Outstanding Rainfall events of Boreal Fall Monsoon Season of Southern Peninsular India associated with the Intensification of Negative Indian Ocean Dipole

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Abstract - The study area southern peninsular India lying between 8◦N to 13◦N latitude and 70◦ E to 80◦E longitudes enjoys both the summer and winter rain fall of Indian monsoon. The stretching of Western Ghats blocking the cross equatorial flow of south west monsoon wind creating rain shadow region of Tamil Nadu to the east coast of the region, the peninsular shape of the area, position of the land in between the dipole, proximity of Walker circulation cell to the east of the study area altogether donate an exclusive variability to the rainfall pattern to southern peninsular India compared to the rest of the country. Any major oscillations taking place in the surrounding sea can imbibe its own impact on the rhythm of rain happening in the area. This study was an attempt to understand the influence of recently found Indian Ocean dipole on boreal fall monsoon of SP. But in the course of analysis it became obvious that Indian Ocean Dipole can affect the course of rain of the area and the intensity of rain can affect the Indian Ocean Dipole vice-versa. In other words Indian Ocean Dipole and boreal fall of SP are found to be complementing each other. Hence the matter of interest of this article is simply confined to the relation between flooding boreal fall monsoon years of southern peninsular India and the subsequent state of Indian Ocean Dipole. A close analysis of various air-sea parameters during all the flooding boreal fall monsoon years of SP for last fifty year per Indian Ocean Dipole make one believe that the strong convection and associated atmospheric circulation during short living excess rainfall events work as a triggering factor for the ocean atmosphere interaction lead to the negative intensification of Indian Ocean Dipole. Another observation is that the interaction with seasonal mean boreal fall monsoon rainfall imposes a biennial tendency in the Indian Ocean Dipole. Cloud cover, surface evaporation and ocean dynamical adjustments are the three vital components of any ocean atmospheric feedback system.

Wind Evaporation Sea surface temperature (WES) feedback system plays an important role in the ocean atmospheric coupling of the region. It can lead to equatorial flow of flux in case mean resultant easterly is prevailing closer to the equator and on the other hand if a resultant westerly is persisting near to the equator it tends to drive off the flux towards the poles. The excess precipitation of the flooding boreal season (October to December) cools down the surrounding seas giving rise to westerly wind anomaly which drives the warm water off to the east which gradually accumulates near to Indonesian region. The increasing wind speed promotes further evaporation and the additional pumping of equatorial warm water into it gives an SST feed back to the process. Continuous shifting of warm water from the west give rise to upwelling of cold water in the west giving rise to the formation of a cool pool on that side. The warming of the Indonesian region and the simultaneous cooling of the west Indian ocean due to upwelling lead to negative Indian Ocean Dipole. Interaction of ocean front and atmosphere contribute to negative feedback to ocean thermodynamics. Warmer flank of a front increase wind speed and sea air temperature intensify turbulent heat flux from ocean finally damping out existing SST perturbation. The circulation pattern during the extreme boreal fall events of SP also are more conducive for the sustenance and intensification of negative Indian Ocean Dipole or nullifying an already existing positive Indian Ocean Dipole.

Keywords - Boreal fall, Dipole mode, Indian Ocean Dipole, North east monsoon, Warm pool, Wind Evaporation feedback system,

Introduction

During boreal fall eastern side of southern peninsular India receives about 68% of its annual mean rainfall and the western edge of SP receives only 21% of the annual mean rainfall. This is an attempt to understand the influence of recently found Indian Ocean Dipole of Indian Ocean on winter rain fall of southern peninsular India. Indian Ocean Dipole is a coupled ocean atmosphere bonding that can imbibe direct variation to the intra-seasonal and inter-annual climatic condition of the place. The reversing equatorial zonal winds associated with SST anomaly along equatorial Indian Ocean decides and control the mode of Indian Ocean Dipole and vice-versa. During the positive phase of Indian Ocean Dipole the eastern side of Indian Ocean is found to be cooler compared to the west and hence a zone of high temperature gradients rise is expected at the east. Naturally it results in dominant zonal wind swing in Indian Ocean from westerly to easterly. Boreal summer monsoon and boreal winter monsoon display different identity to the basin wide warm mode of Indian Ocean SST.

