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Relative role of individual variables on a revised Convective System Genesis Parameter over north Indian Ocean with respect to distinct background state.

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Abstract. Tropical storms are intense low pressure systems that form over warm tropical ocean basins. Depending upon the intensity, they are classified as depressions, cyclones and severe cyclones. Northern Indian Ocean (NIO) is highly prone to intense tropical storms and roughly 5-7 tropical storms are forming over this basin every year. Various Cyclogenesis indices are used to forecast these tropical storms over various basins including NIO. In this aspect we propose a revised Convective System Genesis Parameter (CSGP) to identify regions favourable for storm genesis. The revised CSGP is constructed by using different combinations and thresholds of five variables namely, the Low Level Relative Vorticity, the Low Level Convergence, the Shear co-efficient, the Convective Instability parameter and the Humidity parameter. The relative role of each individual variable on CSGP is analysed separately for different categories of the storms over both Arabian sea and Bay of Bengal. The composite structure of the CSGP for different categories of the storms is further evaluated separately for distinct large scale background state. The results show that the revised CSGP is capable of distinguishing different categories of the storms. The CSGP exhibits large variability during distinct large scale background state. It is also found that the individual variables contribute in a different way during monsoon and non-monsoon seasons. The revised CSGP can be used to forecast all categories of convective systems such as depressions, cyclones and severe cyclones over NIO during the monsoon as well as non-monsoon seasons.

1 Introduction

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Tropical storms are intense low pressure systems that form over warm tropical ocean basins. India Meteorological Department (IMD) has classified these convective systems that form over NIO depending upon their intensity based on the wind speed criteria. The systems are broadly classified as depressions, cyclones and severe cyclones. Table 1. shows the classification of convective systems by IMD by using the wind speed criteria. If the wind speed of the convective system is between 32-50 kmph it is called a depression and the wind speed is between 50-59 kmph it is called a deep depression. These depressions and deep depressions produce good amount of rainfall in the coastal and inland areas of the Indian sub continent. The frequency of these depressions and deep depressions are more in the Bay of Bengal (BB) compared to the Arabian Sea (AS). Intense systems are further classified into matured and developing convective systems such as cyclones (wind speed between 60-90 kmph), severe cyclones (90-119 kmph), very severe cyclones (119-220 kmph) and super cyclones (> 220 kmph). Generally all the categories of the convective systems except the depressions and deep depressions are called the tropical cyclones in various tropical ocean basins. These tropical cyclones cause severe damage to the structures near the coastal areas due to high wind and storm surge during their land fall. Though the origin of the tropical cyclones are not fully understood, studies have shown that there are few environmental parameters such as Sea Surface Temperature (SST), Low Level Relative Vorticity (LLRV), Low Level Convergence (LLC), Vertical Wind Shear (VWS), Middle Tropospheric Relative Humidity (MTRH), Convective Instability (CI) and Middle Tropospheric Instability (MTI) known to control the formation and further intensification of a tropical cyclone (Gray., 1968; 1998; Palmen., 1948; Gray et.al., 1975).

Various authors have discussed that sea surface temperature and ocean thermal energy play an important role in the formation and existence of the tropical cyclones. And it is observed that tropical cyclones form over the warm oceanic regions where the sea surface temperature is higher than 26°C Palmen (1948). The importance of thermal buoyancy from the surface to middle levels for cumulonimbus convection has been discussed by (Palmen., 1948, 1957). Tropical cyclones generally do not form near the equator, because it requires a minimum magnitude of Coriolis force for its genesis. Studies and observations show that the frequency of cyclone genesis is more over the regions where seasonal value of middle-level humidity is high. The process of initiation of sustained low level circulation centre is called cyclogenesis. Gray., (1968) has discussed about the relative roles of various air-sea interaction parameters for the initiation and intensification of the tropical cyclones and found that, strong low-level relative vorticity and small vertical shear of the horizontal wind play an important role in the formation and intensification of tropical cyclones.

Gray., (1975) introduced six primary genesis parameters for the formation of tropical cyclones. This study stated that the seasonal tropical cyclone frequency is directly linked to a combination of these six physical parameters and is a function of seasonality on a climatological basis. Which thereafter referred to as primary climatological genesis parameters. These parameters are (1) Low level relative vorticity, (2) Coriolis parameter, (3) The inverse of the vertical shear of the horizontal wind between the lower and upper tropsphere, (4) Ocean thermal energy or sea temperature above 26^{o}C to a depth of 60m, (5) Vertical gradient of equivalent potential temperature between the surface and 500mb level and (6) Middle troposphere relative humidity. The first three parameters are called the dynamic potential and the last three parameters are called the thermal potential. The product of the dynamic and thermal potentials is referred to as the Seasonal Genesis Parameter (SGP).

The SGP is usually calculated from the seasonally averaged climatological atmospheric or oceanic fields for each of the four three month seasons: winter (JFM), spring (AMJ), summer (JAS) and autumn (OND). Gray., (1975) has also proposed a Yearly Genesis parameter (YGP) and it is calculated as the sum of the four SGPs in four seasons. The thermal potential of the SGP delimits the regions and the seasons of possible tropical cyclone formation. The dynamical factors determine the synoptic conditions favourable to the formation of tropical cyclones. The YGP which incorporates both thermal and dynamical parameters is able to identify the regions having a high probability of tropical cyclone formation on climatological time scales. Gray., (1979) validated YGP against observations of the reported detection locations of storm systems which later became tropical cyclones, according to WMO criteria, during 1958-1977. The calculations made by Gray are based on climatological observations averaged over the same period, and have shown that the SGP is able to reproduce seasonal frequency distribution of observed tropical cyclones and their geographical distribution over the different ocean basins. In the northern hemisphere the average cyclogenesis is reasonable (but slightly over estimated in the northwest Pacific in spring and Autumn). In the southern hemisphere, cyclone frequency is over estimated by the YGP especially in southern Indian Ocean and south west Pacific. Royer et.al. (1998) modified Gray's YGP by replacing the thermal potential with the convective potential. The convective potential is defined as; "Convective Potential = k x P_c" over the oceans and for $|Ø| \leq 35^{o}$ lat. Where P_c is the seasonal mean convective precipitation in mm/ day computed by the model, and Ø is the latitude, and the numerical value of k is 0.145. This modified YGP is called the Convective Yearly Genesis Parameter (CYGP), which is found as successful as the original YGP for reproducing the main areas of tropical cyclone genesis.

McBride and Zehr, (1981) introduced a Daily Genesis Parameter (DGP). This parameter is calculated as the difference of relative vorticity at the upper level (200mb) and the lover level (900mb). It is defined as ($\zeta_{900\ mb}$ - $\zeta_{200\ mb}$). This parameter could describe that (1) both non-developing and developing systems are warm core in the upper levels. The temperature (and height) gradients are more pronounced in the developing systems, but the magnitudes are so small that the differences would be difficult to measure for individual systems. (2) the developing or pre-typhoon cloud cluster exists in a warmer atmosphere over a large horizontal scale. (3) there is no obvious difference in vertical stability for moist convection between the systems. (4) there is no obvious difference in moisture content or moisture gradient (5) pre-typhoon and pre-hurricane systems are located in large areas of high values of low level relative vorticity. The low level vorticity in the vicinity of a developing cloud cluster is approximately twice as large as that observed with non developing cloud clusters. (6) Mean divergence and vertical motion for the typical western Atlantic weather system is well below the magnitudes found in pre-tropical storm systems. (7) Once a system has sufficient divergence to maintain 100 mb or more per day upward vertical motion over a 4^o radius area, there appears to be no relationship between the amount of upward vertical velocity and the potential of the system for development. (8) cyclogenesis takes place under conditions of zero vertical wind shear near the system center. (9) There is a requirement for large positive zonal shear to the north and negative zonal shear close to the south of a developing system. There is also a requirement for southerly shear to the west and northerly shear the east. The scale of this shear pattern is over a 10^o latitude radius circle with maximum amplitude at ~6^o radius.

Zehr., (1992) introduced a parameter called Genesis Parameter (GP) to quantify the cyclogenesis over the north-west Pacific Ocean. GP is the product of three dynamic parameters such as Low Level Relative Vorticity at 850 hPa, Low Level Convergence (negative of Divergence) at 850 hPa and Shear Co-efficient. This study showed that this genesis parameter was useful in differentiating between the non-developing and developing systems in the western North Pacific. Roy Bhowmic (2003) used this Genesis Parameter to study the developing and non-developing systems over NIO, and observed GP values around $(20.0)10^{-12}\ S^{-2}$ against T-No: 1.5 has the potential to develop into a severe cyclonic storm. Kotal et.al. (2009) proposed a cyclone genesis parameter for the Indian Seas, termed as the Genesis Potential Parameter (GPP). This parameter is defined as the product of four variables, namely vorticity at 850 hPa, middle tropospheric relative humidity, middle tropospheric instability and inverse of vertical wind shear. The parameter is tested with a sample dataset of 35 non-developing and developing low pressure systems that formed over the Indian Seas during the period of 1995-2005. The result shows that there is a distinction between GPP values is found to be around three to five times greater for developing systems than for non-developing systems. The analysis of the parameter at early development stage of a cyclonic storm appears to provide a useful predictive signal for intensification of the system.

Philander, (1985) discussed about the El-Niño Southern Oscillations (ENSO) phenomena occurring over the tropical Pacific Ocean basin which affects the global climate through teleconnection. This is mainly influenced by the weakening and strengthening of trade winds over the tropical belt through the modulation of Walker circulations. The amplitude of fluctuations in the trade winds over the Pacific Ocean is associated with the abnormal warming or cooling of the sea surface over eastern Pacific Ocean. The trade winds and Walker circulation in turn gets modulated through the abnormal warming (cooling) over eastern Pacific Ocean known as El-Niño (La-Niña). Scientists have observed that varius ocean atmospheric processes over the globe are affected by these El-Niño and La-Niña events. The frequency variations of tropical cyclones over various basins during the El-Niño and La-Niña years have been studied by Nakazawa., (2001), Cahn., (1985), Chia and Ropelewski., (2002) and Dong., (1988) The results show that the frequency of tropical cyclones is found to be more during the El-Niño years over some basins and in some other basins the frequency is more during the La-Niña years.

Ashok etal., (2007) proposed the new type of El-Niño and La-Niña events which is different from the canonical El-Niño and La-Niña conditions. These events are termed as El-Niño Modoki and La-Niña Modoki. The El-Niño Modoki event is defined as the warmer sst's in the central pacific ocean and cooler sst's in both east and west pacific ocean. And a La-Niña Modoki event is defined as the cooler sst's in the central pacific ocean and warmer sst's in the east and west pacific ocean. Sumesh and Ramesh Kumar., (2013) have studied the influence of El-Niño Modoki events on the tropical cyclones over north Indian Ocean. They observed that there are more cyclones over AS during the El-Niño Modoki years than the El-Niño years. And in the case of severe cyclones over AS the frequency is more during the El-Niño Modoki years than the El-Niño years, where as in BB the frequency is more in the El-Niño years than the El-Niño modoki years.

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The present study is an attempt to evaluate the relative contribution of potential dynamical and thermo dynamical parameters in the formulation of the revised CSGP. The main objectives of the study are to quantify the composite variation of the revised CGSP over NIO. The cyclogenesis over a particular basin is mostly linked to warm SST boundary and associated large scale circulation pattern. Hence, the variation of this CGSP and individual parameters are studied with respect to distinct background state. In this present study we have studied the frequency variations of all the convective systems over NIO during the El-Niño, El-Niño Modoki, La-Niña, La-Niña Modoki, Positive IOD, Negative IOD years. We have also selected some years as Neutral years in which there were no significant warming or cooling of ocean water over equatorial Pacific or Indian Ocean basin.

2 Methods and data used

2.1 The revised Convective System Genesis Parameter (CSGP)

The Convective System Genesis Parameter (CSGP) is a new modified index and it is different from the Genesis Parameter (GP) defined by Zehr (1992) and the Genesis Potential Parameter (GPP) defined by Kotal (2009). We use the dynamical parameters defined by Zehr (1992), the humidity parameter defined by Kotal (2009) and the Convective Instability parameter defined by Gray, (1975). Hence the revised index is a product of five parameters and it is defined as

CSGP = (850VOR • 850LLC • S • HUM • CI)

Where

1) 850VOR= Low Level Relative Vorticity at 850 hPa (LLRV)

2) 850LLC= Low Level Convergence (negative of Divergence) at 850 hPa (LLC)

3) VWSC= Shear Co-efficient = 25.0ms-1 - (200-800 SHEAR) / 20.0ms-1 (SHR)

4) HUM = [RH – 40] / 30, Middle tropospheric relative humidity. (Where RH is the mean relative humidity between 700 and 500 hPa)

5) CI = (ThetaE_1000 – ThetaE_500), Vertical gradient of Equivalent potentail temperature, between 1000hPa and 500hPa.

