An analysis of TC activities interacting with tropical waves

Lin Ching[1] Chung-Hsiung Sui[2,1] Ming-Jen Yang[1,2]

[1]*Department of Atmospheric Sciences, National Central University, Taiwan*

[2]*Institute of Hydrological and Oceanic Science, National Central University, Taiwan*

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Record-breaking five tropical cyclones (TCs) formed in June 2004 and two of them made landfall over Japan. This special month, which is in a transition to the usual typhoon season, was an unusual event which contained many high-frequency wave motions with a strong convective phase of the Madden-Julian oscillation (MJO) in the developing stage of a warm (El Niño) episode. We report on two different mechanisms which maintained the large-scale cyclonic circulation anomaly: the tropical deep convection associated with MJO system, and the warm sea surface temperature anomalies (SSTA) associated with the developing stage of a warm (El Niño) episode. The MJO-forced Rossby wave response induced MRG-TD wave train, which propagated westward and reflected to the MJO envelop in WNP. TCs may formed in the active phase of MRG-TD waves. MRG-TD waves also may be generated by TCs. This complex interaction was well present by the special case.

1.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. 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.

2.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 for more details.

3.Modulation effect by ENSO events

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^{o}E (Fig. 1,2). 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.

4.Relationship between MJO and TC

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.

The number of TC formation in 2004 shows a large month to month variation. More TCs than climatological values in May, June, and August, and less TCs than climatological values in July, September, and October. Such an inter-month variation is well correlated with intraseasonal oscillations as shown by the Hovmöller diagram of space-time filtered OLR at MJO band from mid-May to August in 2004 (Fig. 3). Compared to the phase of MJOs, from June to September, more TCs formed in the month corresponding to the convective phase of MJOs, i.e. June and August. Especially in June, five TCs formed in a strong MJO convective phase accompanied many high-frequency wave variations (Rossby wave and MRG-TD wave). The MJO suppressed phases corresponded to less TC genesis in July and September.

5.Relationship between each wave in June 2004

In addition to the favorable environmental conditions provided by El Niño and MJOs, tropical waves were also active during 2004 warm season. 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).

Figure 3 shows that a Rossby wave series started in SCS from May. The Rossby wave phase propagated westward while the group velocity is eastward. This wave series reached the date line and persisted to mid-July. Four of five TCs in June occurred near the positive vorticity region of the Rossby wave. The Rossby wave was not significant after mid-July. Only one positive vorticity of the Rossby wave occurred in August, and three TCs formed near the convective region during this period.

The wave length of westward-propagating MRG-TD wave is shorter. But the group speed of MRG-TD is eastward and is similar to the eastward phase speed of MJO (Straub and Kiladis, 2003). In early-June, one series of MRG-TD wave variation developed from SCS. This MRG-TD wave series occurred behind the equatorial convective region of MJO. Two TCs formed near the convective zone of the MRG-TD wave series in late-June. Another organized MRG-TD wave series occurred from early August coincide with the second strong MJO convective phase. The MRG-TD wave series crossed the date line in late August.

Focusing on the five TC formations in June, different waves played varied roles in each TC genesis. The first TC in June (TC A) was related by both MJO and Rossby wave. The second TC (TC B) formed near the convective region of MJO, but in a suppressed region of Rossby wave. The third TC (TC C) formed near the core of the convective region of MJO, east of a convective region of Rossby wave. It seemed that MJO, Rossby wave and MRG-TD wave all related to the genesis of the fourth and fifth TCs (TC D and TC E). The highly active wave motions may be related to the high number of TC fomation in June 2004.

6.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.

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Table 1. Numbers of Western North Pacific Tropical Cyclones in June. Light (dark) gray boxes represent ENSO warm (cold) years based on Oceanic Niño Index (ONI). The italic and bold type represents the TC numbers of TC-active years (more than 3 TCs occur). Those for TC-inactive years (no TC) are denoted in bold type with under line. 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
TC	***3***	1	2	2	2	2	2	2
MJO	act 27.4		act 25.1	act 31.2	act 27.4	act 21.8	inact 19.9	
	1990	1991	1992	1993	1994	1995	1996	1997
	3	1	2	1	2	2	**<u>0</u>**	***3***
		act 21.4				inact 25.2	inact 23.5	inact 34.6
1998	1999	2000	2001	2002	2003	2004	2005	2006
<u>0</u>	1	**<u>0</u>**	2	***3***	2	***5***	**<u>0</u>**	2
				act 19.9	inact 32.8	act 23.9	inact 19.6	inact 27.4