Most of the climatic variability study were concentrated on the ENSO and its associated basin wide warm mode of Indian Ocean SST until the end of 20 century when Webster et al put forward the suggestion of independent inter annual mode of Indian Ocean SST. Indian Ocean Dipole is an ocean– atmosphere coupled phenomena in Indian Ocean with anomalous cooling of SST in the southeastern equatorial Indian Ocean and a warming in the western equatorial Indian Ocean (Yamagata et al., 2003). Even though it is well documented that the positive phase of Indian Ocean Dipole mode can cause excess rainfall over

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East Africa and drought over Indonesia its influence on India and Sri Lanka is vague due to the position of these region in the middle of the dipole. Later studies revealed that the large scale convection due to warm SST anomaly in the Arabian Sea during positive Indian Ocean Dipole event is enhancing boreal fall monsoon rainfall over South East Asia and Sri Lanka.

The existence of dipole in the Indian Ocean can be confirmed on removal of ENSO effect which is quite unseen both in southern oscillation of the Pacific and in the North Atlantic oscillation. The zonal Walker circulation is the atmospheric bridge that ties up Indian Ocean Dipole with ENSO (Yamagata et al 2002). The intrusion of ENSO signals into eastern Indian Ocean near west coast of Australia during boreal fall is known as Clarke Meyer's Effect [*Hendon*, 2003; *Yamagata*, 2003]. This enhances ENSO Indian Ocean Dipole relation during boreal fall. It is claimed that an anomalous walker cell evolves only in Indian Ocean during pure Indian Ocean Dipole (Yamagata et al 2003). During Indian Ocean Dipole period the walker circulation cell of Indian Ocean is more dominant than its counterpart found in Pacific Ocean. Changes in walker circulation associated with ENSO can control Indian Ocean Dipole evolution through monsoon circulation. And of course Indian Ocean Dipole can modulate Darwin's pressure variability and vice versa. Very recent analysis of (George G 2011) suggest that the strength index of boreal fall monsoon is strongly influenced by the sea level pressure difference between west Pacific region and West Indian Ocean which forms an abnormal walker circulation with subsidence over west Pacific off Philippines and convection over north west side of Indian Ocean. The intensity of this anomalous walker circulation is capable of explaining the influence of ENSO and Indian Ocean Dipole on the strength of boreal fall monsoon during the analysis period of 50 years.

The winter storm track activity during austral winter of SH is heavily manipulated by the Indian Ocean Dipole induced circulation anomaly. Both Indian Ocean Dipole and ENSO can generate anomalous westerly in SH. Positive Indian Ocean Dipole and El Nino can reduce winter precipitation of many parts of South Australia and New Zealand. Sub Tropical Jet Stream strengthens during El Nino reducing storm track activity of South Pacific and South of Australia. Storm track carry within big synoptic scale eddies that can transport angular momentum, sensible heat and moisture which can modify the general circulation and thereby the weather of the place. Strong Sub Tropical Jet stream and intense ocean front along Antarctic Circumpolar current are two major factors that can detect the storm track of South pacific. The ENSO feedback forcing on SH storm track is mainly positive in Sub tropical Indian Ocean and widely negative over South Indian Ocean, New Zealand and South America. Since the Indian Ocean Dipole and ENSO can control the austral storm tack in winter the inter-annual variability of rainfall of the region can also be decided by the same.

Indian Ocean Dipole index can be derived from the disparities of various air sea parameters like SST anomaly, Zonal wind anomaly, Sea surface height anomaly, Sea level anomaly and OLR (outgoing long wave radiation) anomaly. Because of the smart relation between surface signals and subsurface signals during Indian Ocean Dipole the index calculation is done by taking the area average of heat anomalies of 125 m. Dipole Mode Index is defined as the SST anomaly between western (50°E–70°E, 10°S–10°N) and eastern (90°E–110°E, 10°S–Eq) side of tropical Indian Ocean. This anomaly keeps uniform polarity inter annually keeping in pace with ENSO mode (Cadet 1985). The maximum correlation of DMI is with the SST of Nino – 3

major El Nino events show that changes occur not only to local Hadley circulation but also to Walker circulation during such events. During 1997 El Nino the strong zonal gradient found in the velocity potential over the latitude of Indonesia and eastern Indian Ocean can be considered as an indicative to changes happened to the local Hadley cell. This circulation is distinct from the mean reverse Hadley circulation or lateral monsoon circulation which has its descending branch over Mascarene High. Changes in the local Hadley circulation may play an important factor in affecting the inter-annual variability of Asian summer monsoon, the synoptic and sub-seasonal behavior of the Indian summer monsoon during 1997 (Webster and Yang (1992).

