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MONSOON SIMULATION OF 1991 AND 1994 BY GCM: SENSITIVITY TO SST DISTRIBUTION

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One of the major forcings for the interannual variability of Asian Summer Monsoon is the Sea Surface Temperature (SST) distribution in tropical Pacific Ocean. El Nino years are characterized by negative Southern Oscillation Index (SOI) and a decreased monsoon rainfall over India, leading to drought conditions. On the other hand, La Nina years are characterized by positive SOI and generally good monsoon over India.

The monsoon ENSO relation is not a consistent one. The monsoons of 1991 and 1994 are good examples. The spring SOI was same (-1.3) during both years. However, All India Summer Monsoon Rainfall (AISMR) was 91.4% in 1991 and was 110% in 1994. Though SOI was same during spring of both years, the spatial distribution of SSTs was different.

In the present study impact of different SST distributions, in tropical Pacific Ocean, on monsoon simulation of 1991 and 1994 has been examined to assess the UKMO-unified model's sensitivity to SST. It is observed that simulated monsoon is much stronger in 1994 than in 1991, in terms of precipitation and circulation. The wind and Outgoing Long-wave Radiation (OLR) simulated by the model are compared with NCEP reanalyses data, while precipitation is compared with Xie-Arkin rainfall data.

Introduction

The southwest monsoon season produces All-India Summer Monsoon Rainfall (AISMR) of 852.63 mm, with a standard deviation of 84.3 mm. The highest rainfall observed was 1020.5 mm in 1961, while the lowest rainfall was 604.4 mm in 1877 (Parthasarathy *et al* 1994). Rainfall during this season is the prime source of water for Indian agriculture and hence Indian economy, since 70 to 90 % of the annual rainfall is received during this period. AISMR varies on a spectrum of spatial and temporal scales (Intra-seasonal, interannual and inter-decadal scales). The associated meteorological features and governing factors are shown in Table I.

Interannual variability of AISMR during 1871-1995 (Figure 1.) (Pant and Rupa Kumar 1997) indicates several departures exceeding one standard deviation both on positive and on negative sides. It shows the occurrence of drought years and flood years. It is observed that, in recent years - 1950, 1956, 1965, 1966, 1972, 1979, 1982, 1985 & 1987 were drought years.

While - 1961, 1964, 1967, 1973, 1975, 1981, 1983 & 1988 were years of above normal rainfall. Among the teleconnections shown in Table 1., El Nino and Southern Oscillation are most keenly observed and studied phenomena in relation to interannual variability of monsoon. Studies by Pant and Parthasarathy (1981); Keshavamurthy (1982); Bhalme *et al* (1983); Mooley and Parthasarathy (1983); Parthasarathy *et al* (1988); Bhalme and Jadhav (1984); Rassmusson and Carpenter (1983) have clearly established the simultaneous ENSO-Monsoon relationship. Several studies have reported that the monsoon rainfall is significantly correlated with ENSO indices only during and after the monsoon season (Pant and Parthasarathy 1981; Angell 1981; Shukla and Paolino 1983). More recently studies by Kripalani and Kulkarni (1997, 1997b), and Webster *et al* (1998) bring out interdecadal variability and epochal nature of the ENSO-monsoon relation.

There are many diagnostic and prognostic studies on interannual variability of monsoon. Monsoon Numerical Experiment Group (MONEG) workshop held at National Center for Atmospheric Research (NCAR) from 21 - 24 October 1991, mainly focused on the results from coordinated experiments using atmospheric GCMs simulating the summer monsoon of 1987 and 1988 (WCRP-68). A majority of the models simulated qualitatively correctly, the gross features of year to year difference of monsoon circulation of 1987, featuring El Nino and 1988, featuring La Nina. Simulation of 1987 and 1988 monsoon has also been carried out using UKMO model. The simulated differences between 1988 and 1987 circulation were in response to SST anomalies in the tropical Pacific Ocean.

The relationship between ENSO (El Nino & Southern Oscillation) and monsoon rainfall over India is not always a consistent one. The most recent example being the monsoon of 1997. Though strong El Nino conditions prevailed over eastern equatorial Pacific Ocean, the AISMR for 1997 was normal. During spring season of 1991 and 1994, the SOI was -1.3, however, monsoon rainfall over India in these years, were very different. Kripalani and Kulkarni (1997, 1997b) propose that the impact of El Nino on monsoon rainfall is more severe during the epochs of bellow-normal rainfall. During the epochs of above-normal rainfall and in years of shift in epoch, the impact is not seen to be substantial. In 1991 the rainfall over the country was 91.4% of the seasonal normal. This was correctly forecast by statistical methods. In contrast 1994 seasonal rainfall was 110%. The statistical models predicted a weaker than normal monsoon for this year. It is now discovered that the period 1990-1994 featuring persistent positive SST anomalies in central Pacific Ocean, was a unique episode (Halpert *et al* 1996).

