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1. Introduction

In the western North Pacific, an average of about 30 tropical cyclones (TCs) formed every year, the most prolific of all the ocean basins (McBride 1995). Among them, some occurred in the South China Sea (SCS, defined for the purpose of the present study as the sea area within 10-25°N, 105-120°E) and can affect the South China coast and Hong Kong. The present study analyses how TC activity in the SCS varies with time on both interdecadal and interannual time scale.

Trend analysis suggested that between 1961 and 2004, the annual number of TCs occurring in the SCS has been decreasing at a rate of 0.8 per decade (Yeung *et al*., 2005). In the recent 10 years of 1995 to 2004, there were 8 years with annual number of TCs fewer than the 1961-1990 long-term average of 12.4. The probable cause of this recent decline in TC activity is discussed from an observational perspective.

2. Data

In this study, TC activity in the SCS and the western North Pacific between 1961 and 2004 is represented by the annual number of TCs occurring in these two ocean basins. The source is the Hong Kong Observatory's best track data. Large-scale sea surface temperature (SST) fields and wind fields at vertical levels: 1000 hPa, 850 hPa, 500 hPa and 200 hPa are drawn from the United States National Centers for Environment Prediction – National Center for Atmospheric Research (NCEP-NCAR) re-analysis data (Kalnay et al., 1996). Relative vorticity fields are derived from the wind fields.

Classification of El Niño-Southern Oscillation (ENSO) episode and its strength are based on that of National Climate Center of the China Meteorological Administration (Li and Zhai 2000). Pacific Decadal Oscillation (PDO) index defined as the leading empirical orthogonal function (EOF) of SST anomaly in January to March in the North Pacific Ocean, poleward of 20°N (Mantua *et al.* 1997), is sourced from NCEP-NCAR.

3. Interdecadal and interannual variations of TC activity in the SCS

Following the practice of Wigley and Raper (1990) in their study of the natural variability of climate systems, oscillations with periodicities of 10 years and longer are defined as low frequency or long-term variations, and oscillations with periodicities shorter than 10 years are defined as high frequency or short-term variations. In the context of this paper, the former will be referred to as interdecadal variations and the latter interannual variations.

Spectral analysis using the Multitaper method (MTM) is applied on the time series of the annual number of TCs occurring in the SCS. Compared with Fourier and other traditional methods of spectral analysis, the spectral estimates given by MTM have lower variance and higher resolution (see for example, Ghil *et al.* 2002). The analysis yields a spectral peak of periodicity of 3.6 years (Figure 1) which exceeds the 95% confidence limit when tested against the red noise spectrum (Yeung *et al.*, 2005). There is no spectral peak for periods of 10 years or more.

The 3.6-year spectral peak coincides with the periodicity of the ENSO. For moderate to strong El Niño onset year (E0) or the year immediately following the onset E1, fewer than normal TCs occurred in the SCS (Figure 2). This was due in part to a weaker subtropical ridge over the western North Pacific which steered TCs more to the northwest than to the west, away from the SCS (Chan 2000, Leung and Leung 2002, Wu *et al.* 2004). For moderate to strong La Niña onset year (L0) or the year immediately following the onset (L1), more than normal number of TCs occurred in the SCS before the mid-1970s but fewer than normal thereafter (Figure 2). This may be related to the modulation of the PDO.

In 1977, the PDO switched from a low phase (warmer than normal waters in the central North Pacific, and cooler than normal waters along the west coast of North America) to a high phase (cooler than normal waters in the central North Pacific, and warmer than normal waters along the west coast of North America) (Mantua *et al*. 1997).

Chan and Zhou (2005) investigated the interdecadal variations in the early summer monsoon rainfall over South China and found that the variations are related to the coupling effect of ENSO and the PDO. The TC activity in the SCS may also be modulated by PDO in addition to ENSO as suggested by Table 1. The modulation effect of PDO was most prominent in La Niña years, with above normal number of TCs associated with a low PDO and below normal number of TCs associated with a high PDO. The modulation effect of PDO in El Niño years was not obvious, most of which having below normal number of TCs.

By applying a low-pass Guassian filter (see for example, Hanna and Cappelen 2003) to remove variations with periodicities that are less than 10 years in the time series of the number of TCs occurring in the SCS, it is observed that interdecadal variations are not obvious in the Guassian filtered series (Figure 2), consistent with the spectral analysis result that no spectral peak are found for periods of 10 years or more. It is interesting to note also a rather rapid drop in the number of TCs since the mid-1990s. The reasons for this rapid decline are discussed in Section 4.

