INTERANNUAL VARIATIONS OF TROPICAL CYCLONE ACTIVITY IN THE SOUTHERN HEMISPHERE

Johnny C L Chan* and Kin Sik Liu
Guy Carpenter Asia-Pacific Climate Impact Centre, City University of Hong Kong, Hong Kong, China

1. INTRODUCTION

Many previous studies (e.g., Nicholls, 1979, 1984, 1985 and 1992) have investigated the relation between the El Niño/Southern Oscillation (ENSO) phenomenon and tropical cyclone (TC) activity in the Australian region. More recently, Ramsay et al. (2008) investigated the role of large-scale environment factors in the interannual variability of TC activity in the Australian region. Kuleshov et al. (2008) further examined the connection of the ENSO to TC activity in the Southern Hemisphere (SH) and found differences in TC cyclogenesis and occurrence in El Niño and La Niña years. In addition to the effect of ENSO, Grant and Walsh (2001) examined the relation between the interdecadal variability of TC formation in the northeastern Australian region and the Interdecadal Pacific Oscillation.

It is obvious from this brief review that previous studies on SH TC activity have mainly focused on the Australian region but very few have been devoted to variations of TC activity in the entire SH. This study represents an attempt to investigate the interannual variation of the overall TC activity in the SH based on an empirical orthogonal function (EOF) analysis. Possible linkages of such variations to climatic oscillations are also explored.

2. DATA & METHODOLOGY

2.1 Data

2.1.1. Best track data

The 6-hour best-track positions of TCs over the SH occurring between 1983 and 2007 are obtained from the website of the Joint Typhoon Warning Center (https://metocph.nmci.navy.mil/jtwc/best_tracks/), which are used to define the pattern of frequency of TC occurrence. Only the positions at which a TC has at least tropical storm intensity are considered to reduce the uncertainty in defining the tropical depression.

2.1.2. Indian Ocean Dipole index

The Indian Ocean Dipole (IOD) has been documented to have an effect on the oceanic and atmospheric conditions so that the SH TC activity may be linked to this phenomenon. The Dipole Mode index (DMI) obtained from the Frontier Research Center for Global Change is defined as the difference in sea-surface temperature (SST) anomaly (derived from the HadISST dataset) between the tropical western Indian Ocean (60°E-80°E, 10°S-10°N) and the tropical south-eastern Indian Ocean (90°E-110°E, 10°S-0°) (Saji and Yamagata 2003).

2.2. Frequency of TC occurrence

The spatial distribution of TC activity in a year is represented by the annual frequency of TC occurrence. The 6-hourly positions of the TCs occurring between 1983 and 2007 are extracted from the best-track dataset first. The region 40^{o}S–0^{o}N, 30^{o}E–120^{o}W is divided into 5^{o} latitude × 5^{o} longitude grid boxes. The annual number of TCs passing through each box is then calculated. If a TC passes the same box for more than one time, it is counted only once. An EOF analysis is then applied to obtain the dominant modes of TC occurrence pattern.

3. EOF ANAYSIS OF TC OCCURRENCE FREQUENCY

3.1 Mode 1 (ENSO mode)

The first EOF (PC1) of the TC occurrence frequency explains ~12.5% of the total variance, with positive loadings over the South Pacific Ocean (Fig. 1a). Two centers of maximum are found near 15^{o}S, 170^{o}E and 15^{o}S, 170^{o}W, suggesting a higher frequency of TC genesis over these areas during the positive phase of this pattern. TCs formed over the latter area tend to move southeastward and have longer lifespan, resulting in a large area of positive loadings east of 170^{o}W. A board area of negative loadings is found west of 120^{o}E, extending from northwest Australia to Madagascar. Therefore, this mode represents the east-west oscillation between the anomalous TC activity over the South Pacific and the South Indian Ocean.

The time series of PC1 generally shows positive values in El Niño and negative in La Niña years, suggesting a possible connection of this mode to ENSO events (Fig. 1d). As ENSO events usually peak in winter, the mean Niño3.4 index between December and February is used to represent the strength. The PC1 is positively correlated with the Dec-Feb Niño3.4 index (r = 0.63). Of the five years with the highest values of PC1, all of them are associated with El Niño events (1982/83, 1986/87, 1991/92, 1997/98 and 2004/05). Note that the intensity of these events is strong except for the event of 2004/05. For other weaker El Niño events (1987/88, 1994/95, 2002/03 and

* *Corresponding author address:* Johnny Chan, Guy Carpenter Asia-Pacific Climate Impact Centre, City University of Hong Kong, Tat Chee Ave., Kowloon, Hong Kong, China; e-mail: johnny.chan@cityu.edu.hk.