Consistent with the SST anomalies, sea-level pressure was below normal over east-central Pacific and above normal over eastern Indian Ocean and Northern Australia, accompanied by persistent pattern of weaker-than normal low-level easterlies and enhanced convection over equatorial Pacific. All these conditions reflect a prolonged warm episode considered as longest on record (Trenberth and Hoar 1996). Though SOI was same in these two years, the spatial distribution of SSTs in Pacific was different. Positive SST anomalies were observed in central Pacific during both years. However, in west Pacific, negative anomalies were seen in 1991 and positive anomalies in 1994 (Figure 2). In a recent study using a GCM, Soman and Slingo (1997) have shown that, the interannual behavior of Asian summer monsoon during 1987 and 1988 is sensitive to the patterns of SST anomalies in the Pacific Ocean. Further, the warm anomalies in the west Pacific during 1994 are conjectured to have enhanced the strength of convection in west Pacific and over the monsoon region.

In this study, a simulation experiment is done using United Kingdom Meteorological Office (UKMO) Unified Model (UM) version 4.0, to test models ability to simulate the observed disparity of monsoons of years 1991 & 1994. The observed SSTs are used as boundary condition. The model is integrated for 120 days from 1st of June 1991 and 1994. The model output for these two monsoon seasons are analyzed in detail.

Model Description

The UKMO-Unified model is a grid point GCM. The model can be integrated at different resolutions, i.e. as a meso-scale model, limited area model, global forecast model and as a global climate model. The details of various aspects of the model are given briefly in Table 2. For detailed description of the model and parameterization schemes used, readers may refer to Johns (1996).

Results

Real SSTs are prescribed as boundary conditions to test if the UKMO model can simulate weak and strong monsoon of 1991 & 1994 respectively. In the following discussion sensitivity of the simulated monsoon to different SSTs is assessed in terms of-

(a) Strength of the monsoon circulation

(b) The precipitation

The results are compared with the observations. For this purpose, NCEP/NCAR reanalyses wind and OLR fields, rainfall data of India Meteorological Department and Xie-Arkin merged rainfall data are used. Xie-Arkin merged data is used to compare simulated rainfall over data sparse oceanic regions.

The strength of the monsoon circulation.

Panels in Figure 3 show the difference (1994-1991) in the monsoon circulation corresponding to the simulation and reanalysis, for the region- 30° E-150° E and 20° S-40° N. Figure 3 (a) shows the simulated difference (1994-1991) of seasonal winds at 850 hPa. Similarly Figure 3 (b) shows the difference (1994-1991) of seasonal winds at 850 hPa as observed in NCEP/NCAR reanalysis. These figures indicate stronger monsoon of 1994. Magnitude of winds indicates that the model overestimates the stronger monsoon of 1994. Figure 3 (a) shows stronger monsoon current (southwesterly current) that extends far into South-China sea and the west Pacific in 1994 simulation. Strong cyclonic circulation over head Bay of Bengal also indicates strong monsoon of 1994. Though there are large differences over Indian Ocean and West Pacific, it can be seen that over Indian peninsula model simulation is in agreement with NCEP.

Webster & Yang (1992) introduced the concept of monsoon index M_i to quantify the evolution of large-scale flow over India and over Southeast Asia in terms of 200hPa and 850hPa wind. Also called as shear index, it is defined by

$$M_i = u_{850} - u_{200}.$$

Interannual variability of monsoon index indicates the large-scale interannual variability of the strength of monsoon fairly well. In the present study this index is computed for the area bound by latitude 0° -20° N and longitude 60° -100° E. Simulation shows slightly greater monsoon index for 1994 (Table 3).

Area averaged seasonal mean zonal component of wind at 850 hPa is greater for 1994 compared to 1991 simulation. At 200 hPa it is stronger in 1991 compared to 1994 simulation. Thus stronger lower tropospheric winds in 1994 simulation are alone responsible for stronger 1994 monsoon simulation.

Precipitation.

