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Performance of Regional Climate Model in Simulating Monsoon Onset Over Indian Subcontinent

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Abstract—The performance of various Convective Parameterization Schemes (CPSs) of Regional Climate Model version 4.3 (RegCM-4.3) for simulation of onset phase of Indian summer monsoon (ISM) over Kerala was studied for the period of 2001–2010. The onset date and its associated spatial variation were simulated using RegCM-4.3 four core CPS, namely Kuo, Tiedtke, Emanuel and Grell; and with two mixed convection schemes Mix98 (Emanuel over land and Grell over ocean) and Mix99 (Grell over land and Emanuel over ocean) on the basis of criteria given by the India Meteorological Department (IMD) (Pai and Rajeevan in Indian summer monsoon onset: variability and prediction. National Climate Centre, India Meteorological Department, 2007). It has been found that out of six CPS, two schemes, namely Tiedtke and Mix99 simulated the onset date properly. The onset phase is characterized with several transition phases of atmosphere. Therefore, to study the thermal response or the effect of different sea surface temperature (SST), namely ERA interim (ERSST) and weekly optimal interpolation (OI_WK SST) on Indian summer monsoon, the role of two different types of SST has been used to investigate the simulated onset date. In addition, spatial atmospheric circulation pattern during onset phase were analyzed using reanalyze dataset of ERA Interim (EIN15) and National Oceanic and Atmospheric Administration (NOAA), respectively, for wind and outgoing long-wave radiation (OLR) pattern. Among the six convective schemes of RegCM-4.3 model, Tiedtke is in good agreement with actual onset dates and OI_WK SST forcing is better for simulating onset of ISM over Kerala.

Key words: Onset of monsoon over Kerala, regional climate model (RegCM), monsoon variability, convective parameterization scheme (CPS).

1. Introduction

Southwest monsoon is a large scale synoptic system which reliefs the Indian subcontinent from the dry and hot summer, and provides more than 80% of total annual rainfall during the monsoon season (June–September). Summer monsoon has the crucial dominance on Indian agriculture, economy as well as hydroelectric power industry. Indian summer monsoon (ISM) rainfall (ISMR) is associated with four different phases viz. onset, active, break and withdrawal phase of monsoon. The onset phase implies the commencement of the monsoon experience over the Indian region which is well recognized with distinct changes in large scale circulation and rainfall distribution over the Indian subcontinent and adjacent oceanic region. This includes the northward displacement of upper tropospheric westerly flow to the north of Himalayas, and establishment of upper tropical easterly jet (TEJ) stream (Koteswaram 1958) and the lower tropospheric westerly jet (Somali jet) over the Arabian Sea (Findlater 1969). Progress of monsoon onset is associated with a broad sector of convection and development of low level jet (LLJ) and has examined by Joseph et al. (2006). Based on the state of atmosphere several studies have considered by the climate scientists to define monsoon (Bhatla and Chattopadhyay 1999; Raju et al. 2005, 2007; Bhatla et al. 2016a). Joseph et al. (2009) proposed that the zonal wind at 850 hPa level can be used as a parameter to fairly determine the monsoon onset. The dense rain gauge rainfall network was utilized as an objective criterion for the onset date of ISM by Ananthakrishnan and Soman (1988). Puranik et al. (2013) were introduced an index to identify the onset of southwest monsoon over Kerala, emerged

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with outgoing long-wave radiation (OLR) and averaged kinetic energy.

During recent decades, regional climate model (RCM) becomes extensively useful to study the climate simulation over different Coordinated Regional climate Downscaling Experiment (CORDEX) domain. Raju et al. (2015) has revealed the better simulation of summer monsoon characteristics by regional climate model version 4.3 by ICTP (RegCM-4.3) with the combination of the mixed convective parameterization scheme (CPS) over South Asia CORDEX domain. The arrival of monsoon onset over the Kerala coast is very important for the seasonal rainfall. Patwardhan et al. (2014); Bhatla et al. (2016b) have identified the skill of RegCM to capture the onset phase characteristic of ISMR. Bhatla and Ghosh (2015), Ghosh et al. (2018), Bhatla et al. (2018), have contributed their significant contribution on intra-seasonal and interannual monsoon variability using RegCM. It has to be noted that Indian summer monsoon onset phase is proficient compliantly simulated through RCM studied by Lucas-Picher et al. (2011). Ashfaq et al. (2009) have shown with a nested RegCM that enhanced greenhouse forcing results in overall suppression of summer precipitation which causes a delay in monsoon onset and an increase in the occurrence of monsoon break periods. The role of surface heat fluxes and variation in meteorological field during the onset phase of summer monsoon studied by Bhatla et al. (2016c). The onset over Kerala has been experienced due to SST anomalies of Indian Ocean and Pacific Ocean examined by Joseph et al. (1994). The use of global SST field for long-lead prediction of ISMR was carried out by Sahai et al. (2003). It was studied that earliest transition feature of Asian summer monsoon atmospheric circulation, remarkable convection related to thermal response of SST of Bay of Bengal (Hsu et al. 1999). Ghosh et al. (2018) have extensively studied on the RegCM dependency with different SST forcing on the mixed scheme of RegCM for simulating the phases of monsoon.

