

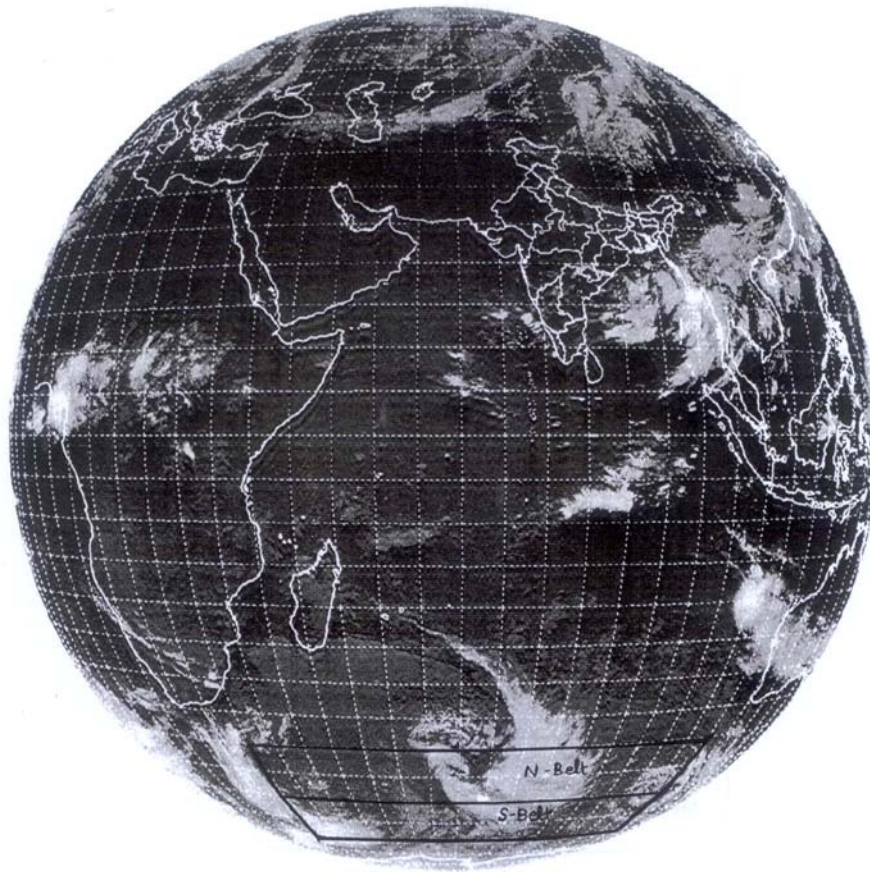
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**ON THE CORRESPONDENCE BETWEEN  
RAINFALL ANOMALY OVER INDIA AND THE  
EXTRA-TROPICAL CYCLONES OVER SOUTH  
INDIAN OCEAN**

Present work is an investigation of the correlation between pre-monsoon wave activity and the rainfall anomaly for the monsoon season. Sikka and Gray (1982a&b) had pointed out that during Asian summer monsoon the passage of baroclinic waves across Southwest Indian Ocean strengthens the low level monsoon flow and that in turn becomes conducive to the

formation of vortices over the North Indian Ocean and thus rainfall. Similar connection between monsoon flow strength and passage of baroclinic waves across Mozambique channel were shown by Sikka (1980) and also by other authors.

We propose an index for the wave activity based on the passage of extra-tropical vortices in the South Indian Ocean during April-May that can be determined from routine infra red (IR) and visible satellite cloud imageries. For analyzing the passage of extra-tropical vortices, the INSAT satellite IR and visible imageries available in the data base of Satellite Meteorological Division, India Meteorological Department, New Delhi were used. The



**Fig. 1.** INSAT-2E cloud imagery in IR band ingested at 0600 UTC of 16 May 2002. Imagery shows an extra-tropical vortex with center in the 40-50° S belt and cold front extending northward to 25° S Lat. Boundaries of North and South belts have been marked in dark lines

proposed index of the continuation of mid-latitude baroclinic wave activity of Mozambique channel and thence passage over South Indian Ocean during April and May would be used as a precursor for similar activity during June to September. Which may find utility as a potential predictor for All India Monsoon Rainfall.