The surface fluxes are identified as the main factor that combines ENSO and Indian Ocean Dipole. El Nino and La Nina are often found followed with reduced and enhanced phases of cloud cover respectively and corresponding increased and decreased solar radiation. Enhancement and reduction of wind speed is another major factor influencing the surface latent flux. Indian Ocean Dipole is phase locked to the seasonal cycle in Indian Ocean and the peak strength of its anomalies occurs during boreal fall. During the positive phase of Indian Ocean Dipole converging wind pattern, transports the moisture from Southeast Indian Ocean and Bay of Bengal over southern peninsular India. In contrast negative phase reveals wind diverging from south India result in deficient boreal fall.

The connection of Indian Ocean region to ENSO appears to be largely through the atmosphere via shifts in Walker circulation and associated flux and wind forced evaporative system. (Lau 2003) The basin wide warming in the tropical Indian Ocean is possible by anomalous surface heating flux associated with the descending branch of anomalous walker circulation (Jing 2010). Indian Ocean Dipole can induce large convective adiabatic heating anomalies and can effect equatorial walker circulation and ENSO evolution (Yamagata 2003). However anomalous events happening in the Indian Ocean and adjacent areas can result in the amplification of coupled Indian Ocean mode. Needless to say two main external or internal forces that can modify the natural mode of Indian Ocean are wind and precipitation. Especially the processes that initialize the positive feedback to Indian Ocean Dipole can be wind driven flux or increased convectional processes, and probably the negative feedback is the excess precipitation. The dipole mode of SST can be traced in the subsurface level of Indian Ocean as well as to the atmospheric temperature. A study of surface and subsurface signals of dipole season in the western and eastern side of Indian Ocean display reversing relation with corresponding and close coupling with equatorial wind anomalies (Yamagata 2002).The evolution of major subsurface dipole is controlled by equatorial ocean dynamics controlled by zonal wind This proves that dominant mode of subsurface variability that is coupled with surface wind provides necessary feed back to SST during Indian Ocean Dipole events (Yamagata et al 2003b). It can be assumed that the subsurface dipole is providing the delayed time that is required for the reversal of the surface dipole. The turnabout of subsurface dipole leads to quasi biennial oscillation found in Indian Ocean and in turn affects the QBO of Pacific Ocean also. The influence of Indian Ocean Dipole is not only limited to Indian Ocean, it remain worldwide because of its influence in the atmospheric circulation (Yamagata, 2003b). For example, the Indian Ocean Dipole influences the Southern Oscillation in the Pacific, rainfall variability during the Indian summer monsoon (Ashok et al., 2001), the summer climate condition in East Asia (Guan and Yamagata, 2003b; Guan et al., 2003), the African rainfall (Black et al., 2003; Clark et al., 2003; 2003b;), the Australian winter climate (Yamagata et al., 2003b). Because of the frequency of occurrence of Indian Ocean Dipole is far less and it is short lived compared to ENSO, Indian Ocean Dipole gets only second place among major worldwide oscillations (Yamagata 20030. At times Indian Ocean Dipole are found preceded by ENSO event. But ENSO cannot be considered as the triggering mechanism for Indian Ocean Dipole genesis although it can affect the intensity of ongoing Indian Ocean Dipole both positively and negatively. Three major ENSO years (1972, 1982, 1997) were associated with major positive Indian Ocean Dipole years. Just as in the case of summer monsoon of India the correlation between Indian Ocean Dipole and ENSO undergo decadal modulation.

Objective

The occasions with excess amount of boreal fall monsoon rainfall unassociated with cyclonic activity has increased considerably in southern peninsular India. The time series analysis of boreal fall monsoon area averaged over southern peninsular India for the past four decades shows that ten peak precipitation events, evidently not coinciding with the dates of cyclonic disturbance happened in Bay of Bengal. (Table-1).The detailed analysis of those events lead to link on the developing stage of Indian Ocean Dipole Negative phase. The main objective of the study is to establish that the negative phase of Indian Ocean Dipole is triggered as well as encouraged by the excess precipitation events happening in the southern peninsular India which are not associated with cyclonic activity. First table shows years that had several showering days during winter monsoon with precipitation amount above 20mm. Ten such years marked in the first table is followed by a subsiding phase or opposite phase of Indian Ocean Dipole in the subsequent years. Prima –facie it leads one to think that the excess water discharge to the ocean can promote the reversal of positive Indian Ocean Dipole existing thereby. Further study of various air sea parameters in the surrounding area of Southern Peninsular India not only verify but also substantiate the above observations.

