Chapter 7

Conclusion and Future Prospects

Climate prediction has been and will continually be a topic of deep and intense research as it has a huge impact on the society and its environment. Moreover, in order to improve the predictability of natural systems, models have been proposed from very simple conceptual models, like the Lorenz (Lorenz, 1963) equations to very complex state-of-the art General Circulation Models (GCM). These models may be generally categorised into three main alternatives:

(i) linear or nonlinear mechanisms that are driven by linear stochastic forcing,

(ii) non-linear mechanisms without stochastic forcing, and

(iii) non-linear stochastic forcing representing

(a) interaction of a rapidly varying forcing (like the atmosphere) with a slowly varying forcing (like the ocean),

(b) interaction of noise with an intrinsic component of the process, or

(c) interaction of noise with an external deterministic forcing.

The present work is an attempt to appreciate the quintessence of various developments in mathematical modelling ranging from simple conceptual models to state-of-art coupled models in order to simulate the natural systems with greater realism.

In the same pursuit, the bifurcation analysis of low order models were attempted to explore the nature of transition between the different types of chaotic attractors with a possibility of mimicking the natural systems at conceptual level. Bifurcation analysis of a non-linear dynamical system throws useful light on the behaviour of the system in different parameter ranges. Bifurcation behaviour of a forced Chen system (Chen and Ueta, 1999; Ueta and Chen, 2000) is analyzed as the
system parameter $c$ and forcing parameter $F$ are varied. For certain value of system parameter $c$ and forcing parameter $F$, return map of Lorenz model, Lu model and Chen model split into two cusps in Chen system. In addition, three one sided attractors are found which are visually different and the return maps for them are also different.

The Lorenz system of equation is most well known example of a system of three ordinary differential equations in three variables, which exhibit chaotic behaviour in some of its parameter ranges and has been widely used to model diverse real world phenomena. The Chen system belongs to a family of generalized Lorenz system. In the parameter regime for which Chen system has chaotic attractors, topologically different types of chaotic attractors are observed depending upon the system parameters. These attractors have been named Lorenz type (L), Lu or Transition type (T), Chen type (C) and Transverse 8 type (S). These different types of chaotic attractors are visually distinct when the parameters are widely separated. However, there is a need for identifying the precise point where the transition from one type of chaotic attractor to another takes place. Yu et. al., (2007) proposed that Generalized Competitive Modes (Yao et. al., 2002, 2006) could be used to distinguish between Lorenz system and Chen system, as the Lorenz attractor had one pair of modes in competition in Lorenz system, whereas the Chen attractor had two pairs of modes in competition in Chen system. We have observed that a range of parameter values for which the nature of the topological attractor for the Chen system is not in accordance with that expected from Generalized Competitive Mode analysis on a coarse scale, limited to a resolution of 0.1 in $c$. Instead, we find that return maps more reliably characterize the transition between different types of attractors.

Traditional statistical approaches to modeling and prediction have met with limited success (Peters, 1991). These approaches have their basis in the linear
regression formulation which is the simple and the most commonly used statistical model \( (Mason \text{ and } Baddour, 2008) \). Lepedes and Ferber \( (1987) \) reported that simple neural networks can outperform than traditional methods. Early attempts were made using neural networks for seasonal climate forecasting \( (Derr \text{ and } Slutz, 1994; Tang \text{ et. al.}, 1991; Tang \text{ et. al.} \ 1994) \). The results were of mixed success and could, to an extent, led to the conclusion that ANN models may perform better than the traditional linear statistical methods. We had compared the performance of ANN models with linear Multivariate Regression model to justify the use of a non-linear model in seasonal climate forecasting.

Significant positive correlation between sea surface temperature (SST) indices of Niño-1+2, Niño-3, Niño-3.4 and Niño-4 regions and Indian summer monsoon rainfall index (ISMRI) is found before the onset of monsoon. Based on this analysis five predictors have been selected which have confidence level above 99%. The Artificial Neural Network (ANN) and multiple linear regression models were used to study the predictability of ISMRI with above five indices individually as well as in various combinations. We have found that the performance of the ANN model is better than all the linear regression models, thereby implying that the relationship between the Niño indices and the ISMRI is essentially non-linear in nature.