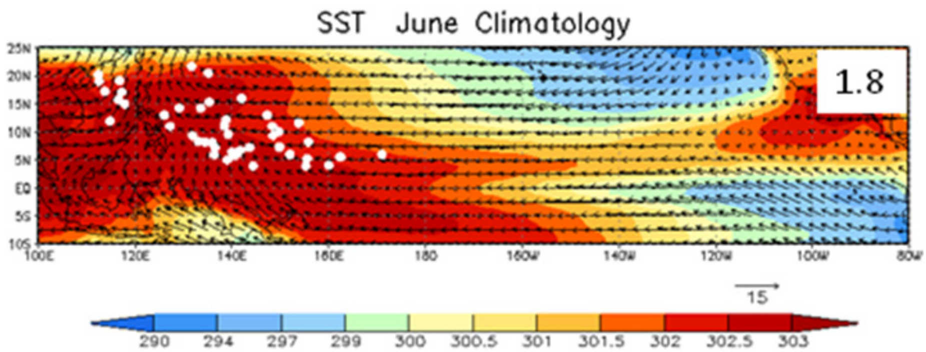

Fig. 1 Winds (850hPa) and SST in June averaged from 1982 to 2006. TC genesis positions are described by white dots.

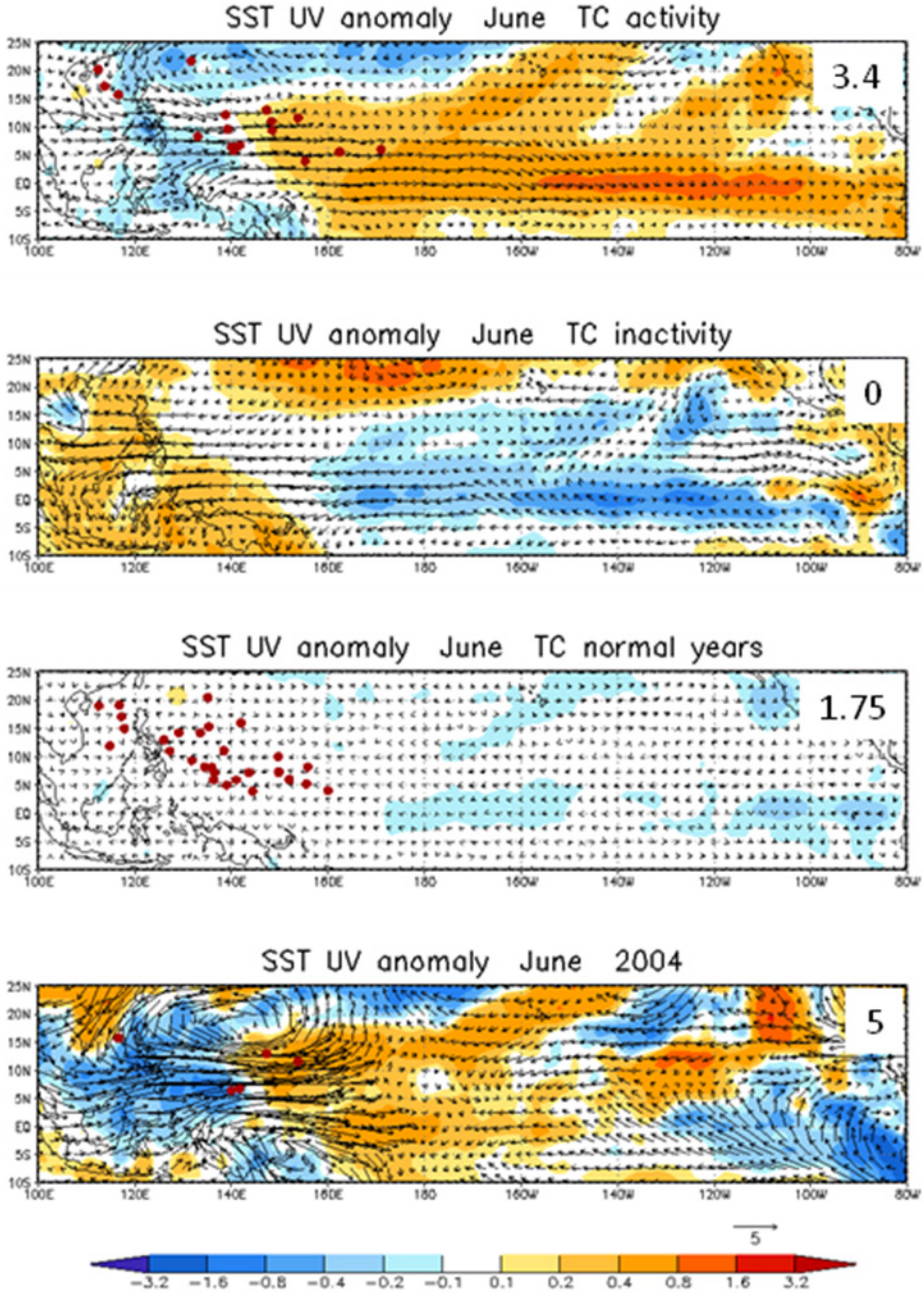

Fig. 2 Same as Figure 3 but for anomaly fields in (a) TC-active years (1982, 1990, 1997, 2002, 2004), (b) TC-inactive years (1996, 1998, 2000, 2005), (c) normal years (1983, 1984, 1985, 1986, 1987, 1988, 1989, 1991, 1992, 1993, 1994, 1995, 1999, 2001, 2003, 2006), and (d) 2004. The mean numbers of TC are described in the higher-right corner.