4. Possible mechanism for recent decline in TC activity in the SCS

By decomposing the number of TCs occurring in the SCS into two parts: (a) those which formed in the SCS (Figure 3a) and (b) those which formed east of 120^{o}E (i.e. outside the SCS) in the western North Pacific but entering the SCS (Figure 3b), it can be seen that the rapid drop in the number of TCs occurring in the SCS since the mid-1990s is mainly due to the decease in the number of TCs entering the SCS rather than the number of TCs which formed in the SCS. The decrease in the number of TCs entering the SCS is related to both a decrease in the number of TCs that formed east of 120^{o}E in the western North Pacific and a change in TC track as discussed below.

Unlike TC activity in the SCS, spectral analysis of the annual number of TCs forming east of 120°E in the western North Pacific using MTM yielded spectral peaks of periodicity of 3.3 year, 3.6 year, 14.7 year and 23.3 year, all of which exceeded the 95% confidence limit when tested against the red noise spectrum. This indicates the presence of interdecadal modulation on the TC activity.

Periods of active phase (1960s and from late 1980s to mid-1990s) and quiet phase (early 1970s to late 1980s and from mid-1990s to mid-2000s) in the activity of TCs forming east of 120°E can be identified (Figure 4). The decrease in the number of TCs forming east of 120°E since the mid-1990s is probably a manifestation of the interdecadal variation of TC activity. The latter may be explained in terms of the anomalous coupled ocean-atmosphere conditions.

Figure 5 shows that generally lower than normal sea surface temperatures (SSTs) in the subtropical western North Pacific (5-25°N, 120-180°E) and higher SSTs in the subtropical eastern North Pacific (5-25°N, 180-120°W) were observed in active TC phases, and vice versa in quiet TC phases. The troughs (peaks) of decadal variations in the number of TCs that formed east of 120°E generally correspond to the peaks (troughs) of the difference in SSTs between the subtropical western North Pacific and the subtropical eastern North Pacific (Figure 6). In fact, the two time series in Figure 6 are highly correlated with correlation coefficients of - 0.82.

This dipole like structure of SSTs between the west and the east have great impacts on the Walker circulation (Xie 1998), which in turn affects the pattern of low-level convergence, upper-level divergence and vertical wind shear which are dynamical factors for TC formation (Gray 1975). For SSTs in the subtropical western North Pacific higher than the subtropical eastern North Pacific, cyclonic flow patterns were found in the 200 hPa wind field (Figure 7a) and anticyclonic flow patterns in the 1000 hPa wind field (Figure 7b) in the subtropical western North Pacific. This lowering in both upper-level divergence and low-level convergence were unfavourable for TC development. Analysis of the mean vertical wind shear (defined as the difference between winds at 200 hPa and 1000 hPa) in the subtropical western North Pacific also revealed that the wind shear was smaller in active TC phases than in quiet TC phases (Table 2).

Areas with fewer TCs than normal in mid-1990s to mid-2000s generally coincide with areas of negative anomalies of 850 hPa cyclonic relative vorticity, and vice versa for areas with more TCs than normal (Figure 8). The role of low-level relative vorticity in enhancing the genesis of TCs was described in Gray (1975).

Apart from TC formation, a change in the track of TCs is also observed in mid-1990s to mid-2000s, when compared with TCs in 1961-1990 (Figure 9). Fewer TCs forming east of 120°E were found moving towards and entering the SCS. This anomaly in tracks is likely due to a shift in the 500 hPa flow pattern with which TCs over the area 10-20°N and 125-150°E, where most TCs are formed, were steered towards the vicinity of Japan rather than into the SCS (Figure 9).

5. Conclusion

For TC activity in the SCS, there was a decreasing trend of 0.8 per decade between 1961 and 2004. Interannual variation is dominated by ENSO, but also appears to be modulated by PDO.

TC activity in the SCS declined rapidly since the mid-1990s due to oscillation in the coupled ocean-atmospheric circulation in the subtropical Pacific, which affected the number of TCs forming in the western North Pacific as well as their tracks.

References

Chan, J.C.L., 2000, “Tropical cyclone activity in the western North Pacific associated with El Niño and La Niña events”. *J. Climate*, **13**, 2960-2972.

Chan, J.C.L. and K.S. Liu, 2004, “Global warming and Western North Pacific typhoon activity from an observational perspective”. *J. Climate*, **17**, 4590-4602.

Chan, J.C.L. and J. Shi, 1996, “Long-term trends and interannual variability in tropical cyclone activity over the western North Pacific”. *Geophys. Res. Lttrs*, **23**, 2765-2767.