The aim of the present study is to find the appropriate CPS among six (Emanuel, Kuo, Grell, Tiedtke, Mix98 and Mix99) of RegCM-4.3 for better simulating onset date and associated spatial transition features of atmosphere during onset phase over

Kerala using criteria given by India Meteorological Department (IMD) (Pai and Rajeevan 2007). Further, the examination of the impact of different SSTs forcing to simulate the onset phase has also been carried out.

2. Data and Methodology

2.1. Description of Model

In this study, the RegCM-4.3 is used to study the performance of different convection schemes to simulate/predict onset phase of ISMR. The initial and lateral boundary forcing is derived from 6 hourly fields of ERA Interim (EIN15) reanalysis provided with a horizontal grid of $1.5^{\circ} \times 1.5^{\circ}$ and 37 vertical levels. The land surface parameterization has been adopted from Biosphere–Atmosphere Scheme (BATS) (Dickinson et al. 1989) and planetary boundary layer parameterization is given by Holtslag (Holtslag et al. 1990). In RegCM-4.3, there are four CPS, namely Kuo, Tiedtke, Emanuel and Grell; with two mixed convection schemes Mix98 (Grell over ocean and Emanuel over land) and Mix99 (Grell over land and Emanuel over ocean). Each experiment has been set up over the domain 20°S to 50°N and 10°E to 130°E from 1st May to 30th September for each year during time period 2001–2010 with 50 km horizontal grid spacing.

2.2. Experiment Design

First, evaluation of monsoon onset date over Kerala using six CPS of RegCM-4.3 has been carried out for the period of 2001–2010 by considering IMD onset criteria (Pai and Rajeevan 2007). The first criterion is that 2.5 mm or more rainfall for minimum two consecutive days after 10th of May should be reported over 60% station. The stations are Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Alapuzha, Kottayam, Kochi, Thrissur, Kozhikode, Thalassary, Cannur, Kasargode and Mangalore. In the second criteria, the depth of westerlies should be maintained up to 600 hPa level over the region 0°–10° N and 55°–80° E. The speed of zonal wind should be between 15–20 knots at 925 hPa levels over the

region 5°–10°N and 70°–80° E which is the third criteria. In the fourth criteria, the OLR should have to be less than 200 W/m². For this criterion, we have considered the mode-derived OLR instead of INSAT OLR over the considered region.

Second, the effect of thermal response over onset phase has been examined using two different types of sea surface temperature (SST) forcing i.e., ERSST (6 hourly with resolution of 1.5° × 1.5° from ECMWF) and optimum interpolation sea surface temperature in weekly pattern (OI_WK SST). Atmospheric circulation features such as wind and mean sea level pressure (MSLP) has been studied using two different types of SST forcing for 5 days before and after the onset date. These circulation features are compared with wind and MSLP of National Centers for Environmental Prediction (NCEP) and EIN15, respectively. For depth analysis, northward propagation of convection (OLR) and wind pattern have been examined with two different SST forcing and compared with EIN15 and National Oceanic and Atmospheric Administration (NOAA) for wind and OLR, respectively.

3. Results and Discussion

The onset of the ISM over Kerala is characterized by commencement of rainfall along with abrupt changes of LLJ and convection over large area. The present study defines the monsoon onset on the basis of rainfall, depth of westerly, speed of zonal wind and OLR criteria using RegCM. The suitable scheme out of six CPSs have been considered to simulate the onset dates over Kerala during 2001–2010.

3.1. Monsoon Onset Date Simulation Using Different Convective Schemes

The simulated onset date for each year during 2001–2010 over Kerala using six CPSs of RegCM-4.3 (i.e., Kuo, Grell, Emanuel, Tiedtke, Mix98 and Mix99) are shown in Table 1 along with actual onset date given by IMD. All five schemes such as Kuo, Grell, Emanuel, Tiedtke and Mix99 have been considered for the further study except one mixed convection scheme (Mix98) which is unable to