Here in the Shear parameter we have kept the maximum magnitude as $25 ms^{-1}$, the magnitude greater $25ms^{-1}$ it will reduce CSGP to zero. The unit of this index is $10^{-10}s^{-2}$ degree K. In this study we have analysed all the convective systems that formed over NIO during the study period (1979-2008). We have also classified the convective systems in three categories as (1) depressions (which include both depressions and deep depressions), (2) cyclones (which include only cyclones) and (3) severe cyclones (which include severe cyclones, very severe cyclones and super cyclones). And we have analysed the characteristics of this Index (CSGP) for all the categories in both monsoon (JJAS) and non monsoon (JFMAM-OND) months.

2.2 Datasets used and selection of distinct background state

We have used NCEP/NCAR- Reanalysis 2 (Kanamitsu et.al., 2002), atmospheric data set (daily mean) to calculate and analyse the dynamic as well as thermodynamic parameters. These cyclogenesis parameters are averaged over the period of the convective systems. The spatial resolution of this data is 2.5 x 2.5-degree grid. We have considered the whole NIO basin covering the area bounded by 50^oE to 100^oE, and 0^o to 25^oN. In the present study, composite of all the individual parameters during the period of the each convective systems over NIO for all distinct basic states namely the El-Niño, El-Niño Modoki, La-Niña, La-Niña Modoki and both negative and positive phases of Indian Ocean Dipole (IOD) and the Neutral years have been evaluated. We have further divided the convective systems as they have formed in the monsoon and non-monsoon seasons. The individual parameters and CSGP in the monsoon and non-monsoon seasons is then composited separately irrespective of the large scale background state. Spatial correlations have been computed between each of the individual parameters with the CSGP. Further we have computed the correlation between each parameter and CSGP averaged around the convective system.

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3 Results and discussion

3.1 Grouping the storms into different categories of basic state

In the present study we have analysed the characteristics of the Convective System Genesis Parameter (CSGP), over NIO for all the cases of convective systems such as (1) Depressions, (2) Cyclones and (3) Severe cyclones. The entire study period is divided into El-Niño, El-Niño Modoki, La-Niña, La-Niña Modoki, Positive IOD, Negative IOD and the Neutral years. We have again sub divided the convective systems for their formation in the monsoon seasons as well as the non-monsoon seasons of each years. The ENSO and IOD years we have take from the recent publications. To avoid the combined effects of ENSO and IOD and we have selected these years in such a way that the ENSO and IOD activities are not occurring simultaneously. And we have also selected some years as the Neutral years, in which there were no establishment of either ENSO activity over the Pacific Ocean or an IOD activity over the NIO. Table 2. Shows the selected ENSO and IOD activity years during the study period. There were four El-Niño years, seven El-Niño Modoki yeras, six La-Niña years, two La-Niña Modoki years, one Positive IOD year and three Negative IOD years during the study period. Table 3. Shows the total frequencies of the convective systems formed over NIO during the study period. In the case of depressions over AS, there have been 10 depressions during the monsoon seasons and 17 depressions during the non-monsoon seasons, and in the case of depressions over BB, there have been 63 depressions during the monsoon seasons and 44 depressions during the non-monsoon seasons of the study period. In the case of cyclones over AS, there have been 3 cyclones during the monsoon seasons and 5 cyclones during the non-monsoon seasons, and in the case of cyclones over BB, there have been 8 cyclones during the monsoon seasons and 27 cyclones during the non-monsoon seasons of the study period. And in the case of severe cyclones over AS, there have been 5 severe cyclones during the monsoon seasons and 11 severe cyclones during the non-monsoon seasons, and in the case of severe cyclones over BB, there have been 3 severe cyclones during the monsoon seasons and 42 severe cyclones during the non-monsoon seasons of the study period

The black and grey histograms in figure 1. Shows total number and per year count (frequencies) of the depressions over NIO during the study period. From figure 1(a), the black histograms show the frequencies and per year values of the depressions over AS. It is observed that, the frequency is

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more during the El-Niño, El-Niño Modoki, La-Niña and the Neutral years, and it is less during the PIOD and NIOD years. And the gray histograms, show the per year values of the depressions over AS during the study period. It is observed that the per year value is more (greater than 1 depression per year) for the El-Niño, La-Niña, PIOD and Neutral years, and the per year value is less for the El-Niño Modoki and NIOD years. From figure 1 (b), the black histograms show the frequencies of the depressions over BB. It is observed that, the frequency is more during the El-Niño, El-Niño Modoki, La-Niña, NIOD and Neutral years, and it is less during the La-Niña Modoki and PIOD years. The Irrespective of the background state, all per year value is found to be greater than 3.0 for the depressions over BB. However, both IOD years shows more favourable condition for the depression to form over BB.

Further we analysed the depression frequencies separately for monsoon and non-monsoon seasons. Figure 2, gives the seasonal frequencies of depressions and its count per season over NIO during the monsoon and non-monsoon seasons. From figure 2 (a), the black histograms show the number of depressions over AS during the monsoon seasons. It is observed that, the La-Niña years show maximum frequency with per season values close to 1(0.83). And the minimum frequency is observed during the El-Niño Modoki, NIOD and Neutral years. It is evident from the figure that all other background states are not favourable for the formation of depression over AS during monsoon months. The black histograms in figure 2 (b) shows the number of depressions over AS during the non-monsoon seasons. The maximum number is observed during the El-Niño Modoki years and the minimum frequency is observed during the PIOD years. And it is also noticed that a good number of depressions have formed during the El-Niño, La-Niña and the Neutral years. The gray histograms show the per seasonal values for the depressions oer AS. It is observed that, the per seasonal values are more for the El-Niño, PIOD and Neutral years, and it is less for the El-Niño Modoki and La-Niña years. From figure 2 (c) shows the number of depressions over BB during the monsoon seasons. It is observed that, the depression count is more during the El-Niño, El-Niño Modoki, La-Niña and the Neutral years. And the frequency is less during the La-Niña Modoki, PIOD and NIOD years. It is clear from the figure that the per seasonal values of depression over BB during monsoon season is more (greater than 3 per season) during El-Niño and PIOD years. The per seasonal count is close to 2 for all other categories of years during monsoon season. From figure 2 (d), the black histograms show the number of depressions over BB during the non-monsoon seasons. It is observed that, the El-Niño Modoki years are having the maximum frequency, and the La-Niña Modoki and PIOD years are having minimum frequency. And it is also observed that a good number of depressions have formed during La-Niña, NIOD and PIOD years. The gray

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histograms show the per seasonal frequencies of depressions over BB during the non-monsoon seasons. It is found that more than 2 depressions per season were formed during El-Niño Modoki, PIOD and NIOD years. In general the frequencies of depressions over BB are more during the monsoon seasons of El-Niño, El-Niño Modoki, La-Niña and Neutral years as compared to the non-monsoon seasons.

Figure 3, gives the total number and per year frequencies of the cyclones over NIO. From figure 3 (a), the black histograms show the count of cyclones over AS. It is observed that, the frequency is more during the El-Niño Modoki and Neutral years, and it is less during the La-Niña and PIOD years. The gray histograms show the per year values of the cyclones over AS. The per year values of less than 1 shows that almost all categories of years are not conducive for the development of cyclones over AS. From figure 3 (b), the black histograms show the total number of cyclones over BB during different background states. It is observed that, more number of cyclones were formed during the La-Niña and Neutral years, and it is less during the PIOD years. The gray histograms show the per year values of the cyclones over BB. It is observed that, on an average more than 2 cyclones are formed during La-Niña Modoki and Neutral years.

Figure 4. Gives the seasonal and seasonal frequencies of cyclones over NIO during the monsoon and non-monsoon seasons. It is seen from figure 4(a) that, only very few cyclones were formed over AS during the monsoon seasons of El-Niño Modoki, PIOD and the Neutral years, and no cyclones were formed over AS during the monsoon season of the other selected years. The gray histogram shows frequency of the per seasonal values of the cyclones over AS during the monsoon seasons. From figure 4 (b), shows the total number and seasonal frequencies of the cyclones over AS during the non-monsoon seasons. It is observed that there were only very few (5) cyclones formed during the non-monsoon months of El-Niño Modoki,Neutral and La-Niña years. From figure 4 (c) the total number and seasonal frequency of cyclones over BB during monsoon moths are more during La-Niña and NIOD years the seasonal frequency is less than 0.25 during El-Niño and Neutral years. It is observed from figure 4(d) that, the frequency of occurrence of cyclones during non-monsoon months are more during La-Niña Modoki and neutral years. And it is also observed that there were good number of cyclones over BB during the non-monsoon seasons of El-Niño, El-Niño Modoki, La-Niña, La-Niña Modoki years.

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Figure 5. Gives total number and yearly frequencies of the severe cyclones over NIO. It is observed that from figure (5a) the total number and the frequency of severe cyclones over AS is more during the El-Niño Modoki, La-Niña, NIOD and Neutral years. On an average, PIOD and NIOD years shows at least one severe cyclone per year. It is clear from figure 5(b) that the total number and the frequency of occurrence of severe cyclone over BB is more during the La- Niña and El-Niño years and it is less during the PIOD years. It is also observed that at least one severe cyclone have formed over BB during all categories of background state. Figure 6. Shows the total number and seasonal frequencies of the severe cyclones over NIO during the monsoon and non-monsoon seasons of the study period. It is found from figure 6(a) that the total number and a seasonal frequency of severe cyclones over AS during monsoon season are very low for all different categories of years. It is seen from figure 6 (b) that the frequency of occurrence of Severe cyclone over AS during non-monsoon month is maximum during El-Niño Modoki years., From figure 6 (c, it is clear that formation of severe cyclone over BB is rare during monsoon months except for the two cyclones formed during El-Niño and Neutral years. It is observed from figure 6(d) that total number and seasonal frequencies of the formation of severe cyclone over BB during non-monsoon months are more during La-Niña and El-Niño years. It is also noticed that a good number of severe cyclones have formed during all selected years of different background state.

3.2 Spatial variation of CSGP with respect different seasons

Figures 7-9 presents variations of the CSGP for the convective systems over NIO during monsoon as well as non-monsoon seasons of the study period. The categories of the convective systems have been named as DD for depressions, CS for cyclones and VS for severe cyclones. And the genesis locations are represented as black dots. Figure 7 shows the variations of CSGP for the depressions formed over NIO. It is observed that the genesis points of the depressions over AS during the monsoon seasons are clustered around the region of 14^{o}N – 20^{o}N and 64^{o}E – 72^{o}E. But during the non-monsoon seasons the genesis points of the depressions are spread widely in the region of 5^{o}N – 20^{o}N and 58^{o}E – 77^{o}E. Whereas over BB, the genesis locations of the depressions during monsoon season are clustered in the area of 14^{o}N – 22^{o}N and 83^{o}E – 93^{o}E. This region corresponds to the eastern end of monsoon trough and large values of CSGP found along the monsoon trough region. However, during the non-monsoon seasons the genesis locations spread over a large area of 5^{o}N – 20^{o}N and 78^{o}E – 97^{o}E. Most favourable genesis locations with higher values of CSGP is found around the region of 5-15N and 83-90E. It is found that lower values of CSGP favours the

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formation of DD over AS during both the seasons. On the other hand, higher values of CSGP is found over BB around the genesis locations of the DD during both the seasons.

Figure 8. Shows the variations of CSGP for the cyclones formed over NIO. Figure 8 (a), shows the variations of CSGP for cyclones formed over AS during the monsoon seasons. As seen from figure 4(a) that, the formation of cyclone is rare over AS during monsoon season and there is no specific favourable genesis locations observed. Figure 8 (b), shows the variations of CSGP for cyclones formed over AS during the non-monsoon seasons. Only few cyclones have formed over AS during non-monsoon months and the genesis locations are mostly confined to a narrow region of 65-75E and 10-20N. During both the seasons, relatively lower values of CSGP is found over AS. Figure 8 (c), shows the variations of CSGP for cyclones formed over BB during the monsoon seasons. Very few cyclones have formed over BB during monsoon season and most of them formed over the head BB with moderate values of CSGP. Figure 8 (d), shows the variations of CSGP for cyclones formed over BB during the non-monsoon seasons. Most favourable genesis locations of cyclones are found over south BB between 10-15N and 83-95E with higher values of CSGP around the storm genesis locations.

Figure 9. Shows the variations of CSGP for the severe cyclones formed over NIO. Figure 9 (a), shows the variations of CSGP for severe cyclones formed over AS during the monsoon seasons. It is noticed that the severe cyclones have formed at moderate values of CSGP. Most of the sevre cyclones during monsoon season originated off the west coast around 70-75E and 10-18N. Figure 9 (b), shows the variations of CSGP for severe cyclones formed over AS during the non-monsoon seasons. Most of the severe cyclone over AS during non-monsoon months have been formed around the region of 60-75E and 5-15N with a slightly higher values of CSGP as compared to monsoon season. Figure 9 (c), shows the variations of CSGP for severe cyclones formed over BB during the monsoon seasons. Most of the severe cyclones during monsoon season formed north of 10^0N around the head BB with very high values of CSGP (0.0 to 3.0 x$10^{-10}s^{-2}$degreeK). Figure 9 (d), shows the variations of CSGP for severe cyclones formed over BB during the non-monsoon seasons. It is observed that most of the severe cyclones have formed south of 18N between 85-95E with very high values of CSGP (0.0 to 2.0 x$10^{-10}s^{-2}$degreeK). And in the case of severe cyclones the large positive values of CSGP is concentrated around the genesis locations of the severe cyclones over both the basins.

