# Response of Sensitivity Experiment over South China Sea on the Monsoon Variability using a RegCM3 Model

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**ABSTRACT**

Purpose of this paper is to establish teleconnections between the convection changes of the South China Sea (SCS) and the rainfall anomalies over India particularly over northeast and east coast of India. It has been observed in the present study that negative (positive) AMJ (April, May, June) Sea Surface Temperature (SST) anomalies over east end of the positive Tropical Indian Ocean dipole events induced an enhanced cyclonic (anti-cyclonic) circulation over the SCS and this not only cools (warms) SST, but also decreases (increases) Outgoing Longwave Radiation (OLR) anomalies in the SCS. This produced significant impact over Indian summer monsoon rainfall (ISMR) particularly over the northeast and east coast. The correlation of OLR between two regions, Equatorial Eastern South Indian Ocean (EQ.ESIO) and SCS are opposite during this event. The anomalous surface divergence in the eastern tropical Indian Ocean is liable to accelerate the deep convection over SCS. The observed results are verified with the RegCM3 model in its sensitivity experiment. The enforced perturbation in SST over the SCS by +0.5$^0$C throughout the summer monsoon season is generated and the simulated summer monsoon circulation at 850 hPa and ISMR are analyzed. The simulated vertical Water Vapour Mixing Ratio (WVMR) centered at 65$^0$E and 77.5$^0$ E longitudes in the warm SCS are also studied to examine the moisture availability over the Indian subcontinent and adjoining seas.

***Keywords:*** *Outgoing Longwave Radiation, Water Vapour Mixing Ratio, Tropical Indian Ocean Diode.*

## 1. Introduction

The SCS is connected to the Pacific Ocean (PO) in the east through the Luzon Strait and to the Indian Ocean (IO) in the west through the Malacca Strait. Due to its geographical location, SCS is largely influenced by the anomalous events occurring in the PO and IO. Although the El-Nino Southern Oscillation (ENSO) is a PO event with SST anomalies occurring in the equatorial eastern and central pacific, it affects the global ocean (Wang and Ding, 2006). While ENSO peaks during the boreal winter, but its influence on other ocean basins normally peaks 1-2 seasons later (Alexander and Scott, 2002). Klein et al. 1999 and Wang et al. 2002 suggest that the influence of ENSO on other tropical oceans is transmitted through the atmospheric bridges of atmospheric circulation changes. They show that the Walker and Hadley circulations can serve as an atmospheric bridge through the variations in surface wind, air temperature, humidity and cloud cover that in turn influence surface heat fluxes and ocean circulations over other ocean basins and hence change SST. Thus every ENSO event is associated with a change in the SCS SST anomalies and it experiences significant interannual variability in summer that is correlated with eastern Pacific SST at a half-year lag (Ose et al. 1997; Wang et al. 2000b). In spite of a strong ENSO impact on the SCS (Wang et al. 2002, Xie et al. 2003, Qu and Lindstrom, 2004 and Liu et al. 2004), the large scale circulation and SST is dominantly influenced by the seasonal reversal of the monsoon winds. Thompson and Tkalich, 2012 emphasis in his study the interannual variability of SST over the southern SCS during the ENSO and Indian Ocean Dipole (IOD) events. The climatologically impact of east pole during positive tropical IOD was found over southwest BOB which resulted deficient rainfall over East Coast particularly over Tamilnadu and Coastal Andhra Pradesh (Choudhary et al., 2014). Due to the geographical location of Vietnam in the northwest of SCS, the upwelling over the Vietnamese coast takes place in summer during the southwest monsoon. Wyrtki, 1961 and Huang et al., 1994 pointed out the seasonal upwelling and showed that there is a more than $1^0$C drop in SST off Vietnam in summer. Forced by observed winds, several models were also able to produce the summer upwelling and SST cooling off the Vietnamese coast (Pohlmann, 1987; Shaw and Chao, 1994). Our aim in this study is to discover the emergence of summer deep convection over SCS due to the important events like ENSO and Tropical Indian Ocean Dipole (TIOD). The impact of deep convection over SCS on monsoon variability is discussed in details. A high resolution Regional Climate Model (RegCM3) configured for the SCS is used for the sensitivity experiment to examine the performance of the model in simulating the monsoon circulations, moisture content in terms of vertical WVMR and precipitation.

## 2. Data, Methodology and Model Description

Monthly $1^0$x$1^0$ gridded SST anomalies obtained from Smith and Reynolds, so called National Oceanic and Administrative Agency/National Climatic Data Centre (NOAA/NCDC) and Extended Restructured Sea Surface Temperature (ERSST) v2. The OLR and wind anomaly datasets from NCEP/NCAR (National Center for Environment Prediction/National Center for Atmospheric Research, USA) reanalysis dataset has been used in the present study. Time series of seasonal rainfall for the regions under consideration has been taken from the Indian Institute of Tropical Meteorology (IITM) dataset generated from the station rainfall data of the India Meteorological Department (IMD). The domains examined in this study are $10^0$S-Equator, $90^0$E-$110^0$E (EQ.ESIO) for SSTA and OLR, $5^0$N-$13^0$N, $79^0$E-$89^0$E (SWBOB) for OLR, SST and wind anomalies. The strong positive SST dipole years were considered those years having dipole Index (TIODI) $\geq$1 SD when averaged from April to September during the study period (1980-2009). The TIODI is defined as the difference of SST anomalies between two ends of dipole i.e. $10^0$S-$10^0$N, $50^0$E- $70^0$E and $10^0$S- 0, $90^0$E- $110^0$E.

In the present study, a warm SST experiment is conducted by increasing temperature $0.5^0$C of SCS over the oceanic region ($5^0$N – $25^0$N and $98^0$E – $112^0$E) in the model domain and the simulated wind fields at 850 hPa and 200 hPa, vertical WVMR and rainfall are compared with CTL experiment of the model. The control runs are integrated from April 1 to October 1 for the years 2005, 2006, 2007, 2008 and 2009. In all experiments, the central longitude and central latitude is centered at 80 $^0$E and 16 $^0$N. The model domain covers the area approximately 48 $^0$E to 112 $^0$E and 40 $^0$N to 10 $^0$S with a horizontal grid distance of 50 km. The grid is defined on a Normal Mercator (NORMER). The lateral boundary conditions are updated and fed every 6 hour into the model and the time step of the integration has been kept at 75 second. The experiments are conducted for Grell cumulus parameterization schemes with Arakawa–Schubert as the closure scheme.