Chan, J.C.L. and W. Zhou, 2005, “PDO, ENSO and the early summer monsoon rainfall over south China”. *Geophys. Res. Lttrs*, **32**, L08810, doi:10.1029/2004GL022015.

Ghil, M, M. R. Allen, M. D. Dettinger, K. Ide, D. Kondrashov, M.E. Mann, A. W. Robertson, A. Saunders, Y. Tian, F. Varadi and P. Yiou, 2002, “Advanced spectrum methods for climatic time series”. *Rev. Geophys.*, **40**, 1-1-1-41.

Gray, W.M., 1975, “Tropical cyclone genesis”. Dept. of Atmos. Sci. Paper No. **232**, Colorado State University, Ft. Collins, CO, 121 pp.

Hanna, E. and J. Cappelen, 2003, “Recent cooling in coastal southern Greenland and relation with the North Atlantic Oscillation”. *Geophys. Res. Lttrs.*, **39**, 32-1-3.

Kalnay, E. and Coauthors, 1996, “The NCEP/NCAR 40-year reanalysis project”. *Bull. Am. Meteorol. Soc.*, **77**, 437-471.

Leung, Y.K. and W.M. Leung, 2002, “Effect of ENSO on number of tropical cyclones affecting Hong Kong”. *HK. MetS Bulletin*, **12**, Number 1/2.

Li, X. and P. Zhai, 2000, “On indices and indicators of ENSO episodes”. *ACTA Meteorol. Sinica*, **88**, 102-109.

Mantua, N.J., S.R. Hare, Y. Zhang and J.M. Wallace, 1997, “A Pacific interdecadal climate oscillation with impacts on salmon production”. *Bull. Am. Meteorol. Soc.*, **78**, 1069-1079.

McBride, J.L., 1995, “*Tropical cyclone formation, Chapter 3, Global Perspectives on Tropical Cyclones*”. R.L. Elsberry, Ed. Tech. Doc. WMO/TD No. 693, World Meteorological Organisation, Geneva, Switzerland, 63-105.

Wigley, T. M. L., and C. B. Raper, 1990, “Natural variability of the climate system and detection of the greenhouse effect”. *Nature*, **344**, 324-327.

Wu, M.C., W.L. Chang and W.M. Leung, 2004, “Impacts of El-Nino Southern Oscillation Events on Tropical Cyclone Landfalling Activity in the Western North Pacific”. *J. Climate*, **17**, 1419-1428.

Xie, S.P., 1998, “Ocean-Atmosphere Interaction in the Making of the Walker Circulation and Equatorial Cold Tongue”. *J. Climate*, **11**, 189-201.

Yeung, K.H., M.C. Wu, W.L. Chang and Y.K. Leung, 2005, “Long-term Change in Tropical Cyclone Activity in the Western North Pacific”. Presented in the Scientific Assembly of International Association of Meteorology and Atmospheric Science (IAMAS) 2005, Beijing, China, 2-11 August. *Hong Kong Observatory Reprint No.* **601**.

Table 1. Comparison of the annual number of TCs in the SCS during different ENSO/PDO phases. Anomaly is with reference to the 1961-1990 mean.

ENSO status	Anomaly in the annual number of TCs in the SCS	Low PDO	High PDO
El Niño years	positive anomaly	0	2/8
	negative anomaly	5/5	6/8
La Niña years	positive anomaly	5/5	0
	negative anomaly	0	6/6

Table 2. Relationship between the anomaly in the annual number of TCs forming east of 120^{o}E in the western North Pacific and the vertical wind shear anomaly averaged over the region 5-25^{o}N, 120-180^{o}E in May-November. Anomaly is with reference to the 1961-90 mean. Negative values are shaded in light grey.

Period	Anomaly in annual number of TCs forming east of 120^{o}E	Vertical wind shear anomaly
1961-1969	3.5	-1.2
1970-1988	-1.8	0.5
1989-1994	3.1	-0.1
1995-2004	-3.6	0.6

