Chapter 5

Decadal Variation in the Intensity and Frequency of Tropical Cyclones and Monsoon Depressions of North Indian Ocean

5.1 Introduction

The North Indian Ocean cyclones are known to have a bimodal distribution with a primary maximum around October to December and a secondary maximum around March to May (Atlas IMD, 1979; McBride, 1995). The two sub-basins of North Indian Ocean, viz., Arabian Sea and Bay of Bengal, show major differences in tropical cyclone activity. The cyclone activity is more over Bay of Bengal compared to that of Arabian Sea. In the present study we examined the variability of tropical cyclones and monsoon depressions of North Indian Ocean basin. There are two types of climatic variations (a) Type-1: decadal changes (a few decades of increased activity followed by a few decades of decreased activity) a sort of long duration oscillation, and (b) Type-2: long term increase or decrease (trends).
5.2 Results and discussion

5.2.1 Decadal variations of monsoon depressions

Several studies reported that the annual frequency of monsoon depressions has a large decreasing trend (e.g., Bhalme, 1972; Joseph and Xavier, 1999; Kumar and Dash, 2001; Dash et al, 2004). Joseph and Xavier (1999) analysed the annual frequency of tropical cyclones and monsoon depressions of North Indian Ocean for the period 1891-1998 and found that the third harmonic (of period 36 years) has the largest amplitude. The present study focused on the variations in the annual frequency of occurrence of monsoon depressions from 1891 to 2009. Annual frequency of monsoon depressions from 1891 to 2009 is given in figure 5.1. There is a statistically significant and strong decreasing linear trend with a superposed multidecadal oscillation as shown by the 5-year moving average. Harmonic analysis indicates a prominent third harmonic of period 39 years as marked in the figure. We designated this feature as a Four Decade Oscillation (FDO). The frequency of monsoon depressions had reduced from a large number of occurrences (≈ 12 per year) in the 1890’s to a much small number (3-4 per year) in the recent years. The major part of the decrease in monsoon depressions has occurred after 1950s. Separate linear trends for the periods 1891-1960 and 1950-2009 are also shown in figure 5.1. The FDO signal has amplitude of about 1 depression above or below its mean state. In the recent period, FDO amplitude attained the maximum around 1970 and minimum around 1990. During the last 60 years (1950 to 2009) high quality re-analysed data are available (Kalnay et al, 1996). Monsoon depressions and tropical cyclones of the period 1965 to 2009 have been monitored using data obtained from weather satellites. Thus the FDO cycle from 1965 to 2009 had very reliable observational data.

Studies have attributed the changes in the frequency of monsoon depressions to the climate change in the Indian Ocean region especially the changes in SST (Rajeevan et al, 2000; Jadhav and Munot, 2008). Dash et al (2004) found a decrease in the horizontal and vertical wind shears of the mean monsoon flow over India as well as over the Bay of Bengal and decrease in the moisture and convection over the Bay of Bengal area. According to Sikka (1977) one of the
The major synoptic conditions for the genesis of monsoon depression is the strong flow of monsoon LLJ through peninsular India and Bay of Bengal. Monsoon depression is known to be formed in the cyclonic vorticity area associated with LLJ (Sikka, 1977). Studies reveal that the intensity of the LLJ had a decreasing trend during 1950 to 2002 (Joseph and Simon, 2005).

The decrease in the intensity of LLJ (June-September averaged zonal wind through an area bounded by latitudes 10°N to 20°N and longitudes 75°E to 90°E from 1950 to 2009 is shown in figure 5.2. A 5-year running mean is marked in the figure. A 35-45 year filter has been applied to the data and this variation is also marked. It is hypothesized that the FDO and decreasing trend in monsoon depressions are caused by the change in intensity of the monsoon LLJ. In order to find out the strength of the relationship, a correlation analysis has been carried out between the strength of LLJ and the frequency of monsoon depressions during each monsoon. The correlation coefficient increases from 0.35 to 0.56 when 5 year

Figure 5.1: Annual frequency of monsoon depressions from 1891 to 2009.
5.2.2 Rapid warming of the Indian Ocean as related to monsoon depressions