simulate the onset dates during year 2001–2010. In 2001, three schemes of RegCM-4.3 (Tiedtke, Emanuel and Mix99) are able to simulate the onset date. The Tiedtke and Mix99 are shown less deviation from actual onset date which showed 1 day deviation from the actual onset date, while Mix99 scheme showed 3 days early onset prior to actual onset date. However, the Emanuel scheme simulates the monsoon onset date 2 days prior to the actual onset. In the year 2002, wide range of deviation has been observed in all schemes of RegCM-4.3 (± 10 days from actual onset date). In India, year 2002 was severe drought which was associated with strong ENSO event. It might be a reason behind strong deviation observed in onset date prediction/ simulation by RegCM. During 2003, all the CPSs of RegCM-4.3 are able to simulate onset date. For Tiedtke and Mix99 scheme, deviation of onset date has been simulated 1 day and 4 days earlier than actual. This year deviation of onset date obtained 6 and 5 days early to actual onset date for Emanuel and Kuo scheme. Grell scheme simulates onset date for year 2003 is 8 days before the actual onset date. Further, in 2004, two schemes of RegCM-4.3 i.e., Mix99 and Emanuel show slight deviation in simulated onset dates from actual onset date. Whereas other two schemes such as Tiedtke and Kuo are not able to simulate onset date closely to actual onset date (i.e., 18 days after the onset date). The year 2004 was a dry monsoon year hence model simulation effected by drought condition. The onset date identified with the Mix99, Kuo and Tiedtke scheme have shown less departure from actual onset dates. The Mix99 and the Kuo scheme have simulated onset date with 2 and 4 days after the actual onset date, respectively, while the Tiedtke scheme has observed 2 days prior to the actual onset. The Emanuel scheme in year 2005 shows 8 days deviation to the actual onset date.

During 2006, all the CPSs (Mix99, Emanuel and Tiedtke schemes) have simulated the monsoon onset within 2 days from actual onset date except Kuo scheme. During 2007, The Tiedtke and the Emanuel scheme have simulated onset date with deviation of 2 days after actual onset. In addition, a large deviation in onset date has been observed in Mix99 performance. In the year 2008, the Mix99 scheme shows better results than the Tiedtke and

Table 1

Onset dates simulated by six convection schemes and IMD onset date

Year	Actual IMD	Mix99	Mix98	Emanuel	Kuo	Grell	Tiedtke
2001	23 M	20 M	–	21 M	–	–	24 M
2002	29 M	17 M	–	18 M	22 J	–	20 M
2003	08 J	04 J	–	02 J	03 J	31 M	07 J
2004	18 M	20 M	–	19 M	06 J	–	05 J
2005	05 J	07 J	–	13 J	09 J	–	02 J
2006	26 M	25 M	–	24 M	19 J	–	24 M
2007	28 M	17 J	–	30 M	–	–	30 M
2008	31 M	31 M	–	24 M	–	–	22 M
2009	23 M	10 J	–	09 J	–	–	26 M
2010	31 M	19 M	–	21 M	–	–	20 M

M May, *J* June

Emanuel scheme. The onset date simulated by Mix99 has captured same as actual onset date. The Tiedtke scheme simulates onset date of 9 days before to actual onset date. In addition, in this year, simulation of onset date by Emanuel scheme has been identified as 7 days before actual onset date. During the year 2009, simulated onset date observed 2 days after the actual onset date for Tiedtke scheme. While Emanuel and Kuo scheme shows a large deviation in capturing onset date whereas Mix99 was not able to simulate the onset dates in the year of 2009. All schemes are showing a large deviation in simulating onset date over Kerala from actual onset date in the year 2010. The above analysis shows that the Tiedtke and the Mix99 schemes of RegCM-4.3 are simulating the onset date very well over Kerala. In addition, it has been noted that out of 10 years, for 6 years (about 60% of cases) the onset date simulation is showing less deviation and within ± 5 days for the Tiedtke scheme from the actual monsoon onset date.

3.2. Monsoon Onset Date Simulation Using Different SST Forcing

Further, the responses of different SSTs forcing (OI_WK SST & ERSST) using the Tiedtke scheme of RegCM-4.3 to simulate onset date are shown in Table 2. This table clearly shows that the Tiedtke convection scheme captured the onset date very well in correspondence to the actual onset date in the year 2001 using two SSTs OI_WK and ERSST forcing i.e.

24 May (+1 day deviation) and 22 May (− 1 day deviation), respectively. During the year 2002, the onset date simulation shows much deviation for both SSTs forcing i.e., ± 10 days from actual monsoon onset date. The response of ERSST forcing on Tiedtke simulation is insufficient to simulate the onset in the year 2003, it was 6 days after the actual onset date. On the other hand using OI_WK SST forcing in RegCM, model is able to simulate onset on 7 June, one day before actual monsoon onset date. In the year 2004, again performance of the model to capture the onset date was poor due to prevailing drought condition. The Tiedtke scheme shows monsoon onset on 5 June and 6 June with OI_WK SST and ERSST forcing, respectively, where the actual monsoon onset date was observed on 18 May. According to the actual onset date in the year of 2005, onset date deviation simulated by the model based on OI_WK SST (− 3 days deviation) and ERSST (+ 4 days deviation). In the year 2006, model simulated same onset date, i.e., 24 May (− 2 days deviation from actual onset date) using both types of SST forcing. During the year 2007, Tiedtke scheme well simulates using OI_WK SST forcing onset date on 30 May as compared to actual onset on 28 May. On the other hand, simulated monsoon onset has been observed before 11 days to the actual onset date with ERSST forcing. Monsoon onset date was not perfectly captured by the Tiedtke model scheme either with ERSST or OI_WK SST, i.e., 23 May and 22 May as compared to actual onset date (31

