CHAPTER 5

Effects of Arabian Sea Surface Temperature on the Summer Monsoon over Peninsular Indian Region

5.1 INTRODUCTION

The southwest summer monsoon, occurring every year from June–September, is one of the most well known seasonal phenomena for the Indian subcontinent, which is also a dominant feature of the general circulation of the atmosphere. The extended range forecasting (ERF) of monsoon is done with the help of statistical models by the India Meteorological Department (IMD) ever since Walker (1923) presented their mathematical foundation in his pioneering work. However, the prospect of seasonal forecasting of the Indian summer monsoon must also be investigated with numerical models because they are fairly complete and sufficiently sophisticated to reproduce the weather and climate features. In this regard, Charney and Shukla (1981) stressed the relative importance of sea surface temperature (SST) and land-surface conditions as sources of anomalous forcing for the large scale atmospheric flow.

The interannual variability in monsoon activity depends on air-sea interactions, during the course of travel of the monsoon current across the Ocean. One of the important surface boundary conditions which influence the Indian summer monsoon rainfall (ISMR) is sea-surface temperature (SST). Several investigators have done extensive work on the sensitivity of SST on the monsoonal circulation and associated rainfall patterns. Chandrasekar and Kith (1998) carried out an
experiment with a GCM to examine the sensitivity of the monsoon circulation and ISMR to SST anomalies over the Indian Ocean. They found that an increase (decrease) in rainfall over the Indian Ocean is associated with a warm (cold) SST anomaly. The Indian Ocean plays a very important role in the ISMR interannual variability due to its proximity and the importance of both the land-sea meridional thermal contrast and the SST-convection relationship for the strength of ISMR.

Tropical atmospheric convection is highly sensitive to the sea surface temperature (SST) of the underlying ocean. Deep atmospheric convection in the tropics is found to increase sharply when SST exceeds a threshold of about 27.5°C. The convection is also sensitive to fluctuation in SST above 28°C. Although SST above 28°C is not sufficient to produce organized deep convection in the tropical atmosphere, it is a necessary condition. Therefore, oceanic regions with SST above 28°C, known commonly as warm pools, occupy a significant place in tropical climate.

Shukla (1975) tested the hypothesis that colder SST anomalies over the west Arabian Sea may significantly influence the ISMR by a numerical experiment with the GFDL general circulation model. His experiment shows that the imposition of a persistent 1-3°C colder SST anomaly over the Somalia coast and the Arabian Sea lead to an increase of surface pressure and a significant reduction of cross equatorial moisture flux, which in turn is associated with a decrease in evaporation. The interesting result of this experiment is the reduction in the rainfall rate by 40-50% over India and the adjoining seas. The reduction in rainfall is remarkable at and near the colder SST anomaly regions and over the remaining parts of India it is less. Washington et al (1977) examined the impact of different types of idealized SST anomalies over the tropical Indian Ocean to ISMR. They found an increase in rainfall and vertical velocity over the warm SST anomalies in
their experiments. However, the statistical relationship between model-simulated rainfall and wind anomalies obtained in his experiment was insignificant.

Some of the previous observational studies have shown that the Indian Ocean has no significant influence on ISMR interannual variability. This was due to lack of significant statistical relationships between various ISMR indices and Indian Ocean SST \( (Shukla \ 1987; \ Webster \ et \ al \ 1998)\). Recent modeling studies have shown that the SST anomalies over the Indian Ocean in certain areas and under certain conditions can have a significant effect on ISMR variability \( (Meehl \ and \ Arblaster \ 2002)\). Most of the past studies on the SST-monsoon relationships are based mainly on the GCM simulations. Though GCMs capture the large scale features of the monsoon circulation reasonably well, their performance in representing the regional climate details are very poor \( (Rind \ et \ al \ 1989; \ Mearns \ et \ al \ 1990)\). Previous investigators \( (Giorgi \ et \ al \ 1994; \ Jones \ et \ al \ 1995)\) have shown that rainfall distribution simulated by a regional climate model (RCM) contain a strong orographically related component on scales not resolved by the GCMs. Considering the complex nature of the ISMR and its spatial variability due to complex orography, it is essential to study its characteristics in detail using Regional Climate Models. Although the Regional Climate Model (RegCM) has been used widely for various mesoscale studies \( (Qian \ and \ Giorgi \ 1999; \ Pal \ et \ al \ 2000; \ Giorgi \ et \ al \ 2003)\), it has not been tested to study the characteristics of circulation features and associated rainfall over India. Only a few studies, mainly by Shekhar and Dash \( (2005)\) and Dash et al \( (2006)\), have used the National Center for Atmospheric Research (NCAR) RCM (version-II) in the study of ISMR. Singh and Jai \( (2007)\) also has studied the effect of SST on ISMR with an SST increment of 0.6°C.

