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Tropical cyclones over north Indian Ocean during Indian Ocean Dipole years

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Abstract: *Indian Ocean Dipole (IOD) events over the tropical Indian Ocean, influence the formation and intensification of tropical cyclones over north Indian Ocean (NIO) basin. The strengthening of IOD activity is noticed during the post-monsoon (October-December) season, this enhances the formation and intensification of tropical cyclones over NIO during this season. The maximum number of tropical cyclones form in this basin during the peak of IOD. It is observed that, there is a great chance of getting tropical cyclones during the summer monsoon months, when there is an IOD activity in this basin. Recent studies show that the positive (negative) phase of IOD can make less (more) tropical cyclones over this basin. The influence of various air-sea interaction parameters such as Middle Tropospheric Instability, Middle Tropospheric Relative Humidity, Low Level Relative Vorticity, Low Level Convergence and the Vertical Wind Shear, have been studied on the formation and intensification of the cyclones and severe cyclones over this basin during all the recent IOD (both Positive and Negative) events. Results show that the intensification of cyclonic storms to severe cyclonic storms is more during the negative IOD years than the positive IOD years over this basin. And further results that the higher magnitudes of Middle Tropospheric Instability and Low Level Relative Vorticity and the lower magnitudes of Vertical Wind Shear play a major role for the formation and intensification of tropical cyclones over this basin.*

Key words:- *Indian Ocean, IOD, air-sea interaction parameters, El-Niño and La-Niña.*

Introduction

Tropical cyclones are intense low pressure systems that form over warm tropical ocean surfaces, where the Sea Surface Temperature (SST) is more than 26.5°C. Various environmental parameters are also helpful for the formation of a tropical cyclone, namely large magnitudes of low level relative vorticity, coriolis force and middle tropospheric relative humidity and low magnitudes of vertical wind shear. About 85 tropical cyclones form globally every year. The NIO, both Arabian Sea (AS) and Bay of Bengal (BB) accounts for 7% of global tropical cyclones. The intensification of tropical cyclones depend up on various air-sea interaction parameters, mainly low level convergence, middle tropospheric instability, middle tropospheric relative humidity and the position of the ascending limb of the Walker circulation. Mooley (1980,1981) studied the frequency of severe cyclonic storms during the period of 1877-1977 and found that the percentage of storms intensifying into severe cyclonic storms are high during the period of 1965-77.

Indian Ocean Dipole (IOD) (Saji et al. 1999; Webster et al. 1999) event is characterized by the anomalous warming and cooling of SST over the western and eastern equatorial Indian Ocean, this is a coupled ocean atmospheric process over tropical Indian Ocean and independent of the ENSO in the Pacific Ocean. There are two types of IOD events namely Positive IOD (PIOD) and Negative IOD (NIOD). A positive IOD event is characterized as warmer than normal SSTs over the western tropical Indian Ocean and cooler than normal SSTs over eastern tropical Indian Ocean. A negative IOD event is characterized as cooler than normal SSTs over the western tropical Indian Ocean and warmer than normal SSTs over eastern tropical Indian Ocean. Both these IOD events have significant impacts on the formation and intensification of tropical cyclones over this basin. Indian Ocean Dipole is deferent from the air-sea interaction processes like El-Niño and La-Niña, which also has got significant impacts on the formation and intensification of tropical cyclones over various basins including NIO.