Table 2

Onset date simulated using Tiedtke scheme with different types of SST forcing

Year	IMD	Tiedtke OI_WK	Tiedtke ERSST
2001	23 M	24 M	22 M
2002	29 M	20 M	19 M
2003	08 J	07 J	14 J
2004	18 M	05 J	06 J
2005	05 J	02 J	09 J
2006	26 M	24 M	24 M
2007	28 M	30 M	17 M
2008	31 M	22 M	23 M
2009	23 M	26 M	28 M
2010	31 M	20 M	26 M

M May, *J* June

May) in the year 2008. Model using OI_WK SST forcing shows better simulation of the onset date rather than the ERSST, i.e., 26 May which is 3 days after actual onset in the year 2009. In the year 2010, performance of model scheme in capturing the onset date was not good using both types of SST (OI_WK SST and ERSST) forcing. Overall analysis indicates that performance of the model RegCM-4.3 using the Tiedtke scheme for onset date simulation with OI_WK SST forcing shows less deviation from actual onset date than ERSST forcing.

3.3. Circulation Features Associated with Monsoon Onset

This section describes the response of model using the Tiedtke convection scheme with OI_WK SST and ERSST forcing for the composite MSLP and their comparison with NCEP MSLP during onset are shown in Fig. 1a–c, respectively. It is observed that the distribution of MSLP shows little difference between simulated using OI_WK SST (Fig. 1a) and ERSST (Fig. 1b) forcing with NCEP (Fig. 1c). A low-pressure area observed over the Tibetan plateau and having magnitude of 970 hPa during onset period. Further, over the north India and most part of the Indo-Gangetic plain, MSLP lies in between 990 to 995 hPa level (Fig. 1a). In addition, similar pattern is found with ERSST forcing (Fig. 1b). Figure 1c shows that the model has not captured low pressure over the Tibetan plateau. However, the

low-pressure area has been observed from Punjab to east Uttar Pradesh. At the same time of onset, pattern of MSLP by NCEP is well matched with pattern of MSLP by the OI_WK SST as well as ERSST forcing over Peninsular India, west central and adjoining area of western and eastern costal area.