From this analysis it is found that, all the depressions have formed at the low positive values of CSGP (~ 0.0 to 0.5 x$10^{-10}s^{-2}$degreeK), all the cyclones have formed at the high positive values of CSGP (~ 0.5 to 1.0 x$10^{-10}s^{-2}$degreeK) and all the severe cyclones have formed at a high positive values of CSGP (~ 1.0 to 3.0 x$10^{-10}s^{-2}$degreeK). From this study it is observed that the new modified CSGP is capable of distinguishing the intensity variations of the convective systems over NIO.

3.3 Relation between individual variables and CSGP over NIO during different season

Case. 1 Depressions over NIO

Figure 10 gives the correlations between the individual parameters and the CSGP for the depressions formed over AS during the monsoon and non-monsoon seasons of the study period. Figure 10 (a) gives the spatial correlations of the LLC with CSGP for the depressions formed over AS during the monsoon seasons. It is observed that high positive correlation values (0.0 - 0.5) for the genesis of the depressions during this season around the storm genesis locations. Figure 10 (b) gives the correlations of the LLC with CSGP for the depressions formed over AS during the non-monsoon seasons. It is found that high positive correlation values (0.0 - 0.5) are seen over a large area near the genesis locations of the depressions during this season and the genesis region is also distributed over a large area. Figure 10 (c) shows correlations of the LLRV with CSGP for the depressions formed over AS during the monsoon seasons. It is observed that high positive correlation values (0.0 - 0.5) over the genesis regions of the depressions during this season. Figure 10 (d) gives correlations of the LLRV with CSGP for the depressions formed over AS during the non-monsoon seasons. It is observed that high positive correlation values (0.0 - 0.5) for the genesis of the depressions during this season. Figure 10 (e) gives correlations of the VWSC with CSGP for the depressions formed over AS during the monsoon seasons. It is observed VWSC is negatively correlated (-0.5 - 0.0) with CSGP over the genesis region of the depressions during this season. Since the VWSC includes the shear component and is magnitude is large during monsoon season, large negative correlation exists between the Shear component and around the genesis of the depressions during this monsoon season. Figure 10 (f) gives correlations of the VWSC with CSGP for the depressions formed over AS during the non-monsoon seasons. It is found that small negative correlation exists (-0.3 - 0.0) exists for the genesis of the depressions during this season. Figure 10

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(g and h) presents correlations of the HUM with CSGP for the depressions formed over AS during the monsoon and non-monsoon seasons. It is observed that irrespective of the season, high positive correlation values (0.0 - 0.5) is found over the genesis region of the depressions during both the season. This means that HUM parameter is an essential ingredient to the CSGP and large values of mid-level humidity contributes to the formation of DD over AS during monsoon and non-monsoon months. Figure 10 (i and j) gives correlations of the CI with CSGP for the depressions formed over AS during the monsoon and non-monsoon seasons. High positive correlation values (0.0 - 0.5) is found near the genesis region of the depressions during both the seasons.

Figure 11 gives the correlations between the individual parameters and the CSGP for the depressions formed over BB during the monsoon and non-monsoon seasons of the study period. Figure 11 (a) gives the spatial correlations of the LLC with CSGP for the depressions formed over BB during the monsoon seasons. It is observed that a high positive correlation (0.0 – 0.6) exists over the genesis region of the depressions near the head BB during monsoon season. Figure 11 (b) gives the correlations of the LLC with CSGP for the depressions formed over BB during the non-monsoon seasons. High positive correlation (0.0 – 0.6) values is distributed over the BB region as the genesis locations are also spread over BB. Figure 11 (c and d) shows correlations of the LLRV with CSGP for the depressions formed over BB during the monsoon and non-monsoon seasons. It is observed that a high positive correlation (0.0 – 0.6) exists near the genesis locations of the depressions during both the season. Figure 11 (e) presents correlations of the VWSC with CSGP for the depressions formed over BB during the monsoon seasons. It is observed small positive correlation values are found for the genesis of the depressions during this monsoon season. This implies that depression can form over head BB region even at moderate values of VWSC component. Figure 11 (f) gives correlations of the VWSC with CSGP for the depressions formed over BB during the non-monsoon seasons. It is observed that lower values of positive correlation exist for the genesis of the depressions during non-monsoon season. This suggests that during non-monsoon months, contribution of shear component to CSGP is less for the formation of depression over BB. Figure 11 (g) gives correlations of the HUM with CSGP for the depressions formed over BB during the monsoon seasons. It is observed that a moderate positive correlation (0.0 – 0.3) exists for most of the depressions during this season. Figure 11 (h) shows correlations of the HUM with CSGP for the depressions formed over BB during the non-monsoon seasons. It is observed that a high positive correlation (0.0 – 0.6) found near the genesis locations of the depressions during this season. Figure 11 (i) give the spatial correlations of the CI with CSGP for the depressions formed over BB during the monsoon seasons. It is observed that low positive correlation (0.0 – 0.2) exists for the genesis of the depressions during this season. Figure 11 (j) gives correlations of the CI with CSGP for the depressions formed over BB during the non-monsoon seasons. It is observed that moderate positive correlation (0.0 – 0.4) exists for the genesis of the depressions during this season. It is found that humidity and thermal instability parameters are more important over BB for the formation of depression during non-monsoon seasons.

Case. 2 Cyclones over NIO

Figure 12 gives the correlations between the individual parameters and the CSGP for the cyclones formed over AS during the monsoon and non-monsoon seasons of the study period. Figure 12 (a) gives the spatial correlations of the LLC with CSGP for the cyclones formed over AS during the monsoon seasons. It is observed that high positive correlation (0.0 – 0.9) exists for the genesis of the cyclones during this season. Figure 12 (b) gives the correlations of the LLC with CSGP for the cyclones formed over AS during the non-monsoon seasons. High positive correlation (0.0 – 0.7) found near the genesis region of the cyclones during this season. Figure 12 (c) gives the spatial correlations of the LLRV with CSGP for the cyclones formed over AS during the monsoon seasons. It is observed that a high positive correlation (0.0 – 0.9) exists for the genesis of the cyclones during this season. Figure 12 (d) gives the spatial correlations of the LLRV with CSGP for the cyclones formed over AS during the non-monsoon seasons. It is observed that high positive correlation (0.0 – 0.7) exists for the genesis of the cyclones during this season. Figure 12 (e) gives the spatial correlations of the VWSC with CSGP for the cyclones formed over AS during the monsoon seasons. It is observed that negative correlation (-0.9 - 0.0) exists for the genesis of the cyclones during this season. Figure 12 (f) gives the spatial correlations of the VWSC with CSGP for the cyclones formed over AS during the non-monsoon seasons. It is observed that negative correlation (-0.7 – 0.0) exists for the genesis of the cyclones during this season. Figure 12 (g) gives the spatial correlations of the HUM with CSGP for the cyclones formed over AS during the monsoon seasons. It is observed that high positive correlation (0.0 – 0.9) exists for the genesis of the cyclones during this season. Figure 12 (h) gives the spatial correlations of the HUM with CSGP for the cyclones formed over AS during the non-monsoon seasons. It is observed that high positive correlation (0.0 – 0.7) exists for the genesis of the cyclones during this season. Figure 12 (i) give the spatial correlations of the CI with CSGP for the cyclones formed over AS during the monsoon seasons. It is observed that high positive correlation (0.0 – 0.9) exists for the genesis of the cyclones during this season. Figure 12 (j) gives the spatial correlations of the CI with CSGP for the cyclones formed over AS during the non-monsoon seasons. It is observed that high positive correlation (0.0 – 0.7) exists for the genesis of the cyclones during this season. It may be noted that in-order to compensate for large negative contribution from VWSC to CSGP during monsoon season over AS, all other contributing parameters like LLC, LLRV, HUM and CI has to be higher as evident from the large positive correlation between these parameters with CSGP.

Figure 13 gives the spatial correlations between the individual parameters and the CSGP for the cyclones formed over BB during the monsoon and non-monsoon seasons of the study period. Figure 13 (a) shows the spatial correlations of the LLC with CSGP for the cyclones formed over BB during the monsoon seasons. It is observed that high positive correlation (0.0 – 0.5) exists for the genesis of the cyclones during this season. Figure 13 (b) gives the spatial correlations of the LLC with CSGP for the cyclones formed over BB during the non-monsoon seasons. It is observed that high positive correlation (0.0 – 0.6) exists for the genesis of the cyclones during this season. Figure 13 (c) gives the spatial correlations of the LLRV with CSGP for the cyclones formed over BB during the monsoon seasons. It is observed that high positive correlation (0.0 – 0.5) exists for the genesis of the cyclones during this season. Figure 13 (d) gives the spatial correlations of the LLRV with CSGP for the cyclones formed over BB during the non-monsoon seasons. It is observed that high positive correlation (0.0 – 0.6) exists for the genesis of the cyclones during this season. Figure 13 (e) gives the spatial correlations of the VWSC with CSGP for the cyclones formed over BB during the monsoon seasons. It is observed that high negative correlations (-0.5 - 0.0) exists for the genesis of the cyclones during this season. Figure 13 (f) gives the spatial correlations of the VWSC with CSGP for the cyclones formed over BB during the non-monsoon seasons. It is observed that low negative correlations (-0.3 – 0.0) exists for the genesis of the cyclones during this season. Figure 13 (g) gives the spatial correlations of the HUM with CSGP for the cyclones formed over BB during the monsoon seasons. It is observed that a low values of positive correlation exists for the genesis of the cyclones during this season. Figure 13 (h) gives the spatial correlations of the HUM with CSGP for the cyclones formed over BB during the non-monsoon seasons. It is observed that a high positive correlation (0.0 – 0.6) exists for the genesis of the cyclones during this season. Figure 13 (i) give the spatial correlations of the CI with CSGP for the cyclones formed over BB during the monsoon seasons. It is observed that low values of positive correlation exist for the genesis of the cyclones during this season. Figure 13 (j) gives the spatial correlations of the CI with CSGP for the cyclones formed over BB during the non-monsoon seasons. It is observed that a high positive correlation (0.0 – 0.6) exists for the genesis of the cyclones during this season. From this analysis it is generally observed that, the dynamical parameters like, LLC, LRV are more positively contributing towards the development of cyclones over BB during monsoon season. However during non-monsoon months, thermodynamic parameters like HUM and CI is equally contributing to the CSGP parameter along with other dynamical parameters.

Case. 3 Severe cyclones over NIO

Figure 14 presents the spatial correlations between the individual parameters and the CSGP for the severe cyclones formed over AS during the monsoon and non-monsoon seasons of the study period.

Figure 14 (a) gives the spatial correlations of the LLC with CSGP for the severe cyclones formed over AS during the monsoon seasons. It is observed that high positive correlation (0.0 – 0.7) exists for the genesis of the severe cyclones during this season. Figure 14 (b) gives the spatial correlations of the LLC with CSGP for the severe cyclones formed over AS during the non-monsoon seasons. It is observed the high positive correlation (0.0 – 0.5) exists for the genesis of the severe cyclones during this season. Figure 14 (c) gives the spatial correlations of the LLRV with CSGP for the severe cyclones formed over AS during the monsoon seasons. It is observed that high positive correlation (0.0 – 0.7) exists for the genesis of the severe cyclones during this season. Figure 14 (d) gives the spatial correlations of the LLRV with CSGP for the severe cyclones formed over AS during the non-monsoon seasons. It is observed that high positive correlation (0.0 – 0.5) exists for the genesis of the severe cyclones during this season. Figure 14 (e) gives the spatial correlations of the VWSC with CSGP for the severe cyclones formed over AS during the monsoon seasons. It is observed that negative correlation (-0.7 – 0.0) exists for the genesis of the severe cyclones during this season. Figure 14 (f) gives the spatial correlations of the VWSC with CSGP for the severe cyclones formed over AS during the non-monsoon seasons. It is observed that positive correlation (0.0 – 0.6) exists for the genesis of the severe cyclones during this season. But the shear component is having negative correlations with the CSGP. Figure 14 (g) gives the spatial correlations of the HUM with CSGP for the severe cyclones formed over AS during the monsoon seasons. It is observed that high positive correlation (0.0 – 0.7) exists for the genesis of the severe cyclones during this season. Figure 14 (h) gives the spatial correlations of the HUM with CSGP for the severe cyclones formed over AS during the non-monsoon seasons. It is observed that a high positive correlation (0.0 – 0.5) exists for the genesis of the severe cyclones during this season. Figure 14 (i) give the spatial correlations of the CI with CSGP for the severe cyclones formed over AS during the monsoon seasons. It is observed that high positive correlation (0.0 – 0.7) exists for

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the genesis of the severe cyclones during this season. Figure 14 (j) gives the spatial correlations of the CI with CSGP for the severe cyclones formed over AS during the non-monsoon seasons. It is observed that high positive correlation (0.0 – 0.5) exists for the genesis of the severe cyclones during this season. As in the case of cyclones over AS, each individual parameters shows high correlation with CSGP during monsoon months. Another important finding is that the VWSC shows large positive correlation with CSGP over AS during non-monsoon months and this implies that low values of shear co-efficient is essential for the development of severe cyclones over AS during non-monsoon months.

