Interrelationship between Indian Ocean Dipole (IOD) and Australian Tropical Cyclones

Kamal Kumar Saha and Saleh A. Wasimi

Abstract—**Indian Ocean Dipole (IOD) index plays an important role in shaping the weather conditions in the Indian Ocean and surrounding areas. It has a strong correlation with Darwin pressure. This paper attempts to unfold its relationship with the occurrence of Tropical Cyclones (TCs) in the Australian basin. An analysis of 30 years' data (1976-2006) reveals that individual IOD pole (Western or Eastern) has peak negative correlation (-.5 and -.4, respectively) with the seasonal occurrences of TCs in Australia. Mainly the TC occurrences in Western and Eastern sub-regions are correlated with IOD index of both the poles. Northern sub-region is more or less free from the influence of IOD index. These findings provide further insight in understanding the genesis of tropical cyclones in the Australian region.**

Index Terms—**TC characteristics, occurrences, relationships and genesis.**

I. Introduction

Tropical cyclones (TCs) are major environmental hazards in Australia. The tropical parts of this country experience a number of cyclones every year. The number of occurrences varied from 6 to 13 with a mean of 11 in a TC season during the period 1976-2006. Australian TC season usually runs from the month of November to April every year. The genesis of TC is related with the overall pattern of tropical atmosphere [1]. The variation in the number of occurrences also depends on the change of behaviour of environmental parameters [2], [3]. Nicholls [4] presented the relation of Australian TC occurrences with the pressure anomaly in Darwin and proposed a procedure of predicting the number of genesis. But the accurate prediction is still an issue of extensive research.

Sea Surface Temperature (SST) in the Indian Ocean is an important factor for Australian climate. The SST differences of two small rectangle shaped areas in the Western (50°-70°E, 10°S-10°N) and Eastern (90°-110°E, 10°-0°S) areas of tropical Indian Oceans (Fig. 1) are termed as the Indian Ocean Dipole (IOD) effects. Many scientific studies [5], [6] [7] reported that IOD has a strong impact on Australian rainfall. They specifically mentioned that warmer than average Indian Ocean SST's near Australia (negative phase of IOD events) may enhance Australian rainfall whilst cooler than average SST's (positive phase of IOD events) can result in reduced rainfall. But the total impact of IOD events in Australian climate is a potential research area as mentioned in the BOM webpage [http://www.bom.gov.au/watl/about-weather-and-climate/australian-climate-influences.html?bookmark=iod]. Another important environmental index ENSO in Australian context is sometimes followed by IOD events. For example, positive phase of IOD sometimes occur during El Niño events and negative phase of IOD in La Niña events. TCs' occurrences in the Australian basin have been found to be strongly related with the periodical events of ENSO [8]. These interrelated events initiate a research loop to investigate whether there is any relationship between IOD and the occurrences of tropical cyclones in the Australian region. This is the focus of the present study.

Francis *et al.* [9] found that the positive phase of IOD can be activated through the occurrences of severe tropical cyclones in the Bay of Bengal. They explained that after a severe TC in the Bay of Bengal, the meridional pressure gradient along the eastern equatorial Indian Ocean (EEIO) tends to be strong with the intensification of the upwelling favourable south easterlies in Sumatra coast. At the same time water vapour reduces with the suppression of convection across EEIO. This causes extra convection over the western equatorial Indian Ocean (WEIO) and weakening of the westerlies along central equatorial Indian Ocean (CEIO). A positive dipole event could be triggered between these two events and last for a longer period than the synoptic scale. The whole procedure could sometimes occur in the region of Australian tropics and then the positive IOD event influences the occurrence of tropical cyclones.

The organisation of the paper is as follows. The second section contains the data sources and its description. Data analysis procedure and results are detailed in section three and some concluding remarks are made in the last section.