Figure 1d–f illustrate the wind at 850 hPa level with two types of SST forcing and compared with EIN15, respectively. The circulation features at 850 hPa level with two SST forcing shows that the Somali Jet is reasonably well simulated and comparable to wind pattern shown in EIN15(Fig. 1f). Findlater (1969) and Rao (1976) described that LLJ was related to onset of monsoon and cross-equatorial flow is the consequence of LLJ. The cross-equatorial flow has a role to bring moisture from equatorial region to Indian subcontinent. It is clearly seen from Fig. 1d that the core portion of Jet has covered wind speed (above 15 knot) and extends up to the west coast and the southern parts of India. Significant wind (more than 15 knot) is present over Northeast region and the Bay of Bengal. Stronger wind is observed over Northwest and adjacent Pakistan. The ERSST forcing wind speed more than 15 knot during onset is observed over the Arabian Sea, but 12–15 knot wind speed are recorded over the Bay of Bengal (Fig. 1e). Whereas larger than 15 knot wind speed exhibits over northeast region. Figure 1f also shows the wind pattern of EIN15 at 850 hPa and almost fitted to both simulations with different SST forcing. Whatever the contrast exists between two simulations for wind
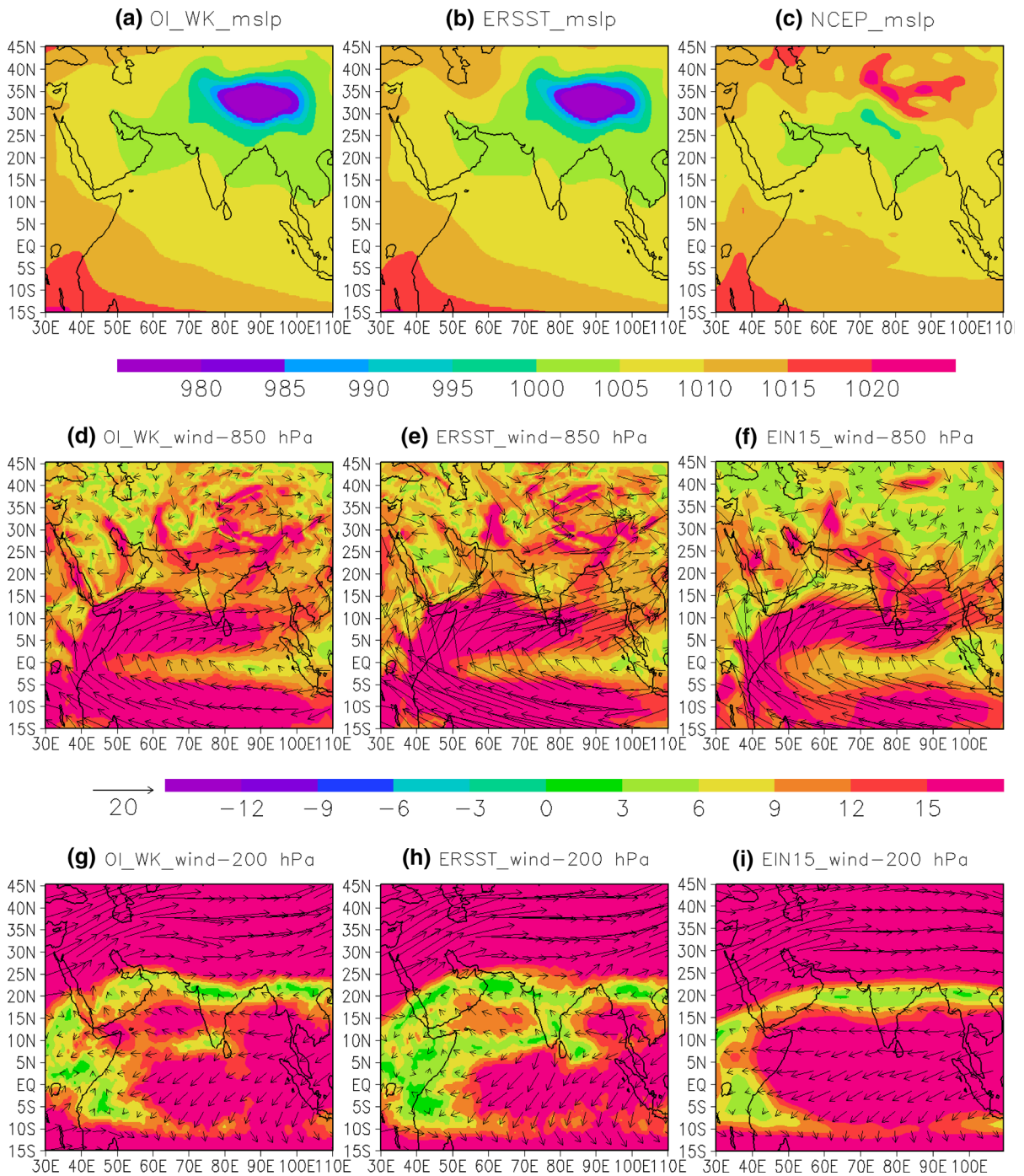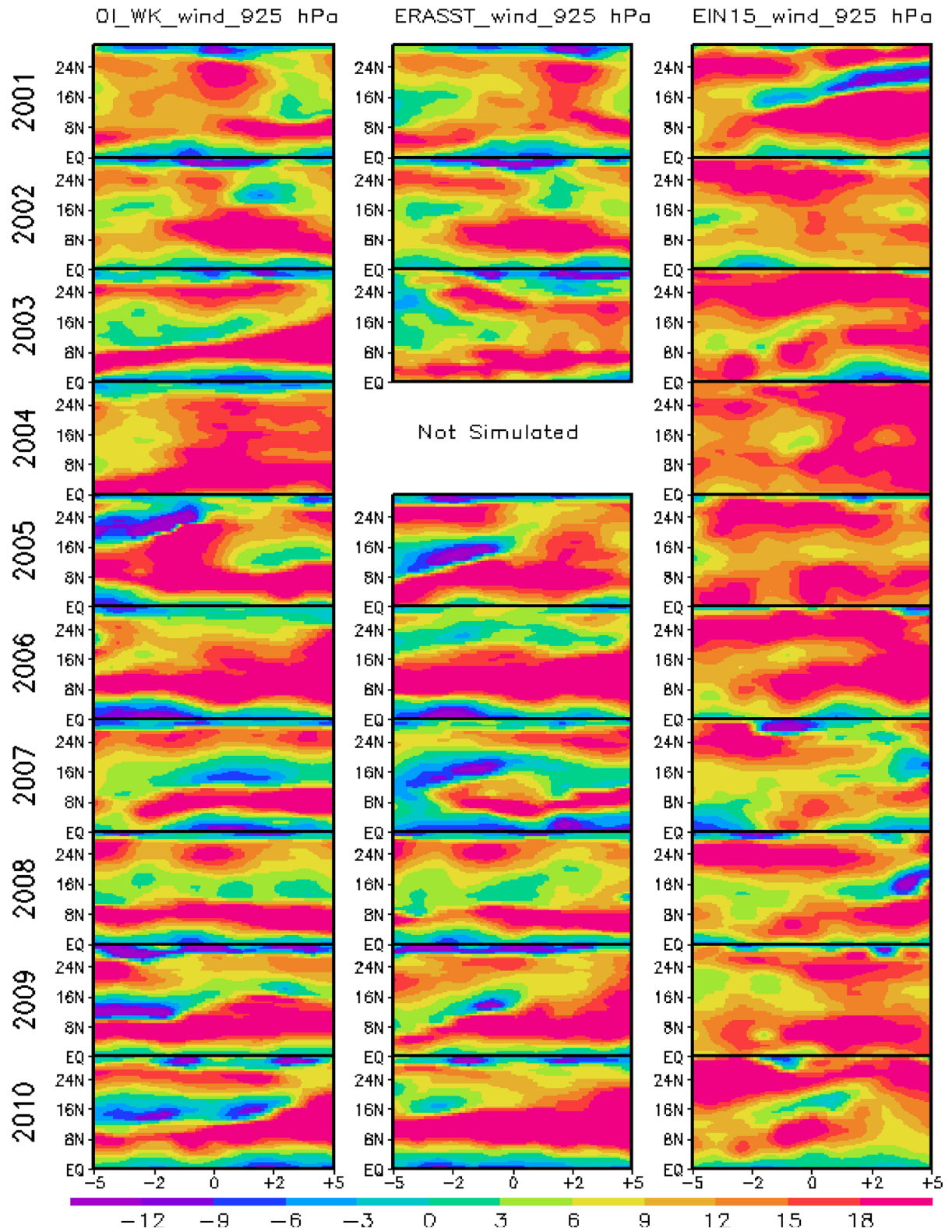
Figure 1
a–i Composite spatial variation of MSLP (hPa) (**a**–**c**), wind (knot) at 850 hPa (**d**–**f**) and 200 hPa (**g**–**i**) over South Asia CORDEX domain. Where first two column stands for Tiedtke-simulated onset date with the OI_WK SST, ERSST forcing and the third column stands for reanalysis data distribution on the IMD declared onset date