The spatial correlations between the individual parameters and the CSGP for the severe cyclones formed over BB during the monsoon and non-monsoon seasons of the study period are shown in figure 15. Figure 15 (a) gives the spatial correlations of the LLC with CSGP for the severe cyclones formed over BB during the monsoon seasons. It is observed that high positive correlation (0.0 – 0.9) exists for the genesis of the severe cyclones during this season. Figure 15 (b) gives the spatial correlations of the LLC with CSGP for the severe cyclones formed over BB during the non-monsoon seasons. It is observed that high positive correlation (0.0 – 0.6) exists for the genesis of the severe cyclones during this season. Figure 15 (c) gives the spatial correlations of the LLRV with CSGP for the severe cyclones formed over BB during the monsoon seasons. It is observed that high positive correlation (0.0 – 0.9) exists for the genesis of the severe cyclones during this season. Figure 15 (d) gives the spatial correlations of the LLRV with CSGP for the severe cyclones formed over BB during the non-monsoon seasons. It is observed that high positive correlation (0.0 – 0.6) exists for the genesis of the severe cyclones during this season. Figure 15 (e) gives the spatial correlations of the VWSC with CSGP for the depressions formed over BB during the monsoon seasons. It is observed that there exist negative correlation values for the genesis of the severe cyclones during this season. Figure 15 (f) gives the spatial correlations of the VWSC with CSGP for the severe cyclones formed over BB during the non-monsoon seasons. Relatively lower values of negative correlation (-0.2 -0.0) is observed for the genesis of the severe cyclones during this season. But the shear component is having negative correlations for the severe cyclones during both the seasons. Figure 15 (g) gives the spatial correlations of the HUM with CSGP for the severe cyclones formed over BB during the monsoon seasons. It is observed that a high positive correlation (0.0 – 0.9) exists for the genesis of the severe cyclones during this season. Figure 15 (h) gives the spatial correlations of the HUM with CSGP for the severe cyclones formed over BB during the non-monsoon seasons. It is observed that positive correlation (0.0 – 0.6) exists for the genesis of the severe cyclones during this season. Figure 15 (i) give the spatial correlations of the

CI with CSGP for the severe cyclones formed over BB during the monsoon seasons. It is observed that there exists positive correlation (0.0 – 0.9) for the genesis of the severe cyclones during this season. Figure 15 (j) gives the spatial correlations of the CI with CSGP for the severe cyclones formed over BB during the non-monsoon seasons. It is observed that low positive correlation (0.0 – 0.3) exists for the genesis of the severe cyclones during this season.

3.4 Role of individual parameters on CSGP

Figure 16, shows the correlations of each parameters with CSGP around the genesis points of the convective systems during the life time of each storms over NIO. Figure 16 (a), shows the correlations of each parameter for the depressions over AS during the monsoon seasons. From figure 16 (a) it is seen that the parameters such as LLC, LLRV, HUM and CI are having positive correlations with CSGP. The SHR (shear component) is having negative correlations with the CSGP during the monsoon seasons. There exist higher positive correlations for LLC, HUM and CI. This means that these parameters are playing important role in the formation of the depressions over AS during the monsoon seasons. Figure 16 (b), shows the correlations between each parameters and CSGP for the depressions over AS during the non-monsoon seasons. From figure 16 (b) it is seen that the parameters such as LLC, LLRV and HUM are having high positive correlations with CSGP. There are positive correlations for CI, but the magnitude is small, it means that its influence is less on the formation of the depressions over AS during the non-monsoon seasons. It is also noticed that the SHR is having negative correlations with the CSGP during the non-monsoon seasons. It is noted that in the case of DD over AS during monsoon season, dynamical parameters such as LLC and LLRV along with thermo dynamical parameters are equally contributing to CSGP to compensate the negative impact of SHR. However, during non-monsoon season LLRV and HUM parameters are the significant contributing parameters to the CSGP and hence for the development of DD over AS.

Figure 16 (c), shows the correlations of each parameter with CSGP for the depressions over BB during the monsoon seasons. From figure 16 (c) it is seen that the parameters such as LLC, LLRV and HUM are having high positive correlations with CSGP. This means that these parameters are playing important role in the formation of the depressions over BB during the monsoon seasons. There are positive correlations for CI, but the magnitude is small, it means that its influence is less on the formation of the depressions over BB during the monsoon seasons. It is also noticed that the SHR is having negative correlations with the CSGP during the monsoon seasons. Figure 16 (d), shows the correlations of the composite of each parameter for the depressions over BB during the non-monsoon seasons. From figure 16 (d) it is seen that the parameters such as LLC, LLRV, HUM and CI is having positive correlations with CSGP. This means that these parameters are playing important role in the formation of the depressions over BB during the non-monsoon seasons. It is also noticed that the SHR is having negative correlations with the CSGP during the non-monsoon seasons. It is noted that for the formation of DD over BB during monsoon season, dynamical parameters such as LLC and LLRV is contributing significantly to CSGP as compared to HUM and CI parameters. However, during non-monsoon months, LLC, LLRV and HUM and CI are equally contributing to CSGP.

Figure 16 (e), shows the correlations of each parameters with CSGP for the cyclones over AS during the monsoon seasons. From figure 16 (e), it is seen that the parameters such as LLC, LLRV, HUM and CI are having positive correlations with CSGP. This means that these parameters are playing important role in the formation of the cyclones over AS during the monsoon seasons. It is also noticed that the SHR is having negative correlations with the CSGP during the monsoon seasons. Figure 16 (f), shows the correlations of the composite of each parameters for the cyclones over AS during the non-monsoon seasons. From figure 16 (f), it is seen that the parameters such as LLC, LLRV HUM and CI are having positive correlations with CSGP. This means that these parameters are playing important role in the formation of the cyclones over AS during the non-monsoon seasons. It is also noticed that the SHR is having negative correlations with the CSGP during the non-monsoon seasons. Since SHR shows high negative correlation with CSGP during monsoon months, formation of cyclones are favoured with large contribution from LLRV, LLC, HUM and CI parameters as seen from the large positive correlation of these parameters with CSGP. During non-monsoon months, large LLRV, LLC and HUM is more important for the formation of cyclones over AS.

Figure 16 (g), shows the correlations of each parameters with CSGP for the cyclones over BB during the monsoon seasons. From figure 16 (g) it is seen that the parameters such as LLC, LLRV and HUM are having positive correlations with CSGP. This means that these parameters are playing important role in the formation of the cyclones over AS during the monsoon seasons. There are positive correlations for CI but its magnitude is very less, it means that it is not having much influence on the formation of cyclones over BB during the monsoon seasons. It is also noticed that the SHR is having negative correlations with the CSGP during the monsoon seasons. Figure 16 (h), shows the correlations of the composite of each parameter for the cyclones over BB during the non-monsoon seasons. From figure 16 (h) it is seen that the parameters such as LLC, LLRV and HUM are having positive correlations with CSGP. This means that these parameters are playing important role in the formation of the cyclones over AS during the non-monsoon seasons. There are positive correlations for CI but its magnitude is very less, it means that it is not having much influence on the formation of cyclones over BB during the non-monsoon seasons. It is also noticed that the SHR is having negative correlations with the CSGP during the non-monsoon seasons. It is found that during monsoon season, formation of cyclones over BB is governed by the large dynamical contribution such as LLRV, LLC and thermo dynamical contribution from HUM. However, during non-monsoon months both dynamical and thermo dynamical parameters equally contributes to CSGP for the formation of cyclones.

Figure 16 (i), shows the correlations of each parameters with CSGP for the severe cyclones over AS during the monsoon seasons. From figure 16 (i) it is seen that the parameters such as LLC, LLRV, HUM and CI are having positive correlations with CSGP. This means that these parameters are playing important role in the formation of the severe cyclones over AS during the monsoon seasons. It is also noticed that the SHR is having negative correlations with the CSGP during the monsoon seasons. Figure 16 (j), shows the correlations of the composite of each parameters for the severe cyclones over AS during the non-monsoon seasons. From figure 16 (j) it is seen that the parameters such as LLC, LLRV, HUM and CI are having positive correlations with CSGP. This means that these parameters are playing important role in the formation of the severe cyclones over AS during the non-monsoon seasons. It is also noticed that the SHR is having negative correlations with the CSGP during the monsoon seasons. Formation of severe cyclonic storms over AS during monsoon season is favoured by large contribution from LLRV, LLC, HUM and CI with dynamical parameters are contributing more to the CSGP value. During non-monsoon months, both dynamical and the dynamical parameters are equally contributing to the formation of severe cyclones over AS.

Figure 16 (k), shows the correlations of each parameters with CSGP for the severe cyclones over BB during the monsoon seasons. From figure 16 (k) it is seen that the parameters such as LLC, LLRV, HUM and CI are having positive correlations with CSGP. This means that these parameters are playing important role in the formation of the severe cyclones over BB during the monsoon seasons. It is also noticed that the SHR is having negative correlations with the CSGP during the monsoon seasons. Figure 16 (l), shows the correlations of the composite of each parameters for the severe cyclones over BB during the non-monsoon seasons. From figure 16 (l) it is seen that the parameters such as LLC, LLRV, HUM and CI are having positive correlations with CSGP. This means that these parameters are playing important role in the formation of the severe cyclones over BB during the non-monsoon seasons. It is also noticed that the SHR is having negative correlations with the CSGP during the non-monsoon seasons. Contribution of dynamical and thermo dynamical parameters to the CSGP over BB during monsoon and non-monsoon months exhibits almost similar relationship between each parameter and CSGP. More favourable contribution from both dynamical and thermo dynamical parameters are seen during monsoon season. However, LLRV , LLC and HUM is more contributing to CSGP value during non-monsoon months.

4 Conclusions

We have studied the characteristics of CSGP over NIO during the monsoon as well as non-monsoon seasons of the entire study period. All convective systems are grouped into depressions, cyclones and severe cyclones formed during distinct back ground state such as El-Niño, El-Niño Modoki, La-Niña, La-Niña Modoki, Positive IOD, Negative IOD and the Neutral years of both monsoon and non-monsoon seasons. We have also studied the correlations of the composite of the individual parameters with the CSGP for the various categories of the convective systems. Results show that, the new modified index is capable of identifying the favourable cyclogenesis locations as well its further development and decay.. The correlation of each individual parameter with CSGP during monsoon and non-monsoon months reveals that there exists large negative correlation between shear coefficient and CSGP during monsoon season. This implies that shear is mostly limiting the formation of severe and very severe cyclonic storms during monsoon season. It is found that in order to compensate for large negative impact of the shear on cyclogenesis, other contributing factors such as low level relative vorticity and relative humidity should be large enough to overcome the threshold value of CSGP required for the cyclones to form during monsoon season. However during non-monsoon months, due to lower values of the shear coefficient and its reduced negative impact on GSGP, moderate amount of LLRV and HUM along with positive contribution from LLC and CI favours the formation of severe and very severe cyclonic storms over AS and BB.