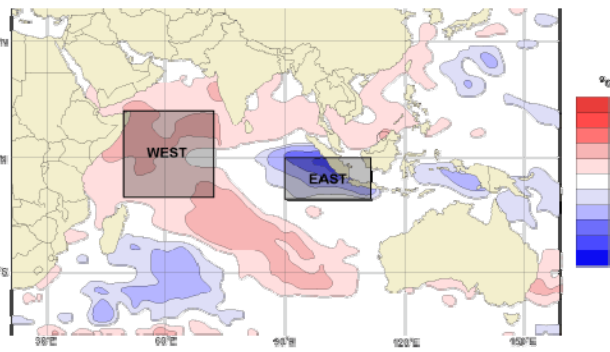

Fig. 1. Location of the East and West dipole in the Indian Ocean

II. Data Preparation and Methodology

TC data from the best track database of the Australian Bureau of Meteorological website has been obtained and analysed in this study. The number of occurrences of

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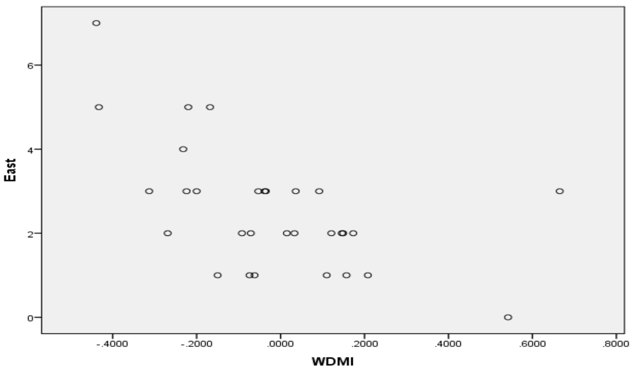
tropical cyclones during the period 1956-2006 has been accounted for. The Indian Dipole data has been collected from the webpage [http://www.jamstec.go.jp/frcgc-/research/d1/iod/sstdmi.txt]. Then a statistical correlation analysis has been performed between the number of TCs in every season with the average SSTs in individual IOD poles and the total IOD effects i.e. the SST differences between western to eastern poles.

III. Results and Discussions

Australian tropical cyclone basin is divided into three sub-regions called Eastern, Northern and Western sub-regions. Among the three sub-regions Western sub-region produces the highest number of cyclones every year. Database used in this study reveals that about 49% of total occurrences is contributed by this sub-region. A thorough correlation analysis has been performed between the tropical cyclone occurrences during the period 1976-2006 and the Indian dipole data. Individual dipole data shows significant correlations with the overall seasonal occurrences and sub-regional occurrences of tropical cyclones in the Australian basin.



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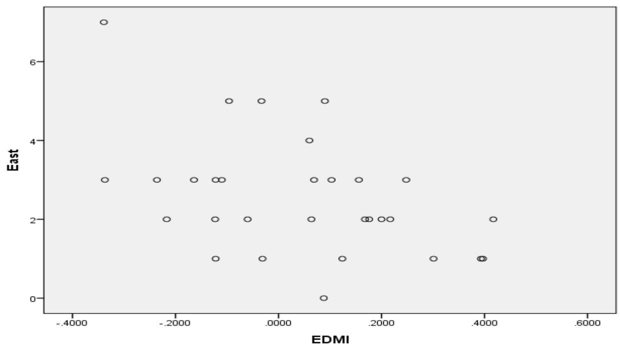

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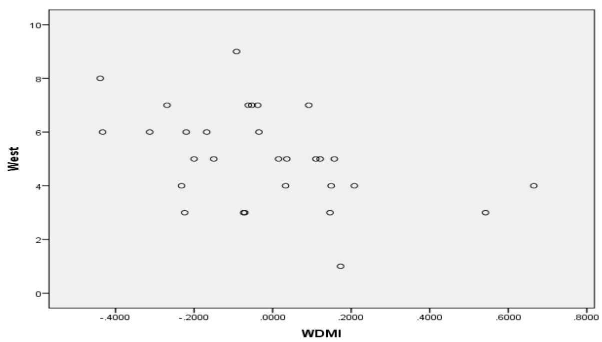