2006/07), this mode is insignificant. The positive phase of this mode therefore appears to be associated with stronger El Niño events. The TC season of 1982/83 is the typical one associated with the strong El Niño event and is dominated by the positive phase of this mode (Fig. 2a). The TC activity over the South Pacific is very high, with 12 tropical storms (the normal being 5.7). In contrast, the TC activity is much lower over the areas west of 120^{o}E.

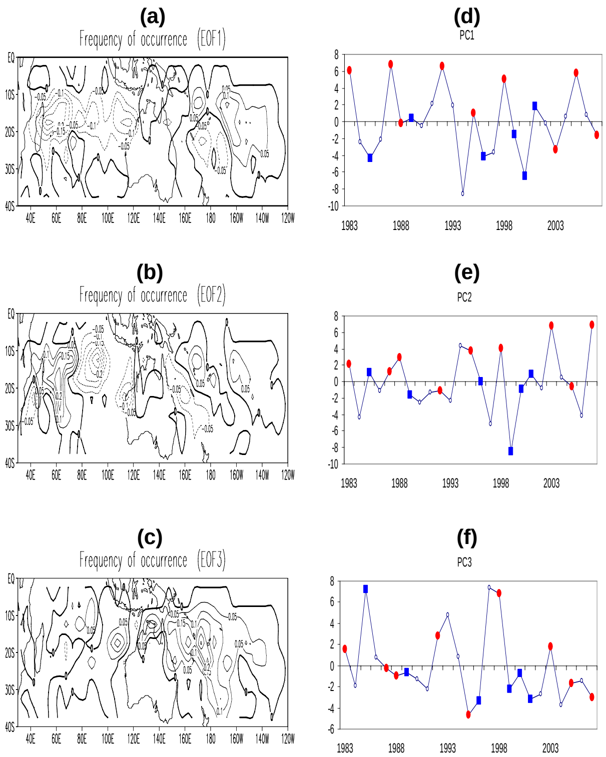

Fig. 1. Loading patterns of anomalous TC occurrence frequency for (a) EOF1, (b) EOF2 and (c) EOF3. Time series of PC1, and PC2 and PC3 are shown in (d)-(f) respectively. Red dots indicate El Niño and blue squares La Niña events.

The negative phase of this mode is mainly associated with the La Niña events (1984/85, 1995/96 and 1999/2000) except for the season of 1994/95. The typical example can be found in the TC season of 1999/2000, which shows higher TC activity over the South Indian Ocean (SIO) and lower TC activity over the South Pacific (Fig. 2b).

The first EOF mode therefore appears to represent the interannual variation of the spatial distribution of TC activity associated with ENSO events, which has been recognized in many previous studies as the main factor affecting SH TC activity. When this mode is dominant, TC activities over all the three basins are affected. The PC1 is positively correlated with the annual TC number over the South Pacific (r = 0.45) but negatively correlated with the annual TC numbers over the SIO and Australia (r = -0.61 and -0.43 respectively).

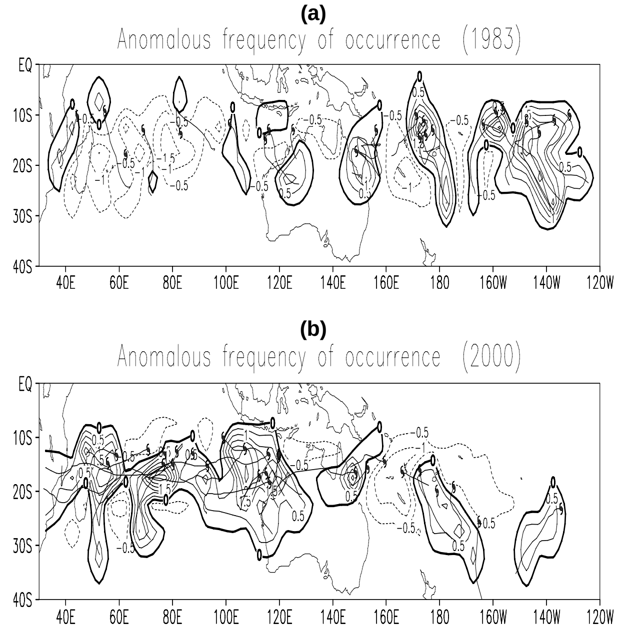

Fig. 2. Anomalous frequency of TC occurrence (contours) in (a) the positive (1982/83) and (b) negative (1999/2000) phase of EOF1 pattern. Typhoon symbols indicate the genesis positions and the thick lines indicate the tracks.

3.2 Mode 2 (IOD/ENSO mode)

The second EOF (PC2) explains ~10.0% of the total variance and its loading pattern is quite similar to that of EOF1 except for the east-west dipole over the South Indian Ocean and the smaller magnitude of loading over the South Pacific (Fig. 1b).