It has been demonstrated that for examining the weather/climate features in greater detail, regional models are more suitable than the global models.
Computationally it is affordable to increase the resolution of regional models so as to resolve regional climatic features reasonably well. Various regional models have been used for a wide variety of applications including operational weather forecasting, studies of the present-day climate and possible future climates over a number of regions throughout the world (Mesinger 1984; Dickinson et al. 1989; Giorgi 1990; Dudhia 1993; Walsh and McGregor 1995; Bhaskaran et al. 1996; Ji and Vernekar 1997).

Simulation of the Indian summer monsoon circulation features and the associated rainfall by a numerical model have been the most challenging problems due to its large variability. Bhaskaran et al. (1996) simulated the Indian summer monsoon using a regional climate model with a horizontal resolution of 50 km nested with global atmospheric GCM. Their study showed that regional model derived precipitation is larger by 20% than GCM.

In this study, a recent version of the NCAR regional climate model (RegCM3) is used to simulate the monsoon over peninsular India for the years 1996, 1997 and 2002, which are considered as WET, NORMAL and DRY years respectively. The monsoon of 2002 has been regarded as the driest and peculiar of the recent drought years. Thus the characteristics of the circulation and the moisture during the year have been studied by many researchers (Vaisala and Ikeda 2005). It is evident that the 2002 mean rainfall was less than normal and an anomalous month-long drought existed in July. Unlike usual drought years, the extreme drought years deserve special attention in their processes. Since the moisture for Indian monsoon rainfall is being carried over and supplemented by the Arabian Sea (Mohanty et al. 1983, 1994), sea surface temperature which influences the circulation and precipitation pattern of monsoon is to be studied in detail. Although the RegCM modeling system has been widely used for different regional
climatic studies (*Giorgi and Mearns 1999*), it has not been extensively tested over the South Asia region, particularly concerning the simulation of Indian summer monsoon. The suitability of RegCM3 model in simulating ISMR has been examined by *Dash et al* (2006). In the present study an attempt has been made to understand the possible effect of the Indian Ocean SST on the summer monsoon circulation and precipitation over the peninsular region in specific, since the orography and spatial distribution of monsoon over this region are very complex.

### 5.2 MODEL DESCRIPTIONS

The modified version of RegCM used in the present study is originally developed by *Giorgi et al* (1993a, b) and then augmented and described by *Giorgi and Mearns (1999)* and *Pal et al* (2000). The dynamical core of the RegCM3 is similar to the hydrostatic version of the NCAR/Pennsylvania State University mesoscale model MM5 (*Grell et al* 1994). The model includes cumulus parameterization schemes, large scale precipitation scheme, planetary boundary layer (PBL) parameterization, state-of-the-art surface vegetation and soil hydrology package, the Biosphere-Atmosphere Transfer Scheme (BATS), Ocean flux parameterization, pressure gradient scheme, explicit moisture scheme, the radiative transfer scheme and the ocean-atmosphere flux scheme.