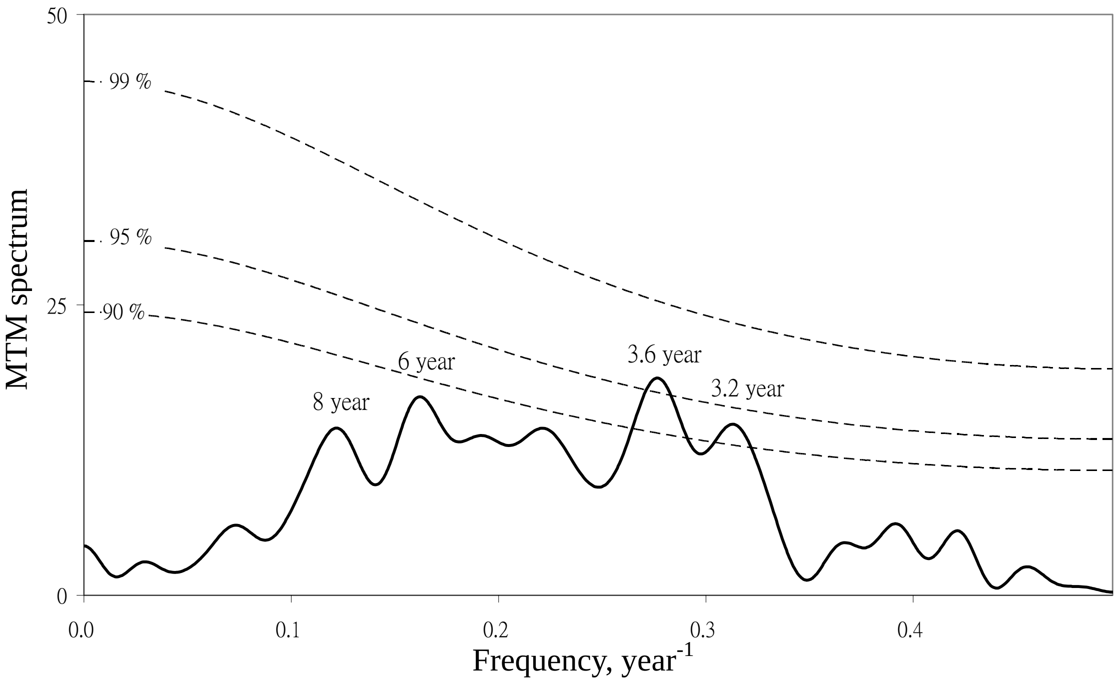


Figure 1. MTM spectrum of the annual number of TCs in the SCS. The 90%, 95% and 99% confidence levels with respect to the red noise spectrum are shown by the dashed lines (from Yeung *et al.* 2005).

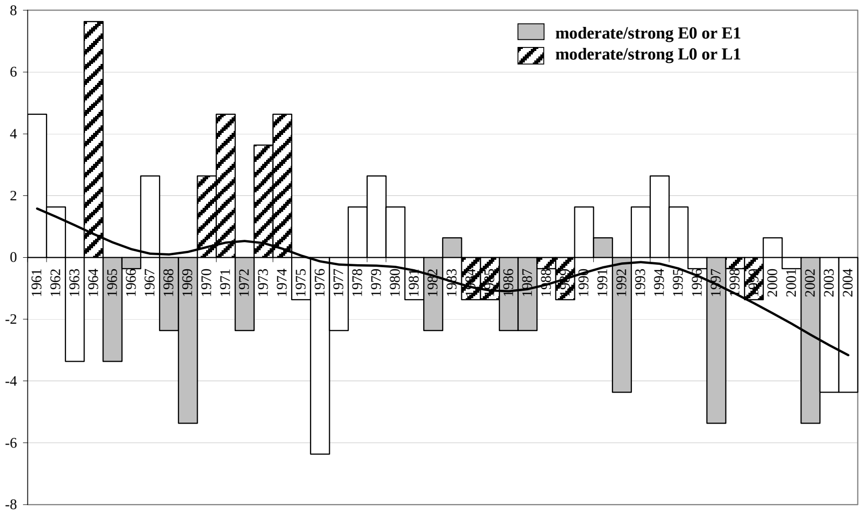


Figure 2. Anomaly in the annual number of TCs occurring in the SCS. Anomaly is with reference to the 1961-90 mean. The dark line shows the Gaussian filtered time series with periodicities of less than 10 years removed.