Francis et.al (2009) showed that a Positive IOD event can be triggered by the occurrence of severe cyclones over BB. Pradhan et.al (2009) showed that the concurrent occurrence of El-Niño Modoki and positive IOD can produce more cyclones over North West Pacific. Yuan and Cao (2012) have showed that, when the Indian Ocean is in a Positive (Negative) phase of the IOD, NIO SST anomalies are warm in the west (east) and cold in the east (west), which can weaken (strengthen) the convection over BB and eastern AS, and cause anticyclonic (cyclonic) atmospheric circulation anomalies at low levels. This results in less (more) tropical cyclone genesis and reduced (increased) opportunities for tropical cyclone occurrence over NIO. Sumesh and Ramesh (2013) showed that there more tropical cyclones over AS than BB during El-Niño Modoki years, and this study also states that the concurrent occurrence of El-Niño Modoki and positive IOD can produce more cyclones over NIO. Since the impacts of IOD events on tropical cyclones are less studied, we propose to study the impact of IOD events on the tropical cyclones over NIO. Even though there are many IOD years, It is hard to fix a pure IOD year, to study the influence of IOD over this basin. Most of the times IOD events are co-existing with the El-Niño or La-Niña events in the tropical Pacific Ocean. We have selected 2007 as positive IOD year and 1989, 1993, 1996 as negative IOD years, during this time no ENSO activity was there over the tropical Pacific Ocean. We have studied the influence of each cyclogenesis parameters over NIO during the PIOD and NIOD years on the formation and intensification of tropical cyclones over this basin.

Materials and Methods

The process of initiation of a cyclone is called cyclogenesis. Many authors have tried to quantify this cyclogenesis over various basins. Gray (1975) introduced six primary genesis parameters for tropical cyclone, known as seasonal genesis parameter (SGP) this is the product of three dynamic parameters as well as three thermodynamic parameters, such as 1. Low level relative vorticity, 2. Coriolis parameter, 3. Inverse of the vertical shear of the horizontal wind between lower and upper troposphere, 4. Ocean thermal energy or sea surface temperature above 26°C to a depth of 60m, 5. Vertical gradient of equivalent potential temperature between surface and 500mb. 6. Middle tropospheric relative humidity.

Zehr (1992) proposed a parameter known as Genesis Parameter (GP), which is the product of three dynamical parameters such as low level relative vorticity at 850 hPa, negative of low level divergence at 850 hPa (for low level convergence) and vertical wind shear co-efficient. GP is expressed in units of $10^{-12}S^{-2}$. His study showed that this genesis parameter was useful in differentiating between the non-developing and developing systems in the western North Pacific. In this study Zehr has also found the threshold values for these parameters which are favorable for the formation of a cyclone, such as low level relative vorticity at 850 hPa is (1.05 $x10^{-5}xS^{-1}$), low level convergence at 850 hPa is (0.33 $x10^{-5}xS^{-1}$) and vertical wind shear co-efficient is (10.3 ms^{-1}). In this present paper we are using these threshold values of dynamic parameters for the cyclones over north Indian Ocean.

Roy Bhowmic (2003) used this genesis parameter to study the developing and non-developing systems over NIO, and observed GP values around 20 $x10^{-12}S^{-2}$ against T-No: 1.5 has the potential to develop into a severe cyclonic storm. Kotal et al. (2009) introduced a genesis parameter and termed it as the Genesis Potential Parameter (GPP) for the Indian Seas. The parameter is defined as the product of four variables namely vorticity at 850 hPa, middle tropospheric relative humidity, middle tropospheric instability and the inverse of vertical wind shear. The result shows that there is a distinction between GPP values for nondeveloping and developing systems in more than 85% cases. The composite GPP value is found to be around three to five times greater than for developing systems than for nondeveloping systems. In this study we are using the Zehr's genesis parameter (GP) and two therm-dynamic parameters defined by Kotal et al. (2009) to discuss the dynamic as well as thermo-dynamic features of the cyclones over NIO. In the present paper the favourable values for these thermo-dynamic parameters are kept 23°C for Mid Tropospheric Instability and 40% (M=0) for Mid Tropospheric Relative Humidity.