The numerical climate models can be broadly classified \( (Mason, 2008) \) as the Tier-two (T2) climate models and the Tier-one (T1) or coupled climate models. AGCMs are not too efficient to simulate the rainfall anomalies over summer monsoon region because it has also been observed that ocean-atmospheric coupling for Indian Ocean and western Pacific Ocean SST anomalies are really crucial \( (Wang \text{ et. al.} \ 2004) \). So in the present study seasonal predictability of SNU Tier-1 system was evaluated and compared with observation.
Further, the seasonal mean prediction of rainfall and winds at 850hPa from coupled Atmospheric and Ocean general circulation model (AOGCM) Seoul National University (SNU) Tier -1 system during summer monsoon season (June-July-August) has been compared from observation for the time period 1981-2001 for the region (30°E – 120°E and 30°S – 30°N). It has been found that the SNU Tier -1 system is able to capture all the main features of rainfall and wind at 850hPa. We have performed the statistical skill score measure for each member and ensemble mean of these members for the rainfall over the extended Indian region (5°S-30°N and 60°E – 100°E) and for the zonal and meridional wind for the region (30°E – 120°E and 30°S – 5°S) between Africa and western Australia covering some parts of recently discovered subtropical Indian ocean dipole. It is observed that when we take the ensemble mean of the individual members of the model, the root mean square error is reduced. At the same time it is also observed that the ensemble mean does not, in every case, give better-forecast skill scores in case of dichotomous forecasts.

The importance of air-sea coupling on the predictability of seasonal monsoon during the June-July-August-September (JJAS) season has been investigated with atmospheric model and atmosphere-ocean coupled model. Recently several studies suggest that important elements of atmosphere-ocean co-variability cannot be reproduced when atmosphere is forced to respond passively to the prescribed SST.

Lastly, to understand the important aspects of air-sea coupling, seasonal mean (June-September) of the Asian-Australian monsoon was investigated in four different prediction systems including PACEMAKER, AGCM:pace_obs; rest_clim, CGCM and AGCM/AMIP. Among four prediction systems, we have found that a low-level wind in the PACEMAKER is superior to the other three prediction systems. Consistent with this result, the PACEMAKER is also greater realism of summer mean rainfall pattern, in particular in subtropical western pacific where the maximum rainfall
appears in observation. PACAMAKER also shows high pattern correlation coefficient of 1st EOF and temporal correlation coefficient of 1st PC for rainfall as well.

**Future Prospects**

Applications of the dynamical system theory in atmospheric flows provide meaningful insight to the meteorologists. Forced Lorenz system has also been investigated by Mittal et. al. (2003, 2005) and a prediction rule for regime transition was given by Yadav et al. (2005). Monsoon intra-seasonal oscillations (ISO) between these active and passive spells are an important research topic. Dwivedi et al. (2006) has developed an empirical technique for extended range prediction of the monsoon breaks. They found that the peak anomaly in the active regime is well correlated with the duration of the subsequent break spells of a monsoon ISO and a stochastic forced Lorenz model was proposed as a 'non-linear dynamical model' for monsoon ISO. However, the two-regime classification for monsoon ISO is not as clean as the Lorenz model. As the chaotic attractors of generalized Lorenz models are slightly more complex than those of the Lorenz model, we will investigate how far another attractor of generalized Lorenz system can be used to represent monsoon ISO. The Chen system, which is part of generalized Lorenz system, exhibits chaotic attractors slightly more complex as compared to the Lorenz attractor. The ISO also exhibit behaviour slightly more complex than a simple two-regime behaviour, so, we will explore a stochastically forced Chen system as a prototype for monsoon ISO. An empirical rule for extended range prediction is applied to the dynamical model as well as the observed monsoon ISO datasets.

Long-term prediction of monsoon is still a challenge especially when its failure brings famine to affected region on one hand whereas strong monsoon years result in
devastating floods on the other. In various studies, it has been found that there exists a strong positive correlation between the All India Rainfall Index (AIRI) and tropical sea surface temperature anomaly of Indian Ocean in the preceding December-February but a few studies are in the direction of predictability of Winter Monsoon Rainfall (WMR) of India. We wish to detect a dynamic link for the predictability of winter monsoon rainfall over south Indian using SST variability in the Southern/Tropical Indian Ocean (STIO). STIO SST and WMR relationship could be examined under spatial regions and lead-lag time scales for providing some insight into the possibility of early prediction of monsoon rainfall. This relationship will enable us to understand dependency of monsoon conditions on STIO SST, and in turn may provide important clues to oceanic system memory, which is still poorly understood. Statistical forecast verification method such as the RMS error and other dichotomous forecast skill scores will be taken into consideration to evaluate the accuracy of the prediction.

Climate models (specifically, coupled general circulation models) are the most useful tools for projecting future climate changes and variations across time. However, they are still far from giving accurate prediction of some relevant phenomenon than that of simpler general circulation models. In order to make a better forecast of monsoon, we shall perform sensitivity experiments like new pacemaker scheme. Predictability of climatological precipitation, wind at 850hPa and 200 hPa and SST will be assessed. After removing the mean bias, the monthly and seasonal forecast skill of each variable of each experiment will be estimated.