An analysis of multi-scale nature of tropical cyclone activities in June 2004

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Introduction

A record-breaking five tropical cyclones (TC) formed in the northwestern Pacific (NWP) Ocean in June 2004 (climatological value 1.8) and two of them made landfall over Japan (Fig. 1). In this study, we analyze the weather and climate oscillations of this particular month in relation to other years from 1982 to 2006 to investigate the possible causes of this unusual event.

Data and method

The data we use include the best track data from Joint Typhoon Warning Center (JTWC), NCEP FNL analysis (2000-current), NCEP reanalysis (R2), OISST and NOAA OLR. From the JTWC data, we divide the 25 months of June into TC-active (>3), TC-inactive (0), and normal years (Table 1). To show the interannual to intraseasonal changes, we divide the 25 months of June into warm (1982, 1987, 1994, 1997, 2002, 2004, 2006), cold (1983, 1984, 1988, 1998, 1999, 2000) and normal based on Oceanic Nino Index (ONI, NOAA/NWS/CPC), and MJO-active and MJO-inactive based on the Real-time Multivariate MJO (RMM) indices (Wheeler and Hendon, 2004). See Table 1 and Figure 2 for more details.

TC activities in relation to multiscale oscillations

We performed a composite analysis of SST and 850 hPa winds for the month of June in TC-active years (1982, 1990, 1997, 2002, 2004) and TC-inactive years (1996, 1998, 2000, 2005). Our analysis reveals the low-level mean circulation over the NWP in June for TC-active years and TC-inactive years exhibit large interannual changes from its normal condition with monsoon westerly and easterly trade converging near 120°E (Fig. 3,4). The composite for TC-active (TC-inactive) years resemble the El Niño developing (La Niña) condition, i.e. warm (cold) SSTA occurring in central equatorial Pacific with westerly (easterly) anomaly and the monsoon trough and shear line extending eastward (westward). The SST and low-level winds in June 2004 is quite similar to the June composite of TC-active years but with much stronger amplitude.

We also examine the Madden Julian Oscillation (MJO) for the month of June, 1979-2007. Previous studies show that MJO provides a more favorable condition for TC genesis when its convective phase arrives at the western Pacific, and a less favorable condition when its suppressed phase resides over the western Pacific (Liebmann et al., 1994; Maloney and Hartmann, 2000; Kim et al., 2008). We calculate the integrated amplitude of the first two RMM indices for the active phase (5, 6, 7) and inactive phase (1, 2, 3) in June and designate the month as MJO-active or inactive if the amplitude is larger than 2/3 of the mean MJO amplitude in June (19.58). It turns out that among the five TC-active years, three are associated with active MJO while the four TC-inactive years, two are associated with inactive MJO, indicating a weak positive correlation. This suggests that the favorable large-scale condition brought about by MJO is weak and may not be sufficient for TC genesis. In addition to MJOs, the East Asian summer monsoon also contains a significant spectral peak at quasi-biweekly time scale. The nature of this subseasonal variability and its effect on TC activity awaits further study.

Cyclogenesis mechanism in June 2004

Climate oscillations change the large-scale environment for overall TC genesis. But the actual location and timing of TC genesis is determined by higher-frequency (HF) tropical wave disturbances such as the equatorial Rossby waves, mixed-Rossby-gravity (MRG) waves, and tropical-depression-type disturbances (Holland 1995; Sobel and Bretherton 1999; Kuo et al. 2001; Dickinson and Molinari 2002). The Rossby wave energy dispersion may cause a new TC to form in the wake of a pre-existing TC, resulting a clustering of TC genesis (Fu et al., 2007). How do these TC-wave interaction work for the five typhoons in June 2004 (Conson, Chanthu, Dianmu, Mindulle, and Tingting) are analyzed (Table 2).