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Figure 1. Frequencies and per year values of depressions over NIO during the study period

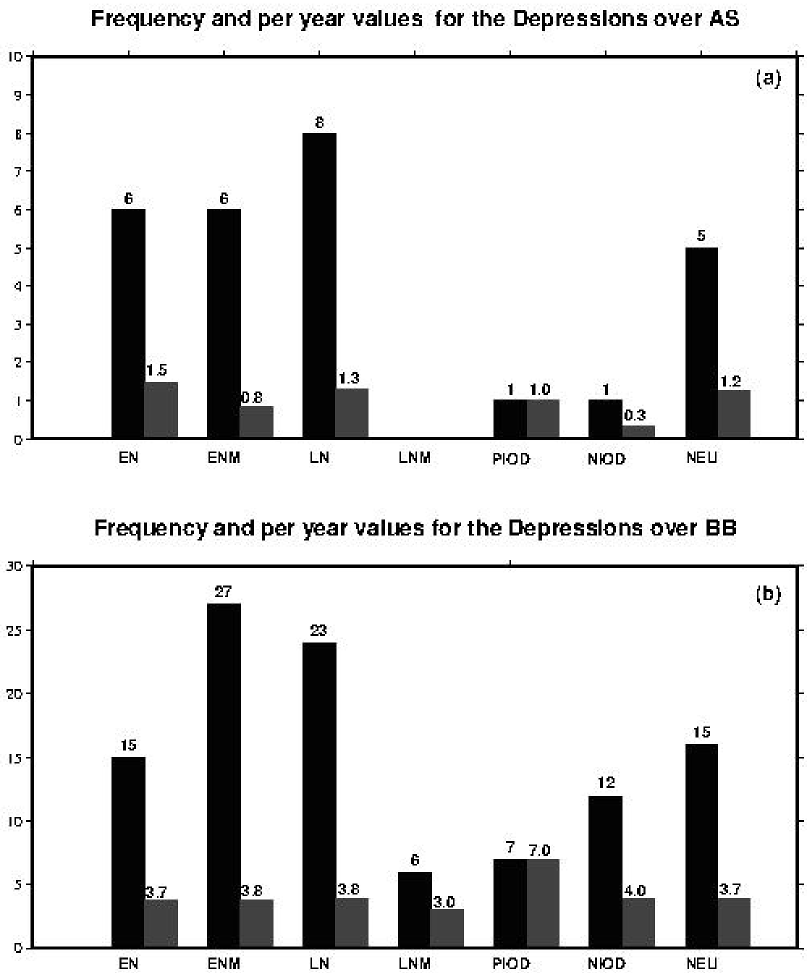

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Figure 2. Seasonal frequencies of depressions over NIO during the Monsoon and Non-Monsoon seasons of the study period

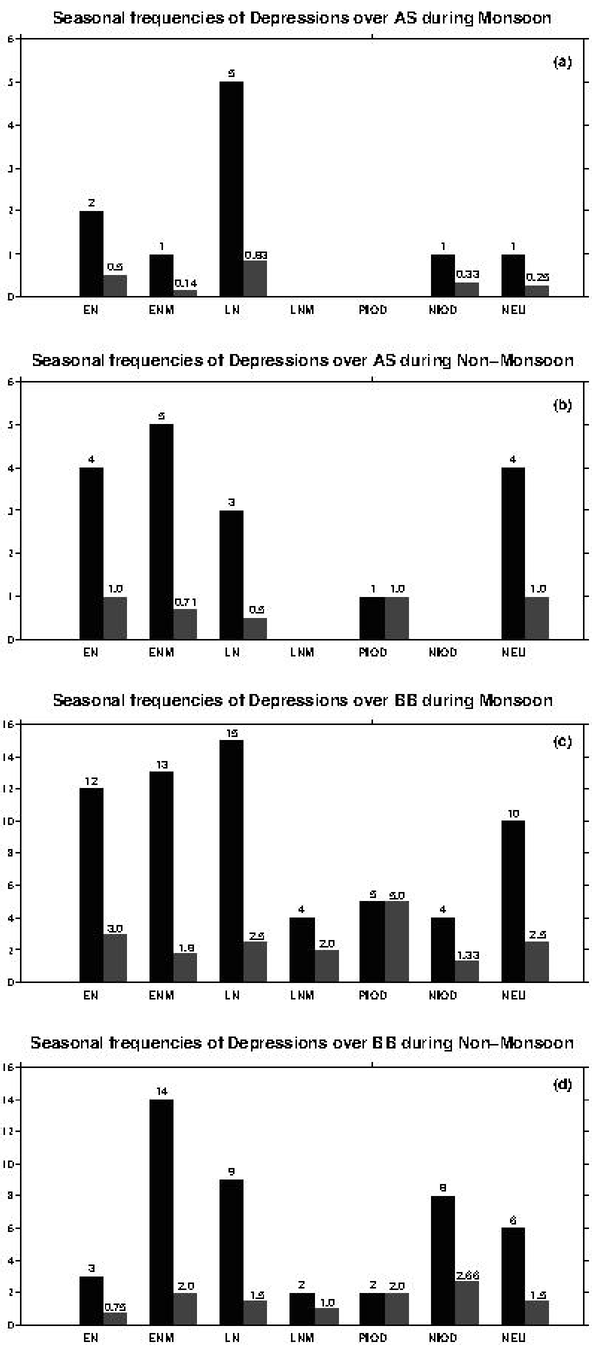

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Figure 3. Frequencies and per year values of cyclones over NIO during the study period

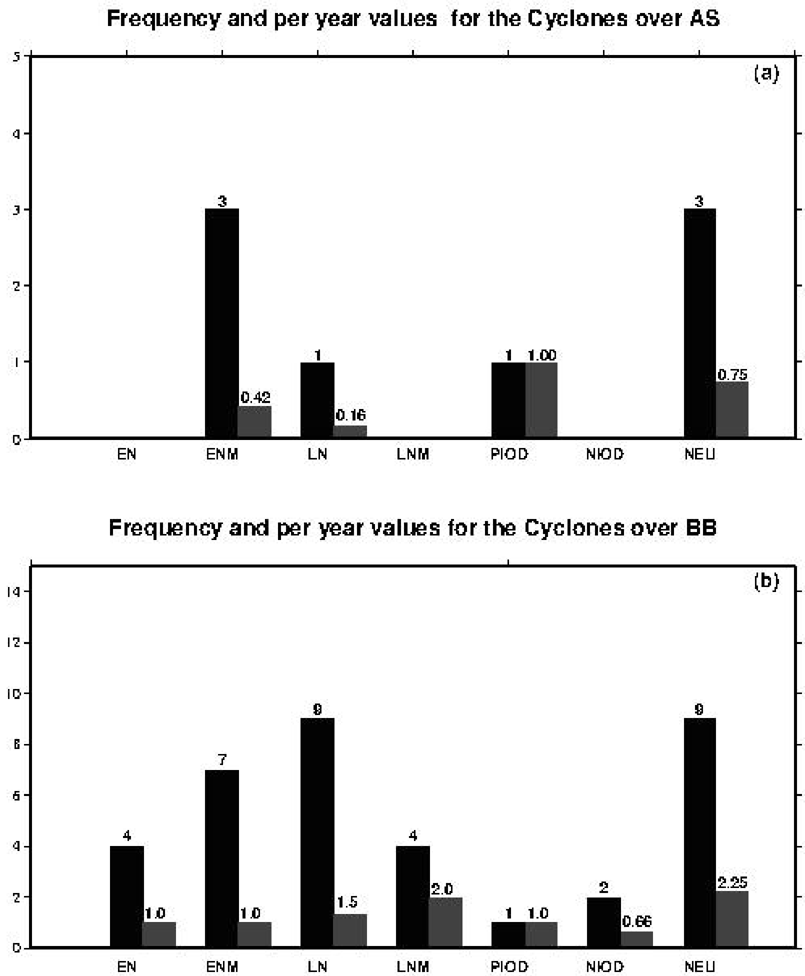

Figure 4. Seasonal frequencies of cyclones over NIO during the Monsoon and Non-Monsoon seasons of the study period

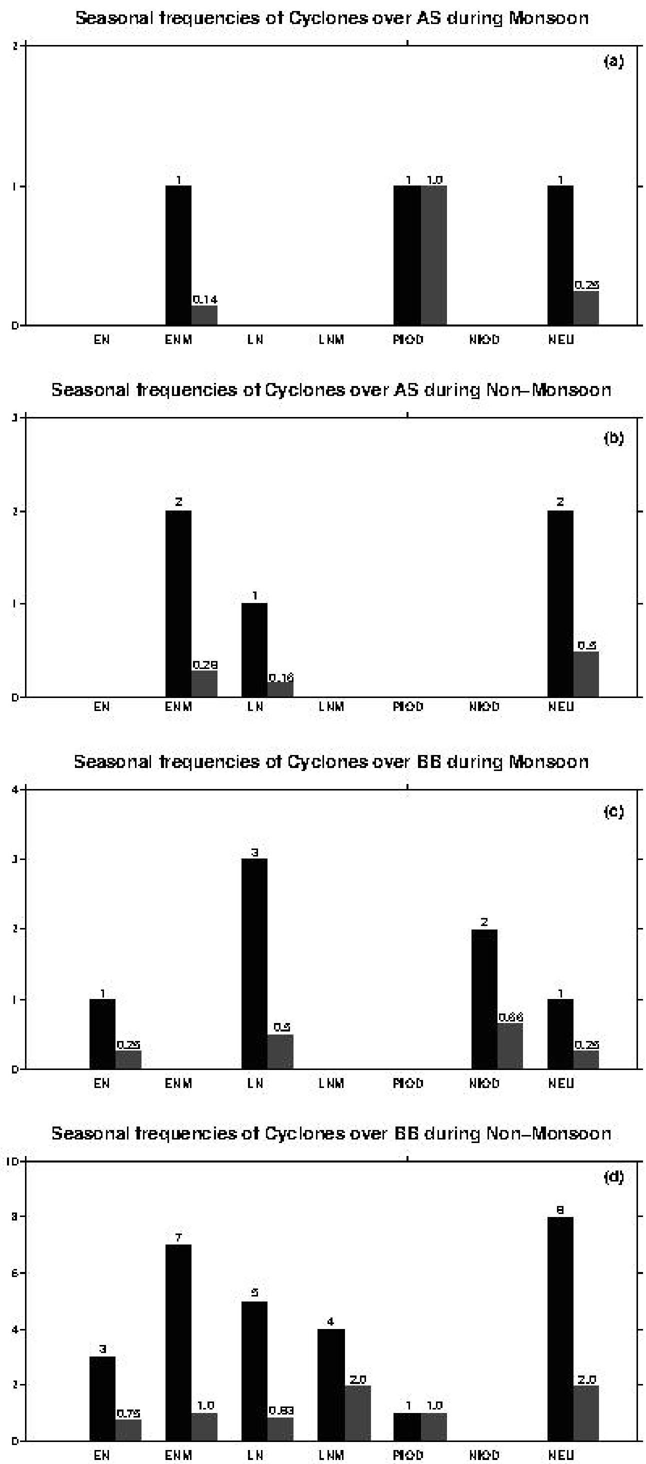

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Figure 5. Frequencies and per year values of severe cyclones over NIO during the study period

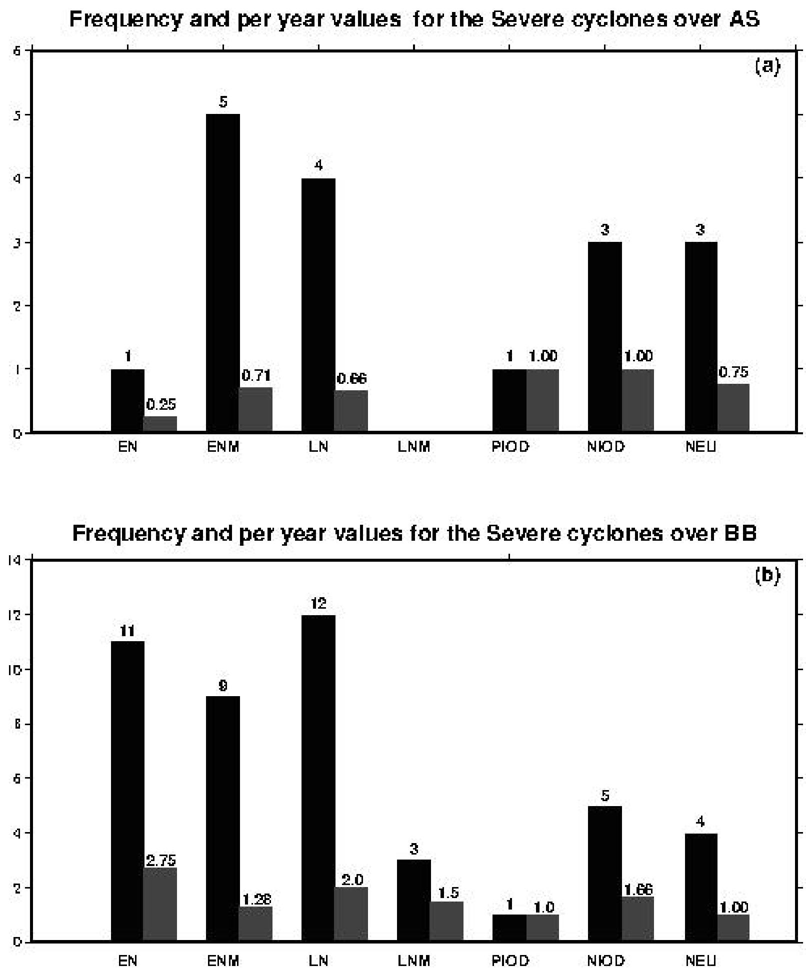

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Figure 6. Seasonal frequencies of severe cyclones over NIO during the Monsoon and Non-Monsoon seasons of the study period