Surface processes are represented via the Biosphere-Atmosphere Transfer Scheme (BATS) (*Dickinson et al* 1989). BATS is a state-of-the-art surface package designed to represent the role of vegetation and interactive soil moisture in modifying the surface atmosphere exchanges of momentum, energy and water vapor. Boundary-layer physics is following the nonlocal vertical diffusion scheme of *Holtslag et al* (1990). Different schemes are available for the generation of precipitation in RegCM3. Nonconvective precipitation can be represented by an implicit scheme.
Convective precipitation can be described using a simplified Kuo-type scheme (Anthes 1977), Grell scheme (Grell 1993) and Massachusetts Institute of Technology (MIT). The newest cumulus convection option to the Regional Climate Model version 3 (RegCM3) is the MIT scheme. More detailed descriptions can be found in Emanuel (1991). In addition to a more physical representation of convection, the MIT-Emanuel scheme offers several advantages compared to the other RegCM3 convection options. For instance, it includes a formulation of the auto-conversion of cloud water into precipitation inside cumulus clouds, and ice processes are accounted for by allowing the autoconversion threshold water content to be temperature dependent. Additionally, the precipitation is added to a single, hydrostatic, unsaturated downdraft that transports heat and water. Under this scheme, fundamental entities are sub-cloud scale draft rather than cloud themselves. The MIT has recently been implemented within RegCM3, and therefore its performance has not been tested extensively to date. This scheme assumes that the mixing in clouds is highly episodic and inhomogeneous and considers convective fluxes based on an idealized model of sub-cloud-scale updrafts and downdrafts. Convection is triggered when the level of neutral buoyancy is greater than the cloud-base level. Between these two levels, air is lifted and a fraction of the condensed moisture forms precipitation while the remaining fraction forms a cloud. The cloud is assumed to mix with air from the environment according to a uniform spectrum of mixtures that ascend or descend to their respective levels of neutral buoyancy. The mixing entrainment and detrainment rates are determined by the vertical gradients of buoyancy in the clouds. The fraction of the total cloud base mass flux that mixes with its environment at each level is proportional to the rate of change in the undiluted buoyancy with altitude. In other words, the mass flux at the cloud base is a function of buoyancy, and the air parcel can lose its buoyancy during
ascent due to the entrainment of dry air from the environment. The Grell scheme is widely used within both the MM5 and RegCM modeling framework. This is a mass flux scheme that includes the moistening and heating effects of penetrative updrafts and corresponding downdrafts. The scheme can use two closure assumptions, the so-called Arakawa-Schubert and Fritsch-Chappel type closures. After a few initial test experiments, we selected the Grell scheme, which yielded generally better results for our domain. In the RegCM3 modelling framework, precipitation is derived by the combined process of resolved (gridscale) precipitation as well as unresolved (sub-grid-scale) precipitation. The resolvable grid-scale precipitation is described using the sub-grid explicit moisture scheme of Pal et al. (2000), which accounts for the sub-grid variability in the clouds by linking the average relative humidity of a grid cell to the cloud fraction and cloud water.

Resolvable scale precipitation is represented via the scheme of Pal et al. (2000), which includes a prognostic equation for cloud water and allows for fractional grid box cloudiness, accretion and re-evaporation of falling precipitation. Cloud radiation is computed in terms of cloud fractional cover and cloud water content, and a fraction of cloud ice is diagnosed by the scheme as a function of temperature. The RegCM3 has 18 vertical levels and a 60 km horizontal resolution.

5.3 DATA AND METHODOLOGY

In this study, RegCM3 has been integrated for simulating the Indian summer monsoon circulation and associated rainfall for the years 1996, 1997 and 2002. The lateral boundary conditions for wind, temperature, surface pressure and water vapor are interpolated from 6 hourly ECMWF reanalysis. The terrain height and land-use data for the given domain are generated from the United States
Geographical Survey (USGS) global 5 min resolution terrain and land-use data. The original weekly averaged optimum interpolated Sea Surface Temperature (OISST) available from the National Oceanic and Atmospheric Administration (NOAA) for the whole year is horizontally interpolated into the specified domain and also in each time step for the model integration. Three typical rain years 1996, 1997 and 2002 are selected for the study. The model domain covers the area approximately 50 °E to 110 °E and 5°S to 40°N with a horizontal grid distance of 60 km. The grid is defined on a Normal Mercator Projection. The control runs are integrated from May 1 to September 30, for every year using the original SST. The initial condition SST input into the model is incremented by steps of 0.1° C in the sensitivity experiments. The experiments are repeated for increment up to 1° C. The difference in wind vectors and precipitation for the CONTROL Run and the Experiments (SST-CTL) are analyzed to get a spatial perspective of the results. In this study, a control simulation is made over the domain and topography as shown in Fig. 5.1. The land-use data used in the model is described in Fig. 5.2.
Fig. 5.1 Model domain and topography used in the model. Contour heights are in meters.