Joseph and Sabin (2008) reported a rapid increase in the SST of the equatorial Indian Ocean during the monsoon season from 1950 which resulted in an increase in the convection over the area. This increased convection resulted in the weakening the monsoon Hadley circulation and the consequent weakening of the LLJ, TEJ and the southern hemisphere STJ (Joseph and Sabin, 2008). The weakening of the LLJ could be the possible cause for the decreasing trend in the frequency of monsoon depressions. The decrease in the intensity of TEJ associated with...
the weakening of monsoon causes a major reduction in the VWS over the region. According to Rao et al (2008) there is a possibility of increasing intensity of the cyclonic disturbances over North Indian Ocean during the summer monsoon. In support of this view, they have shown that a super cyclone *Gonu* formed over the Arabian Sea in 2007 for the first time in the recorded history.

The rapid warming of the Indian Ocean and the corresponding changes in the frequency of monsoon depressions is shown in figure 5.3, 5.4 respectively. For SST, the June-September average over an area bounded by latitudes 5°S to 5°N and longitudes 60°E to 90°E is taken. The SST showed only a small increasing trend prior to 1950 and correspondingly monsoon depressions is also having a small decreasing trend. But after 1950, the SST showed a rapid increasing trend, whereas monsoon depressions showed a rapid decreasing trend during the corresponding period, from about 10 depressions in 1950s to about 3 in 2000s.

**Figure 5.3:** Annual frequency of monsoon depressions from 1891 to 2009.
Figure 5.4: SST of equatorial Indian Ocean averaged over the area 5°S-5°N, 60°E -90°E.

5.2.3 Decadal variation in tropical cyclones

Similar to the climate change in monsoon depressions, the frequency of tropical cyclones in North Indian Ocean basin shows a long-term decreasing trend and a distinct multi-decadal oscillation. Comparing with monsoon depressions, the decreasing trend is smaller in the case of tropical cyclones. The annual frequency of tropical cyclones which formed over the North Indian Ocean basin from 1891 to 2009 is shown in figure 5.5. The filtered 39 year oscillation, 5 year running mean of cyclone frequency and the linear trend are also illustrated. The average number of cyclones has decreased from about 6 in 1890s to nearly 4 in the recent decades. Similar to the decadal oscillations in monsoon depressions, frequency of tropical cyclones also shows multidecadal oscillations with period close to four decades as earlier shown by Joseph and Xavier (1999). The FDO in tropical cyclones has a High Frequency Period (HFP) followed by a Low Frequency Period (LFP).
Similar to monsoon depressions, the FDO signal in tropical cyclones is also having amplitude of about 1 cyclone above or below its mean. In the recent years FDO had its HFP in the decade 1965-1974 and LFP during 1985-1994. These two decades are well covered with the reanalysis datasets and satellite observations.

Although there are multi-decadal modes in the frequency of tropical cyclones reported in other ocean basins, related to Pacific decadal oscillations, Atlantic multidecadal oscillation, and North Atlantic oscillations, none of these is related to the frequency of tropical cyclones and monsoon depressions of North Indian Ocean. The temporal phases of tropical cyclones and monsoon depressions, both are close to each other; there is only a small phase difference of about 4 years, with tropical cyclones leading monsoon depressions as can be seen in figure 5.6 which gives the third harmonic of frequencies of both these systems.

Xavier and Joseph (2000) reported a decadal scale variation in VWS over

Figure 5.5: Annual frequency of tropical cyclones from 1891 to 2009.
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North Indian Ocean which possibly influences the decadal oscillation in frequency of tropical cyclones. Pattanaik (2005) found that it is not SST but the large scale atmospheric circulation that is responsible for the interdecadal variability of cyclones of North Indian Ocean. The FDO in tropical cyclone frequency was studied in detail by considering the variations in Gray (1979) parameters associated with cyclogenesis. Cyclogenesis parameters such as SST, wind at 850 hPa and 200 hPa, VWS, vorticity at 850 hPa, divergence at 200 hPa, and humidity at different levels were analysed. The cyclogenesis parameters were analysed for the area bounded by latitudes 7.5°N-15°N and longitudes 80°E-92.5°E. The cyclogenesis parameters were analysed for this area for the October-December season of 1948 to 2009. Among these variables, VWS and vorticity at 850 hPa has shown a multi-decadal oscillation consistent with the FDO in tropical cyclones. The decadal oscillation in VWS was further analysed for Bay of Bengal considering a larger area bounded by latitudes 7°N-25°N and longitudes 80°E-100°E.