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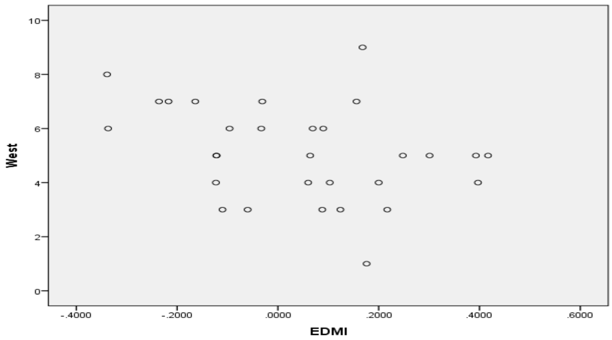

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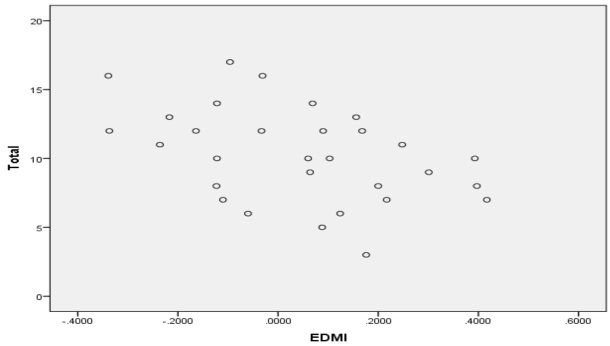

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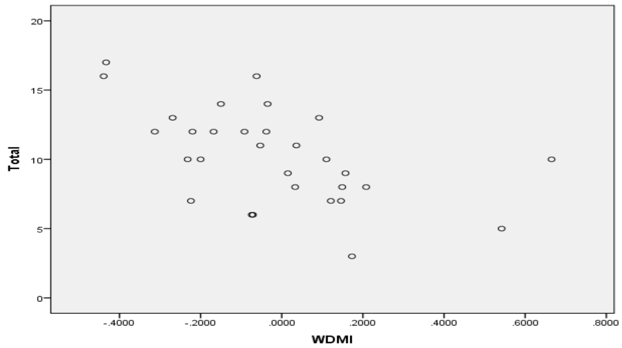

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Fig. 2. Scatter-plots of number of TC occurrences for a) the Eastern sub-region and Western dipole , b) the Eastern sub-region and Eastern dipole, c) the Western sub-region and Western dipole, d) the Western sub-region and Eastern dipole, e) the entire Australian basin and Eastern dipole and f) the entire Australian basin and Western dipole.

Significant relationship between individual dipole indices and the TC occurrences can be noticed in Fig. 2. Correlation coefficients have been calculated and presented in Table I below.

TABLE I: Correlation between Individual Pole IOD and Occurrences in Sub-Regions.

Individual Pole IOD	Sub-regions		
	Eastern	Northern	Western
East DMI	-.450*	-0.058	-0.342
West DMI	-.576**	-0.176	-.448*
Total DMI	0.024	0.143	0.189

**Correlation is significant at the 0.01 level (2-tailed).

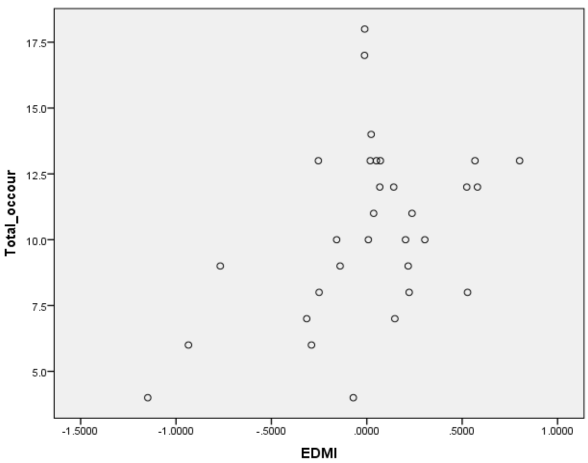
* Correlation is significant at the 0.05 level (2-tailed).

Table I indicates that the Northern sub-region did not register any relation with the individual dipole indices. This could be caused by the land-locked feature of this sub-region. The land-locked feature imposes some special characteristics to the tropical cyclones which make landfall there [10]. The other two sub-regions and total dipole event showed significant negative relationships. Total occurrences of TCs are reasonably correlated with individual dipole data (Table II).