The selected cyclogenesis parameters are

i) Low Level Relative Vorticity at 850 hPa

ii) Low Level Convergence at 850 hPa (negative of low level divergence at 850hPa)

iii) S = Shear Coefficient = $\dfrac{[25.0\ mS^{-1} - (200-850\ SHEAR)]}{20\ ms^{-1}}$

iv) Middle Tropospheric Relative Humidity variable (M), $M = \dfrac{[RH-40]}{30}$

(where RH is the mean Relative Humidity between 700 and 500 hPa)

v) Middle Tropospheric Instability (I), I= T850 – T500.

(The temperature difference between 850 and 500 hPa)

The composite anomalies of all the variables namely Low Level Relative Vorticity (LLRV) at 850hPa, Low Level Convergence (LLC) at 850hPa, Vertical Wind Shear (VWS), Mid Tropospheric Relative Humidity (MTRH) and the Mid Tropospheric Instability (MTI) have been prepared using NCEP/NCAR Re-Analysis -II daily data. All the parameters are averaged with the cyclone days, and studied the variations of these parameters for the cyclones during the positive and negative IOD years. The genesis locations of all the cyclones during 1979 to 2010 are obtained from the cyclone e-Atlas prepared by India Meteorological Department (IMD). The study area includes AS [50°E-78°E, 0°N –

30°N] and BB [78°E-100°E, 0°N – 30°N]. Averages of all the parameters are considered for the cyclone days.

Tropical cyclones over NIO during Indian Ocean Dipole years

It is very difficult to fix a pure IOD year, most of the time the IOD events will co-exist with the El-Niño or La-Niña event in the tropical Pacific. It can also co-exist with the El-Niño Modoki or La-Niña Modoki events. There was only one positive IOD (PIOD) year (2007) in this present study because most of the time the PIOD event is co-occuring with the ENSO phase. There are tree years as Negative IOD (NIOD) years these years are 1989, 1993 and 1996 in which no physical activities were there over the tropical Pacific Ocean. When we take the frequencies of the cyclones that formed over the various basins during these PIOD and NIOD years, we can see that the IOD activity over the tropical Indian Ocean has got some influence on the frequencies of the cyclones over various basins. Frequencies of all the cyclonic storms and severe cyclonic storms formed over NIO during these period have been analyzed (Table 1 and 2). From Table 2 we can see that the frequencies of cyclones are more during the NIOD years than the PIOD years. And it is clear that, when we take the ratios for per year frequencies of cyclones and severe cyclones we get the maximum values for the severe cyclones over BB, this means that there is great chance to get a severe cyclone over BB during the NIOD years.

Results and Discussions

From figure (1a), we can see that out of two cyclones all the cyclones have formed above the threshold for MTI, but from figure (1b) they did not cross the thresh old for MTRH, so MTRH is not a favorable parameter over AS during PIOD years. From figure (1c) one out of two cyclone has crossed the thresh old for LLRV but another cyclones did not cross the thresh old. It has formed at a magnitude of LLRV between (0 to 0.5) $x10^{-5}xS^{-1}$. From figure (1d) both the cyclones did not cross the thresh old for LLC, we can see that the magnitude of LLC is very less (0 to -0.2) $x10^{-5}xS^{-1}$, this can be one of the reasons for less number of cyclones over AS during PIOD years. From figure (1e) the magnitude of VWS is very less over AS which is a favorable condition for the formation of cyclones over this basin.

Table. 1: Frequencies of tropical cyclones over NIO during Positive IOD years

years	Arabian Sea		Bay of Bengal	
	Cyclonic storms	Severe cyclonic storms	Cyclonic storms	Severe cyclonic storms
2007	1	1	1	1
total	**1**	**1**	**1**	**1**

Table. 2: Frequencies of tropical cyclones over NIO during Negative IOD years

years	Arabian Sea		Bay of Bengal	
	Cyclonic storms	Severe cyclonic storms	Cyclonic storms	Severe cyclonic storms
1989	0	0	1	2
1993	0	1	0	1
1996	0	2	1	2
total	**0 (0.0)**	**3 (1.0)**	**2 (0.66)**	**5 (1.66)**

