

# Relation of Frequency of Tropical Cyclones Over North Indian Ocean and North West Pacific Ocean with Sea Surface Temperature Anomaly Over Nino 3.4 Region and Indian Ocean Dipole

R. Chand and C. Singh

## 1 Introduction

Tropical cyclones (TCs) are one of the most devastating weather phenomena that cause large number of human casualties and loss of property. It is well known that the TCs over North Indian Ocean (NIO) have caused the maximum loss of human lives. The death toll in Bangladesh cyclone of November 1970 has been estimated to be about 300,000. The tropical depression (Maximum Sustained Surface Wind Speed (MSSWS) 17–33 knots or more) and TCs MSSWS 34 knots or more form over warm ocean surfaces, with SST more than 26.0 °C, low magnitudes of vertical wind shear and large magnitudes of low-level relative vorticity, coriolis force and mid-tropospheric level relative humidity (Gray 1968). Gray (1979), using 20 years of data has shown that the global tropics produce about 80 TCs in a year out of which only 6 form over NIO. Most of the TCs form over NIO during October–December (primary peak season) and March–May (secondary peak season). The period of May–November is the peak season for tropical depressions (TDs) over the NorthWest Pacific Ocean (NWPO).

The genesis of TDs is governed by several coupled ocean atmospheric phenomena in addition to Gray parameters. The El-Niño is manifested as an anomalous warming of the eastern and central tropical Pacific Ocean and La-Niña refers to an anomalous cooling of the eastern and central tropical Pacific Ocean. The SST anomaly over Nino 3.4 region (170.0°–119.0° W and equator to  $\pm 5.0^\circ$  N & S) is commonly used to represent El Nino/La Nina conditions- El Nino, if the departure from normal is  $\geq 0.5^\circ\text{C}$  and La Nina, if the departure from normal is  $\leq -0.5^\circ\text{C}$ .

---

R. Chand (✉) • C. Singh

India Meteorological Department, Mausam Bhawan, Lodi Road, New Delhi 110003, India  
e-mail: [r58.chand@gmail.com](mailto:r58.chand@gmail.com)

Sea Surface Temperature (SST) plays a significant role in the formation and intensification of TCs (Palmen 1949; Miller 1958). The El-Niño Southern Oscillation (ENSO) events have significant impacts on the hurricane intensity (Landsea et al. 1999) and genesis locations (Elsner and Kara 1999) of the TCs. Gray has concluded in his paper that there is a tendency towards less (or more) TCs over the Atlantic basin during the El-Niño (La-Niña) years (Gray 1984). During past few decades, many studies have focused on the relationship between Western North Pacific (WNP) TCs and the ENSO (Chia and Ropelewski 2002; Wang and Chan 2002; Camargo and Sobel 2005; Chan 2007; Huang and Xu 2010; Kim et al. 2011). For example, Wang and Chan (2002) found that a southeastward (northwestward) shift in the positions of TCs genesis in the WNP occurs during El-Niño (La Niña) years which in turn may favour (suppress) the development of intense TCs. Camargo and Sobel (2005) revealed that the accumulated cyclone energy is positively correlated with ENSO indices, suggesting that stronger (weaker) and longer-lasting (shorter-lived) TCs tend to form during an El-Niño (La Niña) event. Following this, Camargo et al. (2007a, b) investigated the impacts of ENSO on the tracks and genesis locations of TCs. Making use of a genesis potential index (Emanuel and Nolan 2004), suggested that vorticity and relative humidity play an important role in the eastward shift in the mean genesis location of TCs over WNP. Chan (2007) also pointed out that interannual variations in intense typhoons over WNP are unlikely to be determined by local SST. But, TCs are related to changes in planetary-scale atmospheric circulation (vorticity and wind shear) and thermodynamic structure (moist static energy) associated with the El-Niño phenomenon. More recently, Huang and Xu (2010) attributed the increase in the number of super typhoons (STYs) in El-Niño years to changes in SST, the monsoon trough, and vertical wind shear. These studies focussed mainly on the effect of ENSO on intense TCs (Chan 2007; Huang and Xu 2010) or considered all TCs as a whole regardless of their intensity (Chia and Ropelewski 2002; Wang and Chan 2002; Camargo et al. 2007b; Kim et al. 2011). Thus, the effect of ENSO on weaker typhoons or TDs is unclear, and the connection between ENSO and TCs with different intensities remains uncertain. In addition, less effort on studying the TC-ENSO relationship during the ENSO transition phase has been found. Frank and Young (2007) suggested that the variance in factors that control the formation of TCs can ultimately result in storms with different degrees of intensity. Thus, the impact of ENSO on TCs with different intensities is also expected to vary. Kessler (1990); Kinter et al. (2002); Zhou and Chan (2007); Wang et al. (1999) indicated that the strongest ENSO signal occurs in the sub-surface as a result of wind stresses driven by ENSO. However, few previous investigations have used upper ocean heat content (OHC) to study the impact of ENSO on TCs. A recent study by Wada and Chan (2008) suggested that a decrease in OHC in the WNP is related to the passage of TCs, though they did not deal deeply into the relationship between OHC, ENSO and TCs. Wada and Chan (2008) described in his paper the role of OHC, to examine the impact of ENSO on TCs with different intensities.