Figure 5.6: Third harmonics of annual frequency of monsoon depressions and tropical cyclones.
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Figure 5.7: The 11-year moving average of VWS over Bay of Bengal (7°N-25°N, 80°E-100°E).

The 11-year running mean of VWS over this area is depicted in figure 5.7. This clearly shows a decadal oscillation in the VWS in phase with the observed FDO in tropical cyclone frequency.

In order to understand the decadal variation in 850 hPa wind flow and vorticity, composites of the parameters are analysed for the HFP and LFP. The difference in 850 hPa wind field between the composites of HFP and LFP is shown in figure 5.8. The normal 850 hPa wind pattern over Indo-Pacific region has westerlies over equatorial Indian Ocean region and easterlies over the equatorial Pacific Ocean which is the lower tropospheric part of the Walker circulation. But from the difference between HFP and LFP (HFP - LFP) (see figure 5.7), it can be seen that the equatorial westerlies over the Indian Ocean region are stronger during HFP compared to the LFP. The equatorial wind averaged over an area bounded by latitudes 2.5°S to 7.5°N and longitudes 50°E to 100°E (marked by a
Box in figure 5.8) shows an FDO in-phase with the tropical cyclone frequency and the vorticity in the cyclone genesis region. The 11 year moving average of North Indian Ocean tropical cyclone frequency, 850 hPa wind over the equatorial Indian Ocean and vorticity at 850 hPa over the cyclone genesis region are shown in figure 5.9. All these parameters are having the same phase. The cyclone genesis region is located just to the north of the area of the equatorial westerly wind which is the cause of the cyclonic vorticity over the genesis region.

The multi-decadal variability in the equatorial westerlies over North Indian Ocean has been analysed in relation to the variations in SST over a large area of the Indian Ocean. The difference between SST of two areas, box-A (5°N-20°N, 80°E-100°E) and box-B (10°S-5°N, 50°E-70°E) (marked in figure 5.10 on either side of the anomalous equatorial westerly wind was calculated. It is hypothesized
that higher SST values over box-A can cause an increase in convection over box-A compared to box-B, which in turn can enhance the westerly flow over the equatorial Indian Ocean. The SST differences between the boxes using HadISST as well as ERSST have been calculated. The 11 year moving averages of the SST difference between the two boxes for the season October-December of 1891 to 2009 are shown in figure 5.11. It can be seen that the SST difference is also showing a decadal oscillation almost similar to the FDO in tropical cyclones. The three cycles of the FDO in tropical cyclones are thus associated with the SST. Accordingly, there is a possibility that the SST difference is forcing decadal changes in atmospheric circulation over North Indian Ocean causing the decadal variation in tropical cyclones. The cause of the FDO in the SST difference between boxes A and B is however not known.

5.2.4 Decadal changes in intensity of tropical cyclones

The long-term trends in the intensity of tropical cyclones are a matter of debate because of the data reliability issues. Although certain studies have shown an increase in intensity of tropical cyclones over the years in some ocean basin
(Emmanuel, 2005; Webster, 2005), reliability of the observed long-term data is a matter of concern. Knapp and Kossin (2007) observed that, Indian Ocean has been poorly monitored until the launch of the MeteoSat-7 satellite in 1998 and the view-angle between the existing satellites and storms in Indian Oceans was often highly oblique. Also studies reveal that the existing global hurricane records are too inconsistent to accurately measure trends from the data (Kossin et al, 2007). Using the available tropical cyclone intensity data from India Meteorological Department, the variations in the intensity of North Indian Ocean tropical cyclones are analysed. Based on the maximum sustained wind associated with the cyclone, two categories of tropical cyclones were studied; cyclonic storms (with maximum sustained wind between 34 and 47 knots) and severe cyclonic storms (with maximum sustained wind above 48 knots).