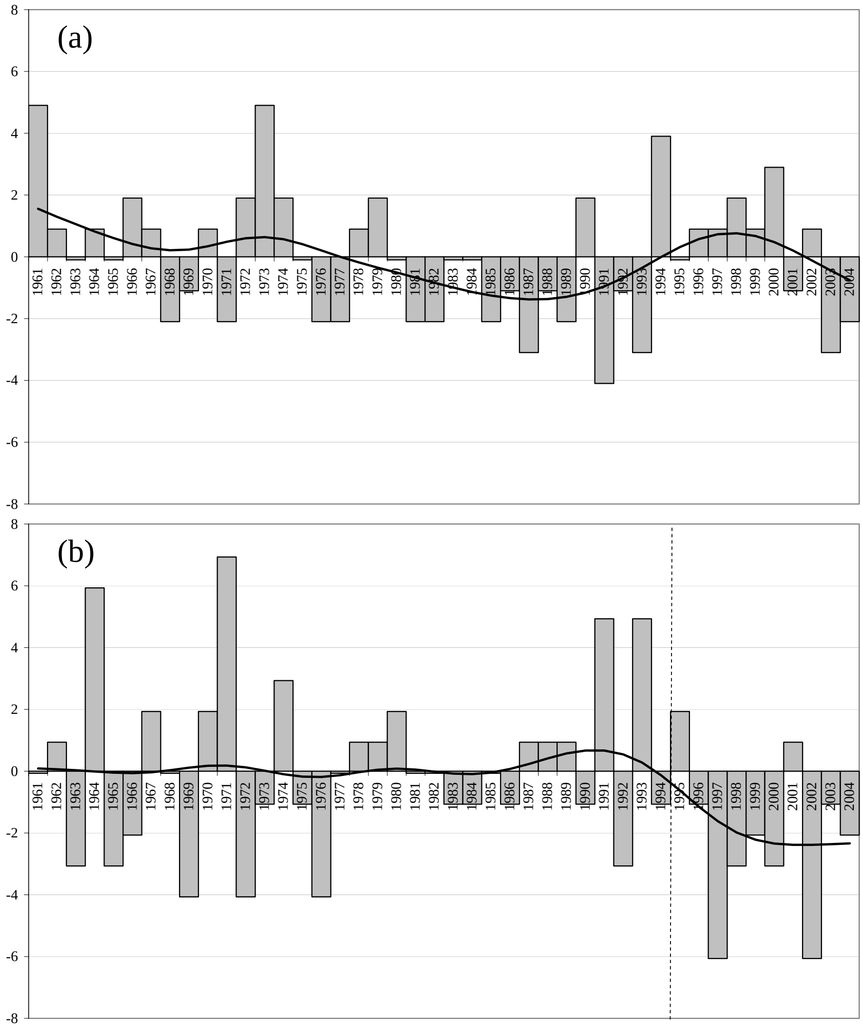


Figure 3. Anomaly in the annual number of TCs which (a) formed in and (b) entering the SCS. Anomaly is with reference to the 1961-90 mean. The dark line shows the Gaussian filtered time series with periodicities of less than 10 years removed.

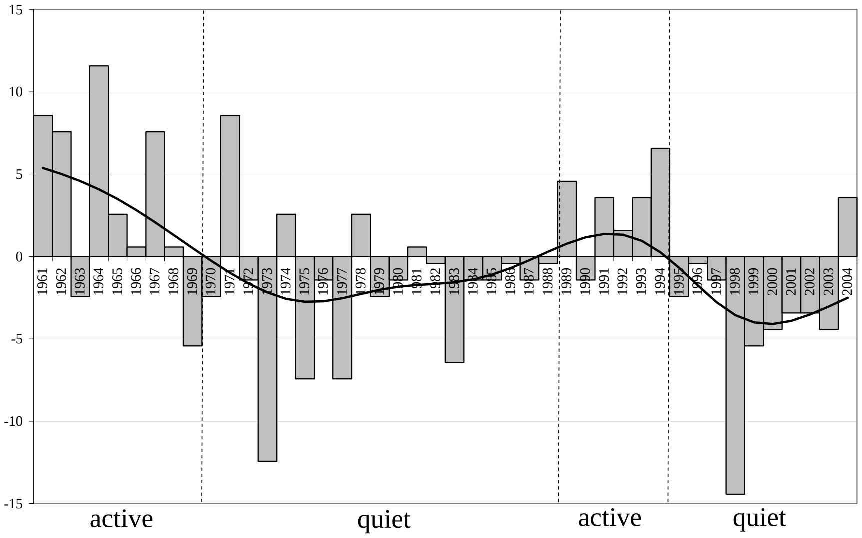


Figure 4. Anomaly in the annual number of TCs which formed east of 120^{o}E in the western North Pacific. Anomaly is with reference to the 1961-90 mean. The dark line shows the Gaussian filtered time series with periodicities of less than 10 years removed. Active TC phases (1961-1969, 1989-1994) and quiet TC phases (1970-1988, 1995-2004) are classified using the Gaussian filtered time series.