In 1997, the year of the strongest El-Niño of the century, the WNP had 23 typhoons (the second largest number of any year on record), an unprecedented number of very intense TCs (11 became STYs) and a large eastward displacement of the genesis location. That year, two TCs (Oliwa and Paka) formed in the Central North Pacific (east of the data line) and entered the WNP before reaching STY intensity (Lander and Guard 2001). Wang and Chan (2002) also noted that the mean lifetime of TCs tends to increase during strong El-Niño events, as more TCs form in the southeast quadrant of the WNP, thus experiencing a longer traveling time (westward and northward) before encountering the continent or colder mid-latitude water. This is one possible explanation for the effect, the tendency towards more intense typhoons in El-Niño years. A few previous studies have briefly documented a relationship between TC intensity and ENSO. The main ones of which we are aware are those of Pudov and Petrichenko (1998, 2001), who found an increase in the intensity of TCs in El-Niño years. Camargo (2005) concluded in his paper that the shifts towards both longer lifetimes and greater intensities in El-Niño years are due to the eastward shift in genesis location, which any one can naturally expect to lead to longer tracks over a warm ocean surface. While this seems plausible, particularly in the case of the lifetime effect, it has not been proven. The intensity effect in particular could also be due to some extent, to other influences of ENSO on the mean regional climate of the NWPO.

Many studies have documented for NWPO, but very few are seen for NIO. On an average about 5–6 TCs with MSSWS 34 knots or more form over this basin every year (Singh 2001) in two cyclone seasons, such as pre-monsoon season (March–May) and post-monsoon season (October–December). Frequency of formation of TDs and their intensification have been studied for NIO by Srivastav et al. (2000). The average frequency of TDs and storms over NIO and NWPO during post satellite era (1960–2013) is discussed in detail in Sect. 3 of present paper. The favourable region of cyclogenesis in the NIO oscillates in both time and space. Ramesh Kumar and Sankar (2010) studied the impact of global warming on the cyclonic storms over NIO, it states that the frequency of storms and severe storms do not show a dramatic rise despite increase over the SST in the Bay of Bengal (BOB) during 1951–2007 compared to the 1901–1951, this study further states that there is large decrease in the mid-tropospheric humidity over the BOB during the period 1951–2007 and the atmospheric parameters such as low-level vorticity, mid-tropospheric humidity and vertical wind shear, all play an important role in the genesis and intensification of storms over this basin.

