety of questions pertaining to ocean atmosphere coupling in the tropics. *(P. Goswami, K. Rameshan* and M. Naveen Kumar, * IIT, Kanpur)*

Basin Scale Ocean Modelling

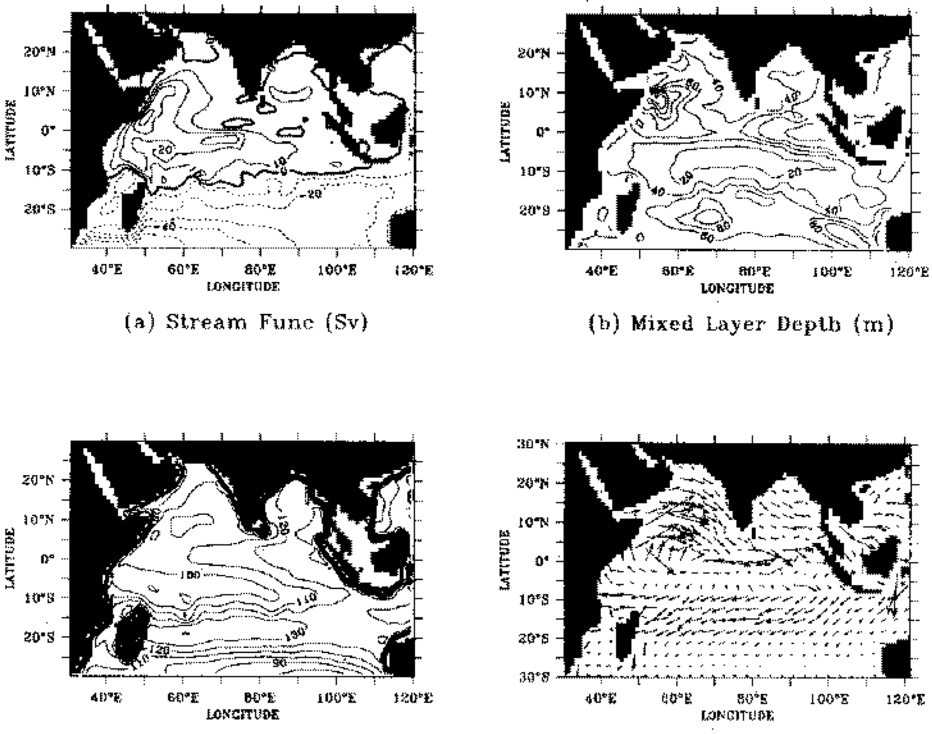
The significant role played by large scale ocean circulation in climate, availability of living marine resources and navigation is well recognized. Due to the sparsity of oceanographic observations, modelling has emerged as a powerful tool for investigating several features of the three-dimensional circulation. In addition, advanced numerical models with data assimilation are expected to become the workhorse of oceanographic investigation in future, akin to the well-developed numerical weather prediction models of the atmosphere.

Ongoing efforts at C-MMACS (Annual Report, 1994-95) were intensified during the current year with the installation of the Modular Ocean Model Ver. 2 (MOM2). Building on the experience gained earlier with a $1° \times 1°$ simulation a new simulation with a finer resolution ($1°$ in the longitude, $\frac{1}{3}°$ in the latitude between $30S$ and $30N$ with coarser resolution towards the poles, and 20 vertical levels with 10 levels in the top $100m$) was generated. The simulation involves a $362 \times 273 \times 20$ grid (approximately 2 million grid points) with four 3-D prognostic variables (u, v, temperature and salinity) and one 2-D prognostic variable (stream function). The time step is 45 minutes. Vertical mixing is by the Philander-Pacanowski's Richardson number based mixing scheme. A realistic bottom topography is generated by interpolation from Scripps $1° \times 1°$ data base. The integration is carried out entirely in double precision in order to avoid round-off error accumulation in vertical diffusion. The model is forced on the surface by climatological Hellerman wind stresses interpolated at each time step to the model grid. Initial conditions for temperature and salinity are prescribed from the Levitus Data base. The surface tracers (temperature and salinity) are damped to climatology.