The first typhoon (Conson) formed due to an easterly wave accumulation within the East-Asia Monsoon trough. Typhoon Chanthu formed in the wake of the pre-existing Typhoon Conson through Rossby wave energy dispersion. E-vector analysis (Trenberth 1986) shows that the pre-existing Typhoon propagating to its rear area (Fig. 5). A cyclone formed in the positive vorticity region of the Rossby wave train of Typhoon Chanthu. This cyclone later grew to Typhoon Dianmu in the monsoon shear line (Ritchie and Holland, 1999). In mid-June, easterly waves were blocked by an anti-cyclonic circulation. A large-scale cyclonic circulation occurred to the right of the anti-cyclonic circulation. Five days later, the large-scale cyclonic circulation concentrated and developed into Typhoon

Mindulle. The last typhoon (Tingting) was formed by Rossby wave energy dispersion in the monsoon shear line. The genesis locations of all typhoons corresponded well to the MJO-related convective region. The interaction between these typhoon activities and the background MJO is being investigated.

Summary

The above result indicates that the high TC genesis in June 2004 is a combined result of favorable large-scale environment provided by a developing El Nino warming condition and an unusually strong MJO that is coupled with high tropical waves-TC activities. In this particular event, TCs and HF wave disturbances appear to interact nonlinearly with the monsoon environment with larger spatial and longer temporal scales, contributing a significant intra-seasonal oscillation in the northwestern Pacific Ocean.

Reference

Dickinson, M. J., and J. Molinari, 2002: Mixed Rossby–Gravity Waves and Western Pacific Tropical Cyclogenesis. Part I: Synoptic Evolution. *J. Atmos. Sci.*, **59**, 2183–2196.

Fu, B., T. Li, M.S. Peng, and F. Weng, 2007: Analysis of Tropical Cyclogenesis in the Western North Pacific for 2000 and 2001. *Weather and Forecasting*, **22**, 763-780.

Holland, G. J., 1995: Scale Interaction in the Western Pacific Monsoon. *Meteor. Atmos. Phys.*, **56**, 57–79.

Kim, J.-H., C.-H. Ho, H.-S. Kim, C.-H. Sui, and S. K. Park, 2008: Systematic Variation of Summertime Tropical Cyclone Activity in the Western North Pacific in Relation to the Madden–Julian Oscillation. *J. Climate*, **21**, 1171-1191.

Kuo, H.-C., J.-H. Chen, R. T. Williams, and C.-P. Chang, 2001: Rossby Waves in Zonally Opposing Mean Flow: Behavior in Northwest Pacific Summer Monsoon. *J. Atmos. Sci.*, **58**, 1035-1050.

Liebmann, B., and H. H. Hendon, 1990: Synoptic-scale Disturbances near the Equator. *J. Atmos. Sci.*, **47**, 1463–1479.

Maloney, E. D., and D. L. Hartmann, 2000: Modulation of Hurricane Activity in the Gulf of Mexico by the Madden-Julian Oscillation. *Science*, **287**, 2002–2004.

Ritchie, E. A., and G. J. Holland, 1999: Large-scale patterns associated with tropical cyclogenesis in the western Pacific. *Mon. Wea. Rev.*, **127**, 2027–2043.

Sobel, A. H., and C. S. Bretherton, 1999: Development of Synoptic-scale Disturbances over the Summertime Tropical Northwest Pacific. *J. Atmos. Sci.*, **56**, 3106–3127.

Trenberth, K. E., 1986: An assessment of the impact of transient eddies on the zonal flow during a blocking episode using localized Eliassen–Palm flux diagnostics. *J. Atmos. Sci.*, **43**, 2070–2087.

Wheeler, M., and H. Hendon, 2004: An All-Season Real-Time Multivariate MJO Index: Development of an Index for Monitoring and Prediction. *Mon. Wea. Rev.*, **132**, 1917–1932.