Data and Methodology

In this study time series analysis of boreal fall monsoon daily rainfall is done by determining strong pulses of rainfall events over southern peninsular India using daily gridded rainfall data from IMD. Excess rainfall event is defined as those events in which the area average daily rainfall of 1st of October to 31st December over the southern peninsular India exceeds 20mm which is four times above the normal seasonal daily mean. Ten such events of excess rainfall seasons are noticed within the forty year period of observation of boreal fall monsoon (Table I). The region enclosed by latitudes 8°N and 13°N and longitudes 70°E and 80°E is taken as southern peninsular India. In order to understand the reversing effect of such boosted rainfall events on Indian Ocean Dipole, changes taking place in the air sea parameters like sea level pressure, sea surface temperature and 850 h. Pa level Zonal wind are also analyzed during these events. SST, SLP, and Zonal wind at 850 h Pa were taken from NCEP/NCAR (National Centre for Environmental Prediction/National Centre for Atmospheric Research) reanalysis data downloaded from internet.

Discussion and Result

The SST based Indian Ocean Dipole Zonal Mode Index (IODZMI) shown in (Table 2) of that of all the excess precipitation events of the analyzed period is evidently favoring the idea that excess boreal fall can be a precursor to negative intensification of Indian Ocean Dipole. 1972, 1977, 1978, 1979, 1983, 1992, 1993 and 1998 all these years experienced at least few days of excessive rain in southern peninsular India during the winter period. If you get boreal fall for more than 10 days continuously in this region it is genuine to believe that it was not singled bout of rain event but a flooding year indeed. So here afterwards it is worth mentioning these years as excess boreal fall years itself rather than peak event years. In 1998 where there was two spells of remarkable excess rainfall events certainly the same year displayed the highest negative IODZMI of -1.2. This is the greatest negative peak value observed in the 40 years of analysis time. The intensity of the rainfall does play a salient role in deciding the intensity index. When the amount of rain is higher at a shorter stretch even then the chances of acquiring high negative IODZMI value is much greater than usual.

There exists specific explanation for just two occasions when IODZMI was zero and +3(Check) after the excess Boreal fall years of 1972 and 1977 respectively the rainfall burst in these two occasions happened in late, December which is not really reflected in October to December mean IODZMI as the season is over. Above all during 1972 and 1977 the daily rainfall amount increase was at a very slow pace followed by an abrupt drop in the peak.

Distribution of SLP, SST and Zonal wind anomaly during extreme rainfall events

When we consider different the contribution of different components of WES feedback system cloud SST feedback are positive or negative according to cloud type. Normally warm oceans with deep convection, the convective cloud-SST feedback is negative while that of cool subtropical oceans, the low cloud-SST feedback is positive. Coming to water vapor feedback increased SST helps ocean surface to emit more infra red radiations, but at the same time increased evaporation and the increased water particles trapped in the atmosphere favors increased downward propagation of infra red radiations. As a net effect the down flow outnumbers the outward heat radiations thereby increasing the SST. Thus water vapor feedback is the major system for inducing global warming by green house effect.

Along major ocean fronts co variability of SST, wind variations and cloud formations are omnipresent. Interaction of ocean front and atmosphere contribute to negative feedback to ocean thermodynamics. Warmer flank of a front increase wind speed and sea air temperature intensify turbulent heat flux from ocean finally damping out existing SST perturbation.

Fig-1 shows that there is a strong association between low pressure anomaly of -0.5hPa noticed all over central Indian Ocean and east Arabian Sea even five days prior to extreme rainfall events. The trough axis remains between 15◦N 65◦E and 25◦S 90◦E. On the day of copious rainfall a strong anomaly of -2.5hPa can be seen at the Arabian Sea coast. The low pressure anomaly finally gets replaced by high pressure anomaly of 0.5hPa 5 days after the peak of rainfall pulse. The weakened low pressure region shifts to northwest of Arabian Sea. This weakening of low pressure can be due to cooling of Arabian Sea. Similarly five days prior to the extreme rainfall event northern hemisphere region of Indian Ocean is found to be comparatively warmer than the northern and western regions of peninsula and Sri Lanka (George G, 2011). Here we like to point out that the circulation pattern associated with heavy boreal fall years of south Asia can amplify the prevailing weak negative phase of Indian Ocean Dipole mode, and can lead to negative intensification of Indian Ocean Dipole or nullifying the effect of pre existing positive phase of Indian Ocean Dipole. Climatology study shows that during the boreal fall north Indian Ocean is dominated with easterly Zonal wind component and equatorial Indian Ocean have a westerly corridor (George G, 2011).