Two latitudinal belts are defined in the South Indian Ocean from 40-50° S (northern belt hereafter N-Belt) and from 50-60° S (southern belt S hereafter S-Belt). The movement of the extra-tropical vortices were monitored in these belts from 30° E to 110° E. From the animation of satellite imageries it is easy to watch passing of extra-tropical vortices, and associated fronts, across Mozambique Channel and then eastward over South Indian Ocean. These vortices can also be traced from east coast of South America and moving across South Atlantic. Here in, this paper a cyclone event was defined as follows. An extra tropical cyclone which existed atleast for about 24 hours and whose front extended northward atleast up to

30° S latitude, was counted as one cyclone event of the north or south belt where cyclone center laid in. Thus, if a cyclone existed in the N-Belt for two days, then it was counted as two cyclone events. Similarly if a cyclone remained two days over N-Belt and three days over S-Belt, those were counted as two cyclone events over N-Belt and three cyclone events over S-Belt. Although it was sometimes difficult to decide near the boundaries, as to which belt a cyclone belonged to; yet its previous position was used in deciding its current belt of movement. An instance of a cyclone located in the belt 40-50° S on 16 May 2002 is presented in Fig. 1. It is seen that associated cold front extends to 25° S Lat.

Though there is some subjectivity in this method, trials showed that the counting of vortices can be carried out consistently and does not depend significantly on the person doing it. Since we are trying to determine the occurrence of events rather than the intensity, the method is quite robust.

Using this method the following numbers were determined :

- $N_1$  - the number of vortices in the northern belt in May,
- $N_2$  - the number of vortices in the southern belt in May,
- $\Delta N_1$  - the change in number of vortices in the northern belt from April to May and
- $\Delta N_2$  - the change in number of vortices in the southern belt from April to May.

Using the number of cyclone events of April and May, a cyclone event index, (CEI) was defined and its correlation with SW monsoon seasonal rainfall anomaly (RA) over India was tested for finding the correspondence between the extra-tropical cyclone events over South Indian Ocean and the summer monsoon rainfall anomaly over India. The proposed Cyclone Event Index (CEI) is defined as follows ;

$$CEI = (\Delta N_1) - (\Delta N_2).$$

CEI is defined in such a way that (a) an increase in the number of cyclones in the northern belt from April to May (b) & a fall from April to May in the number of cyclones in the southern belt together increases the index. It is assumed here that an increase in number of cyclones in the north belt will take place when ridge of high pressure over SIO will be closer to equator. Similarly, an increase in south belt will take place when ridge is away from the equator. Former is considered favorable for increasing the cross equatorial flow over the west Arabian Sea and hence increased rainfall activity over India.

Year wise analysis of the cyclone indices is presented in the Table 1. Symbols have same meaning as given above. CEI were determined for years 1984-2004. Linear correlation between CEI and rainfall anomalies was determined using R-Statistical package. It is seen from the Table 1 that CC of that  $\Delta N_1$  with RA is 0.18 but positive. Whereas  $\Delta N_2$  is negatively correlated with RA by CC of -0.30 (column 2 and 3 of the Table). But CEI, given in column 5 of Table 1 has the highest correlation with RA (CC = 0.31). This is what was envisaged in this study. Magnitude of CC with rainfall anomaly may be low because we have utilized crude data such as number of extra-tropical cyclones, rather than some other relevant parameter which is better estimates of the baroclinicity of the atmosphere. Under col 6, ratio of rainfall anomaly (RA %) with its standard deviation  $\sigma_{RA}$  are given. Similarly col 7 gives ratio of cyclonic event index (CEI)

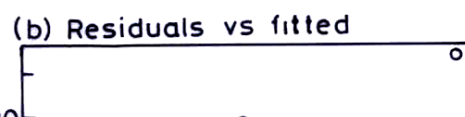
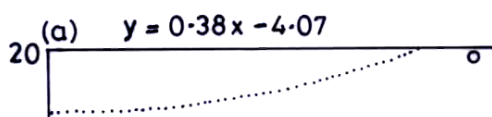
TABLE 1

Symbols  $\surd$  and  $\times$  stand respectively for matching and non matching of the relationship being sought in different years. There are 12 matching relationship years and 9 non matching years. This would not give presence of significant relationship unless reasons, some of which were mentioned here for low values of correlation coefficients, are taken note of