In order to investigate the climate change in the intensity, ratio of the annual frequencies of severe cyclonic storms to the cyclonic storm of North Indian Ocean basin has been calculated from 1891 to 2009. This ratio and its 5 year moving average are given in figure 5.12. The linear trend of this ratio for the full period 1891 to 2009 is marked in this figure. Linear trends representing two different

Figure 5.10: The two areas (A and B) chosen for SST studies.
Figure 5.11: The SST difference between the two areas during October to December.

5.3 Conclusion

Tropical cyclone frequency of North Indian Ocean basin is small compared with other ocean basins, but these cyclones have caused large loss of life to those living around the Indian Ocean. Monsoon depressions are important rain producing systems of the monsoon. An attempt is made to study the multidecadal oscillations and long-term trends in the occurrence of these systems using the historical periods; (a) from 1891 to 1964 where satellite observations were not available and (b) from 1965 to 2009 where satellite data was used in determining the intensity of the cyclone are also shown in the figure. The ratio varied between 20% and 50% in the earlier period. It increased to 50% to 80% in the later period. The observed shift in the intensity of tropical cyclones around 1965 may be due to the better monitoring capabilities of the satellite era. Even in the satellite era, studies (Landsea et al, 2006) have questioned the possibility of false trends arising due to the methods of intensity estimation using Dworak technique, since in the earlier stages of satellite era there were only few satellites with very low resolution.
datasets archived by the India Meteorological Department. Although the long-term trend in both tropical cyclones and monsoon depressions shows a decrease in their annual frequency, decrease of monsoon depression frequency is large and statistically significant. The multidecadal variation in both tropical cyclones and monsoon depressions has a Four Decade Oscillation (FDO) with almost the same amplitude and temporal phase. Since the two systems tropical cyclones and monsoon depressions occur in different seasons and with mostly different atmospheric and oceanic environment, the physical parameters related to these systems were studied separately.

Of the several parameters analysed, it is found that the intensity of the monsoon LLJ is the main factor affecting the variability in monsoon depression frequency. The weakening of meridional monsoon Hadley circulation associated with the rapid warming of the equatorial Indian Ocean has been found related to the weakening the monsoon LLJ. This weakening is a most likely cause of the decreasing trend in the frequency of monsoon depressions. Also, the FDO in the

Figure 5.12: The ratio of cyclones to severe cyclones.
frequency of monsoon depressions is found to be related to the decadal changes in the strength of LLJ passing through peninsular India and the Bay of Bengal. In order to study the multidecadal variations in tropical cyclones, the cyclogenesis parameters were analysed for the October-December season, which is the primary season for tropical cyclone activity in North Indian Ocean. For tropical cyclones the rate of decrease in annual frequency is small compared with that of monsoon depressions. But the predominant variation is a multidecadal variability (FDO). FDO in tropical cyclone frequency are not shown by the cyclogenesis parameters of Gray (1979) except the vertical wind shear (VWS) between 850 hPa and 200 hPa and the 850 hPa vorticity over the tropical cyclone genesis region of Bay of Bengal.

The VWS averaged over an area bounded by latitudes 7°N-25°N and longitudes 80°E-100°E shows a multidecadal oscillation which has the same phase as the FDO in tropical cyclones. The decadal oscillation in 850 hPa vorticity is found to be associated with the changes in atmospheric circulation patterns. An area of anomalous equatorial westerly wind flow exists during the High Frequency Period (HFP) of tropical cyclones over the equatorial Indian Ocean which is causing the FDO in vorticity over the tropical cyclone genesis region. The multidecadal variability in the difference of SST between two areas in the eastern and western parts of North Indian Ocean, shows a irregularity which seems to be causing the FDO in the equatorial westerlies. The three major FDO cycles in the annual frequency of tropical cyclones can be clearly seen in the decadal variations of the SST difference between the two areas.