## 3. Results and Discussion

Interannual variability of the SCS is largely influenced by ENSO and TIOD events. During the period of 1980-1997, MAM SST anomalies over SCS are negative 17 times out of 18, but during 1998-2009, anomalies are positive 10 times out of 12 (Fig.1). The increasing trend of SCS SST in recent years has created great concern among scientists to examine the Indian monsoon variability particularly in the cases of enhanced deep convection in and around SCS. During warm ENSO years, SCS SST anomaly is colder induced by the atmospheric linkage to the cold end of the western Pacific Ocean. During boreal winter, the northeast monsoon is prevailed over SCS and the El-Nino condition in the PO causes to weaken the northeast monsoon resulting warm SST over SCS. The divergence of wind at the western PO towards SCS occurred due to the oceanic thermal gradient and the deep convection increased over northern SCS during the matured stage of the El-Nino event. The anomalous cooling over east pole during pre-monsoon season during positive tropical IOD which coincided with warm ENSO event creates the cyclonic circulation over SCS at low level and accelerates the local convection.

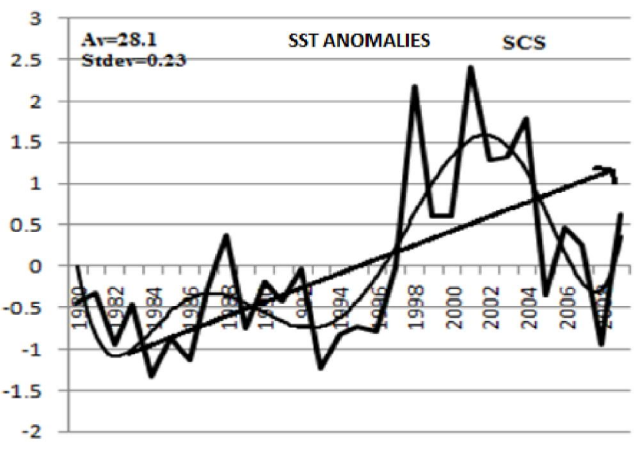


Fig.1 Trend in sea surface temperature over SCS.

Corresponding to El-Nino warm events, SCS SST anomalies are found colder during summer monsoon season except in 2002 which also shows sharp decline after June (Fig.2). The line graphs of SCS SST anomalies are bunched around the horizontal x-axis. These lines have two peaks in June and December during JJAS and OND months. It is seen that after getting first peak in June, it has slope downwards till September and then raised to its second peak in December in almost all warm ENSO years. This shows the enhanced deep convection over SCS during summer monsoon season. The June peak may be due to the anomalous shortwave radiation in the northern hemisphere whereas December peak shows weaker northeast monsoon over SCS due to the El-Nino warm events. OLR anomalies during warm ENSO events are appreciably negative in AMJ months (Fig.3). This low OLR persists in the summer monsoon season also. Reduced OLR in the region followed the enhanced deep convection which in turns caused heavy regional rainfall. Warm SCS in the preceding months of the summer monsoon created suitable thermal gradient and the increased zonal winds from BOB and caused to

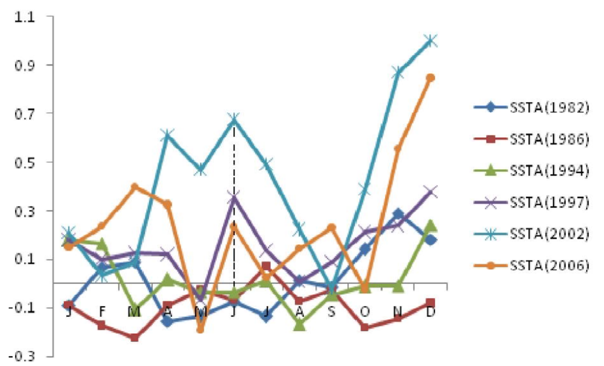


Fig.2 Patterns of annual SSTA over SCS during warm ENSO years in the study period (1980-2009).

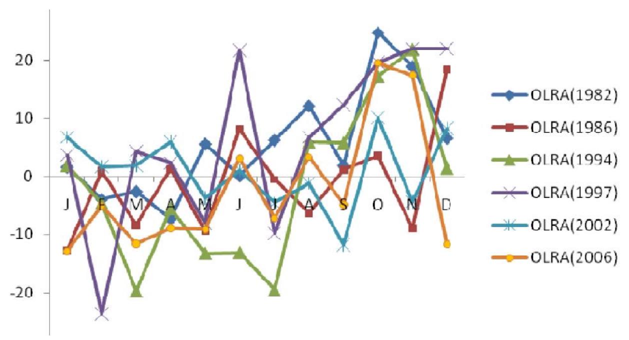


Fig.3 Same as in Fig.2 except for OLRA.

enhance convection in the northern and western SCS (Figure 4). Figure 4 shows a weak monsoon circulation in July of 1994 over entire east coast of India and weak low level convergence over the concerned region can also be seen. The cyclonic southwest monsoon circulation from west and anticyclonic flow from east produces increased upwelling over northern SCS. The anomalous meridional wind from EQ.ESIO also enhanced the convection over SCS in the years of positive tropical dipole events like 1982, 1994 and 2008.

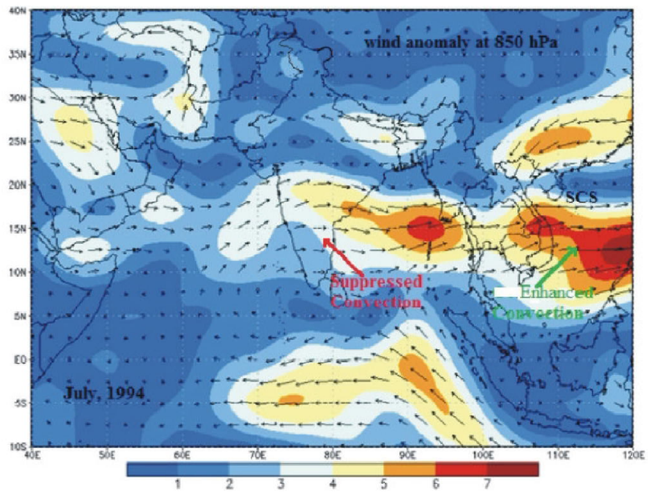


Fig.4 Wind anomaly at 850 hPa during July, 1994.