From figure (2a) it is seen that both the cyclones have crossed the threshold for MTI. From figure (2b) it is seen that both the cyclones have crossed the threshold for MTRH. This means that these thermodynamic parameters are conducive for the formation and intensification of cyclonic storms over BB during the PIOD years. From figure (2c), it is observed that no cyclones have crossed the threshold for LLRV. They have formed at LLRV between (0 to 0.5) $x10^{-5}xS^{-1}$. From figure (2d), it is observed that only one cyclone have crossed the threshold for LLC, and this cyclone further intensified into a severe cyclone. But the other cyclone remained as a cyclonic storm. From figure (2e) it is seen that both the cyclones have formed at very low values of VWS. VWS is a conducive parameter for the formation and intensification of cyclones over BB during PIOD years.

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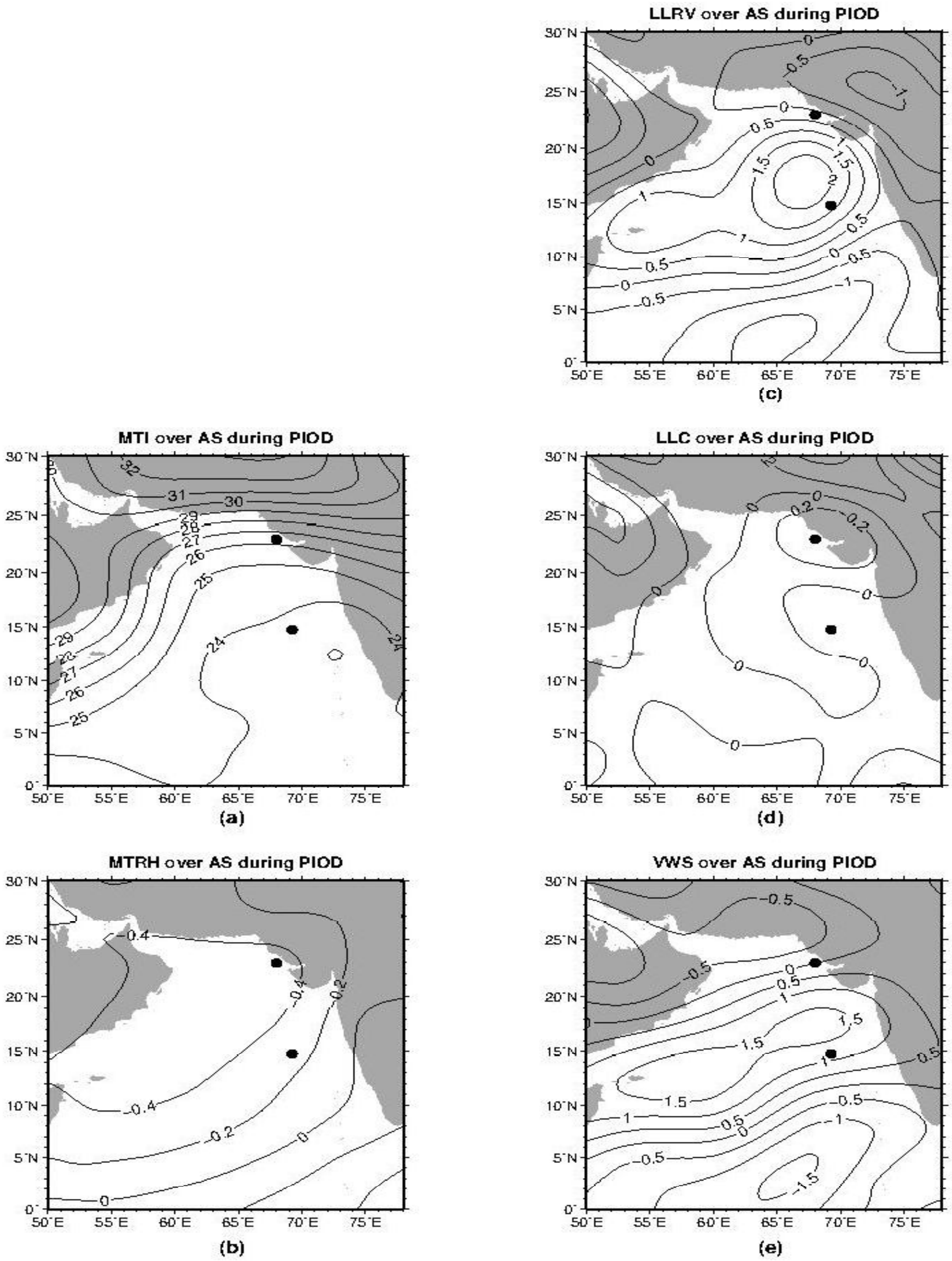