It can be observed that just five days before extreme rain events a strong easterly wind burst happens over South China Sea, South of Thailand and Bay of Bengal (Fig 3). Gradually it gets strengthened up minimizing the easterly anomaly and finally a westerly mean flow gets occupied over the Indonesian region. In response to the warm pool the anomalous westerly flow in the West Indian Ocean strengthen the westerly mean flow and lead to more evaporation and hence cooling by WES feedback (Chang 2006). This anomalous westward flow brings in upwelling flow and shallows the deep temperature gradient zone in the region result in the formation of cool pool. In other words it results in the intensification of preexisting weak negative phase of IODZMI.

These phenomena give rise to zonal and cross equatorial temperature gradients within the ocean. Sea level pressure difference of Siberian high shows a short time weakening exactly at the peak precipitation date. Five days after the extreme rainfall event the easterly anomaly withdrew to Pakistan region, giving way for westerly wind anomaly in the Arabian Sea. There is a weak burst of easterly observed at equatorial central Indian Ocean. Simultaneously a zone of fresh easterly wind anomaly is developed over South China Sea and Bay of Bengal. This phenomenon eventually leads to negative intensification of Indian Ocean Dipole Mode.

The analysis of extreme rainfall event on daily basis suggests a negative intensification of IODZMI after all events. The very fifth day after extreme rainfall event shows a strong negative IODZMI of 0.60◦K in the composite. The negative IODZMI suppress rainfall by associated pressure increase and subsidence occurring over the Arabian Sea, together with it works out as a negative feedback system. Hence the duration of extreme rainfall phase often found to be less than ten days. Another observation related to this matter is the biennial tendency and positive correlation between the boreal fall seasonal mean IODZMI and SPI area average seasonal mean rainfall. The positive (negative) phase of IODZMI favors strong (weak) SPI boreal fall monsoon which in turns lead to a negative feedback for the IODZMI of the following year. The years of strong boreal fall seasonal rainfall 1972, 1977, 1978, 1987 and 1997 are followed by years of boreal fall seasonal mean negative IODZMI. 1966 and 1993 strong boreal fall monsoon years were not followed by negative IODZMI because they were already negative IODZMI years during the first half of the season it was -.3 and remained as -6 IODZMI index value until the end of the season (Table 2). So excess boreal fall over southern peninsular India gradually amplify a feeble negative Indian Ocean Dipole signal persisting in the eastern Indian Ocean into a full-fledged one not only in short time scale but also in biennial scale.

Conclusion

Strong east west asymmetry in equatorial Pacific, Walker circulation and associated easterly wind at the surface and the cold tongue in SST play the backbone for WES feedback system of the tropical oceans.

The existence of an opposite dipole of SST on either side of the equator induce pressure anomaly favoring cross equatorial wind flow that promotes easterly wind to the south and westerly to the north of the equator. Superimposed on the prevailing easterly trades, they intensify or reduce evaporative cooling and this dipole of latent heat flux anomalies acts to amplify the initial SST dipole. Philander (1994) first proposed this wind-evaporation-SST feedback (WES) feedback. WES feedback system can lead to equatorial flow of flux in case mean resultant easterly is prevailing closer to the equator and on the other hand if a resultant westerly is persisting near to the equator it tends to drive off the flux towards the poles. WES feedback is basically thermodynamic in nature and can break equatorial symmetry and can put its own signature in creating dipole pattern of coupled ocean atmospheric anomalies in the zonal direction. In WES feedback system if the coupling coefficient can overcome cooling process dipole can grow in time.

Typically, a strong Indian Ocean Dipole event begins concurrently with the commencement of the Asian summer monsoon peak during boreal fall and decays during the Asian winter monsoon. In boreal winter reversal of trade winds generally discourage the upwelling along Sumatra coast eventually leading to the termination of INOZDM. By the advent of winter the clashing wind anomalies reduces the wind speed controlling entrainment cooling and hence the turbulent heat loss from the ocean surface leading to almost absolute termination of Indian Ocean Dipole (Webster 2006).