The meridional wind arriving in SCS from EQ.ESIO influences the SST pattern over SCS particularly its western periphery. Those TIODs which induce negative SSTA over the eastern end of the dipole throughout the year from its evolution to the maturity northern as well as western SCS gets deep convection enhanced (Fig.5). Fig.5 shows the high convection over northern and

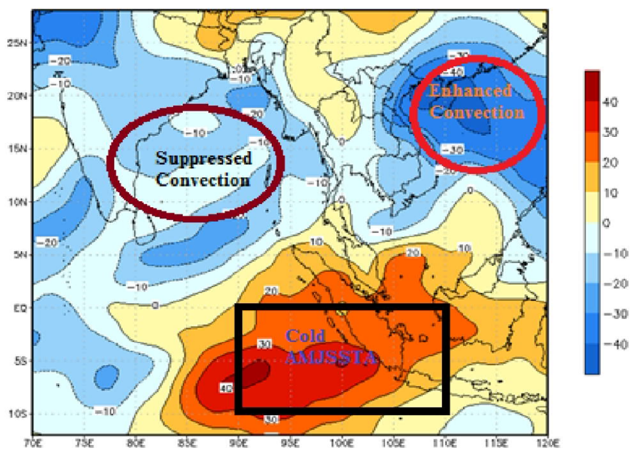


Fig.5 Trend of OLR over EQ.ESIO, SWBOB and SCS in 1 994.

western SCS while low convection over SWBOB in response to the anomalous cooling over EQ.ESIO during positive TIOD event of 1994. This super cooling condition (Negative SST anomalies throughout seven months) influences SWBOB (SCS) by inducing suppressed (enhanced) convection in the summer monsoon season. Thus anomalous convergence of winds over SCS was liable to create negative SSTA during JJAS months (Table 1). The observed rainfall over east coast subdivisions (Tamilnadu and Coastal Andhra Pradesh) and northeast subdivisions (Assam & Meghalaya and Nagaland, Manipur, Mizoram & Tripura) was deficient during these dipole years (1982, 1994 and 2008) (Table 2). Nagaland, Manipur, Mizoram & Tripura subdivision has negative rainfall anomalies of -16.2% and -17.2% in the years 1994 (warm ENSO) and 2008 (cold ENSO) respectively. Low rainfall is also observed during those ENSO years which produced deep convection over SCS. Remarkably, 1997, a warm ENSO year received 18.3% more rainfall over Nagaland, Manipur, Mizoram & Tripura subdivision and normal rainfall over Tamilnadu and Coastal Andhra Pradesh (CAP). Less convection over SCS and high convection over SWBOB in 1997 were found. Similar rainfall pattern was also observed over Assam & Meghalaya subdivision.

### 3.1 Sensitivity experiments over SCS

Focus of this study is to analyze the variabilities in seasonal monsoon circulations at 850 hPa, vertical WVMR (centered at $65^0$E and $77.5^0$ E) and precipitation in warm SST run over SCS to increase SST by $0.5^0$C and to correlate the observed anomalies (rainfall and OLR) over BOB and east coast of India. The enforced warming of SCS causes increased deep convection over the region with enhanced cyclonic circulation. This in turn enhanced the moisture flux from the BOB to SCS. It caused suppressed SW cyclonic circulation over BOB resulting deficient rainfall over east coast region and northeast India. Moreover, warm SCS is associated with arrival of monsoon circulations more northerly in ABS and thus received slightly increased rainfall over Central North East India (CNEI) and West Central India (WCI). Figure 6(a-b) shows the composite mean wind fields and the

**TABLE 1**
**Sea Surface Temperature Anomalies of (SSTA) EQ.ESIO influencing the nature of SSTA over SCS during positive TIOD years**

| | Polarities of SST in EQ.ESIO region | | Polarities of SST in SCS region | |
|---|---|---|---|---|
| Years | AMJ months | JAS months | AMJ months | JAS months |
| 1982 | negative | negative | negative | negative |
| 1991 | positive | negative | negative | negative |
| 1994 | negative | negative | negative | negative |
| 1997 | positive | negative | positive | positive |
| 2006 | positive | negative | positive | positive |
| 2007 | positive | negative | positive | positive |
| 2008 | negative | negative | negative | negative |

**TABLE 2**
**Patterns of observed rainfall over Tamilnadu, CAP and Northeast subdivisions during positive TIOD years**

| Years | Tamilnadu | CAP | Assam&Meghalaya | Nagaland, Manipur, Mizoram &Tripura |
|---|---|---|---|---|
| 1982 | Deficient | Deficient | Deficient | Deficient |
| 1994 | Deficient | Deficient | Deficient | Deficient |
| 2008 | Deficient | Deficient | Deficient | Deficient |

difference in seasonal wind fields at 850 hPa between warm SST and CTL experiments respectively. Figure 6 also shows the southwesterly cyclonic wind fields which are the normal seasonal monsoon circulations at 850 hPa over BOB became weaker in warm SCS SST experiment. The difference of wind fields and direction of wind vectors show that the wind speed is weaker in warm SST in comparison to the CTL experiment over the CAP and Tamilnadu regions. The monsoon circulations over central ABS, northwest India, Gujarat subdivisions and peninsular India are also weaker.