Fig. 5.2. Land-use data used in the model
5.3.1 CONTROL EXPERIMENT

The model was integrated for five months from May to September for the years 1996, 1997. For the year 2002, the model integrations were made from May to August, due to the unavailability of September data from ERA 40. The lateral boundary conditions are updated and supplied every 6 hours into the model and the time step of the integration has been kept at 150 seconds. Compared with the total precipitation from the GPCP data, the model is found to be capable of simulating the monsoon rainfall to a reasonable degree in both spatial distribution and quantity, particularly the large-scale precipitation zones owing to the southwesterly monsoon flow along the southwest to northeast diagonal of the domain and the equatorial region in the whole season.

To facilitate the interpretation of the results of the sensitivity experiments, the total precipitation and horizontal wind fields simulated in CTRL are shown in Figs. 5.3 and 5.4 respectively. Compared with the observational data from the Global Precipitation Climatology Project (GPCP) in 2002 (Fig. 5.3a) the RegCM3 is capable of simulating the basic precipitation pattern over Indian region (CTRL Fig. 5.3b).

5.3.2 SENSITIVITY EXPERIMENT

The interannual variability in the monthly mean SSTs is typically around 0.5-0.6°C over the Indian Ocean (Meehl and Arblaster 2002). To test the influence of warm Indian Ocean SST’s on ISMR, they increased the SST by 0.75°C north of 15°S in their sensitivity (warm SST) experiments. Here we design the sensitivity experiments such that the initial condition Sea surface temperature incremented by 0.1°C to a maximum increment of 1.0°C (hereafter referred to as SST0.1 to
SST1.0 respectively) and the model was run for whole the season for each of these experiments.

The model is integrated from May to September for the year 2002. The first month is taken as the spin up time for the model. The rest four months averaged to get the seasonal averaged values of vertically integrated moisture, wind and precipitation.

5.4 RESULTS

Overall evaluation of the model performance is provided within this section. A comparison of control simulation with observation over the study region is provided. Results of control run simulations with sensitivity experiments are discussed, based on seasonal averages of moisture, precipitation and zonal and meridional wind.

The RegCM3 integration shows that the model simulates the Indian summer monsoon circulation fairly well, even though precipitation is overestimated. The results from the control experiments are compared with observations (Fig 5.3 and Fig 5.4). The discussions in this section are based on seasonally averaged values, i.e. the differences between the seasonally averaged results of a sensitivity experiment and the corresponding results of the control experiment. The seasonal monsoon circulation and precipitation are well represented. For the year 1996, the increment of SST has a negative influence over the peninsular Indian region. Vertically Integrated Moisture, north of 15°N for SST0.1 and SST0.2 increments (Fig 5.5). For SST0.5 and SST0.6, almost entire peninsular India has abundance in moisture except in some pockets of negative anomaly. As SST increased further to 0.9, the northern parts of the study region gets negative anomaly in moisture.
In almost all the experiments, the region south of 15°N shows generally positive anomalies in moisture, though there are spatial inhomogeneity in the distribution of moisture (Fig. 5.5). The sensitivity experiments show that the increase in the total precipitation rate occur for the experiment SST0.3, SST0.4, SST0.5 and SST0.6 over the southern peninsular India (Fig. 5.6). This positive anomaly in precipitation decreases after SST0.7. In all the experiments adjoining Bay of Bengal region also gets benefited from the SST increment. The maximum anomaly in the SST-CTL experiments are to the south of 15° N. The increase in the precipitation are as much as 8-10 mm/day for SST0.4 to SST0.6. Theses results are given in Fig. 5.6.

Results for zonal wind show that the wind anomaly to the north of 15° N over the study region is positive (0.7 m/s) for the experiments SST0.1 and negative anomaly exists over the southern part and adjoining oceanic region. In the successive experiments, the positive anomaly decreases to the north and the negative anomaly to the south begin to increase (Fig. 5.7). The spatial extend of the positive anomaly diminishes and the negative anomaly spreads over the southern peninsula and southeastern coastal region. The maximum negative anomaly covers entire peninsula for SST0.5 and after reaching maximum negative anomaly for SST0.7, the initial pattern reappears gradually and reaches maximum positive value for SST1.0. SST0.9 shows similar pattern for wind anomaly as of SST0.1. For Meridional wind the peninsular India shows negative anomaly for SST0.9 and the maximum value is for SST1.0 (Fig. 5.8). The vector winds show convergence over the peninsular India, which is in agreement with the anomalous precipitation pattern (Fig. 5.9).
Fig. 5.3. Seasonal precipitation from a) GPCP and b) RegCM3 for summer 2002

For the year 1997, the simulated anomaly pattern shows that the increase in SST causes a negative moisture anomaly from SST0.3 to SST0.9 (Fig. 5.10). The maximum spatial coverage for negative anomaly is for SST0.5 and 0.9. In the case of precipitation (Fig. 5.11), for the normal year 1997 there is not much influence of SST over the land area. However, over eastern coastal region and adjoining
oceanic region, there is a feeble increase of 3-5mm/day. The maximum Increase is for SST0.7.