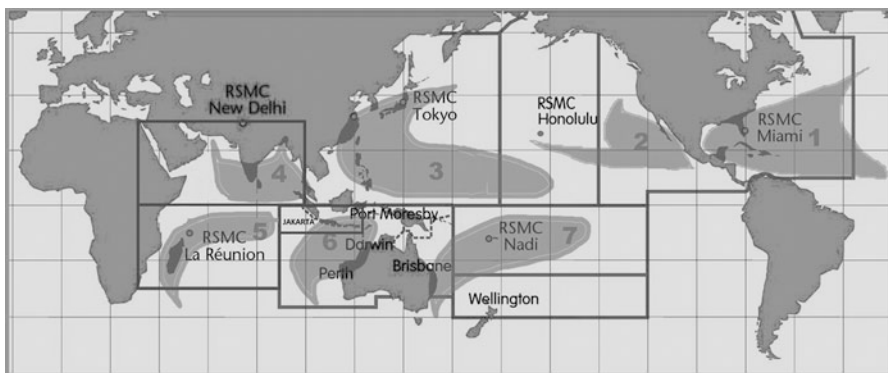
The effect of the Indian Ocean Dipole (IOD) on the formation of TDs over NIO and NWPO is also studied in this paper. IOD is defined by the difference in SST between Arabian Sea in western Indian Ocean and south of Indonesia in the eastern Indian Ocean. In positive phase, the greater-than-average SST and greater precipitation in the western Indian Ocean region, with a corresponding cooling of waters in the eastern Indian ocean which generally tends to cause

droughts in adjoining areas of Indonesia and Australia. The negative phase of the IOD brings about the opposite conditions. The IOD is commonly measured by an index that is the difference between SST in the western ( $50.0^{\circ}$ – $70.0^{\circ}$  E and  $10.0^{\circ}$  S– $10.0^{\circ}$  N) and eastern ( $90.0^{\circ}$ – $110.0^{\circ}$  E and  $10.0^{\circ}$ – $0.0^{\circ}$  S) equatorial Indian Ocean. The index is called the Dipole Mode Index (DMI). Sumesh and Ramesh Kumar (2013) have suggested that the cyclogenesis over the NIO is a complex phenomena, as it is influenced by several coupled ocean atmospheric phenomena such as El-Nino, El-Nino Modki, IOD and MJO. Saha and Wasimi (2013) have analysed 30 years' data (1976–2006) which reveals that individual IOD pole (Western or Eastern) has peak negative correlation ( $-0.5$  and  $-0.4$ , 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.

## 2 Data and Methodology

In present study, the tropical disturbances (TDs) formed over NIO and NWPO under RSMCs New Delhi and Tokyo have been considered, as shown in area 3 and 4 in Fig. 1. The annual frequency of TDs and storms over NIO and NWPO are taken from Regional Specialized Meteorological Centre (RSMC), New Delhi and RSMC Tokyo (website [http://en.wikipedia.org/wiki/2012\\_Pacific](http://en.wikipedia.org/wiki/2012_Pacific)) respectively. Month-wise SST anomaly of Nino 3.4 region is obtained from the website <http://www.cpc.ncep.noaa.gov/products>. Indian Ocean Dipole (IOD) years is obtained from the website <http://www.bom.gov.au/climate/IOD/>.

In present study, statistical methods are used to find the relation of annual frequency of TDs and storms over NIO and NWPO with SST anomaly in Nino



**Fig. 1** The present study areas is shown as area 3 and 4 in above figure

3.4 region which is the most dominant mode in year-to-year climate variations in the tropics, and its impact on depressions and TCs activity. The relation is also studied with the annual IOD conditions as it also affects the formation and intensification of TCs. The student's  $t$ -test at a confidence level of 90 % or more has been used to compare means of two independent groups of above and below average frequency of depressions and TCs with SST anomaly in Nino 3.4 region and annual IOD status to determine if they are significantly different from one another. Similarly, the year with warm and cold anomaly over Nino 3.4 region have been compared with frequency of depressions and storms in corresponding years and the difference in mean frequency with respect to cold and warm anomaly has been tested for significance and analysed. The similar comparison has been carried out with respect to + ve and – ve IOD years.