Table 1. Numbers of Western North Pacific Tropical Cyclones in June. Red (blue) boxes represent ENSO warm (cold) years based on Oceanic Niño Index (ONI). The TC numbers in red represent TC-active years (more than 3 TCs occur). Those for TC-inactive years (no TC) are denoted in blue. The average number of TC in June from 1982 to 2006 is 1.8. The MJO-active and inactive June are marked "act" in red and "inact" in blue along with measures of MJO strength (numbers below) based on RMM indices, i.e. the summation of amplitude of active phase (5, 6, 7) or inactive phase (1, 2, 3) in June larger than 2/3 of mean MJO amplitude in June (19.58).

Year	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
TC	3	1	2	2	2	2	2	2	3	1	2	1
MJO	act 27.4		act 25.1	act 31.2	act 27.4	act 21.8	inact 19.9			act 21.4		
1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
2	2	0	3	0	1	0	2	3	2	5	0	2
	inact 25.2	inact 23.5	inact 34.6					act 19.9	inact 32.8	act 23.9	inact 19.6	inact 27.4

Table 2. Genesis mechanisms of each TC in June 2004.

TC	Name	Monsoon shear line	Monsoon confluence zone	Rossby wave energy dispersion	Easterly wave
A	Conson				yes
B	Chanthu			yes	yes
C	Dianmu	yes		yes	
D	Mindulle		yes	yes	
E	Tingting	yes		yes	

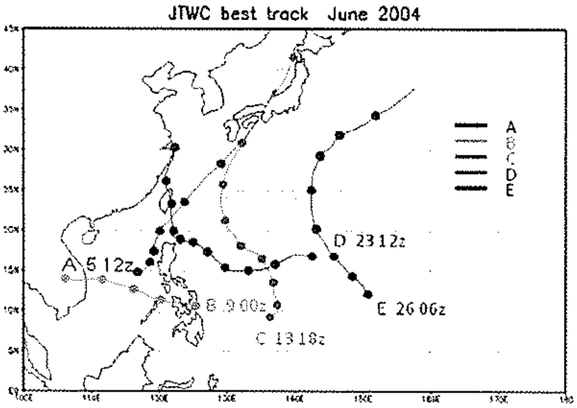


Fig. 1 JTWC best track of TCs in June 2004. The sequence of genesis is from A to E. The Cyclogenesis times are described after the marks. A dot along the track represents the TC center every 24 hours.

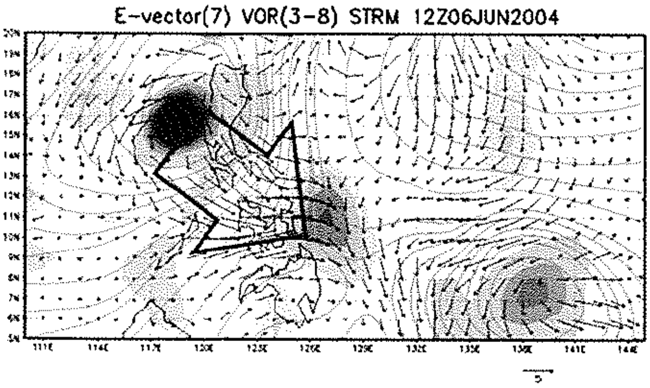


Fig. 5 Horizontal map of E vectors calculated based on Trenberth (1986); $E = \left(\overline{(-u'u' + v'v')}/2 \ , \ \overline{-u'v'} \right)$. The E vectors are summed over a 7-day period centered on 12UTC 6 Jun 2004. The letter "A" marks position of the pre-existing TC. The letter "B" marks position of the following TC. The direction of energy dispersion is represented by black arrow. Also shown are unfiltered streamline (in green) and 3-8 day band-pass filtered vorticity fields (color shaded).