TABLE II: CORRELATION BETWEEN INDIVIDUAL POLE IOD AND TOTAL OCCURRENCES.

Individual Pole IOD	Correlation	Total occurrence
EDMI	Pearson Correlation	.447*
WDMI	Pearson Correlation	-.431*
TDMI	Pearson Correlation	-.523**

The correlation between Eastern dipole SSTs anomaly for the month of October and total occurrences for the following season is .447 and in case of western dipole SST this correlation is -.431. Both these correlations are significant at 5% level of significance. This correlation for total Indian dipole index is -.523, which is significant at 1% level of significance. These values are presented in Table II. But the overall dipole index is more influenced by the west dipole temperature. The west dipole index influenced the larger part of the Australian basin, i.e., Western sub-region and, the whole Australian basin follow the same trend as the Western sub-region.



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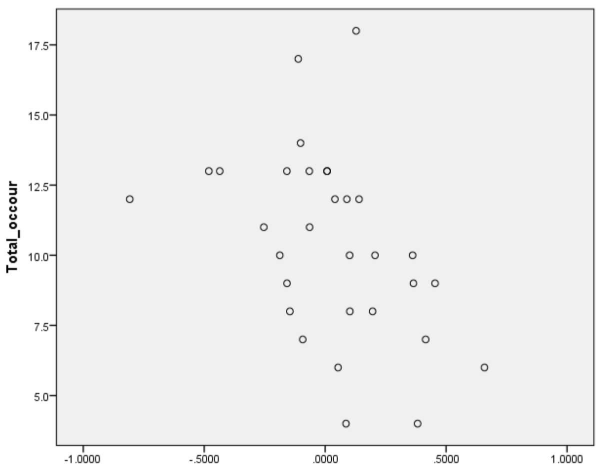

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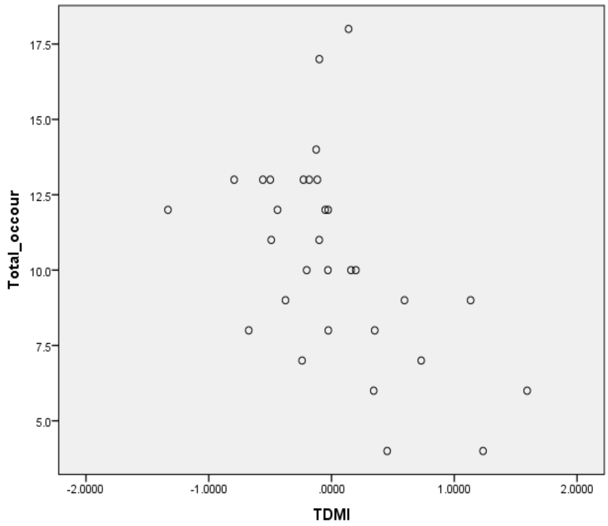

(c)

Fig. 3. Scatter-plots showing correlation between a) Previous month's Eastern dipole and total Australian basin occurrences of tropical cyclones, b) Previous month's Western dipole and total occurrences of tropical cyclones, c) Previous month's overall dipole and total occurrences of tropical cyclones.

The graphs in Fig. 3 capture the relationships between previous month's DMI values for individual dipole and overall TC occurrences in the Australian basin. It is important to note that Eastern and Western pole DMI shows complete inverse trend of relationship whereas total DMI supports the trend of western pole DMI. This phenomenon indicates the importance of western pole DMI in predicting the TC occurrences in the Australian basin.

In Table III the correlation values of number of occurrences of TCs with EDMI, WDMI and TDMI for each month within a cyclone season are presented , whereas in Table IV the correlation values are with the number of TCs that lags other parameters by one month.

For Table III the correlations are calculated for the same month's SST anomalies of the individual dipole areas and TC occurrences in different sub-regions. These results are useful for an insight but have no predictive capability. By contrast, Table IV has a lead time of one month. The results show some promise for improving the prediction of seasonal TC occurrences in the Australian context.

Correlation analysis between monthly dipole and occurrences in the same month within a season establishes the continuity of relationships as described above. The predictive capability as with any statistical analysis should be considered with an appreciation of the variability and uncertainty. Instead of coming up with any confidence interval or significance levels, the raw values are presented in Table IV to have a first-hand look as to how they vary.