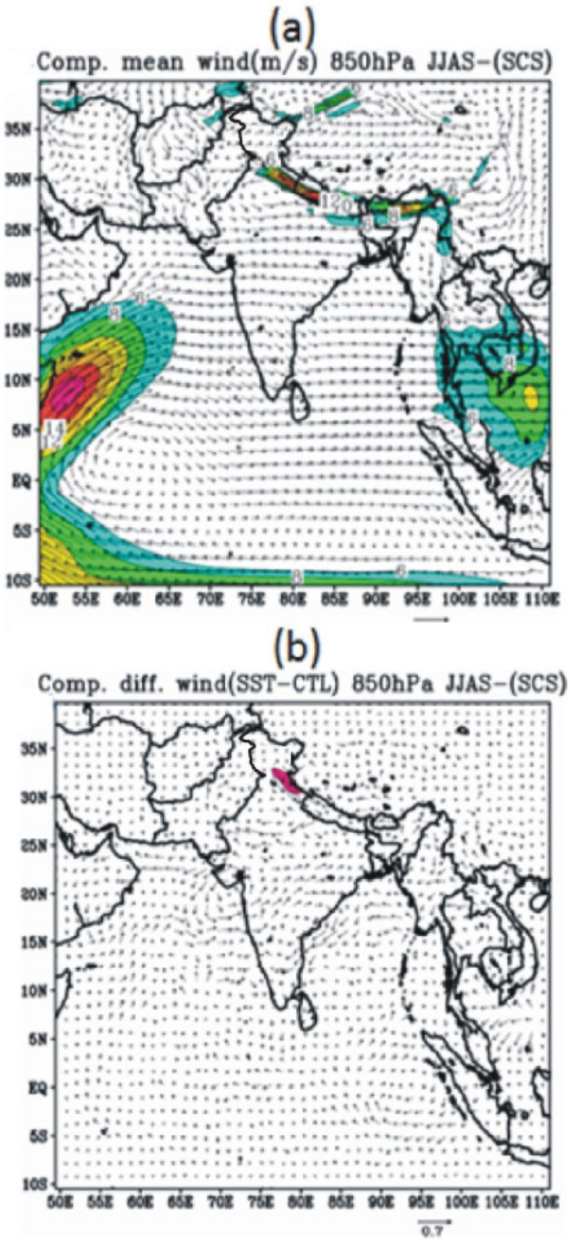


Fig.6 Simulated composite mean field of sensitivity experiment over SCS (a) wind at 850 hPa, (b) difference wind at 850 hPa (SST-CTL).

The composite analysis of the model results shows that the increased SST over the SCS induces cyclonic circulation at 850 hPa level. Negative OLR anomalies with enhanced deep convection over SCS during El-Nino and positive TIOD years (negative AMJ SSTA over EQ.ESIO) are in accordance with the results of warm run of the model. The new findings indicate an ocean atmosphere interaction over the SCS where underlying SST anomalies tend to form a favourable condition for convective activity and sustain enhanced regional precipitation during ISM. This verifies the results presented by the NCEP/CPC Global Monsoon Team. Overall the Asian monsoon rainfall was above normal in summer 2008 which is also the characteristic year of PTIOD having negative AMJ SSTA over EQ.ESIO. According to the NCEP/CPC team, above normal rainfall occurred over the tropical IO (except EQ.ESIO), southern China, northern SCS and much of East Asia and below normal rainfall occurred over central southern India. It is also noticed that stronger southwesterly monsoon circulation persists over southern China and northern SCS. Also the onset of summer monsoon was earlier than normal over SCS and India with distinctive feature of the strong zonal dipole of precipitation over tropical IO with above (below) normal precipitation over the west (east).

Fig.7(a, c) shows composite seasonal mean vertical WVMR at different atmospheric pressure levels centered between 62.5 – 67.5$^0$ E longitude and 75–80$^0$ E longitude. Figure 7(b, d) shows the difference in seasonal mean vertical WVMR at different atmospheric pressure levels between warm SST and CTL experiments respectively. The moisture content available in the ABS along with cross equatorial flow shows insignificant change except marginal increase (by +5%) over central ABS and slight decrease (by -5%) over southwest ABS at the atmospheric level above 600 hPa (Figure 7b). This moisture flux change is well matched with simulated wind fields. As far as moisture available over Indian region is concerned, there is no major change is observed except near the Himalayan region around 35$^0$N (increase in moisture content by 5%-10%) at lower atmospheric level (Figure 7d). Figure 8(a-b) shows the composite mean rainfall and the difference in seasonal rainfall between warm SST and CTL experiments respectively. Major parts of ABS and BOB observed negative rainfall except over the regions bounded by south of 9⁰N and west of 87⁰E including the oceanic regions surrounding Gujarat. The zone of lowest rainfall is northeast BOB in the domain of 12⁰N-20⁰N, 87⁰E-95⁰E. This might be due to the weaker cyclonic monsoon circulation over major parts of BOB. As far as rainfall over Indian subcontinent is concerned, all rainfall zones except central India (CNEI and WCI) received deficient rainfall in this warm SST run. The response of rainfall over CNEI and WCI is positive and it is 9% and 13.1% excess rainfall respectively in the warm SST in comparison to the CTL experiments (Fig.9). Thus, the positive response of warm SST over SCS on the ISMR is not observed. The lowest rainfall (-10.2%) is observed over Northeast India (NEI) (Figure 9). The model results have shown good agreement with the observed rainfall over Tamilnadu, CAP and NEI regions.