pattern, OI_WK SST forcing shows that after crossing the southern tip of peninsula, it is extended over large area with wind speed of more than 15 knot than the ERSST forcing. With ERSST forcing less wind speed has been observed than OI_WK SST over the west central region.

The wind circulation pattern at 200 hPa is depicted in Fig. 1g–i. Wind distribution with OI_WK SST forcing shows westerly subtropical jet extends around from 22°N to 45°N with wind speed more than 15 knot. Model simulation with ERSST forcing is able to simulate similar pattern of wind at 200 hPa but westerly subtropical jet is formed beyond 25°N and it began to strengthen toward northward. While EIN15 produced westerly jet with wind speed greater than 15 knot at 20°N. Further, OI_WK SST forcing has successfully simulated the wind circulation at 200 hPa, maximum wind speed (above 15 knot) occurs over Bay of Bengal, Arabian Sea, north Indian Ocean. Whereas ERSST forcing has captured comparatively less area of the wind speed more than 15 knot. On the other hand, EIN15 reveals wind speed above 15 knot, contain massive area of easterly Jet, distribution of wind having magnitude of 15 knot or more observed over Bay of Bengal, Arabian Sea, southern tip of India and north Indian ocean. The pattern of wind speed with OI_WKSST forcing is more close to reanalysis EIN15 wind pattern than ERSST forcing wind pattern.

The propagation of zonal wind at 925 hPa level during ± 5 days of the onset date for the individual year (2001–2010) has been simulated using the Tiedtke scheme with OI_WK SST and ERSST forcing using Hovmöller diagram over 70° E latitude (Fig. 2). Model-simulated zonal wind is compared well with observed reanalysis EIN15 wind data. The zonal wind is simulated using the Tiedtke scheme using OI _WK SST forcing at 925 hPa level during 2001 which shows a narrow strip below 8°N and intensified after the onset and showing northward propagation. Another center of higher (> 15 knot) wind speed is located between 16°N and 24°N at the time of onset. With ERSST forcing wind speed more than 15 knot have been observed after the onset date (24°N to 8°N). These simulated zonal winds have been compared with the reanalysis data of EIN15 which shows two wide ranges of wind field (greater

than 15 Knot) located around 20°–28°N and gradually extending towards northward. During the year 2002, model-simulated wind circulations (at 925 hPa) show opposite circulation pattern as observed from reanalysis wind (EIN15). In the year 2003, OI_WK SST forcing and reanalyzed EIN15 wind pattern shows similar northward propagated wind with speed more than 15 knot at 925 hPa (between 6°N and 20°N), While ERSST showed scattered wind pattern. During 2004, model-simulated and -observed wind circulation shows abnormal shifting of wind towards north direction with the magnitude of more than 15 knot. The circulation pattern with ERSST forcing is unable to simulate in the year 2004. During the year 2005, the OI_WK SST and ERSST forcing shows a northward propagating wind band having more than 15 knot speed between 8°N and 16°N and extended between 5 days before and after the onset. The model simulated wind pattern is overestimating the observed wind circulation of EIN15. In the year 2006, it is observed that the wind began to build up along 8°N showing the same pattern with OI_WK SST and ERSST forcing model simulations. The wind speed gets intensified up to 7°N to 20°N and shows northward propagation. The reanalyzed model simulation showing two bands: first is along 16°N–26°N and second one originates 2 days before onset date and expands between 8°N and 26°N. A narrow atmospheric wind flow was observed before 3 days of onset in both the model simulations while reanalyzed model shows weak wind circulation after the commencement of onset during 2007. In 2008, both the model and observed winds shows a narrow strip of wind circulation along 8°N in the northward direction. During 2009, a strong westerly wind began to build up around 8°N with OI_WK SST model simulation and is showing upward swelling after the date of onset. The narrow wind band starting along 8°N and clearly shows a northward propagation. Its comparison with reanalysis data shows that model overestimates the wind circulation pattern along 8°N before onset date. Two parallel westerly wind flows (more than 15 knot) are observed along 8°N and 24°N during 2010. The wind flow gets intensified and clearly shows northward propagation covering up to 6°N–20°N with OI_WK SST forcing model simulation. Similar pattern of wind circulation is observed