1	2	3	4	5	6	7	8
Year	$\Delta N_1$	$\Delta N_2$	RA	CEI	RA/ $\sigma_{RA}$	CEI/ $\sigma_{CEI}$	col 6 $\approx$ col 7
1984	2	-2	-4	4	-0.4	0.5	$\surd$
1985	3	1	-7	2	-0.8	0.2	$\times$
1986	9	-3	-13	12	-1.4	1.6	$\times$
1987	3	-3	-19	6	-2.0	0.8	$\times$
1988	7	-9	19	16	2.0	2.1	$\surd$
1989	0	-9	1	9	0.1	1.2	$\times$
1990	5	1	6	4	0.6	0.5	$\surd$
1991	4	-2	-9	6	-0.9	0.8	$\times$
1992	4	8	-7	-4	-0.7	-0.5	$\surd$
1993	0	4	0	-4	0	-0.5	$\surd$
1994	5	-7	10	12	1.0	1.6	$\surd$
1995	3	2	0	1	0	0.1	$\surd$
1996	5	4	3	1	0.3	0.1	$\surd$
1997	6	3	2	3	0.2	0.4	$\surd$
1998	4	-3	5	7	0.5	0.9	$\surd$
1999	3	-10	-4	13	-0.4	1.7	$\times$
2000	-1	7	-8	-8	-0.8	-1.0	$\surd$
2001	-6	11	-8	-17	-0.8	-2.2	$\times$
2002	6	4	-19	2	-2.0	0.3	$\times$
2003	6	7	5	-1	0.5	-0.1	$\surd$
2004	4	2	-13	2	-1.4	0.3	$\times$
Mean	3.43	0.29	-2.86	3.20			
C.C. with RA	0.18	-0.30		0.31			
Std. Dev.	3.22	5.89	9.46	7.58			
			$\sigma_{RA}$	$\sigma_{CEI}$			

with its standard deviation  $\sigma_{CEI}$ . Col 8 shows comparison of ratios of col 6 & col 7. Wherever they are matching mark " $\surd$ " has been put. Wherever they are not, mark " $\times$ " has been put.

Linear regression was carried out on the data for 21 years and is displayed in Fig. 2(a). CEI is given on the x-axis and the percentage departure of the seasonal All India Monsoon rainfall is given on the y-axis. The straight line is the fitted line. The solid curved on both sides of this line gives the 99% confidence interval for the prediction



**Figs. 2(a-d).** (a) Scatter plot of RA ( $Y$ ) Vs CEI ( $X$ ), and the Fitted linear regression line, (b) Predicted (fitted) values of RA,  $Y_i$  Vs Residuals  $(Y_i - \hat{Y}_i)$   $Y = 0$  line has been drawn, (c) Histogram of Residuals,  $(Y_i - \hat{Y}_i)$  and (d) Plot of Quantiles of Residuals Vs the Quantiles of Normal Distributions. Notice the oscillation in the scatter about the fitted line

of the average value of  $y$  for given  $x$ . The dotted curves give the same for prediction of individual values of  $y$  for given  $x$ . The figure shows that there is positive linear correlation between CEI and the RA.

The residuals from the predicted values were tested for normality (Verzani, 2002). The residuals from the fitted values are shown in Fig. 2(b). Histogram of the residuals Fig. 2(c) shows a generally bell shaped figure excluding the extreme negative values. The quantile - quantile (normal plot) of the residuals is shown in Fig. 2(d). The straight line in this figure is drawn through points formed by the first and third quantiles. If the graph

looked like a straight line then the data is approximately normal. However in this figure though the data from approximately a straight line, there is also a regular variation about it. This shows that there is some unexplained relationship between CEI and RA other than linear. However the analysis shows that the positive correlation is valid except in the cases of extreme rainfall anomalies. Thus the technique may not work on one to one basis for the extreme season (drought or excess monsoon). For example in the 21 years data studied in this paper; 1988, 1994 were excess monsoon years and 1985, 1986, 1987, 2002 and 2004 were drought years. And in the year 1992, 2000, and 2001, all India rainfall was

below minus 5% of the normal. Positive relationship between CEI and rainfall fits in some years 1984, 1988, 1990, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 2000 and 2003; but, does not fit in some years 1985, 1986, 1987, 1989, 1991, 1999, 2001, 2002 and 2004.

There is no attempt here to find the reason why should change in baroclinicity (extra-tropical cyclone activity over mid-latitudes) from April to May be related to June to September rainfall. We are contemplating that the trend (increase/decrease) in the number of extra-tropical cyclones in the months of April to May in the belt 40-50° S in comparison to 50-60° S belt in the South Indian Ocean, may contain a trend for monsoon months which in turn will influence the concurrent rainfall (Sikka and Gray 1982). The monsoon flow over India originates from around sub-tropical high of South Indian Ocean. Most changes in structure and / or location of sub-tropical high (Particularly in lower troposphere) during the pre-monsoon season are influenced by the passing of extra-tropical cyclones during this season (April & May).

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