Observed All-India summer monsoon rainfall (% departures) for 1991 and 1994 are shown in Figure 4. Except for the southern parts of peninsula, difference in precipitation in two years is clearly seen, particularly over the western and northwestern parts of India. The evolution of observed and simulated monsoon can be seen in the time series of the daily rainfall

(Figure 5 a and b), computed for land points of the model for area bound by 65° - 95° E and 5° - 30° N. The dominating nature of the 1994 monsoon is clearly seen. The difference (1994-1991) of total precipitation (convective precipitation and large-scale precipitation) for the area bound by- 20° S - 40° N & 30° E - 150° E, is depicted in Figure 6 (a) (simulated) and (b) (Xie-Arkin data). There is an over all increase in the rainfall in 1994 simulation,(seasonal total rainfall 1042 mm for the area enclosed between 20° S - 40° N, 30° E - 150° E), compared to 1991 simulation, (seasonal total rainfall 618 mm for same area) particularly over west coast of India, Bay of Bengal and over west Pacific (Figure 6 (a)). Simulated rainfall in 1994 is double that in 1991 in many isolated areas and west Pacific. The simulation shows that precipitation over northeastern India in 1994 is less compared to 1991 (Figure 6(a)). This is in agreement with the features observed in Figure 4. Figure6 (b) (Xie-Arkin merged rainfall data) also shows that northeastern region received deficit rainfall in 1994 while rest of India received excess/normal rainfall. However the position and magnitudes of excess/deficit, in the model simulation do not agree, with Xie-Arkin merged data over peninsula.

Difference (1994-1991) of seasonal mean outgoing long-wave radiation (OLR) simulated by the model and from NCEP reanalysis are shown in Figure 6 (c) and 6 (d) respectively. Figure 6 (c) shows the Tropical Convective Maximum (TCM) extending from Indian region to west Pacific in 1994. As mentioned earlier, the NCEP OLR data (Figure 6 (d)), shows that during JJAS 1994, the TCM over the Indian region and the west Pacific was stronger than during JJAS of 1991. This indicates that warm SST anomalies in west Pacific during summer 1994 are responsible for enhanced TCM and hence enhanced precipitation. The model does simulate these results.

Conclusions

Analysis of the results show that simulated monsoon is stronger than observed in both the years. Yet model does simulate the observed disparity of monsoons of 1991 and 1994. The lower tropospheric westerlies in 1994 were stronger by 5-7 m/s than 1991 over the Indian region. The Precipitation over the peninsular area including adjacent seas showed marked increase in 1994.

Greater precipitation over the Indian region and the west Pacific in simulation of 1994 shows model's response to warm SST anomalies in west Pacific north of equator. An important feature of the two simulations is the reduced rainfall in the northeastern India in 1994 simulation compared to 1991 simulation. The outgoing long-wave radiation in 1994 simulation indicates a much stronger ITCZ in the Northern Hemisphere, particularly over the monsoon region and over the west Pacific.

To study the interannual variability of monsoon vis-a-vis SST, simulations covering many years with differing monsoon rainfall and SST distributions is required. Long integrations covering several years with different initial conditions will definitely confirm the ability of GCMs to simulate the Monsoon -SST relationship correctly.

Although this is only a single integration comparing two contrasting years, the results show definite possibility of using GCMs for long range forecasting of monsoon using predicted SST values as boundary conditions.

Table 1. Scales of Monsoon variability and possible causal factors.

(Pant and Rupa Kumar. 1997)

Scale	Intraseasonal	Interannual	Decadal and Century	Millennia and longer
Features	Active and break monsoon phases; 30-50 day oscillations	Droughts and floods	Changes in the frequency of droughts and floods	Changes in the areal extents of monsoons
Factors	Atmospheric variability; tropical mid-latitude interactions; soil moisture; sea surface temperature	Atmospheric interactions; El Nino; Southern Oscillation; top layers of tropical oceans; snow cover; land surface characteristics	Monsoon circulation variations; deep ocean involvement; green house gas increase; human activities; biospheric changes; volcanic dust	Global climate excursions; ice ages; warm epochs; sun-earth geometry

Table 2. Specifications of the UKMO Unified Model

Aspects	*Brief description*
Domain	Global
Basic variables	P*, u, v, T, q
Horizontal grid	2.5°lat. *X* 3.75°long. Arakawa - 'B' grid
Vertical grid	19 level hybrid coordinate.
Integration scheme	Split explicit scheme, time step used is 30 minutes.
Stability Filters	Fourier filtering to maintain computational instability.
Convection	Mass flux convection scheme by Gregory.
Radiation	Spectral bands for solar radiation and six bands for long wave radiation (Ingram *et al* 1996)
Large scale cloud and precipitation	Computed from total water variable based temperature and a reference relative humidity; includes liquid and ice phases.
Gravity wave drag	Based on sub-grid scale orographic variance and vertical velocity profile.
Land surface process and boundary layer	Multi layer soil temperature model and soil moisture prediction scheme and a 5 level boundary layer turbulent transport depends on Richardson number.

Table 3. Wind shear index for the area bounded by Lat 0° N - 20° N, Lon 60° E - 100° E

	1991	1994
u_{850}	8.501832	10.22189
u_{200}	-17.416240	-16.23180
M_i	25.918082	26.45369

Figure Captions:

Figure,1. Variation of All-India Summer Monsoon Rainfall anomalies during 1871-1995, based on the area weighted average of 306 stations. (Parthasarathy. Personal communication.)