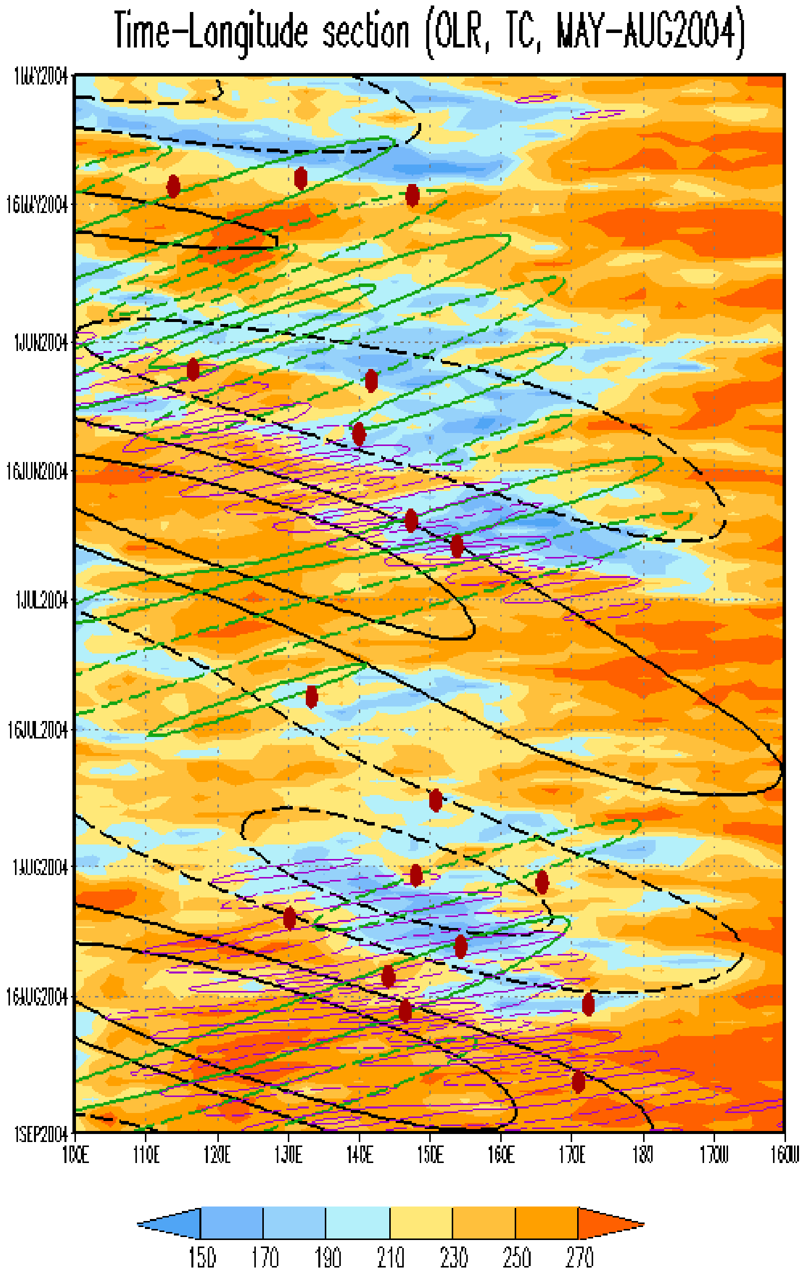

Fig. 3 Hovmöller diagram of OLR averaged from 5oS to 5oN. The period is from 1 May to 1 September. Black contour indicate the OLR of MJO averaged from 5oS to 5oN. Green, and purple contours indicate the vorticity of Rossby waves and MRG-TD waves averaged from 5oN to 15oN , respectively. Solid (dashed) contour lines represent positive (negative) anomalies. Dots indicate the formation longitude and time of tropical cyclones.