Figure 1. Variations of cyclogenesis parameters over AS during Positive IOD years

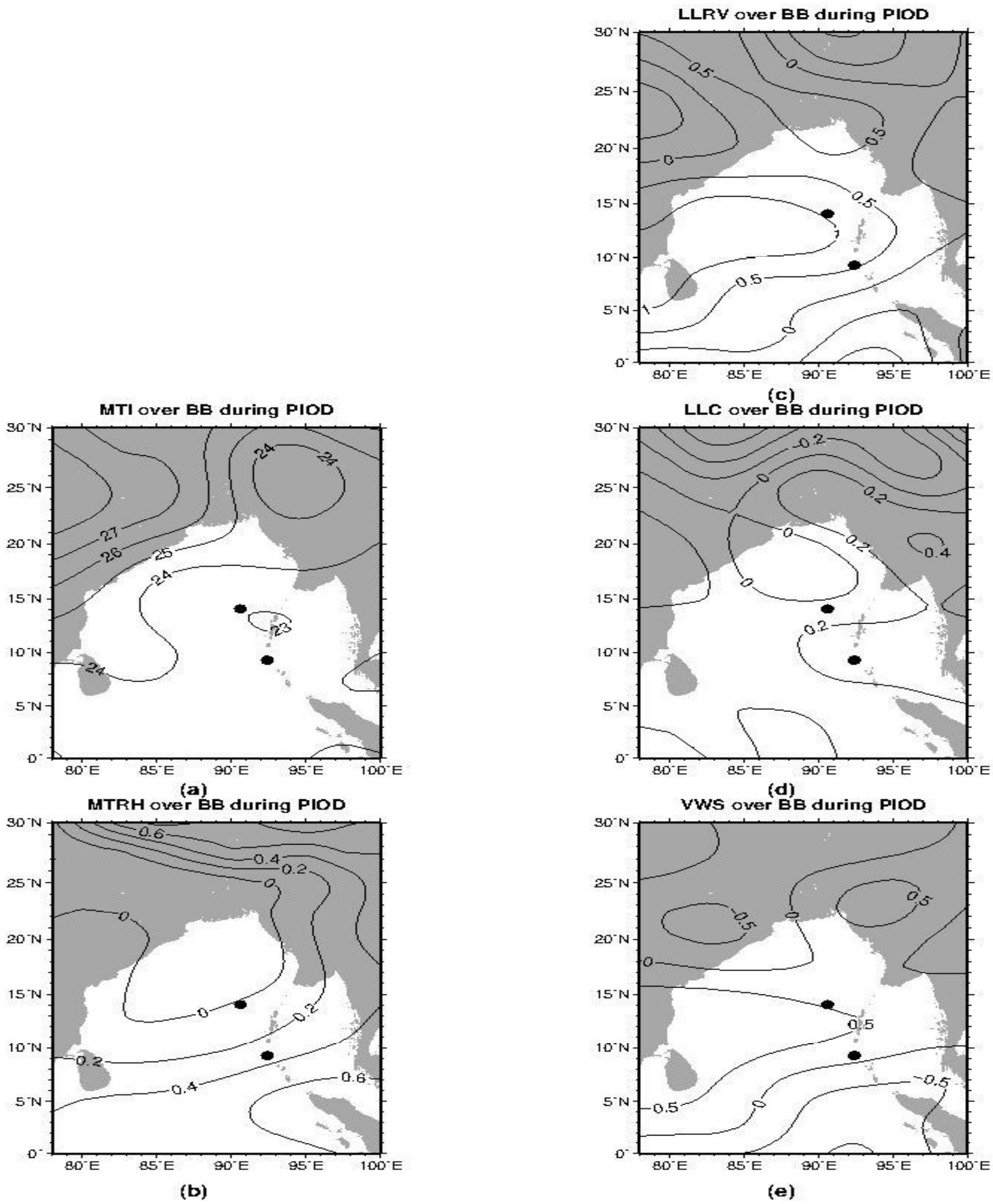

Figure 2. Variations of cyclogenesis parameters over BB during Positive IOD years