Figure,2. Difference (1994 - 1991) of MAM SST over Pacific

Figure,3. Difference (1994 - 1991) of seasonal mean winds,
(a) at850 hPa : Simulated. (b) at 850 hPa : NCEP-Reanalysis.

Figure,4. All-India summer monsoon rainfall, for 1991 and 1994.

Figure,5. Time series of rainfall during the monsoon season in 1991 and 1994.
(a) Observed. (b) Simulated.

Figure,6. Difference (1994-1991) of seasonal,
(a) Simulated precipitation (b) Xie-Arkin merged precipitation
(c) Simulated OLR (W/m^2) (d) NCEP Reanalysis OLR (W/m^2)

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Variation of All-India Summer Monsoon Rainfall anomalies during 1871-1995

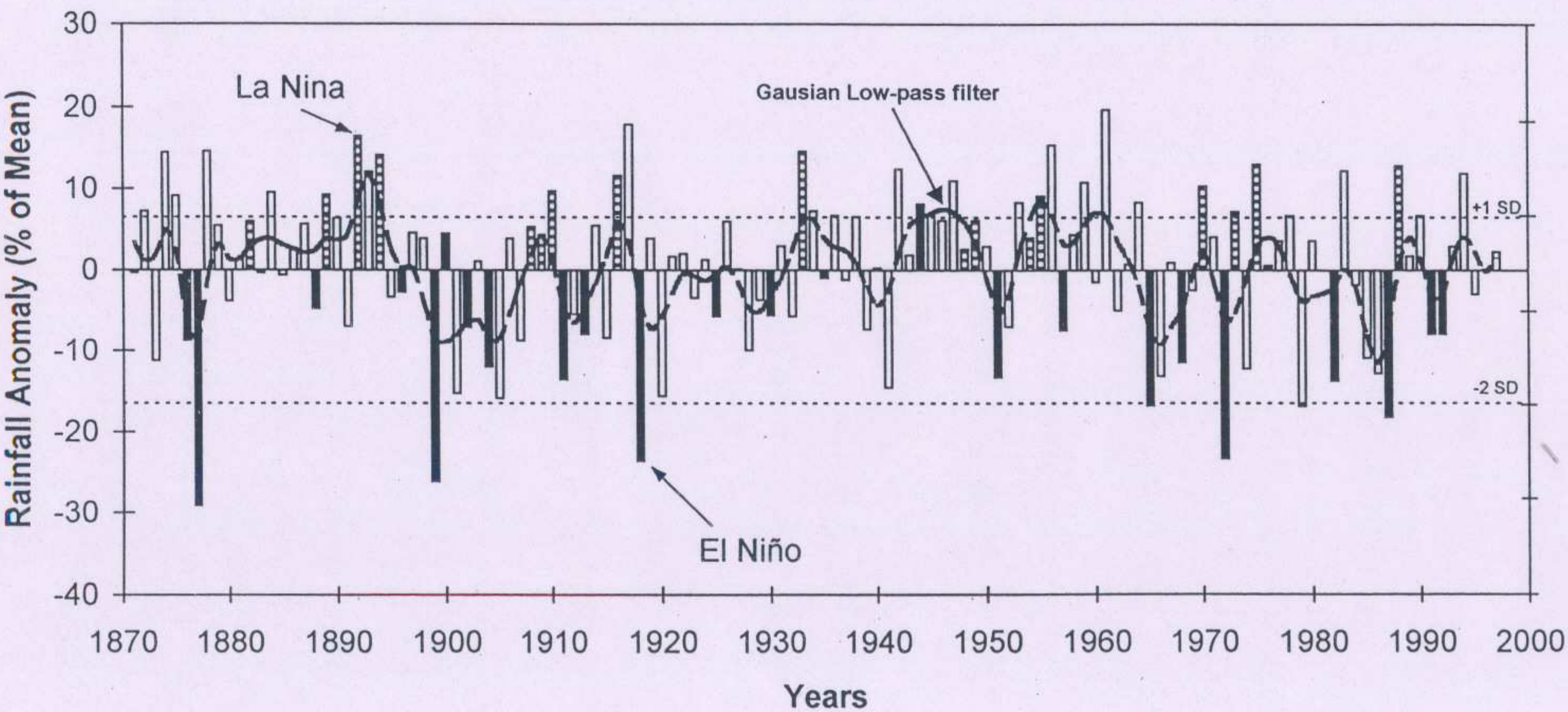

Figure 1.

