Tropical Storms over North Indian Ocean during Summer Monsoon tend to intensify in a Warming Environment

by

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Abstract

Tropical Easterly Jet (TEJ) of summer monsoon over North Indian Ocean is weakening in recent years. This is because of higher warming on the equatorial side of TEJ than on the northern side, although on both sides a significant warming trend is seen. This warming seems to be a part of the general warming trend known to be occurring since mid 1970s. The easterly shear shows a strong positive correlation (significant at 99.9% level by students' t-test) with the number of severe storms suggesting that a decrease in easterly shear is favorable for the formation of more severe storms. Thus if the present decreasing trend of TEJ intensity continues, which is highly probable in view of presently occurring greenhouse warming, there is a strong likelihood of the formation of tropical cyclones of hurricane intensity even during the summer monsoon. Presently these intense systems are known to form only in the pre and post monsoon seasons, when the vertical wind shear is small.

1. Introduction

Many studies suggested (Aravequia et al, 1995; Moorthi and Arakawa, 1985; Mishra and Salvekar, 1980; Shula, 1977, 1979) that the mechanism for the generation of the monsoon depressions which occur during the period June through September is baroclinic instability of tropical easterly jet (TEJ) and the higher shear is favorable for higher growth rates and larger number of depressions. While in a land mark paper (Gray, 1968), it was suggested that the tropical cyclones of hurricane intensity over several ocean basins including North Indian Ocean basin occur only when the vertical wind shear is small (around 10 m s^{-1} between 950 – 200 hPa, according to Zehr, 1992). In another study (De Maria, 1996), using observational and theoretical analysis it was shown that weaker vertical shear is favorable for the tropical cyclone development and intensification. Weaker tropospheric vertical wind shear is shown to be an important factor for the development of intense or major hurricanes in the Atlantic basin (Klotzbach and Gray, 2006). In a recent study, Rao et al. (2004) found that the TEJ strength during the Asian summer monsoon period shows a strong decreasing trend in recent years. It is known that tropical cyclones of hurricane intensity occur in the North Indian Ocean basin only during the pre and post monsoon period. This is probably because of the small vertical shear that occurs in these seasons. While during the summer monsoon season the vertical (easterly) shear is strong and prevents the formation of cyclones of hurricane intensity. But the decrease of vertical shear associated with the decrease of TEJ strength (Rao et al., 2004) might generate conditions favorable for the development of cyclones of hurricane intensity over North Indian Ocean basin even during the summer monsoon season. Thus the purpose of the present paper is to investigate the relationship between the decreasing trend of TEJ strength and the formation of intense tropical cyclones in this region.

2. Data

The data used in this study are: wind and temperature data for the period 1951-2000 obtained from the NCEP-NCAR (National Centers for Environmental Predictions/National Center for Atmospheric Research) reanalysis data set (Kalnay et al., 1996) and data for the cyclonic systems over North Indian Ocean for the same period obtained from the Indian Meteorological Department (IMD) (1979, 1996). Depressions and severe storms are defined according to the wind intensity up to 33 knots and greater than 48 knots respectively (IMD, 1979).

3. Results

Figure 1a shows the average vertical shear between 200 hPa and 850 hPa for the period 1951 – 2000 for the region 0^0 – 5^0 N and 40^0 – 100^0 E (Region – R1). The linear trend during this period of 50 years shows a decrease of 4 m s^{-1} in easterly shear, which is significant at 99.9% level by students't-test. Fig. 1b shows the north-south temperature gradient for the layer, 500 hPa – 100 hPa between 15^0 – 20^0 N (Region – R2) and R1 region for the same longitudinal belt. The linear decreasing trend of temperature gradient for 15^0 latitude width is about 0.8^0 C in 50 years which is also significant at 99.9% level.

Now we show that over both the regions R1 and R2 air temperature shows a strong environmental warming. Nevertheless, temperature over the lower latitudes increases at a higher rate than that of higher latitudes. Figs. 2a and 2b show the 11-year running averages of temperature for the same vertical layer for the lower and higher latitudes respectively (please note the difference in ordinate scale in the figures). At both lower and higher latitudes the 11-year running means show a decrease of temperature from 1956 through early seventies and then an increase up to around middle eighties and then a decrease. But at both latitudes there is a strong and significant linear increasing trend (significant at 99.9% level) during the period considered. In the lower latitudes the linear increase in air temperature is 1.2^0 C compared to 0.3^0 C in the higher latitudes in 50 years. This warming seems to be a part of the global warming trend known to be occurring since 1970s (Jones et al., 1999). Thus as expected, a decrease in the easterly jet shear seen earlier is due to decrease in the temperature gradient or relatively higher warming in the lower latitudes.