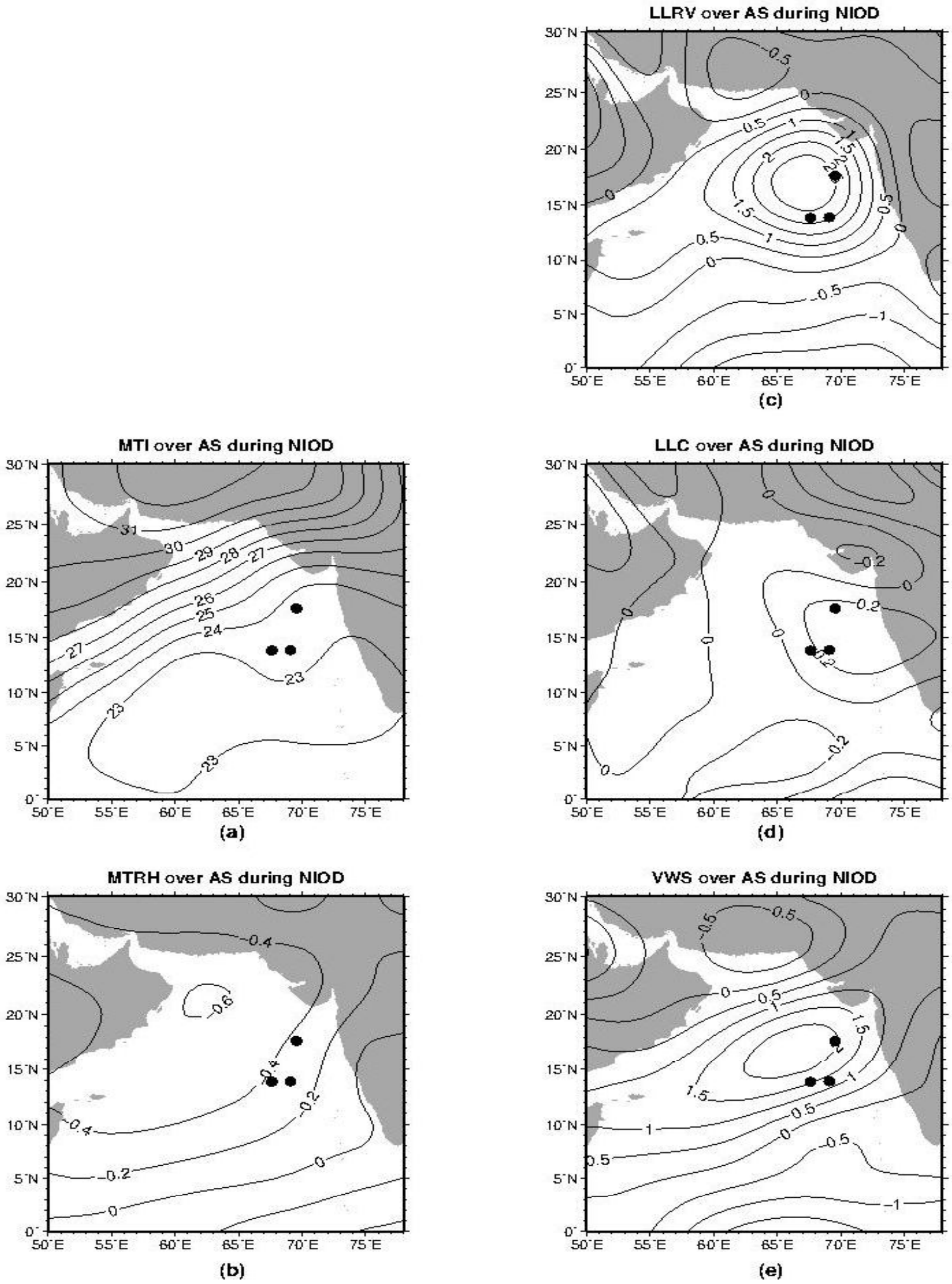

Figure 3. Variations of cyclogenesis parameters over AS during Negative IOD years