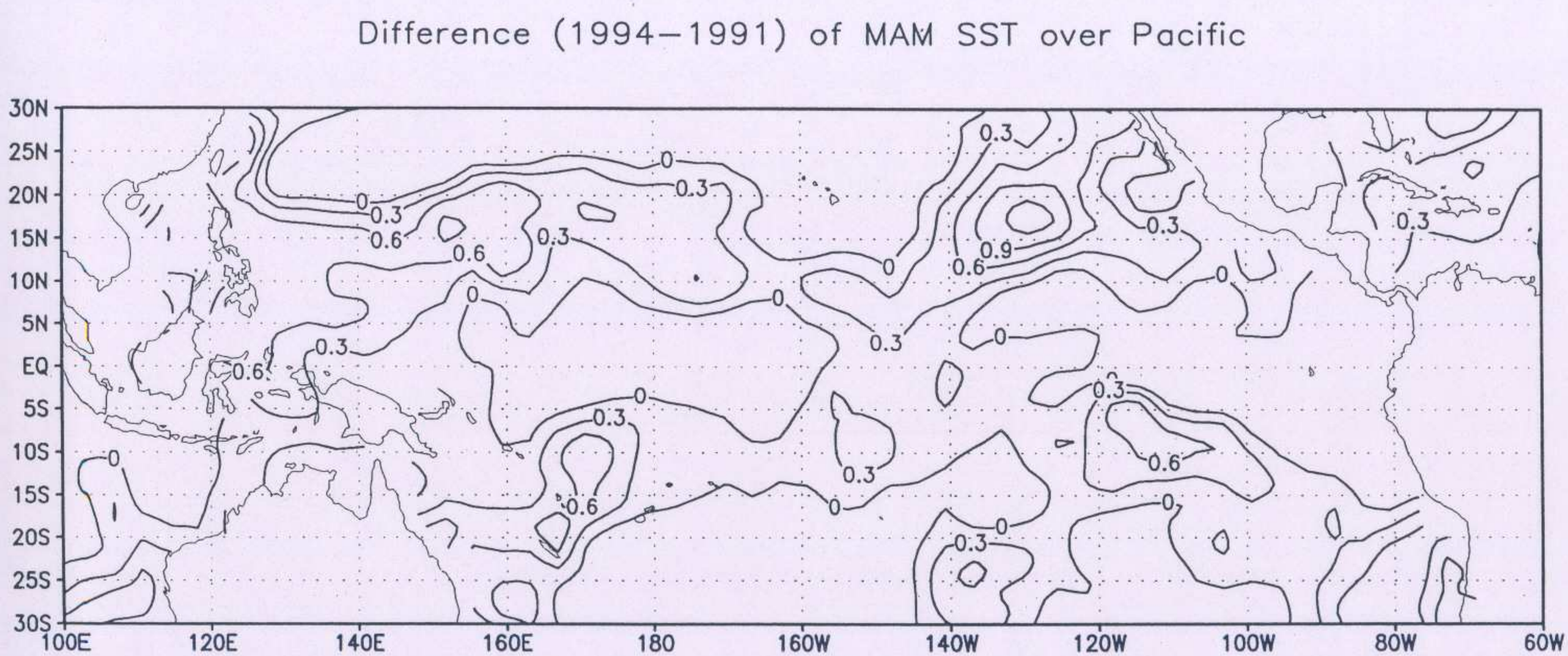
Difference (1994–1991) of MAM SST over Pacific
30N
25N
20N
15N
10N
5N
EQ
5S
10S
15S
20S
25S
30S
100E
120E
140E
160E
180
160W
140W
120W
100W
80W
60W

Figure 2.