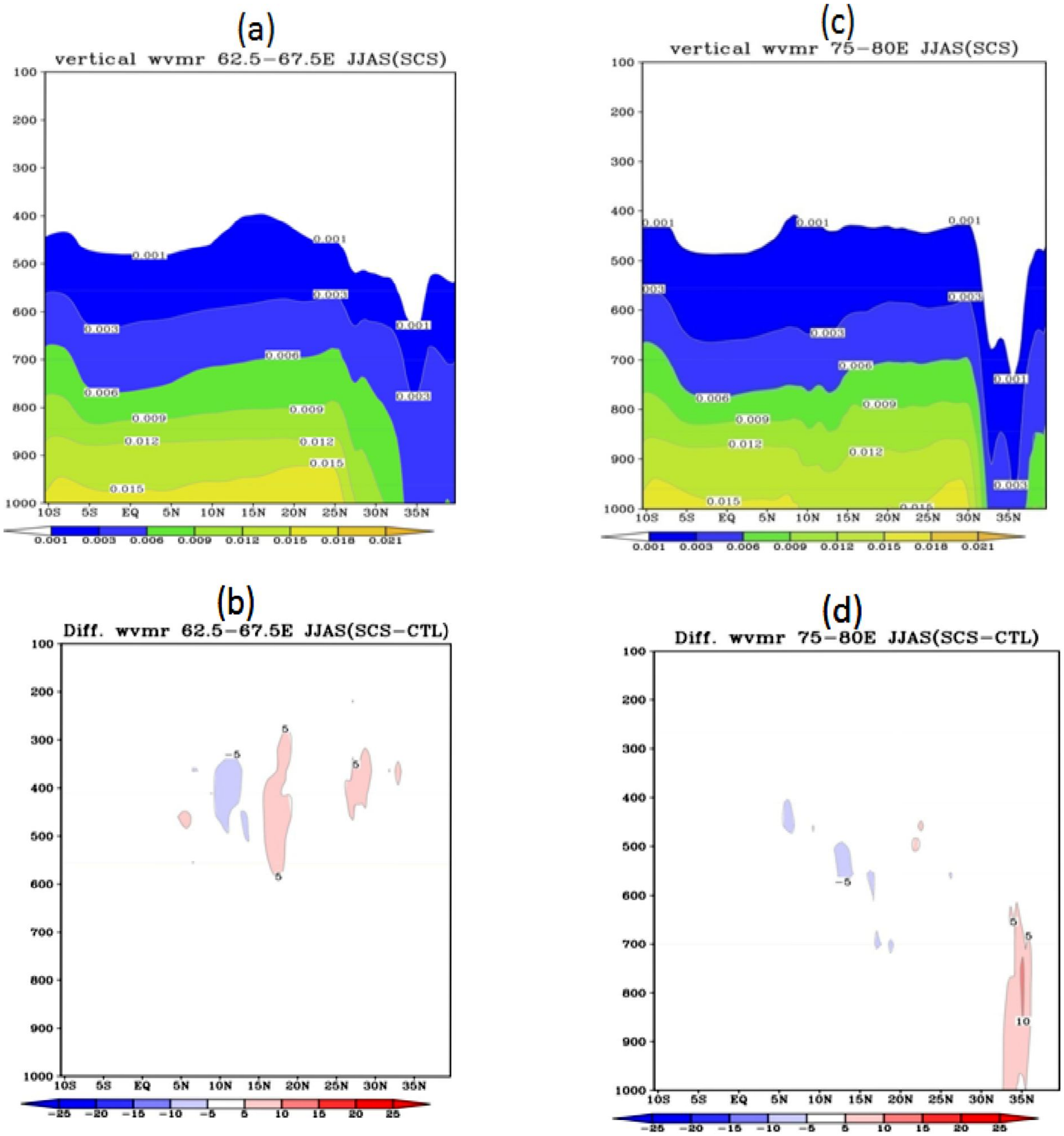


Fig.7 Simulated seasonal vertical WVMR (a) centered at 65⁰E longitude, (b) difference WVMR (SST-CTL), (c) centered at 77.5⁰E longitude and (d) difference WVMR (SST-CTL).

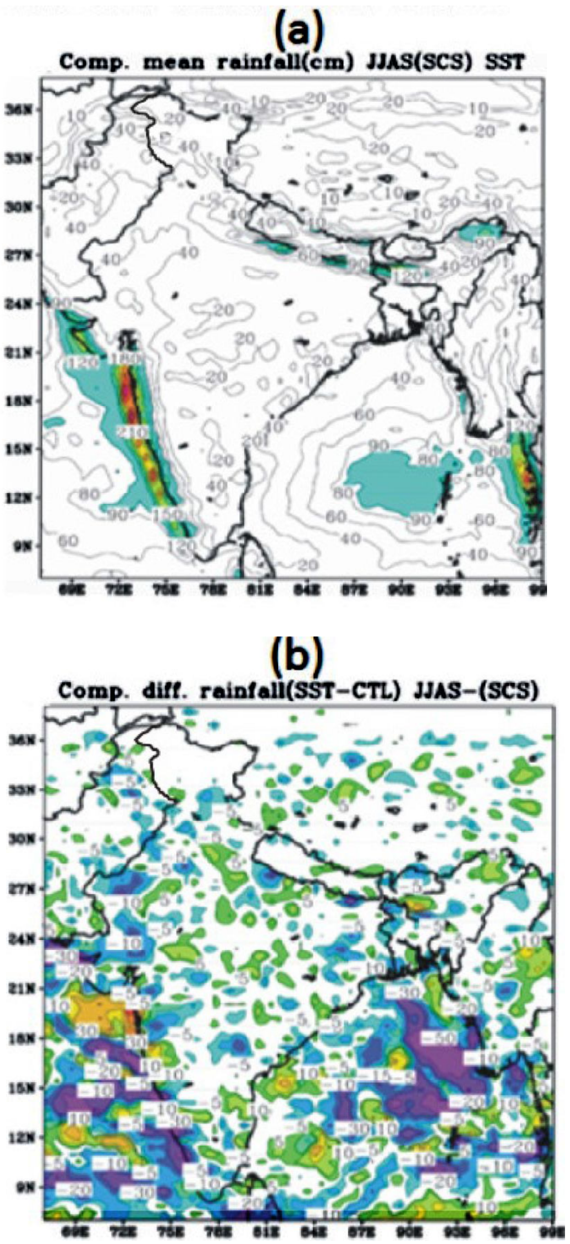


Fig.8 (a) Simulated composite mean rainfall and (b) difference (SST-CTL) rainfall.

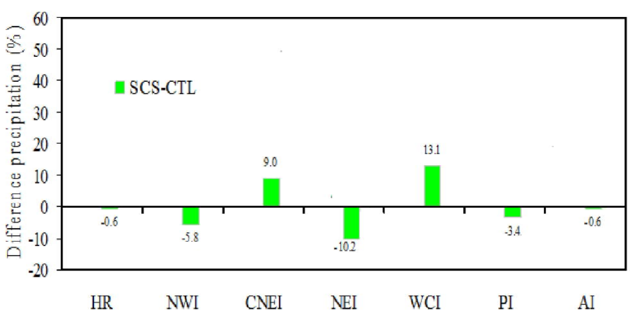


Fig.9 Difference in precipitation (in %) between SST and control experiment over various rainfall zones.