Table 1 shows the correlation between the wind shear over different layers and frequency of depressions and severe storms for the period 1951-2000. In addition to R1 and R2 regions, the correlation values for the intermediate region R3 (5^0 – 15^0 N, 40^0 – 100^0 E) are also given. It is seen in the table that the correlation between the number of depressions and shear is negative (correlations of 0.27, 0.35 and 0.43 are significant at 95%, 99% and 99.9% levels respectively by students' t-test) i.e. higher easterly wind shear generates more depressions. Interestingly on the other hand the correlation between the shear and the frequency of the severe storms is positive i.e. lower shear is favorable for the higher number of severe storms. Last column of Table 1 clearly shows that over

North Indian Ocean basin even during summer monsoon a lower shear is favorable for severe storms. Fig. 3 shows the wind intensity during the last 16 years of cyclonic systems over North Indian Ocean (http://Weather.Unisys.Com/hurricanes/). This figure shows a linear increase of about 35 knots for the last 16 years. A severe storm of category 3 according Saffir – Simpson scale (Simpson, 1974) was recorded in the month of June 1998 for the first time during the summer monsoon season as seen in the above data source. This storm intensified into a category 3 storm from 1st June 1998. The vertical zonal wind shears between 200-850 hPa for 1, 2, 3 and 4th June 1998 are respectively –17, -17, -18 and –17 m s^{-1} compared to June 1998 monthly mean of –26 m s^{-1}. In the previous years 1996 (June) and 1997 (September) two storms of category 1 have occurred. Thus positive correlation noted earlier in the last column of Table 1 together with the increasing tendency in wind intensity of monsoon cyclonic systems seen in Fig. 3 strongly suggests that the decreasing trend of the TEJ favors the formation of intense cyclonic systems in future over the North Indian Ocean basin even during the summer monsoon season. Severe tropical cyclonic systems of hurricane intensity are known to occur only during pre- (April and May) and post-monsoon (October and November) seasons when the vertical wind shear is within Zehr threshold value (Gray, 1968; Zehr, 1992; Rao et al., 2001). With the above noted decreasing trend of wind shear, the season of tropical cyclones of hurricane intensity might extend in future to the months of June and September because of presently existing lesser wind shear in these months compared to that of July and August. Severe cyclonic storms in the recent years of intensity 3, 1 and 1 by Saffir – Simpson Scale noted above occurred either in June or September, thus supporting this conclusion.

Earlier, Rao et al. (2004) found a strong negative correlation between the TEJ strength and the number of Bay of Bengal cyclonic systems of which monsoon depressions form a major part. That is, the number of monsoon depressions tends to decrease with the decrease of TEJ strength. The negative correlation between the vertical shear of TEJ and monsoon depressions in Table 1 confirms this result. The positive correlation in the last column of Table 1, as mentioned above, suggests that the severe tropical storms tend to increase with the decreasing TEJ. This decrease of monsoon depressions and increase of severe storms seem to be associated with the decrease of moderate rain events and increase of extreme rain events during 1981-2000 noted by Goswami et al. (2006). Thus the tendency to increase severe storms together with the increase of extreme rain events increases substantially the disaster potential in this region.

4. Conclusions

The TEJ strength during the summer monsoon period of June through September shows a strong decreasing trend in recent years. This is because of higher warming on the equatorial side of TEJ than on the northern side, although on both sides a significant warming trend is seen. This warming seems to be a part of the general warming trend known to be occurring since mid 1970s. There is a strong positive correlation (significant at 99.9% confidence level) between the easterly shear and the number of severe storms suggesting that a decrease in easterly shear is favorable for the formation of more severe storms. This suggests that if the present decreasing trend of TEJ intensity continues, which is highly probable in view of presently occurring greenhouse warming, there is a strong likelihood of the formation of tropical cyclones of hurricane intensity even during the summer monsoon.

References

Aravequia, J., V. B. Rao, and J.P. Bonatti. The role of moist baroclinic instability in the growth and structure of monsoon depressions. *J. Atmos. Sci.,* 52, 4393 – 4401, 1995.