Difference (1994–1991) of JJAS Wind at 850 hpa
(a) Simulated

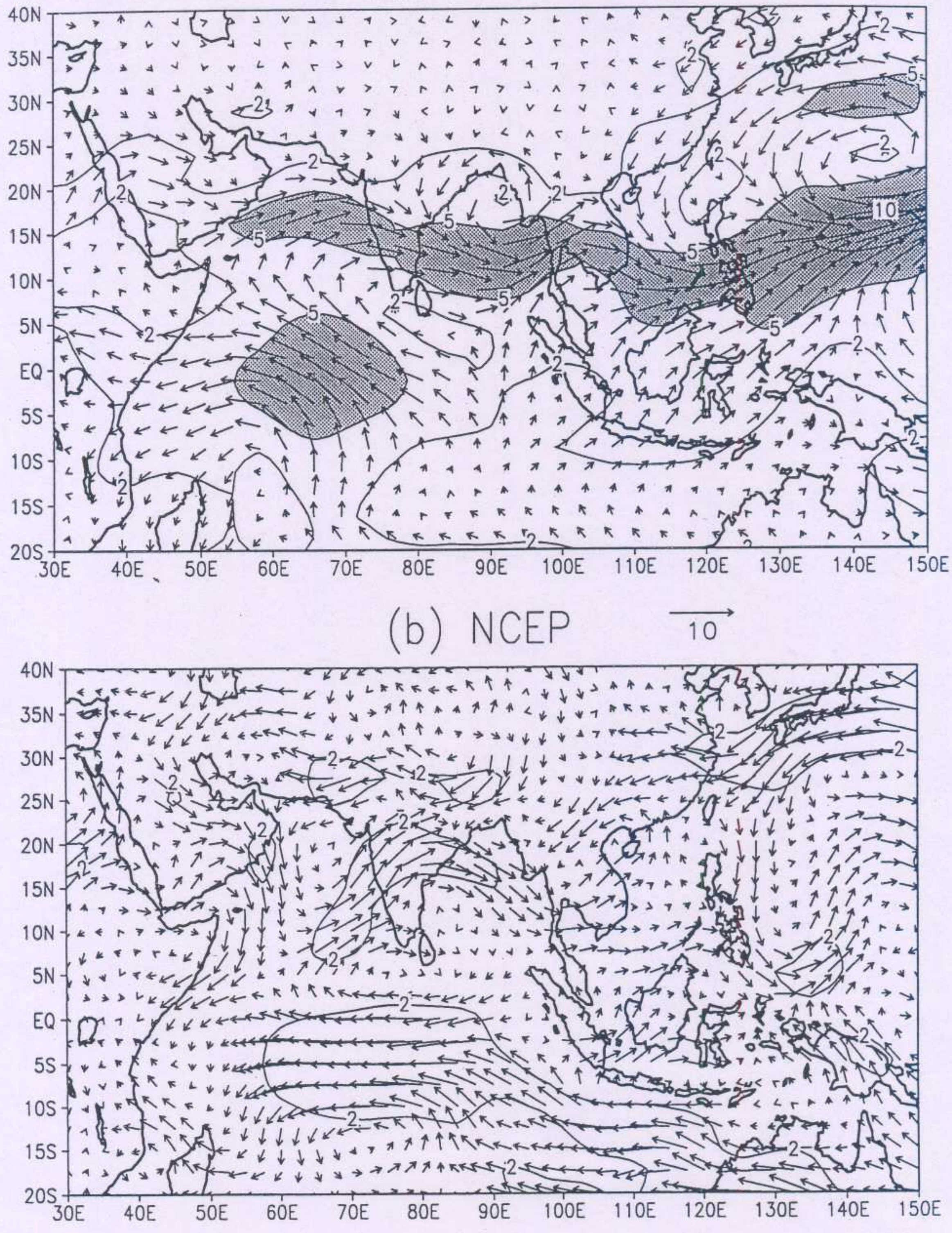

Figure 3.