### 3.2 Monthly analysis of wind fields, moisture contents and precipitation during the monsoon season

Fig.10(a-d) shows the monthly variations of the wind fields at 850 hPa from June to September in sensitivity experiment. The monsoon circulation in ABS is weaker and the directional approach of the cross equatorial flow is more northerly in the month of onset of monsoon (Fig.10a). This is due to stronger cyclonic circulation around $25^0$N latitude and a $65^0$ E longitude. This is the reason behind the positive rainfall anomaly over central India. The changes in wind speed show the weaker winds over CAP and Tamilnadu whereas stronger in southern BOB. The water vapours present in the monsoon circulations are changed only at upper atmospheric levels. The increase is observed by 5% to 10% in comparison to CTL run in June at higher latitudes only (Fig.11a). Obviously the increase in moisture flux in the southern Arabian Sea is less. The arrival of moisture along with cross equatorial flow is decreased as monsoon progresses and decrease in moisture content is significant in July and August [Fig.11(b, c)]. The monthly changes in vertical WVMR in warm SCS experiment is in accordance with changes in the wind fields. Patterns of monthly change of vertical WVMR over Indian region are well simulated by the model and are comparable to the observed moisture content when the increased convection induced over the SCS during positive dipole conditions. There is significant reduction in moisture percentage over Indian region in between $5^0$N and $20^0$N (comprising CAP and Tamilnadu) in the month of June (Fig.12a). This reduction is continued almost in every months of summer monsoon.

Fig.13(a-d) shows the monthly rainfall simulated by the RegCM in warm SST run over SCS. The simulated rainfall over the entire east coast of India has remarkably decreased in this experiment. Except for the central India, the rainfall over northwest and peninsular India showed negative departure. The simulation of Wind fields and vertical WVMR as discussed earlier also supports the rainfall anomalies. Monthly variations of rainfall verify the fact that the variability in wind speed and moisture flux during July and August influence the ISMR largely.

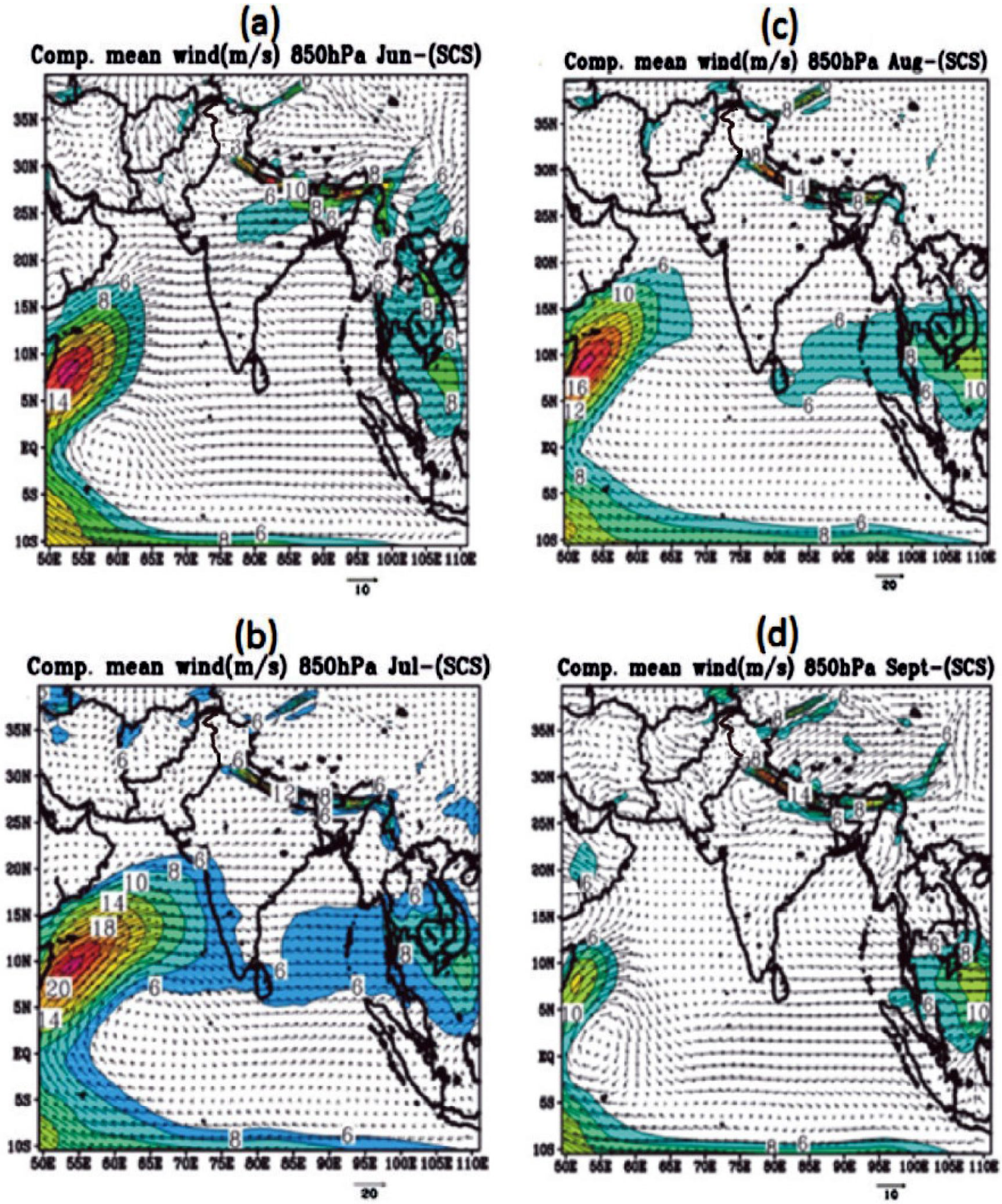


Fig.10 Simulated mean monthly composite wind field at 850 hPa of sensitivity experiment over SCS.