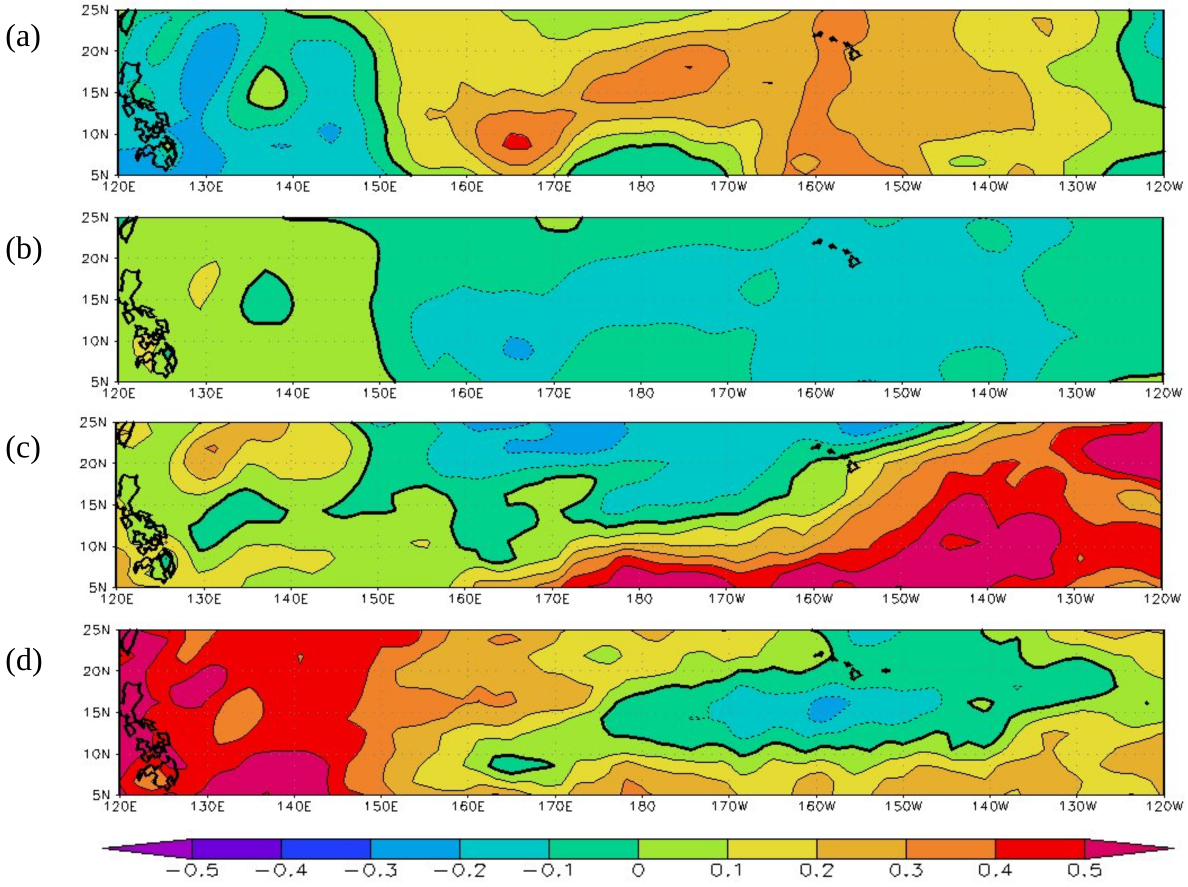


Figure 5. Sea surface temperature anomaly (^{o}C) averaged over May-November for (a) 1961-1969, (b) 1970-1988, (c) 1989-1994 and (d) 1995-2004. Anomaly is with reference to the 1961-90 mean.