The distinct dipole feature of anomalous TC activity over the SIO suggests that this mode may be related to the IOD events. Indeed, the PC2 is highly correlated with both the Sep-Nov DMI and Niño3.4 index, with correlation coefficients of 0.73 and 0.55 respectively. Therefore, this mode may be related to both IOD and ENSO events. In this study, a strong positive IOD event has the Sep-Nov DMI greater than one standard deviation from the mean and a strong negative IOD event with the Sep-Nov DMI less than minus one standard deviation. During the period of 1983-2007, six stronger positive IOD events are found in the autumn of 1982, 1987, 1994, 1997, 2002, 2006, all associated with El Niño events (Fig. 3). The high correlation (r = 0.73) between the Sep-Nov Niño3.4 index and DMI also suggests a possible connection between IOD and ENSO events. Of the six TC seasons followed the positive IOD events, four (1987/88, 1994/95, 2002/03 and 2006/07) are dominated by this mode. It is worth noting that El Niño events associated with these seasons are weaker. For the other two TC seasons associated with stronger El Niño events (1982/83 and 1997/98), the positive phase of mode 1 is dominant. Hence, the positive phase of mode 2 may be prominent when the IOD is in its positive phase and the El Niño event is not strong such as the 2006/07 TC season. A strong positive IOD event developed in the autumn of 2006, as indicated by the large positive value of DMI (1.70). A moderate El Niño event was also observed during the TC season. The TC activity over the South Pacific is not very active (Fig. 4a), which is different from other seasons associated with strong El Niño events. However, a dipole of anomalous TC activity is found over the SIO, with more active TC activity over the area west of 70^{o}E and less east of this longitude.

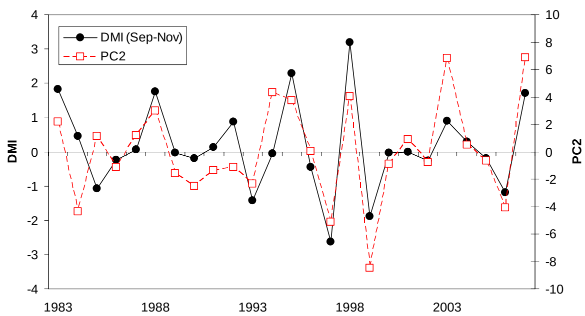

Fig. 3. Time series of the PC2 (red dashed line with empty square) and the Sep-Nov DMI (black solid line with solid circles) between 1983 and 2007.

The connection of negative IOD event to La Niña event appears to be weaker. Out of the four stronger negative IOD events (1992, 1996, 1998 and 2005), only the 1998 event is associated with La Niña event. The typical negative phase of mode 2 can be found in the 1998/99 TC season, in which a negative IOD event (Sep-Nov DMI = -1.89) developed in the fall of 1998. A dipole of anomalous TC activity is found over the South Indian Ocean, with more TC activity over the area west and less east of 70^{o}E (Fig. 4b).

It may be concluded that this mode is related to the IOD and ENSO events. Although no significant correlation exists between this mode and the annual TC number over the SIO, a shift of TC activity is observed, with a westward shift during the positive and eastward shift during the negative phase of this mode. The negative correlation between the PC2 and the annual TC number near Australia also suggests a suppression of TC activity during the positive phase of this mode.

3.3 Mode 3

The third EOF (PC3) explains ~ 9.1% of the total variance and shows positive loadings over most of the areas, with larger amplitude between 150^{o}E and 170^{o}W (Fig. 1c) and represents the overall SH TC activity. Indeed, the PC3 is highly correlated with the total number of tropical storms in the southern hemisphere, with correlation coefficient of 0.73 (Fig. 5). For example, the total number of SH tropical storms is 38 in the TC season of 1996/97 (the normal being 27.5) and positive anomalies of TC activity are found over the entire region (Fig. 6a). In contrast, negative anomalies of TC activity are observed over most of the areas in the TC season of 2000/01 (Fig. 6b).

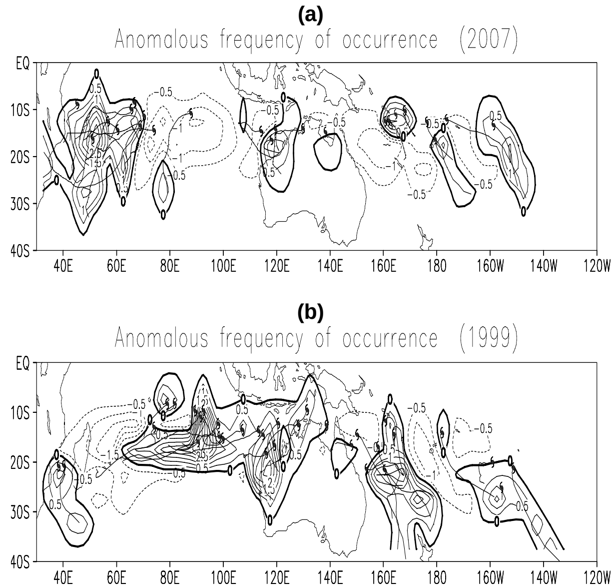

Fig. 4. Anomalous frequency of TC occurrence (contours) in (a) the positive (2006/07) and (b) negative (1998/99) phase of EOF2 pattern. Typhoon symbols indicate the genesis positions and the thick lines indicate the tracks.