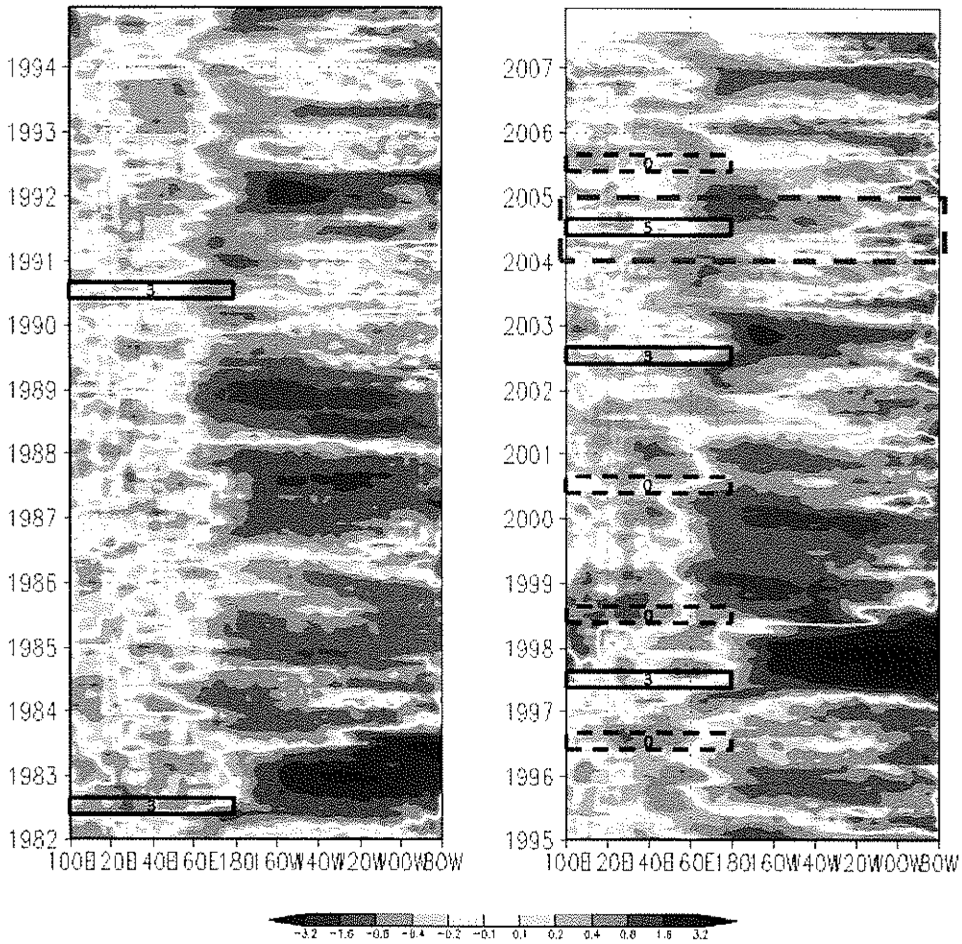


Fig. 2 Hovmöller diagram of SST anomalies averaged from 5°S to 5°N. TC- active and TC-inactive months of June are shown by solid and dashed boxes with the number of TC enclosed. Green box drawn by dashed line depict our case year, 2004.