IV. CONCLUSIONS

The importance of Indian Ocean Dipole Index for the Australian climate hitherto has been well known only in relation to rainfall. According to the Australian Bureau of Meteorology's website it is assumed that IOD might have potentiality to predict the tropical cyclones as well. The present study is an initiative to investigate the potentiality of IOD-Australian tropical cyclones association.

TABLE III: CORRELATION BETWEEN NUMBERS OF TC OCCURRENCES AND SAME MONTH DMIS WITHIN A SEASON

TC Season	EDMI	WDMI	TDMI
1976	-0.51	0.24	0.65
1977	0.26	-0.84	-0.57
1978	-0.30	0.48	0.68
1979	-0.34	0.82	0.87
1980	-0.40	-0.41	0.31
1981	-0.44	-0.14	0.44
1982	0.92	-0.60	-1.00
1983	-0.42	-0.90	-0.71
1984	-0.20	-0.57	-0.23
1985	0.24	-0.52	-0.48
1986	-0.98	0.36	0.99
1987	-0.45	0.79	0.60
1988	-0.58	-0.09	0.81
1989	-0.57	0.30	0.89
1990	0.11	0.34	0.33
1991	0.17	-0.76	-0.63
1992	-0.05	0.60	0.68
1993	-0.30	-0.06	0.14
1994	0.80	-0.08	-0.61
1995	-0.84	0.65	0.88
1997	0.33	0.16	-0.35
1998	0.06	-0.25	-0.16
1999	0.69	-0.37	-0.09
2000	0.90	-0.62	0.41
2001	0.10	-0.36	-0.54
2002	0.99	-0.96	0.94
2003	0.73	-0.69	0.32
2004	-0.22	0.09	-0.44
2005	-1.00	-0.23	-0.42
Validity	0.48	0.52	0.63

TABLE IV: CORRELATION BETWEEN NUMBERS OF TC OCCURRENCES AND PREVIOUS MONTH'S DMIS WITHIN A SEASON

TC Season	EDMI	WDMI	TDMI
1976	0.75	0.33	-0.23
1977	0.17	-0.17	-0.18
1978	0.37	0.52	0.48
1979	0.14	0.05	-0.04
1980	0.05	-0.08	-0.17
1981	0.54	-0.24	-0.75
1982	0.98	-0.07	-0.89
1983	0.04	-0.42	-0.66
1984	-0.3	0.69	0.51
1985	-0.01	0.68	0.44
1986	-0.98	0.27	0.95
1988	-0.56	-0.73	-0.04
1989	0.17	0.46	0.25
1990	0.92	0.01	-0.74
1991	0.58	-0.02	-0.49
1992	-0.09	0.14	0.43
1993	0.66	-0.7	-0.86
1994	0.2	0.98	0.67
1995	-0.38	0.34	0.39
1996	0.96	0.71	-0.81
1997	-0.17	-0.27	0.12
1998	-0.01	0.58	0.2
1999	0.24	-0.37	-0.33
2000	-0.12	-0.98	-0.99
2001	-0.59	0.7	0.67
2002	0.18	-0.08	-0.45
2003	-0.56	0.63	0.6
2004	0.1	-0.07	-0.09
2005	-0.85	0.5	0.8
Validity	0.48	0.55	0.69

The correlations between Australian tropical cyclone occurrences and dipole indices (both individual and overall) were investigated and analysed in this study. A significant correlation has been found between previous month's dipole sea surface temperatures and following month's seasonal occurrences of tropical cyclones. These findings will add to the predictive tools which factors such as ENSO and Darwin pressure anomaly already provide. The prediction of occurrences of TCs is an extremely complex process, they typically provide very little forewarning. Thus, the more tools we have and the more we can integrate the performances of these tools, the better and more reliable will be our predictions. Furthermore, the data collection is not complex because the temperature anomalies are for two reasonably small areas in the Indian Ocean

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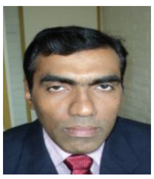

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