### 3 Discussion

In IMD the classification for analysing intensity over the NIO is as follows; it is called a super cyclonic storm (SuCS), if MSSWS is 120 knots and above, a very severe cyclonic storm (VSCS) if MSSWS 64–119 knots, a severe cyclonic storm (SCS) if it is 48–63 knots, a cyclonic storm (CS) if it is 34–47 knots, a deep depression (DD) if it is 28–33 knots and depression (D) it is 17–27 knots. For NWPO, the TDs are of four categories namely as STY, typhoon, tropical cyclone and tropical depression. The STY group includes TCs that reach at least 114 knots (Cat 4 and 5 in the Saffir–Simpson Hurricane Scale), and representing the most intense TCs. The typhoon group comprises moderately strong TCs with a MSSWS between 64 and 114 knots (Cat 1–3 in the Saffir–Simpson Hurricane Scale). The TCs with a MSSWS of 34–63 knots is classified as the tropical cyclone and system with MSSWS between 17 and 33 knots are tropical depression.

The last 54 years (1960–2013) data shows the average annual frequency of tropical depressions or more over NIO is 6.2 with SD 2, CS 3.75 with SD 1.42 and SCS 1.22 with SD 1.19. Similarly, the average annual frequency of Tropical Storms over NWPO is 34 with SD 7, Tropical cyclone 27 with SD 5, Typhoon 16 with SD 4 and STY is 4 with SD 2.

#### 3.1 *Genesis and Intensification of TDs in NIO with Respect to El-Nino/La-Nina Conditions*

SST anomaly in Nino 3.4 region is analysed with respect to above normal, normal and below normal frequency of depression and CS in the NIO region and Student's  $t$  test is carried out to identify statistically significant differences. Table 1 presents the number of years with above, below and normal frequency of depression and CS

**Table 1** Number of years with above, below and normal frequency of depressions and CS over NIO along with SST anomaly in Nino 3.4 region

	Depression (SST anomaly)			CS (SST anomaly)		
	Average anomaly (°C)	SD (°C)	No.	Average anomaly (°C)	SD (°C)	No.
Above average frequency years	0.29	0.75	10	0.55	0.43	4
Below average years	0.69	0.53	3	-0.05	0.66	4
Normal	-0.11	0.60	41	-0.05	0.66	48

**Table 2** Average frequency of SCS over NIO during +ve IOD and neutral years

	Positive IOD Years	Neutral IOD years
Average	2	1.06
SD	1.25	1
No. of years	10	35

**Table 3** No of years with above average, below average and normal frequencies of D, CS, SCS over the NIO corresponding to +ve IOD, -ve IOD and neutral IOD conditions

Years	Depression			Cyclonic storm			SCS	
	Above Avg > 8	Below Avg < 4	Normal 4-8	Above Avg > 5	Below Avg < 2	Normal 2-5	Above Avg > 2	Normal 0-2
+ve IOD	2 (20 %)	1 (33 %)	7 (17 %)	1 (20 %)	0	9 (19 %)	3 (37)	7 (15 %)
-ve IOD	3 (30 %)	0	5 (12 %)	0	0	7 (14 %)	1 (12 %)	7 (15 %)
Neutral	5 (50 %)	2 (66 %)	29 (70 %)	4 (80 %)	1	32 (67 %)	4 (50 %)	32 (70 %)

over NIO along with the SST anomaly in Nino 3.4 region. During the years with below average frequency of D, the Nino 3.4 SST anomaly satisfies the El Nino conditions. On the other hand, the Nino 3.4 SST anomaly satisfies El Nino conditions during the years when of above average frequency of CS over the NIO.