Much of the effort this year was directed towards post-processing of the model output. All the prognostic and diagnostic output from MOM2 was converted to netCDF, a format which is fast emerging as the common currency of the atmosphere and ocean modelling community. Besides GFDL Princeton, C-MMACS is the only site where this conversion on-the-fly has been implemented.

In addition, several packages, such as ferret, netCDF, UDUNITS, NCSA X-DATA-SLICE, MPEG Encode and Play were obtained through Internet and installed at C-MMACS to facilitate state-of- the-art post-processing of MOM output.

Several diagnostics such as surface height, mixed layer depth, dynamic height, geostrophic currents, tracer budgets and time averages have been implemented. Due to the dynamic nature of the computation many of the diagnostics have been animated to get a visual feel of the evolution and variabilty of sev-



(a) Stream Func (Sv)
(b) Mixed Layer Depth (m)
(c) Dyn. Height 0–400 dbar (dyn cm)
(d) Surf. Currents (cm/s)

Fig. 5: July fields over the Indian Ocean, obtained from MOM2

eral parameters. Some representative results from the 12th year of the run are shown in Fig. 5. The results are monthly averages for the month of July over a $1^\circ \times 1^\circ$ subgrid covering the Indian Ocean. In Fig. 5a a strong clockwise transport in the Somali region can be seen arising from strong surface currents is noticed. The deflection of the contours around $60E$, $5N$ is due to topographic effects. In addition, the strong anticlockwise gyre below $10S$ is also seen in Fig. 5a. Sv indicates Sverdrups ($1Sv = 10^{12}cm^3/s$). The mixed layer depth shown in Fig. 5b is in overall good agreement with the climatological atlas of Hastenrath and Greichar although it tends to be shallower south of $20S$ and also near the equator. The mixed layer deepens off the Somali coast. The dynamic heights shown in Fig. 5c are in excellent agreement with Hastenrath's atlas. Fig. 5d shows the surface currents. Noteworthy features are intense currents off the Somali coast (speeds $\sim 200cm/s$), the eastward flowing North Equatorial Current and the westward flowing South Equatorial Current. It is indeed encouraging that so many climatological features are faithfully reproduced in the model. *(P.S.Swathi, K.S.Yajnik and R.C.Pacanowski*, * GFDL, Princeton)*

Sea level change

Sea level changes are signatures of various geophysical processes taking place in ocean/atmosphere and inside the earth and their analysis can provide important constraints to these processes. The annual sea level variations for various coastal stations in the Indian Ocean and the Pacific Ocean for which longer time series data is available, was analysed using both iterated function system (IFS) technique (C-MMACS Annual report 1994-95) and stochastic time series analysis technique. The IFS technique applied to other stations in the Indian ocean namely three

Country	Stations	Data length	ARIMA Model (p,d,q)
India	Bombay	1878-1988	(5,2,1)
	Cochin	1939-1989	(3,2,1)
	Madras	1953-1987	(2,2,1)
	Vizag	1937-1989	(4,2,1)
	Sagar	1937-1987	(1,2,1)
	Calcutta	1932-1988	(2,2,1)
	Diamond-Harbour	1948-1989	(3,2,1)
	Tribeni	1950-1987	(3,4,1)
Singapore	Jurong	1971-1993	(1,2,1)
	Sembawang	1972-1993	(1,2,1)
	Sultan Shaol	1972-1993	(1,2,1)

Table 2: ARIMA model for different stations in the Indian Ocean

stations in Singapore and three in Thailand yielded similar fractal dimensions as obtained earlier between 1.2 and 1.3 for stations in India and China. This implies that the fractal dynamics of sea level remains the same for both the Indian and the Pacific coastal regions.

The linear stochastic time series analysis of the annual data shows that these data sets fit closely to the different orders of the autoregressive-integrated-moving average models, ARIMA (p,d,q) where p refers to the order of autoregressive model, d to the order of difference of time series and q to the order of moving average. The values of (p,d,q) for different stations in the Indian Ocean are given in Table 2.

The monthly sea level data is also analysed for two stations in India, namely, Paradip and Vishakhapatnam. It is seen that the sea level in Vishakhapatnam shows increasing trend while Paradip does not.

The nonlinear time series analysis is also attempted on the annual data of sea level variations. The monthly data is analysed to study the seasonal variations. *(N.K. Indira, R.N. Singh and K.S. Yajnik)*