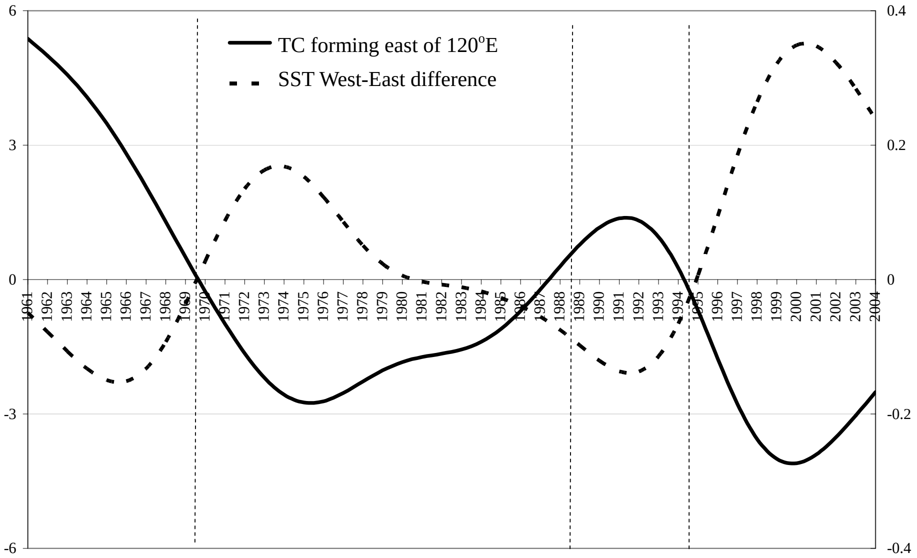
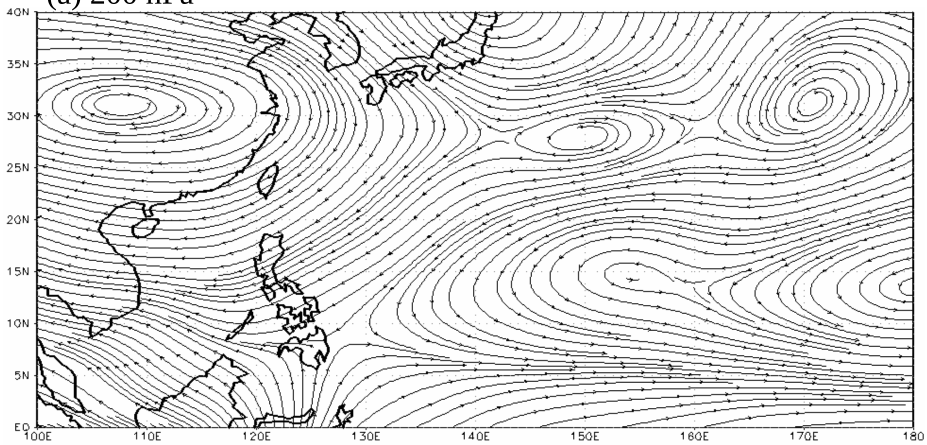


Figure 6. Gaussian filtered time series (with periodicities of less than 10 years removed) of annual number of TCs forming east of 120^{o}E and the SST West-East differences. West-East SST difference is defined as SST averaged over (5-25^{o}N, 120-180^{o}E) minus SST averaged over (5-25^{o}N, 180-120^{o}W).

(a) 200 hPa



(b) 1000 hPa

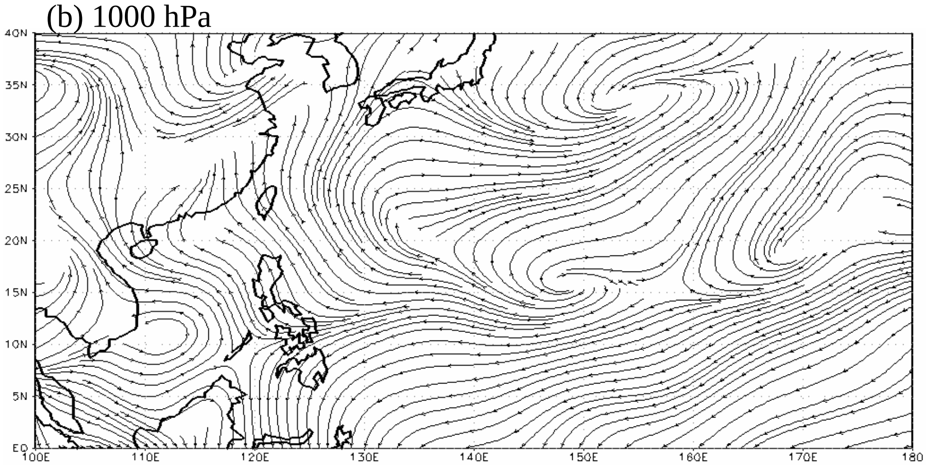


Figure 7. Difference in composite circulations between 1995-2004 (positive West-East SST difference) and 1989-1994 (negative West-East SST difference) at (a) 200 hPa and (b) 1000 hPa levels.