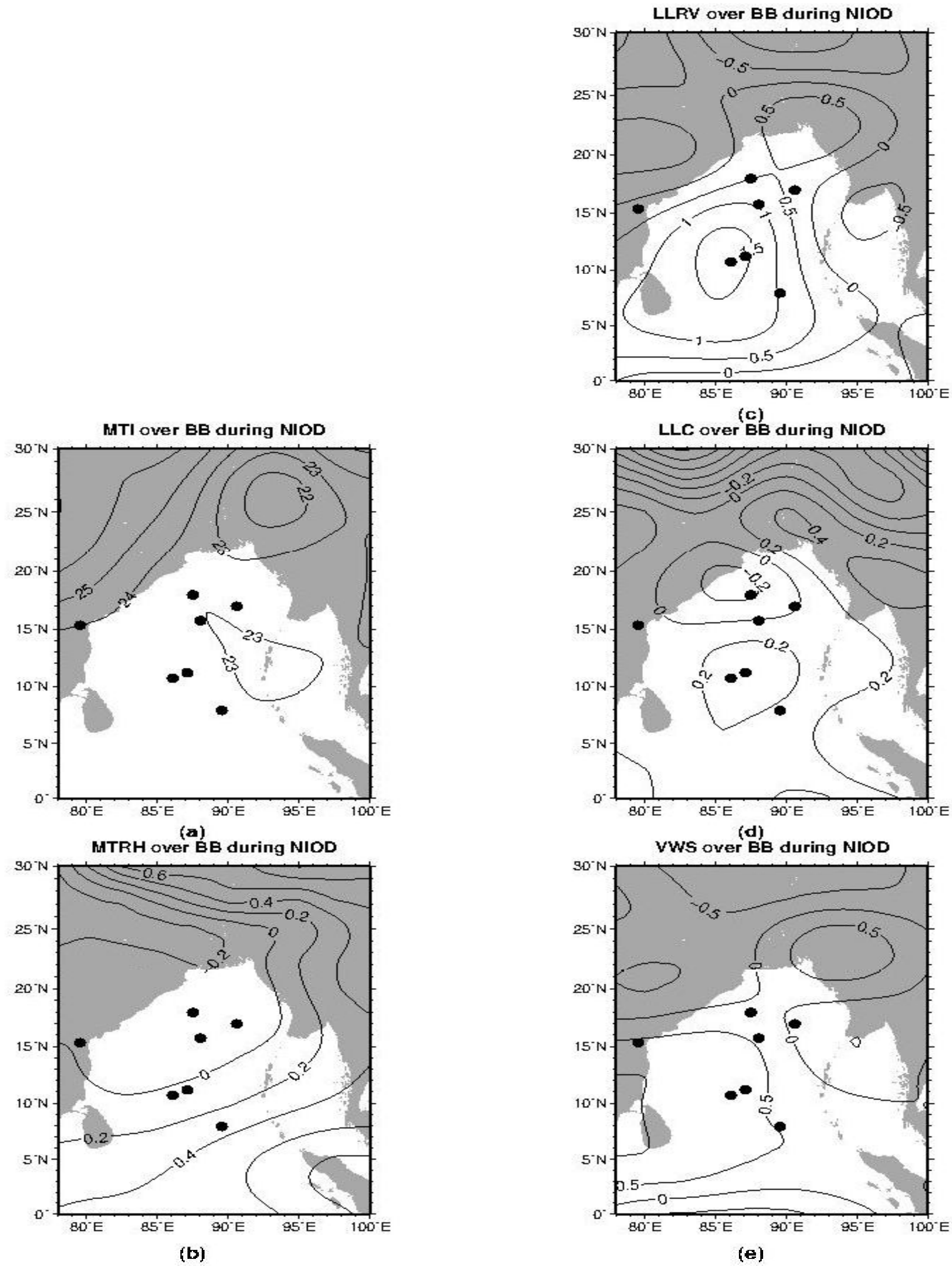

Figure 4. Variations of cyclogenesis parameters over BB during Negative IOD years

From figure (3a), it is seen that all the cyclones have crossed tha threshold for MTI. But from (3b), it is seen that these cyclones did not cross the threshold for MTRH, all the cyclones have formed at MTRH between (-0.2 to -0.4). This means MTRH is not conducive for the cyclones over AS during NIOD years. From figure (3c), it is clear that all the cyclones have crossed the threshold for LLRV, more over that these cyclones have formed at a high magnitude of LLRV, around (2.0 to 2.5) $x10^{-5}xS^{-1}$, which very large magnitude than its threshold, so it can make cyclone to intensify into a severe cyclone. From figure (3d), it is observed that out of 3 cyclones 2 cyclones have formed at LLC around (2.0) $x10^{-5}xS^{-1}$, it is also a large magnitude of LLC since the threshold for LLC is (0.33) $x10^{-5}xS^{-1}$. From figure (3e), it is observed that the magnitude of VWS is very low over AS during the NIOD years.

From figure (4a), it is seen that all the 7 cyclones have crossed the threshold for MTI. So MTI is conducive for the formation and intensification of cyclones over BB during NIOD years. From figure (4b), it is observed that only 3 cyclones have crossed the threshold for MTRH, and 4 cyclones have formed at MTRH between (-0.2 to 0). MTRH is not conducive for the intensification of cyclones over BB during this period. From figure (4c), it is observed that 4 cyclones have reached the threshold for LLRV, and 3 cyclones have formed at LLRV between (0 to 0.5) $x10^{-5}xS^{-1}$. SO LLRV is a conducive parameter for the formation and intensification of cyclone over BB during this period. From figure (4d), it is observed that 3 cyclones have crossed the threshold for LLC, 3 cyclones have formed at LLC between (0 to 0.2) $x10^{-5}xS^{-1}$ and one cyclone have formed at LLC (-0.2) $x10^{-5}xS^{-1}$. This means that LLC is also a conducive parameter for the formation and intensification of cyclones over BB during NIOD years. From figure (4e), it is seen that the magnitude of VWS is very low over BB during this period, so VWS is found to be a conducive parameter for the formation and intensification of cyclones over BB during NIOD years.

4 Summary

The Air-Sea interaction processes such as positive IOD and negative IOD events have significant impacts on the tropical cyclones over NIO. The frequencies of tropical cyclones are found to be less (more) during the positive (negative) IOD years. Results show that the magnitude of LLC is more (less) during the NIOD (PIOD) years, this can produce more (less) number of cyclones over NIO during NIOD (PIOD) years. It is also observed that the smaller magnitudes of VWS larger magnitudes of MTI over NIO during these periods play important role on the formation and intensification of tropical cyclones.

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