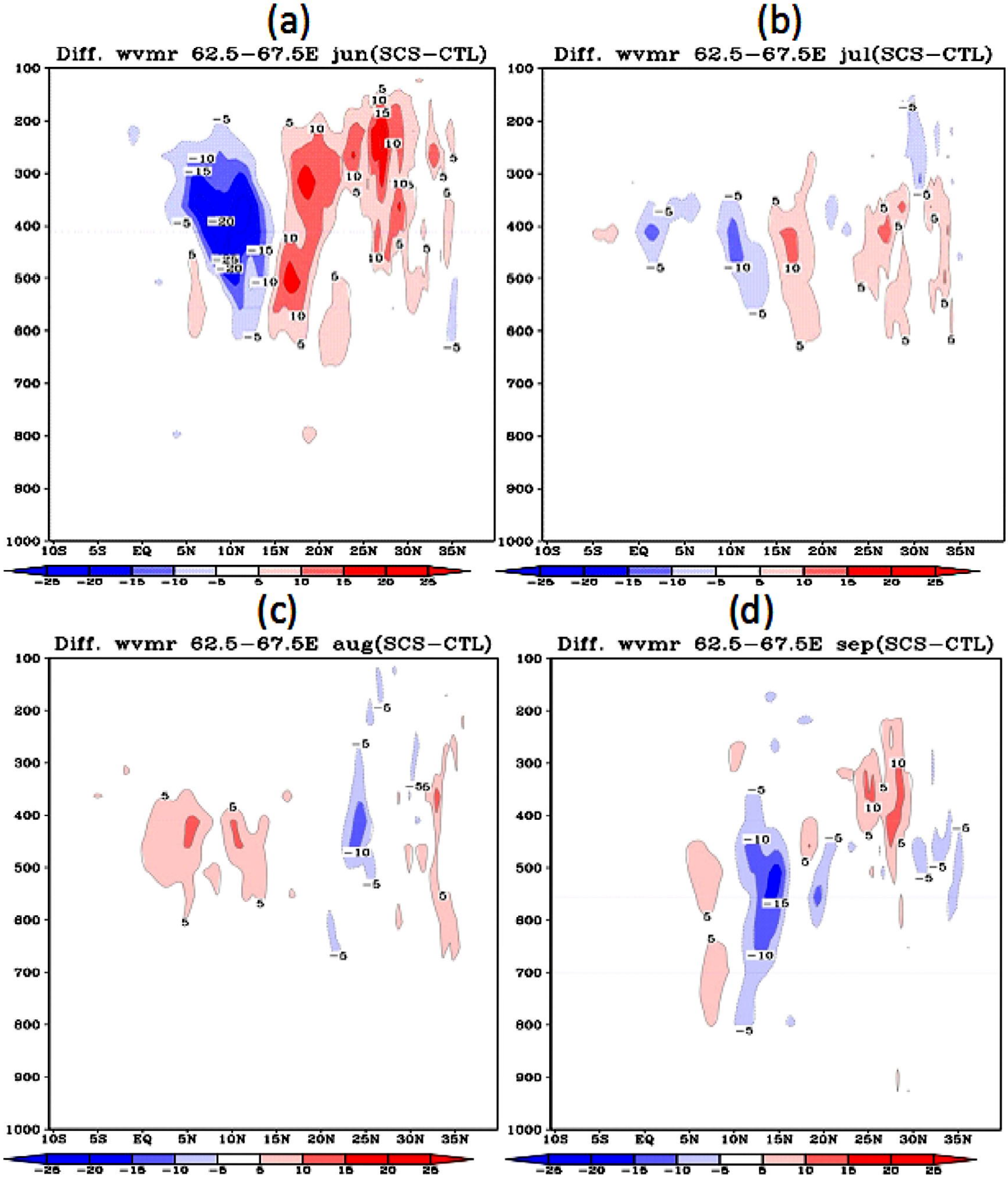


Fig.11 Monthly difference WVMR (SST-CTL) centered at $65^0$E longitude.