All-India summer monsoon rainfall for 1991 and 1994

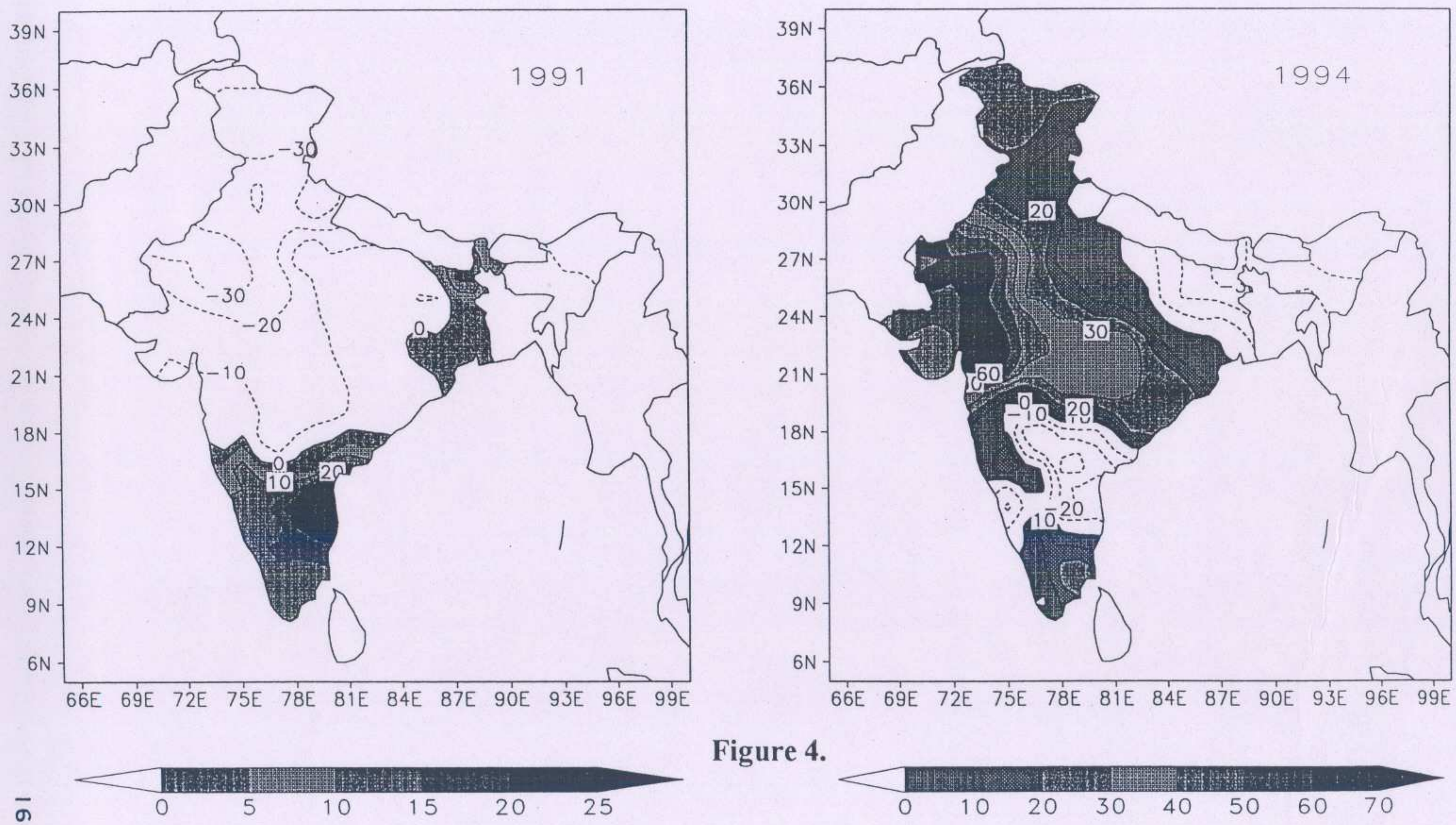

Figure 4.

Time series of rainfall during the monsoon season in 1991 and 1994.
Correlation coefficient (Obs. Vs Simulated) 1991(0.22),1994(.38)

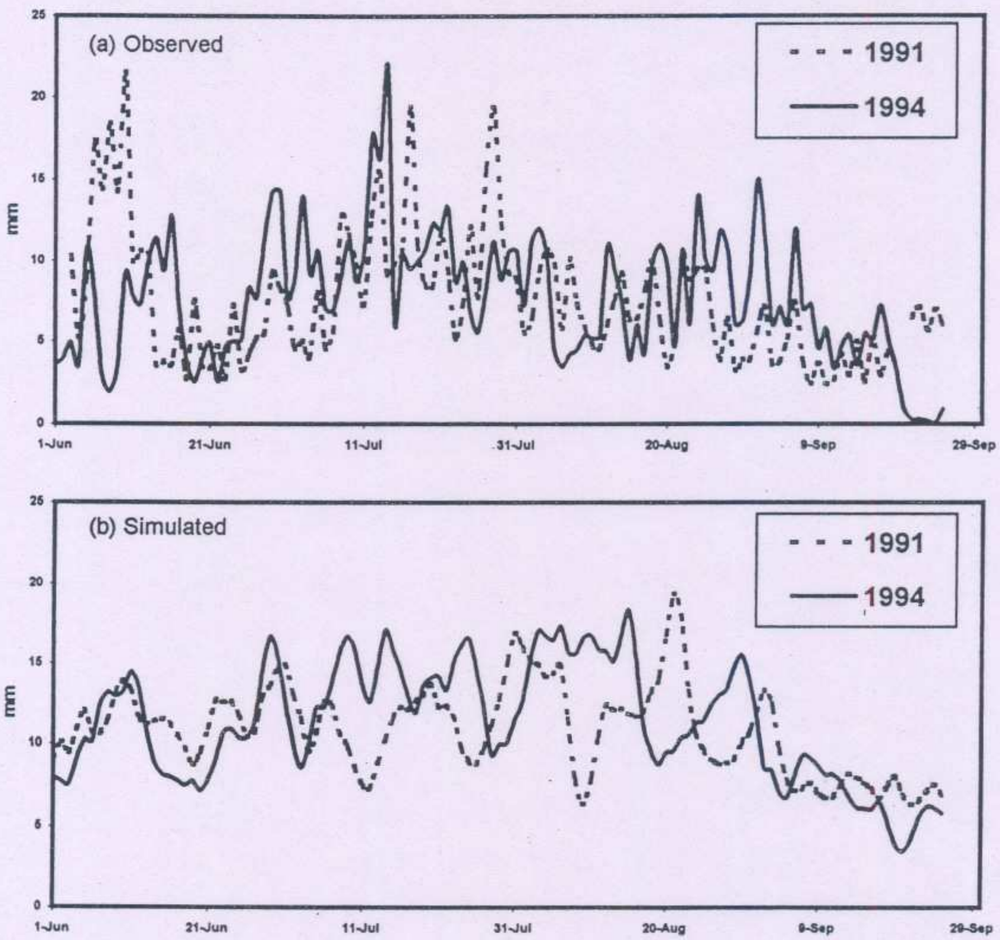

Figure 5.