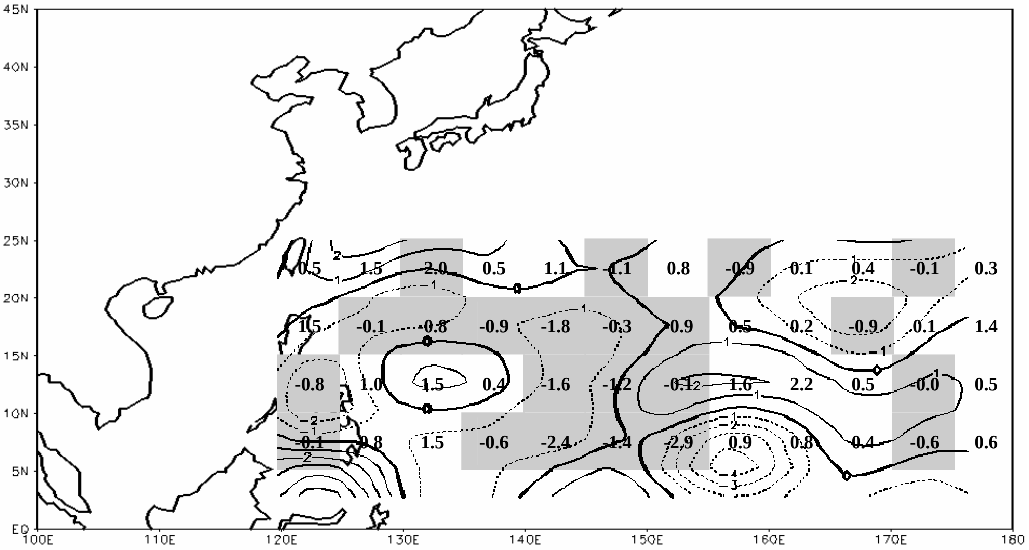


Figure 8. Anomaly in the percentage of TCs forming east of 120°E in the western North Pacific in each 5°x5° longitude-latitude grid area for 1995-2004. Superimposed is the relative vorticity anomaly (unit of 1x10^{-6}s^{-1}) averaged over May-November. Grid areas with fewer TCs formations are shaded in light grey. Anomalies are with reference to the 1961-90 mean.

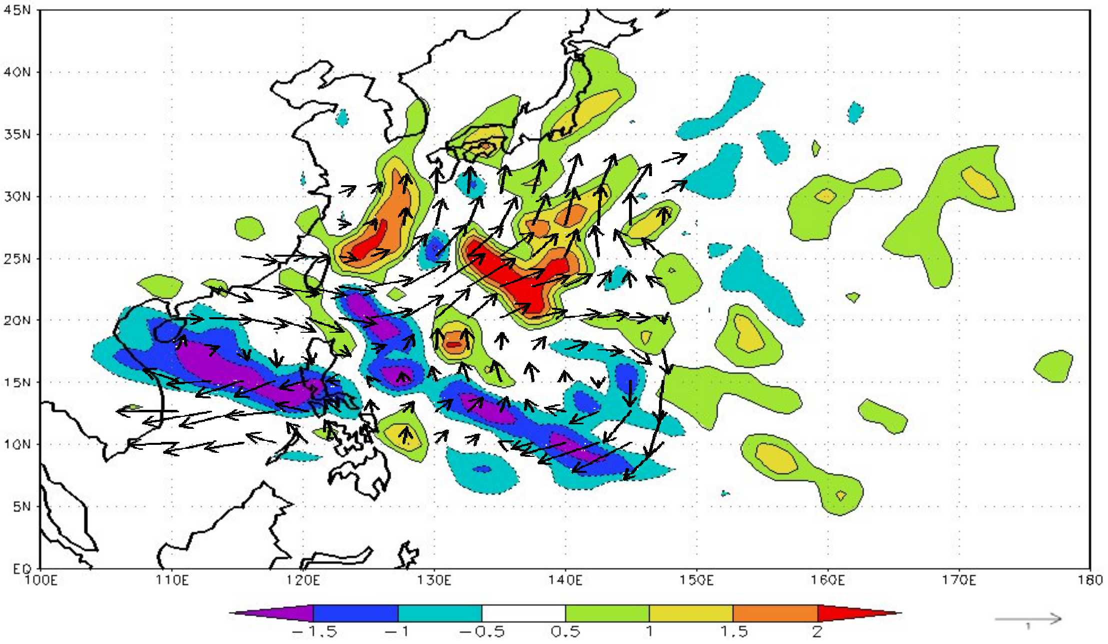


Figure 9. Anomaly in TC track density for 1995-2004. Superimposed is the 500 hPa steering flow anomaly averaged over May-November (unit of ms^{-1}). Anomalies are with reference to the 1961-90 mean.