The excess precipitation may cool the Bay of Bengal, Arabian Sea and West Indian Ocean. The westerly wind anomaly dominating in the equatorial region during the boosted rainfall event collect the warm surface water to the Indonesian region. The wind, evaporation and the SST feedback due to pumping of Equatorial water support the process. The warming of Indonesian region and cooling of West Indian Ocean due to upwelling lead to the formation of negative Indian Ocean Dipole. The heat content anomaly thus maintains the SST anomaly, in turn tied to the wind stress anomalies thereby complete the feedback loop. The circulation pattern associated with short span wide spread extreme rainfall event of South Asian boreal fall can amplify a pre-existing feeble negative Indian Ocean Dipole signal leading to negative Indian Ocean Dipole. The Intra-seasonal as well as inter-annual analysis of boreal fall monsoon also support the very same idea that most of the strong boreal fall monsoon phase is followed by a negative IODZMI (Jing, 2010). This paradigm may also help to explain the biennial oscillation observed Indian Ocean Dipole. The likelihood of lessening temperature gradients caused by enhanced boreal fall play a significant role in Indian Ocean Dipole termination has been proposed by this observation. Goodnight.

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Year	Month	Day	Rainfall Amount (mm)
1966	November	11	23
1972	December	08	25

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1977	October	24	23
1978	November	05	35
1979	November	18	23
1983	December	23	23
1992	November	15	30
1993	November	10	27
1998	November	06	20
1998	December	10	20

Table 1: Extreme rainfall events

Year	DMI Values	DMI	SRNM	Next Year	DMI Values	DMI
1966	0.177544	Negative	Strong	1967	0.425093	Positive
1972	0.664254	Positive	Strong	1973	-0.220716	Negative
1977	0.378757	Positive	Strong	1978	-------	Negative
1978	-------	Negative	Strong	1979	-------	Negative
1987	0.167046	Positive	Strong	1988	--------	Negative
1993	-------	Negative	Strong	1994	1.00999	Positive
1997	0.489672	positive	strong	1998	-0.273898	Negative

Table 2: Generation of negative DMI

SLP Anomaly Unit (0.01 mbar = 1Pa)