### 3.2 Genesis and Intensification of TDs in NIO with Respect to IOD Conditions

Analysis of frequency of depression, CS, SCS and VSCS in the NIO region with respect to positive, neutral and negative IOD conditions indicates significantly higher frequency of SCS over NIO during positive IOD years at 95 % level of confidence (Table 2). There is no significant difference for depression and CS frequency with respect to IOD conditions. Table 3 presents the number of years

with above average, below average and normal frequencies of D, CS, SCS corresponding to positive, negative and neutral IOD conditions. In the case of years with above average frequency of depressions, 20 % are of positive IOD years, 30 %, negative IOD years and 50 % neutral IOD years. For below average frequency of depressions, 33 % are of positive IOD years and 66 % neutral IOD years. In the case of above average frequency of CS years, 20 % are of positive IOD years and 80 % neutral years. In case of above average frequency of SCS, 37 % are of positive IOD years, 12 % negative IOD years and 50 % neutral years.

Difference in frequency of SCS during positive and neutral IOD years is significant at 95 % level of confidence.

### 3.3 Genesis and Intensification of TDs Over the NWPO in Respect of El-Nino/La Nina Conditions

For NWPO the student *t*-test for frequency of disturbances with warm and cold SST anomalies years of Nino 3.4 region gives significant relation for Typhoon and STY with the SST anomaly. The SST anomaly is significantly positive (higher) during the years with above average frequency of typhoons and STYs as compared to years of normal frequency as well as below average frequency. However, no such correlation is found between SST anomaly over Nino 3.4 region with depressions and storms (Table 4). The SST anomaly is significantly positive (higher) for STY in case of above average frequency as compared to normal frequency as well as below average frequency in NWPO (Table 5).

**Table 4** Average frequency of typhoons/super typhoons over NWPO during warm and cold anomaly years

	Warm anomaly years	Cold anomaly years
Average (Typhoon/ST)	17.5/5.05	14.09/3.48
SD (Typhoon/ST)	3.27/2.93	5.45/2.17
No. of years (Typhoon/ST)	20/20	23/23

**Table 5** Mean SST anomaly over Nino 3.4 region during years with above and below average frequency of super typhoons over NWPO

Frequency of years (ST)	SST anomaly, Nino 3.4 region		
	Average	SD	No.
Above average	0.47	0.85	8
Below average	-0.62	0.61	7
Normal	-0.017	0.65	38

**Table 6** Average frequency of super typhoons over the NWPO during +ve, -ve and neutral IOD years

Super typhoon	Positive IODs	Negative IODs	Neutral IODs
Average	5.7	2.44	2.16
SD	2.98	1.88	2.16
No. of years	10	9	35

### 3.4 Genesis and Intensification of TDs Over the NWPO in Respect of IOD Conditions

Student's *t*-test for frequency of disturbances over NWPO with annual IOD conditions yields that the frequency of STY is significantly higher during +ve IOD years compared to -ve IOD years as well as in neutral years. No comparison is found to be significant in case of depression, tropical storm and typhoon with annual IOD conditions (Table 6). Relation of frequency of TDs with annual IOD conditions over NWPO showed that the possibility of genesis of depressions and storms are higher in +ve IOD Years (Table 7). At the same time there seems no relation in frequency of storms and typhoons with IOD condition. However, in +ve IOD years frequency of STY is higher and in -ve IOD years frequency is less.

## 4 Conclusion

The present state of knowledge regarding TC activity in NIO and NWPO basins and the El-Niño phenomenon is reviewed in this study. The genesis of TCs is influenced by various factors such as El-Nino and IOD. Though there is no significant linear relationship between the number of TCs and El-Nino conditions in particular year, a nonlinear relation between El-Nino conditions and the number of TCs has been found in this study. On the basis of analysis of 54 years data of SST anomaly of Nino 3.4 region and annual IOD conditions and frequency of depression, CS and SCS over NIO and NWPO, the following conclusions are drawn:

1. During the years with below average frequency of depressions, the Nino 3.4 SST anomaly satisfies the El Nino conditions. On the other hand, the Nino 3.4 SST anomaly satisfies El Nino conditions during the years when of above average frequency of CS over the NIO.
2. Frequency of Typhoons and STYs is significantly higher over the NWPO during warm anomaly years in Nino 3.4 region. SST anomaly is significantly higher during years with higher frequency of STY.
3. The possibility of genesis of depressions and intensification into storms, typhoons and STYs over NWPO are higher in +IOD years and lower in -ve IOD years.