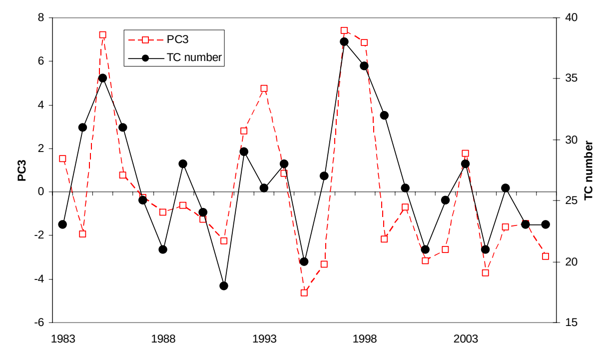

Fig. 5. Time series of the PC3 (red dashed line with empty square) and the annual number of tropical storms in the southern hemisphere (black solid line with solid circles) between 1983 and 2007.

4. SUMMARY

This paper presents results of an investigation on the interannual variability of Southern Hemisphere TC activity for the period 1983-2007. It is shown that the distribution of TC activity mainly exhibits three modes of variability: an ENSO mode, an IOD/ENSO combined mode and a basin-wide mode. A natural follow-up study is to examine the flow patterns associated with each of these modes to understand further such variabilities. Such an understanding could help in the development of a seasonal prediction of the TC activity in each of the three regions.

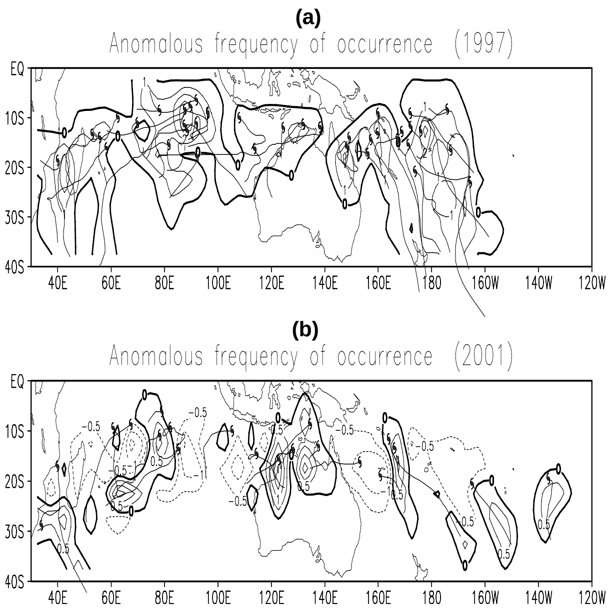

Fig. 6. Anomalous frequency of TC occurrence (contours) in (a) the positive (1996/97) and (b) negative (2000/01) phase of EOF3 pattern. Typhoon symbols indicate the genesis positions and the thick lines indicate the tracks.

REFERENCES

Grant, A. P., and K. J. E. Walsh, 2001: Interdecadal variability in north-east Australian tropical cyclone formation, *Atmos. Sci. Lett.,* **2**, 9–17.

Kuleshov, Y., L. Qi, R. Fawcett, and D. Jones, 2008: On tropical cyclone activity in the Southern Hemisphere: Trends and the ENSO connection, *Geophys. Res. Lett.*, **35**, L14S08, doi:10.1029/2007GL032983

Nicholls, N., 1979: A possible method for predicting seasonal tropical cyclone activity in the Australian region. *Mon. Wea. Rev.,* **107,** 1221–1224.

——, 1984: The southern oscillation, sea-surface temperature, and interannual fluctuations in Australian tropical cyclone activity. *J. Climatol.,* **4,** 661–670.

——, 1985: Predictability of interannual variations in Australian seasonal tropical cyclone, activity. *Mon. Wea. Rev.,* **113,** 1144–1149.

——, 1992: Recent performance of a method for forecasting tropical cyclone activity. *Aust. Meteor. Mag.,* **40,** 105–110.

Ramsay, H. A., L. M. Leslie, P. J. Lamb, M. B. Richman, and M. Leplastrier, 2008: Interannual variability of tropical cyclones in the Australian region: role of large-scale environment. *J. Climate*, **21**, 1083–1103.

Saji, N. H., and T. Yamagata, 2003: Possible impacts of Indian Ocean Dipole Mode events on global climate. *Clim. Res.*, **25**, 151–169.