Fig. 5.4. Seasonal wind vectors for summer A) RegCM3 and B) NCEP

For zonal wind, positive anomaly exists over peninsular India north of about 15° N. This decreases gradually and a negative anomaly establishes over peninsular India by SST0.4 (Fig. 5.12). This zonal wind increases again for SST0.5 to 0.8 reaching a maximum value of 0.7 and a great spatial spread over the entire peninsular India. Again the wind anomaly becomes negative hereafter. Meridional wind for 1997 has a positive anomaly over peninsular India for SST0.1 (Fig. 5.13). For subsequent experiments negative anomaly gets established till SST0.4. Positive anomaly over western peninsular India revives and the negative anomaly gets strengthened. The vector wind (Fig. 5.14) shows convergence over the Bay of Bengal and peninsular India in accordance with the precipitation anomaly pattern.
Fig. 5.5. Vertically integrated moisture simulated by RegCM3. Figures are Expt-Ctrl for an SST increment 0.1 to 1.0 in (a) to (j) respectively for the year 1996
Fig. 5.6. Total precipitation rate (mm/day) simulated. Figures represent Expt-Ctrl for SST increment 0.1 to 1.0 in (a) to (j) respectively for the year 1996.
Fig. 5.7 Zonal wind at 850 hPa simulated by RegCM3. Figures represent Expt-Ctrl for SST increment 0.1 to 1.0 in (a) to (j) respectively for the year 1996.
Fig. 5.8. Meridional wind at 850 hPa simulated by RegCM3. Figures represent Expt-Ctrl for an SST increment 0.1 to 1.0°C in (a) to (j) respectively for the year 1996.
Fig. 5.9. Vector wind at 850 hPa. Simulated Expt-Ctrl for an SST increment 0.1 to 1.0°C in (a) to (j) respectively for the year 1996
For the anomalously DRY year 2002, the integrated moisture shows (Fig. 5.15) very high negative anomaly over peninsular India north of 15° N, though generally positive anomaly patterns exists over south of that. There are no much differences in the amount of total column moisture for the SST experiments. For precipitation (Fig. 5.16), the anomaly patterns are positive over oceanic region leaving the landmass unaffected by increase in SST. However, for SST05 and 0.6, the windward side of the Western Ghats receives increased rainfall.

Zonal wind anomaly shows (Fig. 5.17) negative anomaly over peninsular India for the experiments SST0.1 and this negative anomaly gets replaced by positive values and reaches maximum value of 0.8 m/s by SST0.4 and gradually decreases. From SST0.6 negative wind anomaly spreads over eastern coastal region and reaches a maximum spatial cover by SST1.0.

Meridional wind has positive anomaly to the north of 15° N and this anomaly increases to a maximum value by SST0.4 and then decreases (Fig. 4.18). By SST0.9, some negative anomaly over oceanic region reappears as in the spatial pattern of SST0.1. The vector wind shows maximum increases in wind speeds for SST0.4 in 2002 (Fig. 4.19). Here also the precipitation patterns are in accordance with the convergent zones in the wind pattern.

The Hovmøller diagrams of the daily precipitation rate simulated by RegCM3 shows the distinct features for these contrasting rainfall years. For 1996, which is a wet year for peninsular India, the intraseasonal variability shows lesser period than normal or dry years. The period of intraseasonal variability is of the order of 10 days and the increased SST modifies the intraseasonal variability well for the wet year 1996 (Fig 5.20).
Fig. 5.10. Vertically integrated moisture simulated by RegCM3. Expt-Ctrl for an SST increment 0.1 to 1.0°C in (a) to (j) respectively for the year 1997 are shown.
Fig. 5.11. Total precipitation rate (mm/day) simulated Expt-Ctrl for SST increment 0.1 to 1.0 in (a) to (j) respectively for the year 1997.
Fig. 5.12 Zonal wind at 850 hPa simulated Expt-Ctrl for SST increment 0.1 to 1.0 in (a) to (l) respectively for the year 1997.
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Fig. 5.1.1. Meridional wind at 850 hPa simulated Expt-Ctrl for SST increment 0.1 to 1.0 in (a) to (j) respectively for the year 1997.