De Maria, M. Effect of vertical shear on tropical cyclone intensity change. *J. Atmos. Sci*., 53, 2076-2087, 1996.

Goswami, B. N., V. Venugopal, D. Sengupta, M. S. Madhusoodanan, and P. K. Xavier. Increasing trend of extreme rain events over India in a warming environment. *Science*, 314, 1442-1445, 2006.

Gray, W.M. A global view of the origin of tropical disturbances and storms, *Mon. Wea. Rev.,* 96, 669-700, 1968.

India Meteorological Department, Government of India, New Delhi. Tracks of storms and depressions in the Bay of Bengal and Arabian Sea 1877-1970, 1979.

India Meteorological Department, Government of India, New Delhi. Tracks of storms and depressions in the Bay of Bengal and Arabian Sea 1971-1996, 1996. And also “Daily Weather Reports during 1997 – 2000”.

Jones, P.D., M. New, D.E. Parker, S. Martin, and I.G. Rigor. Surface air temperature and its changes over the past 150 years. *Rev. Geophys.*, 37, 173-199, 1999.

Kalnay, E., et al. The NCEP/NCAR 40 year reanalysis project. *Bull. Am. Meteorol. Soc.,* 77, 437-471, 1996.

Klotzbach, P. J., and W. M. Gray. Causes of the unusually destructive 2004 Atlantic basin hurricane season. *Bull. Amer. Meteor. Soc*., 87, 1325-1333, 2006.

Mishra, S.K., and P.S. Salvekar. Role of baroclinic instability in the development of monsoon depression. *J. Atmos Sci. 37,* 383-394, 1980.

Moorthi, S., and A. Arakawa. Baroclinic instability with cumulus heating. *J. Atmos. Sci.* 42, 2007 – 2031, 1985.

Rao, B. R. S., D. V. B. Rao, and V. B. Rao. Decreasing trend in the strength of Tropical Easterly Jet during the Asian summer monsoon season and the number of tropical cyclonic systems over Bay of Bengal. *Geophy. Res. Let.* 31, doi 10.1029/2004GL019817, 2004.

Rao, D.V. B., C. V. Naidu, and B. R. S. Rao. Trends and fluctuations of the cyclonic systems over North Indian Ocean. *Mausam,* 52, 37-46, 2001.

Shukla, J. Barotropic-baroclinic instability of mean zonal wind during summer monsoon. *Pure Appl. Geophys.* 115**,** 1449-1462, 1977.

Shukla, J. CISK barotropic – baroclinic instability and the growth monsoon depressions. *J. Atmos. Sci.* 35, 495-508, 1978.

Simpson, R.H. The hurricane disaster potential scale. *Weatherwise,* 27, 169– 186, 1974.

Zehr, R.M. Tropical cyclone genesis in the western north Pacific. NOAA Technical Report. NESDIS, 61, NOAA – NESDIS.181 pp, 1992.

Table legend

Table 1: Correlation coefficients between the cyclonic systems and vertical wind shear for the regions R1 (0^0 – 5^0 N, 40^0 – 100^0 E), R2 (15^0 – 20^0 N, 40^0 – 100^0 E) and R3 (5^0 – 15^0 N, 40^0 – 100^0 E). (*, ** and *** indicate the levels of significance, 95%, 99% and 99.9% respectively)

Figure legends

Fig. 1: a) Vertical shear flow for the zonal component (June-September) in R1 (0°-5°N, 40°-100°E) region and b) meridional upper air temperature gradient (R2-R1) for the layer 500-100 hPa (June-September).

Fig. 2: 11-year running averages of mean air temperatures for the layer 500-100 hPa during monsoon season over the region: a) R1 and b) R2.

Fig. 3: Time series of cyclonic wind intensities over North Indian Ocean during monsoon season.

Table 1

Layer	Region	Depressions	Severe Storms
200 – 925 hPa shear	R1	-0.17	0.41**
	R2	-0.11	0.41**
	R3	-0.18	0.53***
200 – 850 hPa shear	R1	-0.22	0.37**
	R2	-0.13	0.38**
	R3	-0.26	0.53***
150 – 850 hPa shear	R1	-0.32*	0.32*
	R2	-0.28*	0.39**
	R3	-0.36**	0.47***