Difference (1994-1991) JJAS

(a) Simulated precipitation (mm/day) (b) Xie-Arkin merged precipitation (mm/day) (c) Simulated OLR (W/m^2) (d) NCEP Reanalysis OLR (W/m^2)

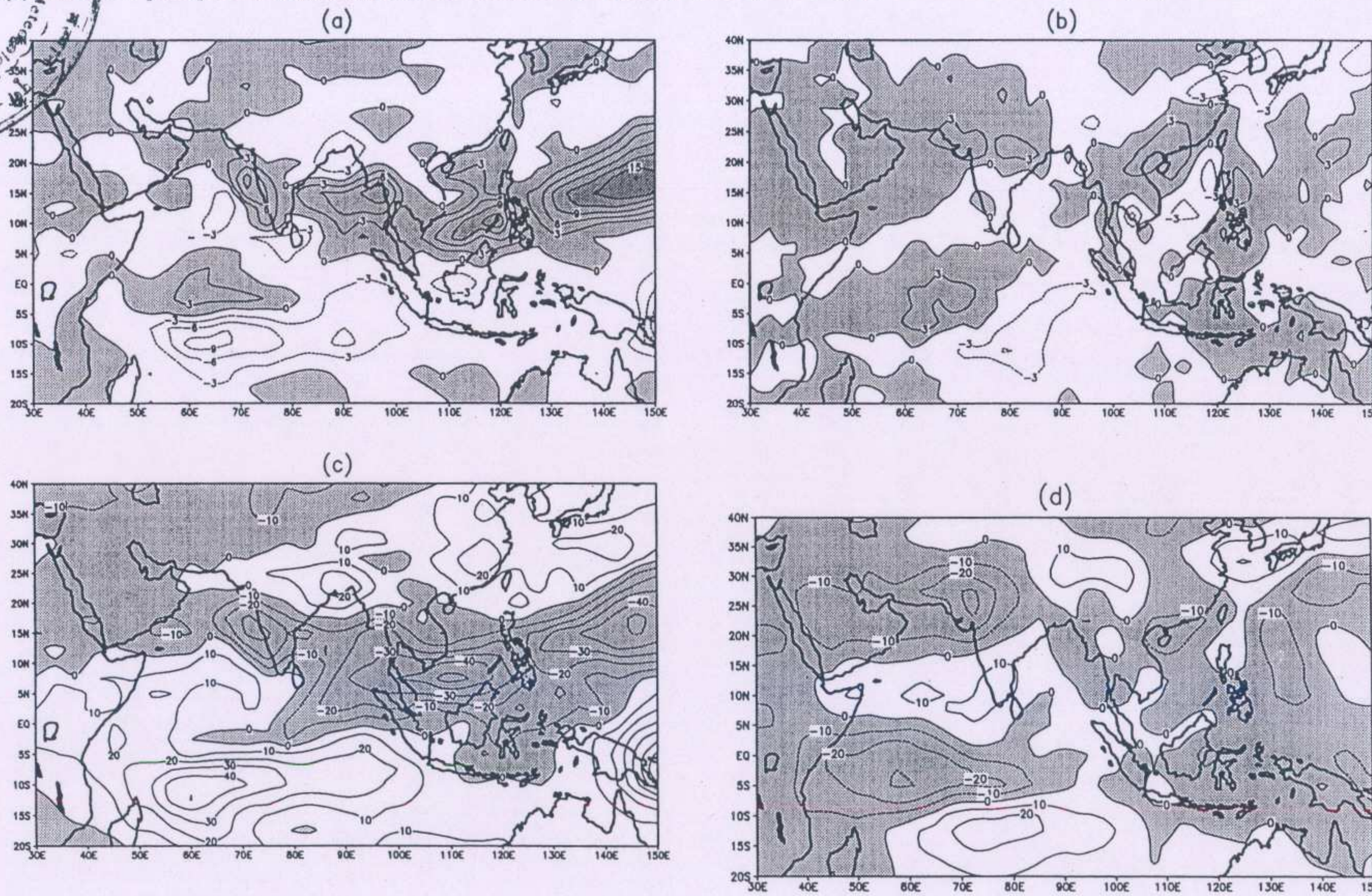

Figure 6.