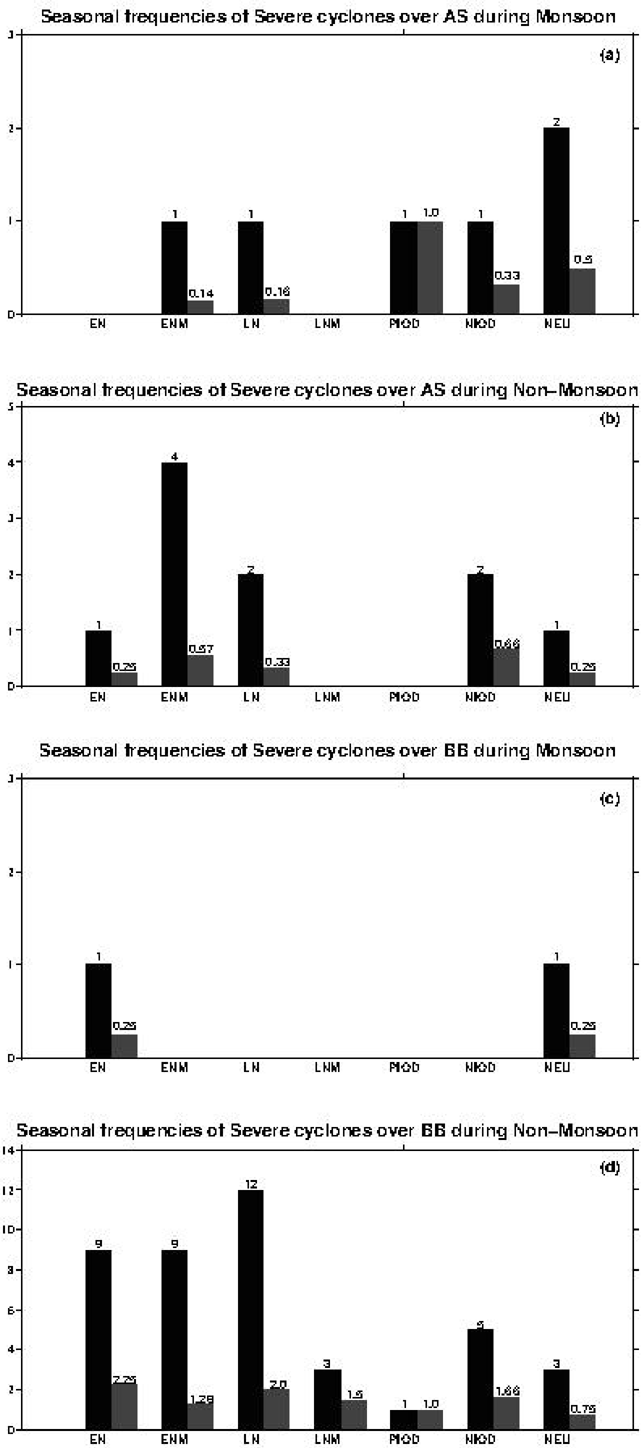

Figure 7. Variations of CSGP for the depressions over NIO during both the seasons of the study period

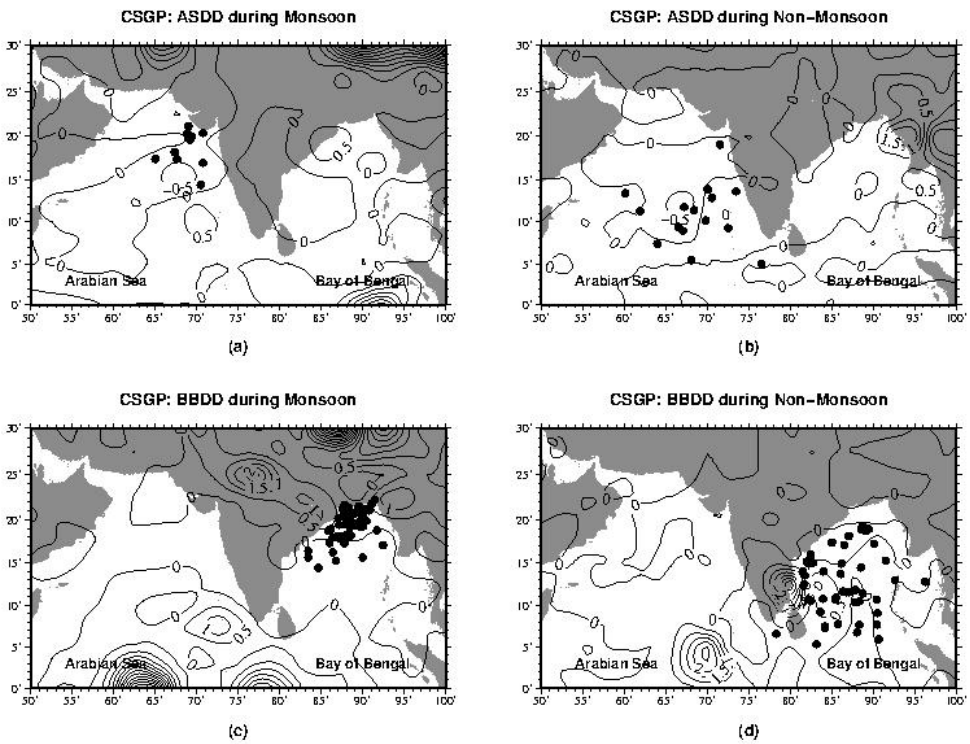

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Figure 8. Variations of CSGP for the cyclones over NIO during both the seasons of the study period

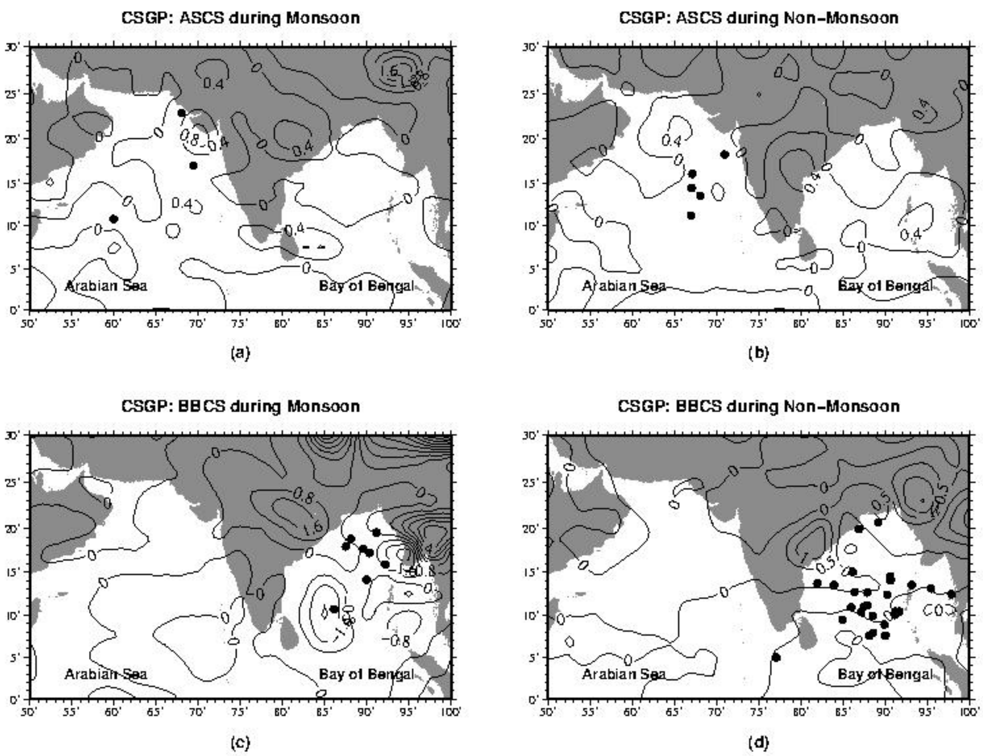

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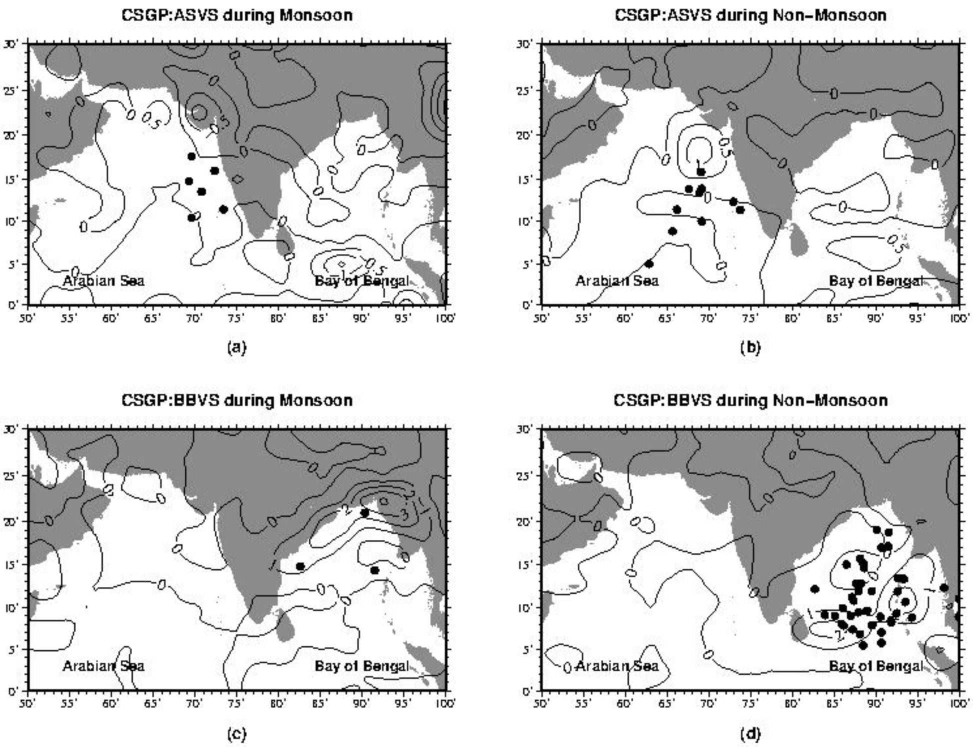
Figure 9. Variations of CSGP for the severe cyclones over NIO during both the seasons of the study period



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1039 Figure 10. Spatial correlations of the composite of each parameters with CSGP for the depressions
1040 over AS during both the seasons of the study period

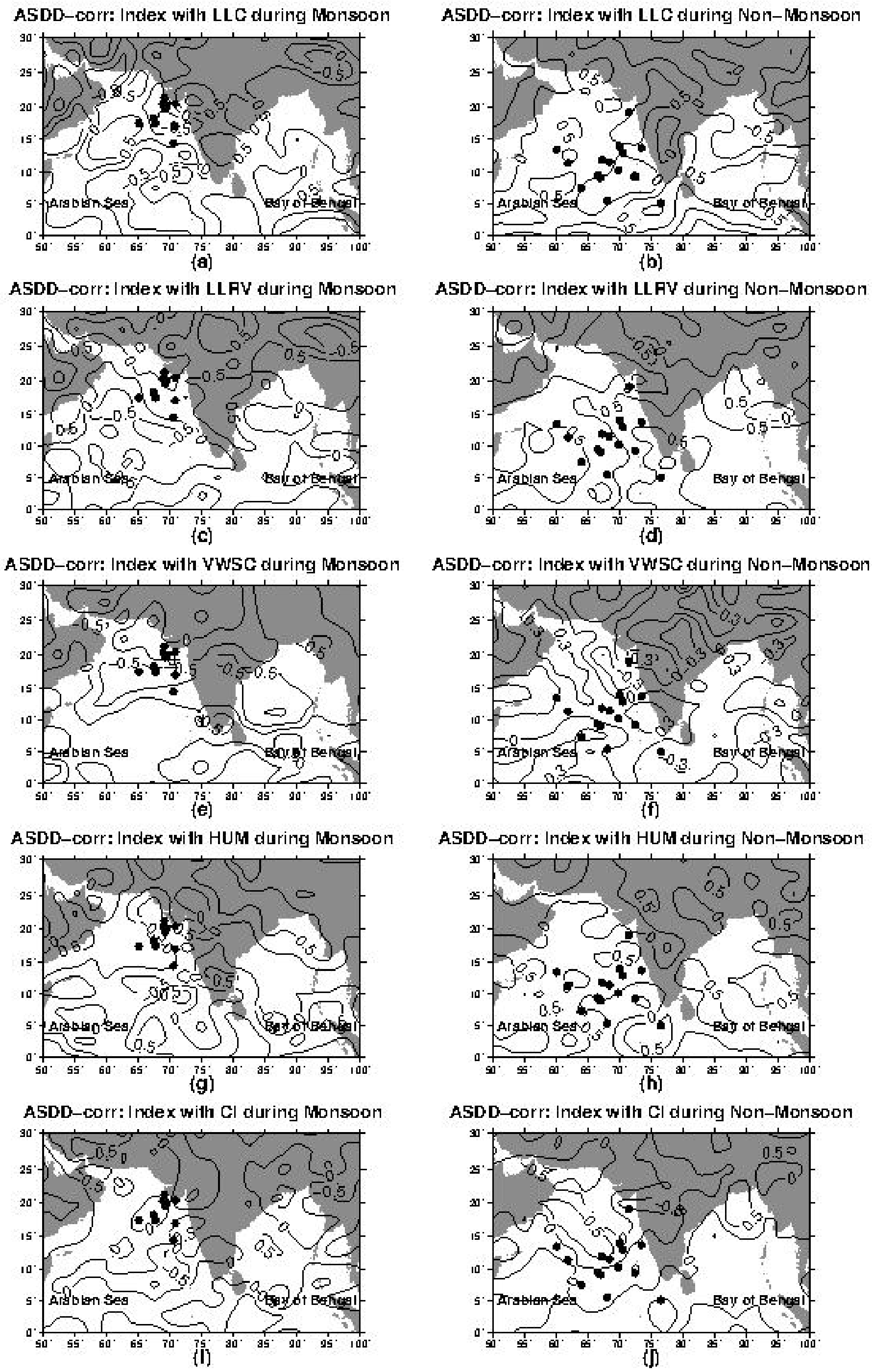

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Figure 11. Spatial correlations of the composite of each parameters with CSGP for the depressions over BB during both the seasons of the study period