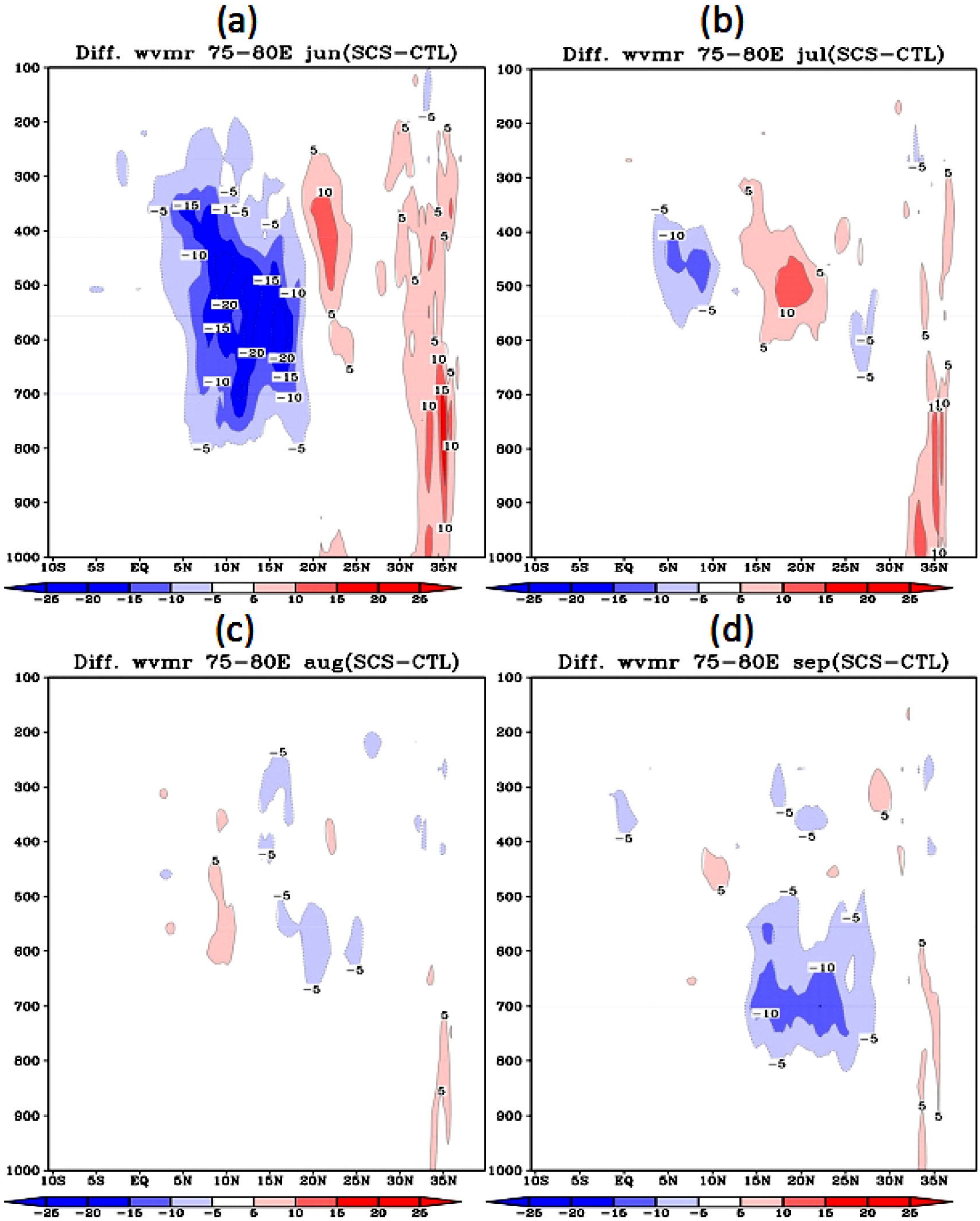


Fig.12 Same as in Figure 12 except WVMR centered at 77.5$^{0}$E longitude.

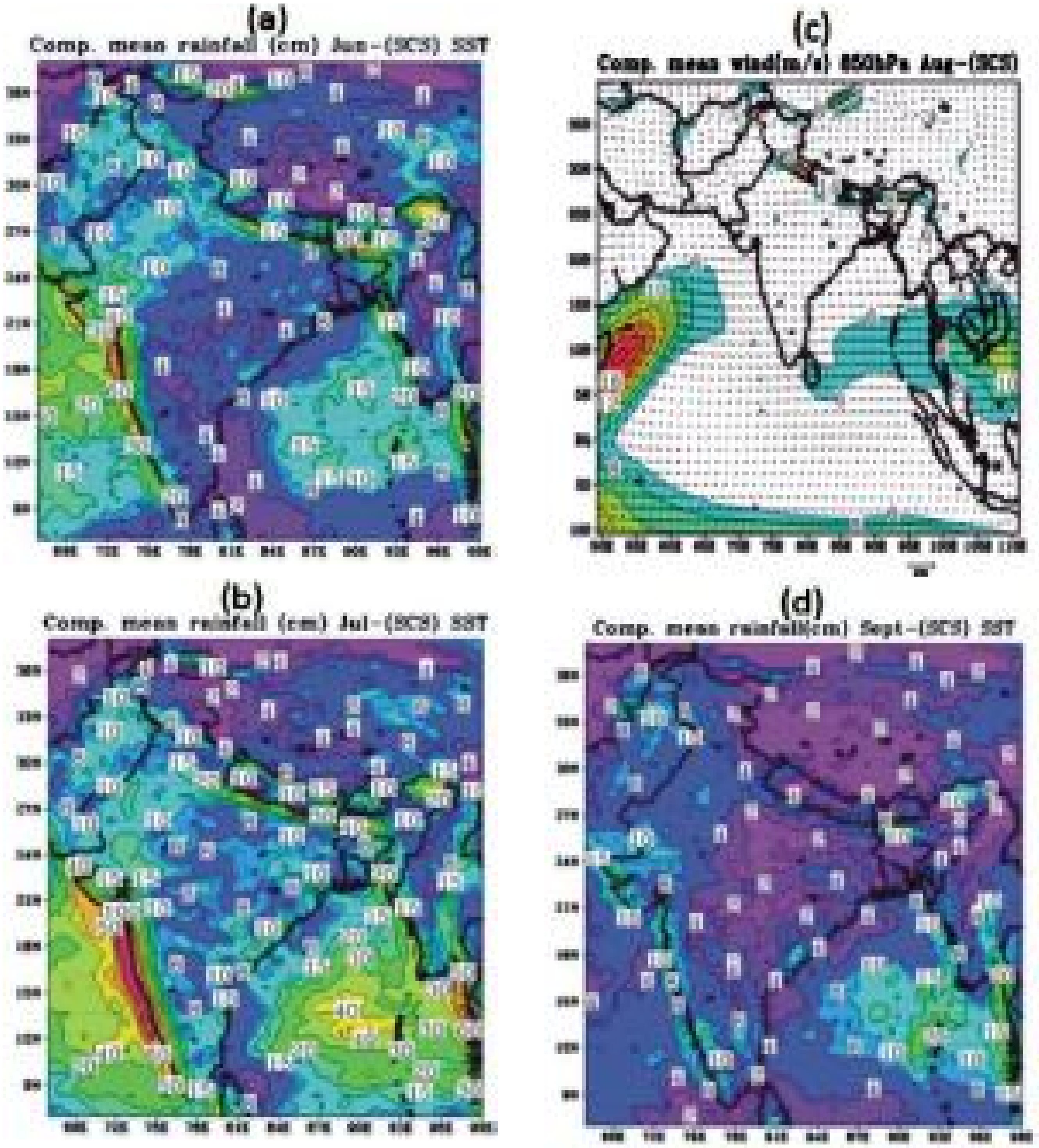


Fig.13 Simulated mean monthly composite rainfall.

## 4. Summary and Conclusions

On analyzing the results of observed and sensitivity experiment over SCS, we arrived on the following conclusions in this study follows:

1) Anomalous cooling from March to September over eastern end of the tropical dipole enhanced the convection over SCS. The EQ.ESIO and SCS have good negative correlation in OLR.

2) Interannual SST and OLR anomalies in the SCS are largely influenced by ENSO and the TIOD driven by atmospheric and oceanic changes.

3) Deep convection in SCS is responsible for the rainfall variability along East Coast and Northeast of India. The negative (positive) rainfall anomalies are observed in the cases of enhanced (suppressed) convection over SCS.

4) The increased convection over SCS in its model domain in the sensitivity experiment projected the weaker monsoon circulations and convergence of moisture (less vertical WVMR) into the ABS and BOB and hence deficient rainfall over major parts of Indian subcontinent. The vertical WVMR shows large reduction in moisture percentage (in the range of 5% to 20%) in between $5^0$N to $20^0$N.

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