with ERSST forcing but covered more area than OI_WK SST simulation. Both model simulated westerlies wind circulation overestimates the reanalysis wind circulation. The reanalyzed EIN15 shows single cell (speed more than 15 knot) along 8° N. Overall observation shows propagation of wind field at 925 hPa level during 5 days before and after the onset simulated by OI_WK and ERSST forcing with reanalysis during the time period of 2001–2010 and depicts that the onset is generally associated with northward propagation of subtropical westerly jet stream. However, wind direction and spatial flows simulated by model overestimate than reanalysis wind. The wind circulation using Tiedtke scheme with OI_WK SST forcing is comparatively similar with reanalyzed model (EIN15).

The OLR for 5 days prior to and after the onset is illustrated in Fig. 3 using OI_WK SST and ERSST forcing along with reanalyzed NOAA OLR for individual years (2001-2010) with the help of Hovmöller diagram. During 2001, using OI_WK SST forcing, the model simulation shows strong OLR of less than 180 W/m^2 for 2 days before onset along 6°N latitude and extends northward. A continuous convective band has been observed with ERSST forcing which extended from the equator to 6°N and equator to 14°N latitude. On other hand, NOAA OLR shows strong and wide convective activity (less than 200 W/m^2) from equator, further its intensity decreased after commencement of onset. With OI_WK and ERSST forcing the model simulation in year 2002, the convection cell appears along 8° N before 3 days of onset. Whereas reanalysis OLR has shown a continuous convection pattern along the equator which is less than 200 W/m^2. However, OI_WK is showing the similar pattern of strong convection band as shown in NOAA OLR but both