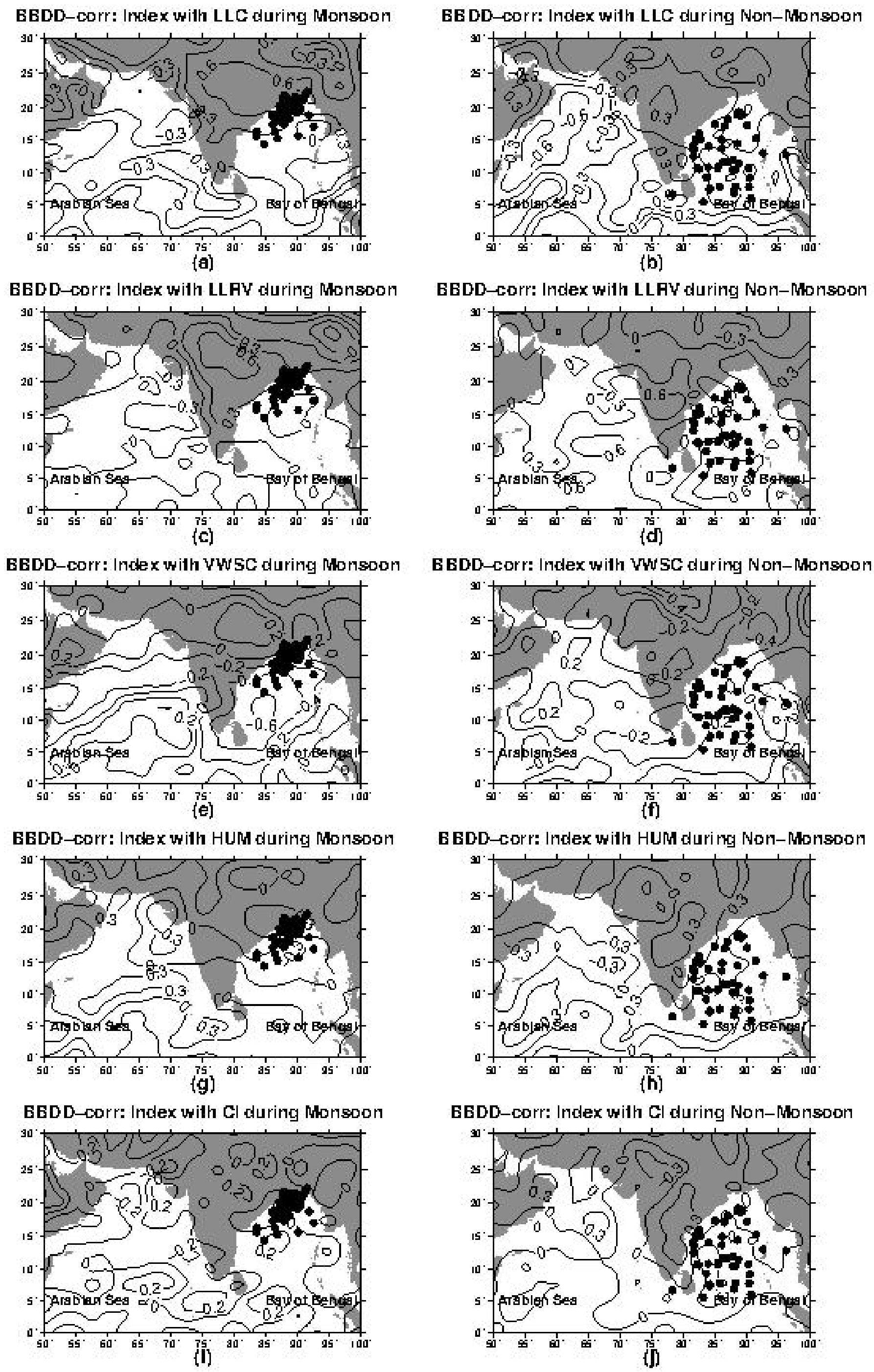

Figure 12. Spatial correlations of the composite of each parameters with CSGP for the cyclones over AS during both the seasons of the study period

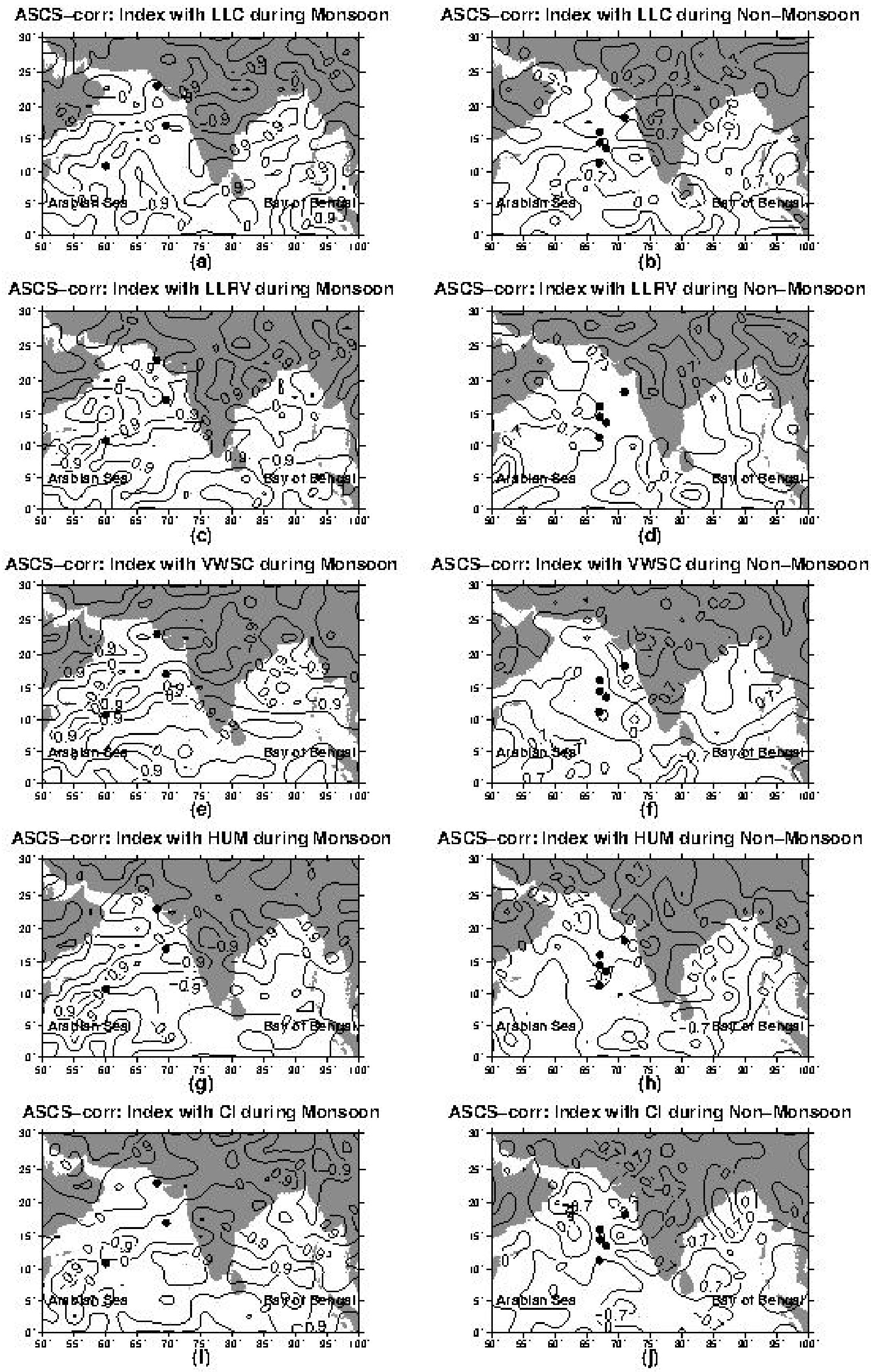

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Figure 13. Spatial correlations of the composite of each parameters with CSGP for the cyclones over BB during both the seasons of the study period

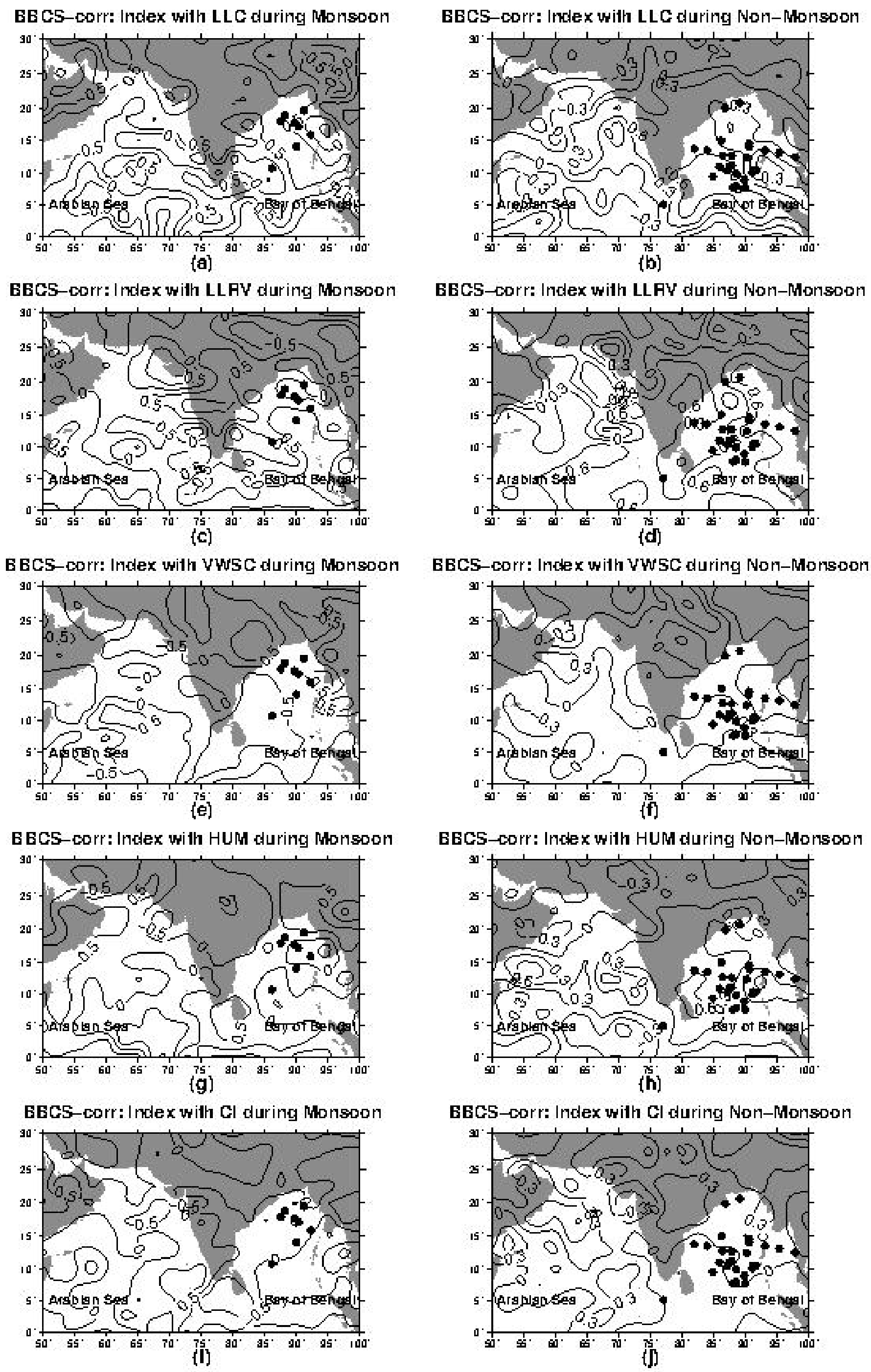

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Figure 14. Spatial correlations of the composite of each parameters with CSGP for the severe cyclones over AS during both the seasons of the study period