**Table 7** Frequency of years with different IOD conditions associated with above average, below average and normal frequency of depression, storm, typhoon and super typhoon over NWPO

IOD years	Depression			Storm			Typhoon			Super typhoon		
	A	B	N	A	B	N	A	B	N	A	B	N
	Avg > 40	Avg < 27	27-40	Avg > 32	Avg < 22	22-32	Avg > 20	Avg < 11	11-20	Avg > 6	Avg < 2	2-6
+ve IOD years	3 (37%)	2 (25%)	6 (16%)	1 (17%)	0	9 (21%)	1 (25%)	1 (12%)	8 (19%)	4 (44%)	1 (14%)	5 (13%)
-ve IOD years	1 (12%)	1 (12%)	6 (16%)	1 (17%)	2 (33%)	6 (14%)	1 (25%)	2 (25%)	6 (14%)	0	4 (57%)	5 (13%)
Neutral years	4 (50%)	5 (53%)	26 (68%)	4 (66%)	4 (66%)	27 (65%)	2 (50%)	5 (63%)	28 (67%)	5 (56%)	2 (28%)	28 (74%)

Note: A above, B below and N normal

**Acknowledgements** We would like to express our sincere thanks to Dr. M. Mohapatra Head (RSMC and cyclone warning division) of IMD for giving constructive suggestions/comments for significant improvement of this paper.

## References

- Camargo, S.J. (2005). Western North Pacific Tropical Cyclone Intensity and ENSO. *American Meteorological Society*, **18**, 2996–3006.
- Camargo, S.J. and Sobel, A.H. (2005). Western North Pacific tropical cyclone intensity and ENSO. *Journal of Climate*, **18**, 2996–3006.
- Camargo, S.J., Robertson, A.W., Gaffney, S.J., Smyth, P. and Ghil, M. (2007a). “Cluster analysis of typhoon tracks”, Part II: Large-scale circulation and ENSO. *Journal of Climate*, **20**, 3654–3676.
- Camargo, S.J., Emanuel, K. A. and Sobel, A. H. (2007b). Use of a genesis potential index to diagnose ENSO effects on tropical cyclone genesis. *Journal of Climate*, **20**, 4819–4834.
- Chan, J.C.L. (2007). Interannual variations of intense typhoon activity. *Tellus A*, **59**, 455–460.
- Chia, H.H. and Ropelewski, C.F. (2002). The interannual variability in the genesis location of tropical cyclones in the northwest Pacific. *Journal of Climate*, **15**, 2934–2944.
- Elsner, J. B. and Kara, A. B. (1999), Hurricanes of the North Atlantic: Climate and Society, New York, Oxford, Oxford University Press.
- Emanuel, K.A. and Nolan, D. (2004). Tropical cyclone activity and the global climate system, Preprints, 26th Conf. on Hurricanes and Tropical Meteorology, Miami, FL, American Meteorological Society, CD-ROM, 10A.2.
- Frank, W.M. and Young, G.S. (2007). The interannual variability of tropical cyclones. *Monthly Weather Review*, **135**, 3587–3598.
- Gray, W.M. (1968). Global view of the origin of tropical disturbances and storms. *Monthly Weather Review*, **96**, 669–700.
- Gray, W.M. (1979). Hurricanes: Their formation, structure and likely role in the tropical circulation. In: Shaw, D.B. (ed.) *Meteorology over the Tropical Oceans*. Royal Meteorological Society, James Glaisher House, Gvenville Place, Bracknell, Berkshire, RG 121 BX, 155–218.
- Gray, W.M. (1984). Atlantic seasonal hurricane frequency. Part I: El Niño and 30 mb quasi-biennial oscillation influences. *Monthly Weather Review*, **112**, 1649–1668.
- Huang, F. and Xu, S. (2010). Super typhoon activity over the western North Pacific and its relationship with ENSO. *Journal of Ocean University of China*, **9**, 123–128.
- Kessler, W.S. (1990). Observations of long Rossby waves in the northern tropical Pacific. *Journal of Geophysical Research*, **95**, 5183–5217.
- Kim, H.M, Webster, P.J. and Curry, J.A. (2011). Modulation of North Pacific tropical cyclone activity by three phases of ENSO. *Journal of Climate*, **24**, 1839–1849.
- Kinter, J.L, Miyakoda, K. and Yang, S. (2002). Recent change in the connection from the Asian monsoon to ENSO. *Journal of Climate*, **15**, 1203–1215.
- Lander, M.A. and Guard, C.P. (2001). Western North Pacific, North Indian Ocean, and Southern Hemisphere tropical cyclones of 1997. *Monthly Weather Review*, **129**, 3015–3036.
- Landsea, C.W, Pielke, R.A, Jr, Mestas-Nuñez, A.M and Knaff, J.A. (1999). Atlantic Basin hurricanes: Indices of climatic changes. *Climatic Change*, **42**, 89–129.
- Ramesh Kumar, M.R. and Sankar. S. (2010). Impact of global warming on cyclonic storms over north Indian Ocean. *Indian Journal of Marine Sciences*, **39**, 516–520.
- Miller, B.I. (1958). On the maximum intensity of hurricanes. *Journal of Meteorology*, **15**, 184–195.
- Palmen, E. (1949). On the formation and structure of tropical hurricanes. *Geophysics*, **3**, 26–38.