SST forcing model simulations has underestimated the convection pattern than reanalysis. In the year 2003, with OI_WK SST forcing the model simulation shows a narrow convection band starting before 5 days of onset which extends from equator to 20°N latitude. The convection band is strong (less than 180 W/m^2) and continuous unlike with ERSST forcing. NOAA OLR shows the significant similar northward propagated convection pattern as compared with OI_WK SST forcing model simulation. However, NOAA OLR shows a broad band of convection along the equator having intensity less than 200 W/m^2. The simulation has not been captured by ERSST forcing model simulation in the year of 2004 and scattered convection was observed by OI_WK SST forcing. In the year 2005, both the SST forcing along with reanalyzed shows similar atmospheric convection pattern. A parallel convection is observed extending from 8°N to 12°N with OI_WK forcing simulation for the year 2006. Whereas ERSST forcing shows a discontinuous convection band which spreads 5 days before and after the onset. On other hand, NOAA OLR shows a small band of convection along 8°N then as we approach onset day rapid transition has taken place. After 5 days of onset, convection band which propagates towards the north, get extended from 8°N to 24°N. During 2007, both the SST forcing simulates a discontinuous convection pattern before and after 5 days of onset. Convection pattern is more dispersed in OI_WK forcing model simulation than the ERSST forcing. Whereas a significant northward propagation with uniform strong convection band originates two days before onset over latitudinal belt. OI_WK forcing model simulation show the strong convection extending from the equator to 12° N latitude in the year of 2008. Whereas ERSST forcing and reanalyzed OLR shows continuous convection band before 3 days of onset and extended up to five days of onset. During 2009, the strong convection pattern shows the northward propagation with OI_WK SST forcing and similar pattern is observed with ERSST forcing but its intensity gets reduced after 2 days of onset. While both the forcings have overestimated the convection (OLR) pattern than the reanalysis data. During 2010, discontinuous pattern of strong convection field (less than 180 W/m^2) has been observed in both the SST
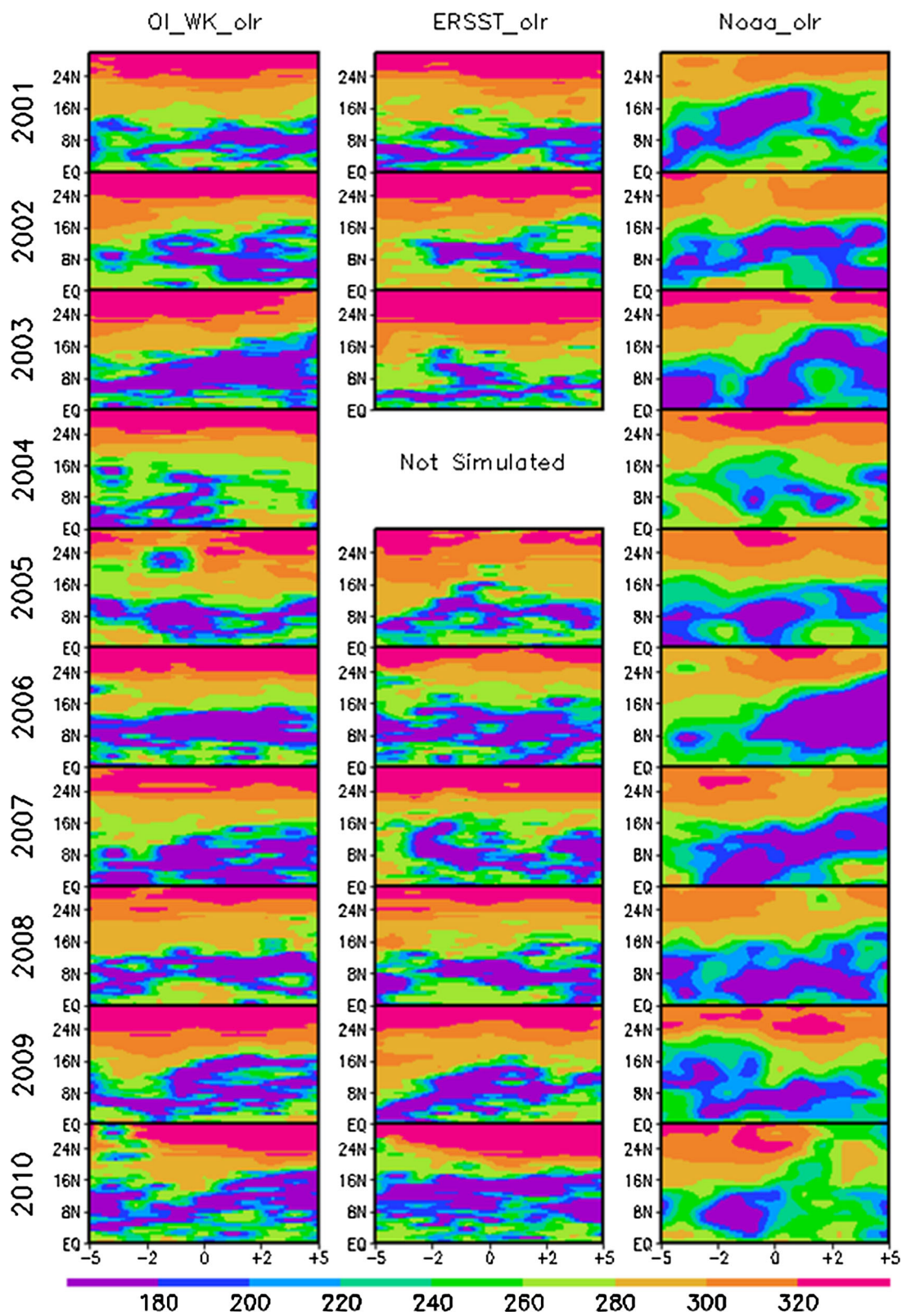
◄Figure 3
Hovmöller diagram of OLR (W m⁻²) from 5 days before to 5 days after the onset date. Where first column indicates the Tiedtke-simulated wind speed with OI_WK SST forcing and second column represents ERSST-forced Tiedtke simulation and has been compared with NOAA OLR reanalysis wind (Third column) during 2001–2010. Where 70°E longitude has been taken as centre

forcing model simulations. However, a single strong convection cell has been observed before 3 days of onset using NOAA OLR. Both the SST forcing model simulation overestimates the OLR distribution during ± 5 days of onset.

4. Conclusions

The broad conclusion of the study is that the Tiedtke and Mix99 convective schemes are more appropriate to simulate the monsoon onset date as compared to other schemes. The shallow convection and entrainment of Tiedtke scheme helps to better simulation of onset date. The performances of all CPS are more or less dependent upon the spatial variation of region. Further, two types of SST forcings (ERSST and OI_WK SST) have been used as lower boundary condition for the Tiedtke scheme for simulation purpose. The results reflect that Tiedtke, Mix99 and Emanuel convective schemes are satisfying the IMD onset criteria. Our study supports Tiedtke CPS for its capability in organizing the good hits of Indian summer monsoon onset (Bao, 2013) with a deviation of ± 5 days during 2001–2010 period, and we conclude that the Tiedtke convection scheme is useful for the simulation of monsoon onset over Kerala.

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