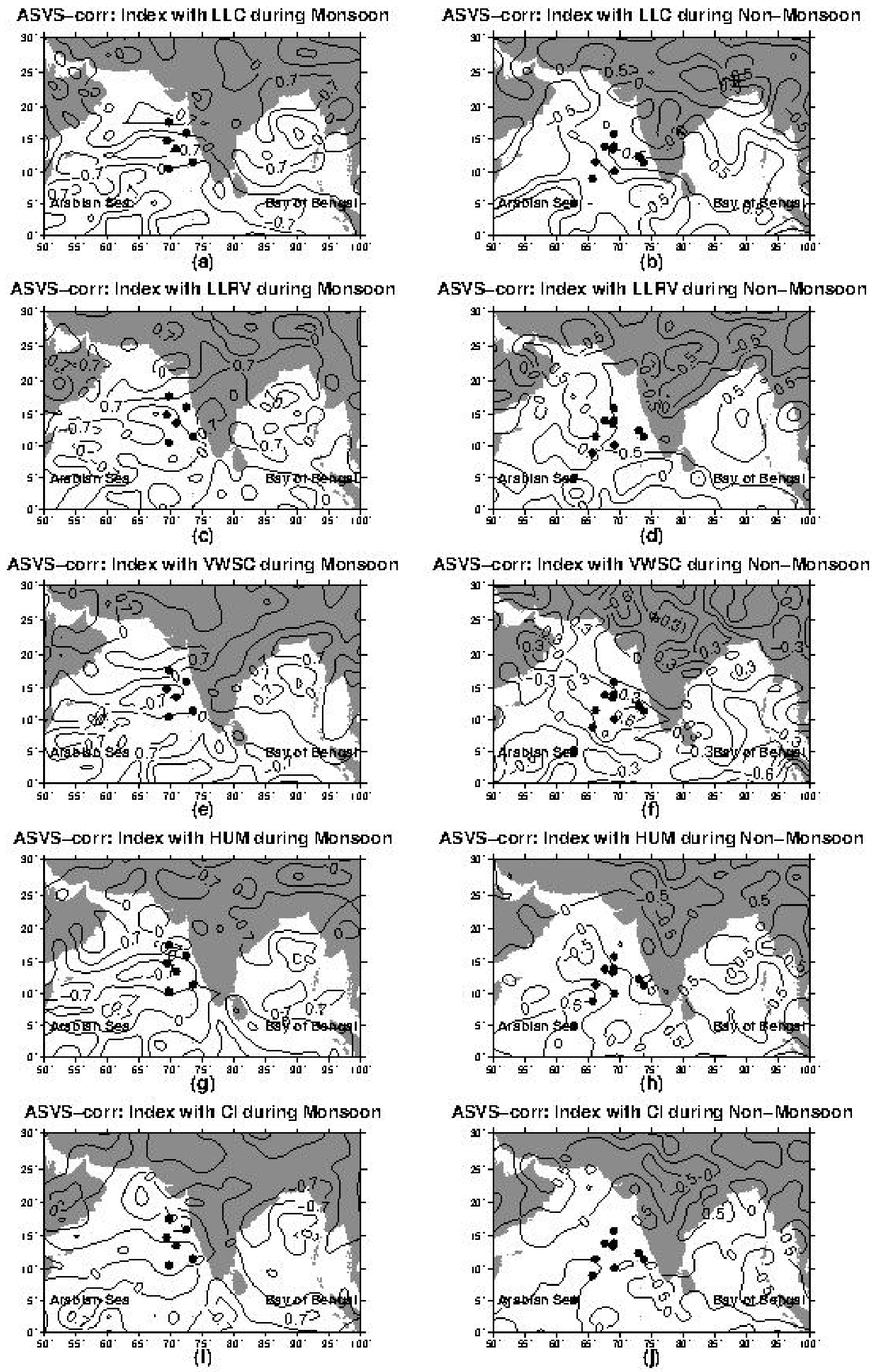
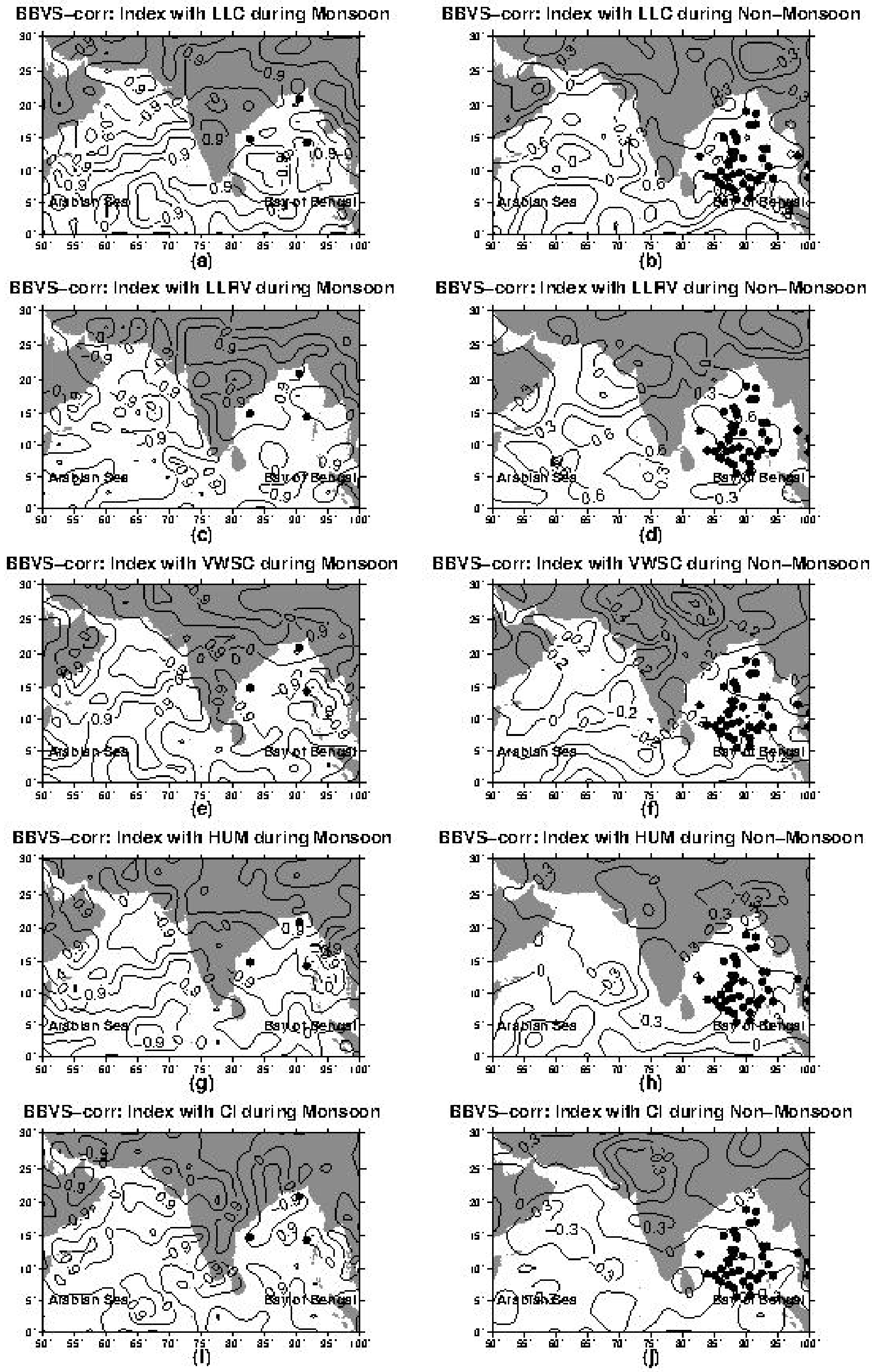


Figure 15. Spatial correlations of the composite of each parameter with CSGP for the severe cyclones over BB during both the seasons of the study period



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1207 Figure 16. Correlation values of each parameter with CSGP for the depressions over NIO

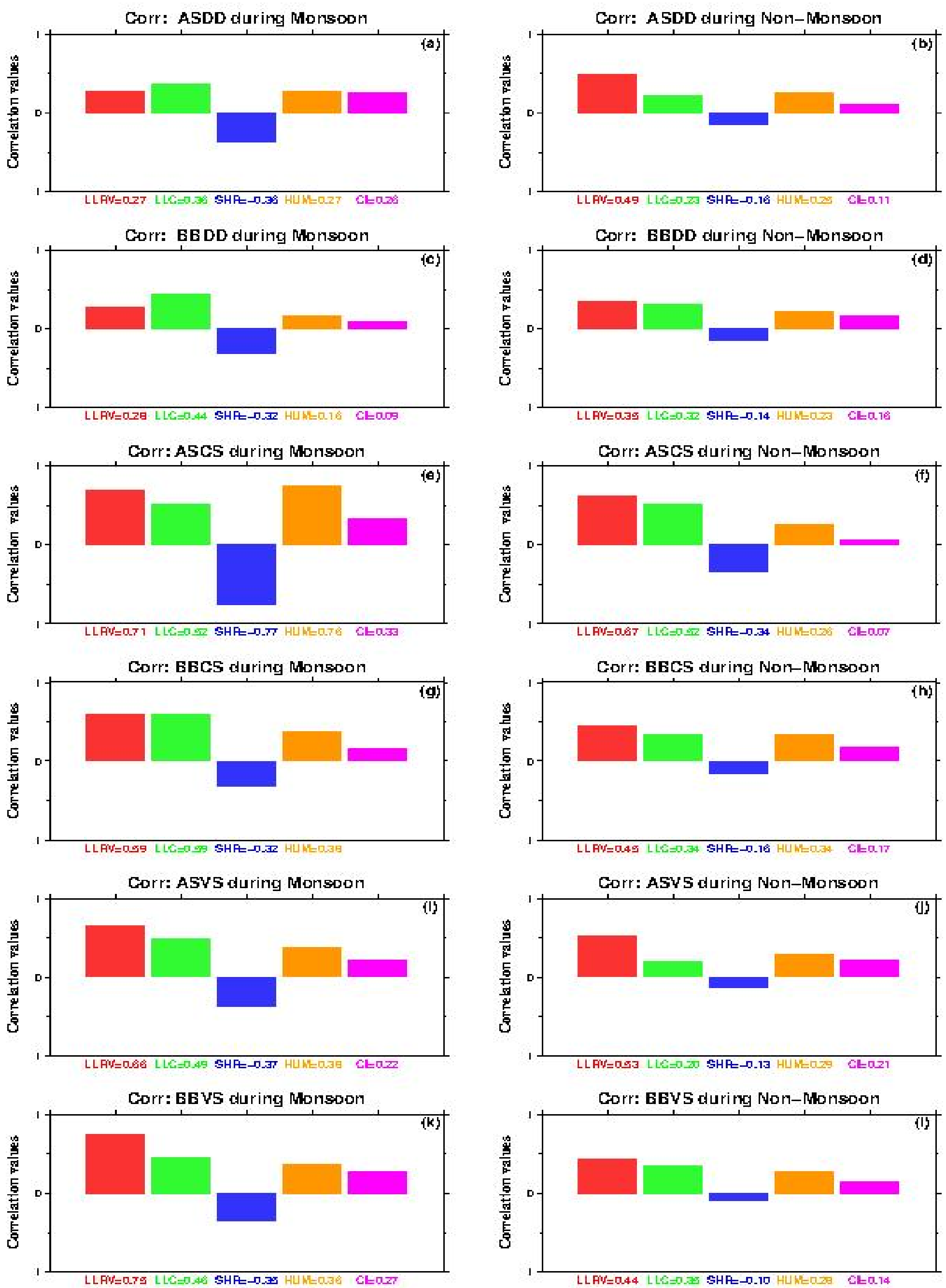

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Table 1. Classification of convective systems over NIO by IMD

Low pressure systems	**Associated wind speeds in Knots / (kmph)**
Low pressure are (LPA)	<17 / (<32)
Depression (D)	17-27 / (32-50)
Deep Depression (DD)	25-33 / (51-59)
Cyclonic storm (CS)	34-47 / (60-90)
Severe cyclonic storm (SCS)	48-63 / (90-119)
Very severe cyclonic storm (VSCS)	64-119 / (119-220)
Super cyclone (SC)	>119 / (>220)

Table 2. Selected ENSO and IOD years during the study period

El-Niño (4)	1982	1983	1987	1997			
El-Niño Modoki (7)	1986	1990	1991	1992	1994	2002	2004
La-Niña (6)	1981	1984	1988	1998	1999	2005	
La-Niña Modoki (2)	2000	2008					
Positive IOD (1)	2007						
Negative IOD (3)	1989	1993	1996				
Neutral (4)	1979	1980	1985	2001			

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Table 3. Total convective systems over NIO in the monsoon and non-monsoon seasons during the study period.

Category	**Arabian Sea**	**Bay of Bengal**		
	Monsoon	Non-Monsoon	Monsoon	Non-Monsoon
Depressions	10	17	63	44
Cyclones	3	5	8	27
Severe Cyclones	5	11	3	42