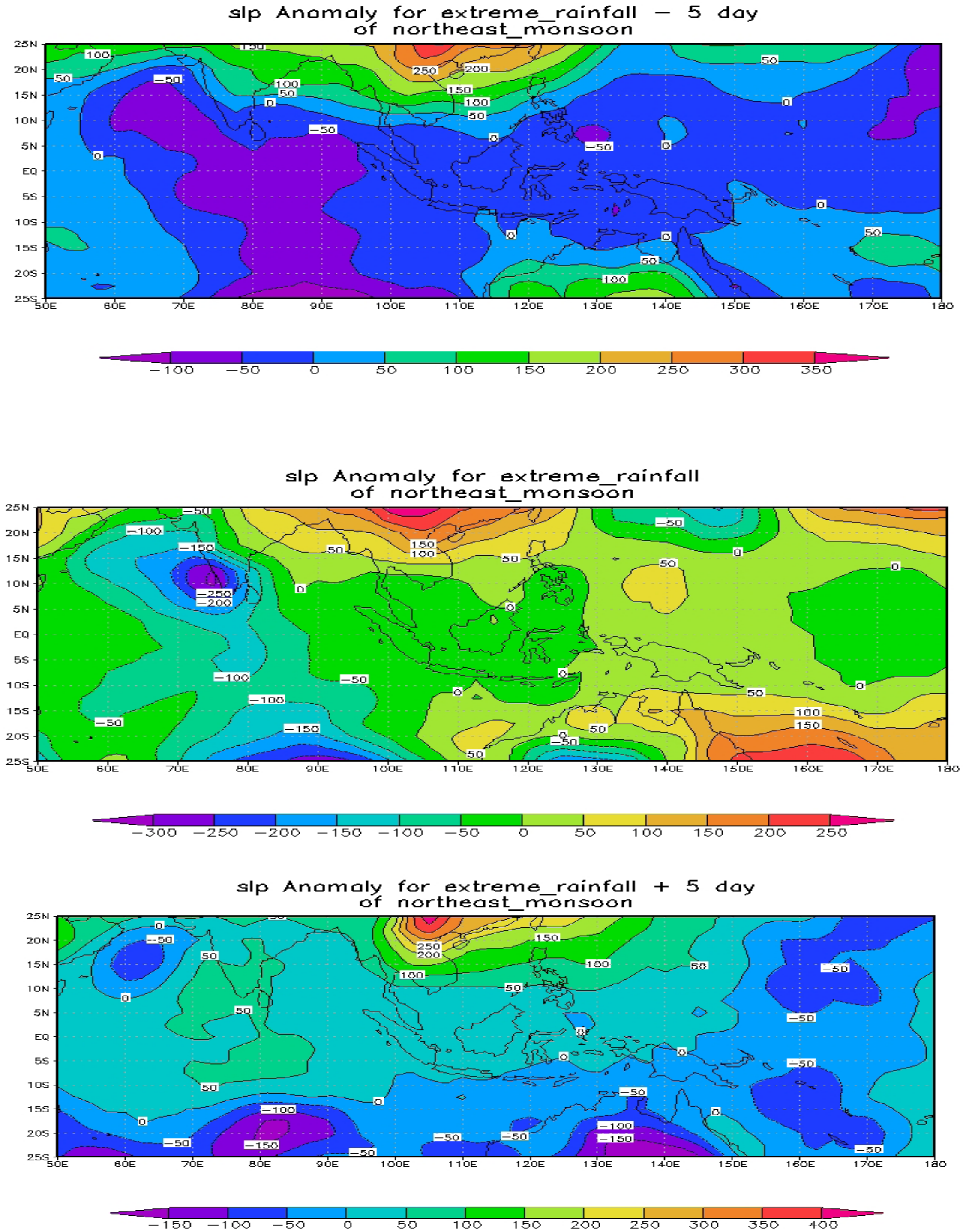

Figure 1: Distribution of SLP anomaly during extreme rainfall events

SST Anomaly unit (^{0}K)

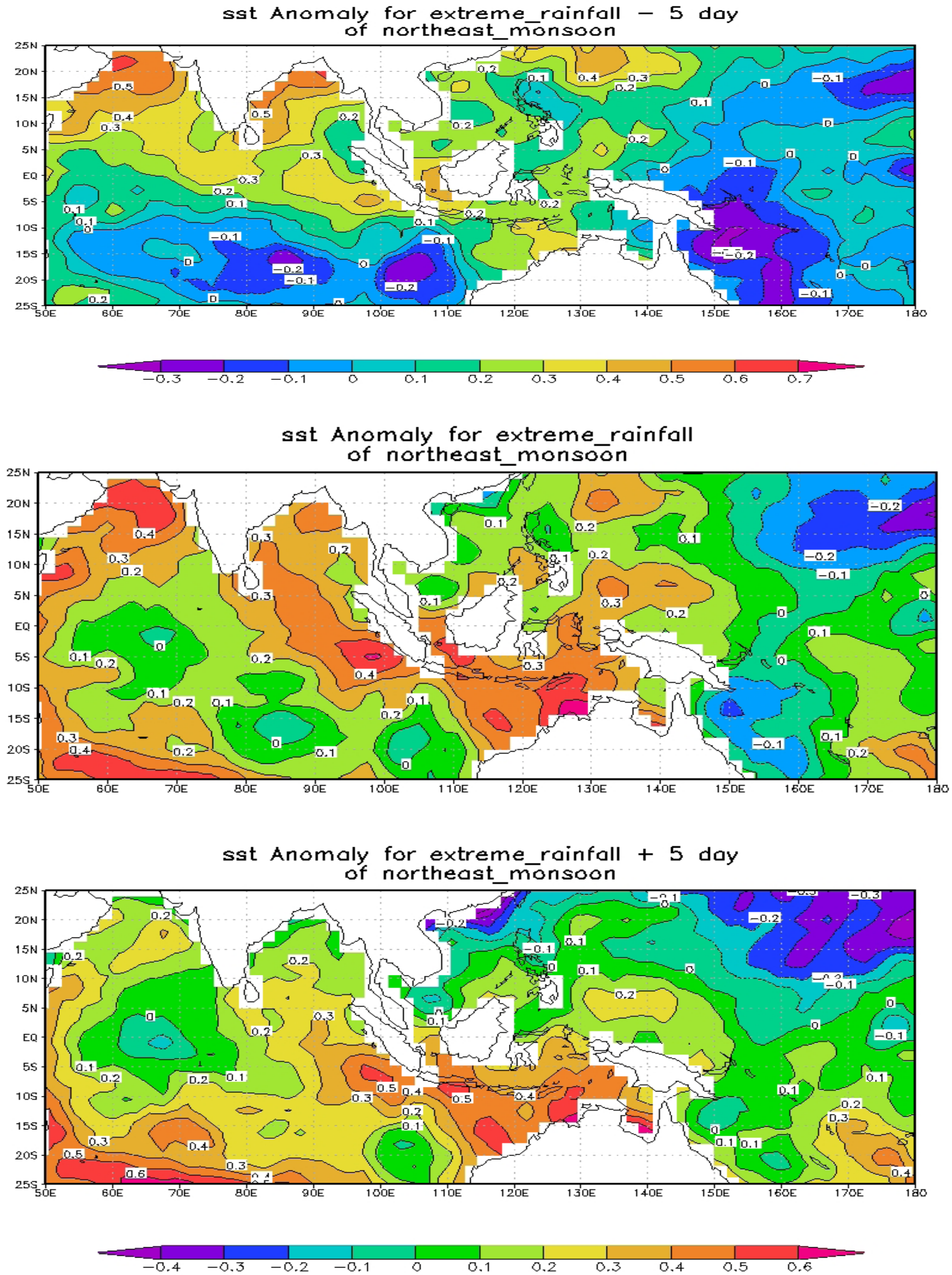

Figure 2: Distribution of SST anomaly during extreme rainfall events

Wind anomaly unit (m/s)