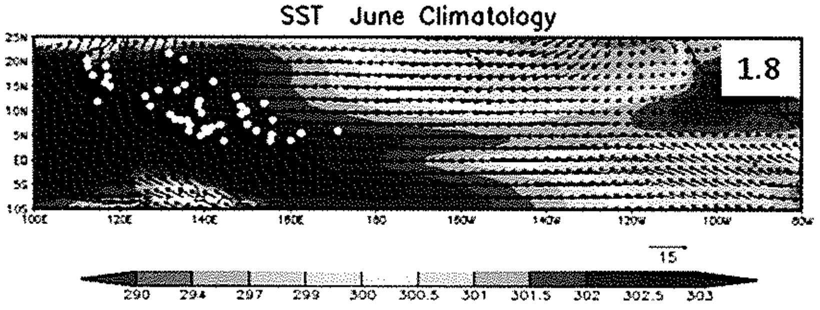
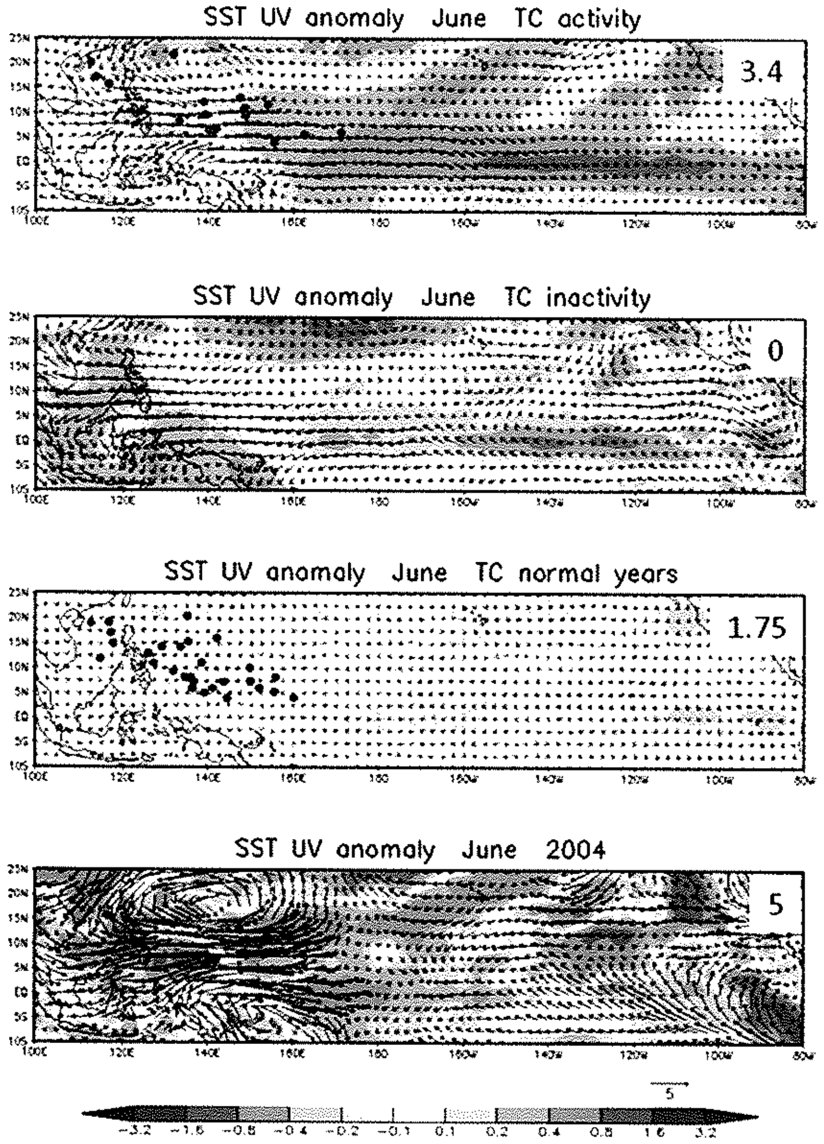


Fig. 3 Winds (850hPa) and SST in June averaged from 1982 to 2006. TC genesis positions are described by white dots.



SST UV anomaly June TC activity

SST UV anomaly June TC inactivity

SST UV anomaly June TC normal years

SST UV anomaly June 2004

Fig. 4 Same as Figure 3 but for anomaly fields in (a) TC-active years (1982, 1990, 1997, 2002, 2004), (b) TC-inactive years (1996, 1998, 2000, 2005), (c) normal years (1983, 1984, 1985, 1986, 1987, 1988, 1989, 1991, 1992, 1993, 1994, 1995, 1999, 2001, 2003, 2006), and (d) 2004. The mean numbers of TC are described in the higher-right corner.