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Fig. 5.14. Vector wind at 850 hPa simulated Expt-Ctrl for an SST increment 0.1 to 1.0°C in (a) to (j) respectively for the year 1997.
Fig. 5.15 vertically integrated moisture simulated Expt-Ctrl for an SST increment 0.1 to 1.0°C in (a) to (j) respectively for the year 2002
Fig. 5.16. Total precipitation rate (mm/day) simulated Expt-Ctrl for SST increment 0.1 to 1.0 in (a) to (j) respectively for the year 2002.
Fig. 5.17. Zonal wind at 850 hPa simulated Exp-Ctrl for SST increment 0.1 to 1.0 in (a) to (j) respectively for the year 2002.
Fig. 5.18 Meridional wind at 850 hPa simulated Expt-Ctrl for SST increment 0.1 to 1.0 in (a) to (i) respectively for the year 2002
Fig. 5.19. Vector wind at 850 hPa simulated Expt-Ctrl for an SST increment 0.1 to 1.0°C in (a) to (j) respectively for the year 2002.
Fig. 5.20. The Hovmöller diagrams of precipitation rate for the summer monsoon 1996 for a) Control experiment b) SST 0.3 c) SST 0.6 d) SST 0.9
Fig. 5.21 The Hovmöller diagrams of precipitation rate for the summer monsoon 1997 for (a) Control experiment (b) SST 0.3 (c) SST 0.6 (d) SST 0.9
Fig. 5.22. The Hovmöller diagrams of precipitation rate for the summer monsoon 2002 for (a) Control experiment (b) SST0.3 (c) SST0.6 (d) SST0.9
For the normal year 1997, (Fig. 5.21) the intraseasonal variability is of a low frequency with average period of 20 days. Here also, the increase in feebly influence the intra seasonal variations in precipitation. For the anomalously dry year 2002 (Fig. 5.22), large gaps in the ISV can be observed. Here also very feeble modifications are seen in the ISV.

5.5 CONCLUSIONS

The study investigates the characteristics of circulation and precipitation during monsoon season over peninsular Indian region, based on the sensitivity experiments performed by a regional climate model for the years 1996, 1997 and 2002. A recent version (Version-III) of National Center for Atmospheric Research (NCAR) Regional Climate Model (RegCM3) was utilised. The planetary boundary layer scheme used is that of Holtslag, cumulus parameterization scheme Grell, SUBEX large scale precipitation scheme and BATS ocean flux parameterization scheme. The model is run from 1st May to 30th September except for 2002 for which the ERA40 data is available only till August. The first month is taken for the spin up. The next four months are taken to study the monsoon. RegCM3 has been integrated at 60 km horizontal resolution over the Indian domain. The experiments are carried out by changing the initial conditions of sea surface temperature by 0.1° C steps i.e. 0.1, 0.2 etc. to 1° C maximum. The sensitivity experiments showed that the wind strength increases significantly to the northeastern and central parts of India. The change in wind strength is pronounced over the southern peninsula when the sea surface temperature increased by 0.4 - 0.7° C. The response in precipitation over the peninsular Indian region is also studied. The monsoon circulation features simulated by RegCM3 are compared with those of the NCEP/NCAR reanalysis and the simulated rainfall is
validated against observations from the Global Precipitation Climatology Centre (GPCC)

Results indicate that RegCM3 successfully simulates some important characteristics of the Indian summer monsoon circulation, such as the 850-hPa westerlies and precipitation. The seasonal mean summer monsoon rainfall simulated by RegCM3 is close to the corresponding GPCP values although the simulated precipitation is overestimated over Central North India and North Eastern India. Compared with the total precipitation from the GPCP data, the model is found to be capable of simulating the monsoon rainfall to a reasonable degree in spatial distribution, particularly the large-scale precipitation zones owing to the southwesterly monsoon flow.

The intraseasonal variability of the summer monsoon has been captured by the model and the results show that the influence of SST increase is more for WET year than for normal year or DRY year. The periods of ISV is shorter in WET year and very large breaks are observed in the DRY year.