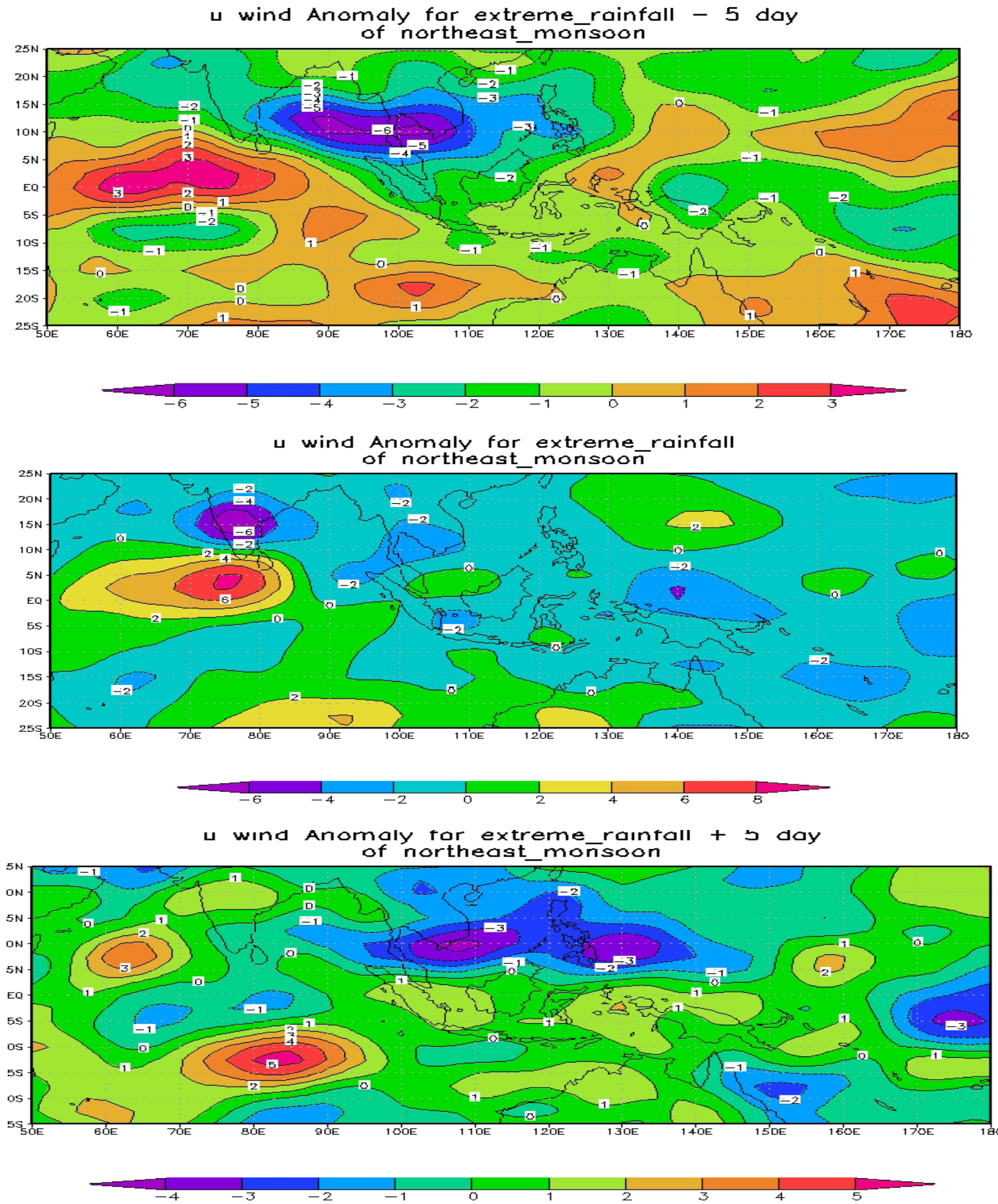

Figure 3: Distribution of zonal wind anomaly during extreme rainfall event