- Pudov, V.D. and Petrichenko, S.A. (1998). Relationship between the evolution of tropical cyclones in the Northwestern Pacific and El Niño. *Oceanology*, **38**, 447–452.
- Pudov, V.D. and Petrichenko, S.A. (2001). 1997–1998 El Niño and tropical cyclone genesis in the northwestern Pacific. *Izvestiya Atmospheric and Oceanic Physics*, **37**, 576–583.
- Saha, K.K. and Wasimi, S.A. (2013). Interrelationship between Indian Ocean Dipole (IOD) and Australian Tropical Cyclones. *International Journal of Environmental Science and Development*, **4**, 647–651.
- Singh, O.P. (2001). Long term trends in the frequency of monsoonal cyclonic disturbances over the north Indian ocean. *Mausam*, **52**, 655–658.
- Srivastav, A.K., Sinha Ray, K.C. and De, U.S. (2000). Trends in the frequency of cyclonic disturbances and their intensification over Indian seas. *Mausam*, **512**, 113–118.
- Sumesh, K.G. and Ramesh Kumar, M.R. (2013). Tropical cyclones over north Indian Ocean during El-Niño Modoki years. *Natural Hazards*, **68**, 1057–1074.
- Wada, A. and Chan, J.C.L. (2008). Relationship between typhoon activity and upper ocean heat content. *Geophysical Research Letters*, **36**, L17603, doi:[10.1029/2008GL035129](https://doi.org/10.1029/2008GL035129).
- Wang, B. and Chan, J.C.L. (2002). How strong ENSO affect tropical cyclone activity over the western North Pacific. *Journal of Climate*, **15**, 1643–1658.
- Wang, B, Wu, R. and Lukas, R. (1999). Roles of the western North Pacific wind variation in thermocline adjustment and ENSO phase transition. *Journal of Meteorological Society Japan*, **77**, 1–16.
- Zhou, W. and Chan, J.C.L. (2007). ENSO and South China Sea summer monsoon onset. *International Journal of Climatology*, **27**, 157–167.