MAUSAM, 48, 2 (April 1997), 189-194

551.515.2(265)

# Sub-seasonal variations of the tropical storm track in the western north Pacific

BIN WANG and LIGUANG WU

*Department of Meteorology, University of Hawaii,*
*2525 Correa Road, Honolulu HI 96822, USA*

**सार** — पिछले बीस वर्षों (1975 से 1994) के जलवायविक आँकड़ों के आधार पर हमें यह ज्ञात हुआ है कि पश्चिम उत्तर प्रशान्त महासागर (0-40° उ., 100-180° पू.) उष्णकटिबंधीय चक्रवातीय तूफानों का क्षेत्र होने के कारण यहाँ पर मई से नवम्बर तक लगभग 40 दिनों की अवधि में स्थाई उप-मौसमी परिवर्तन होते हैं। चक्रवातों के इस क्षेत्र में होने वाले ये परिवर्तन पश्चिम उत्तर प्रशांत महासागर की मानसून के सक्रिय होने के क्षेत्र तथा पश्चिम प्रशांत क्षेत्र के अर्ध उष्णकटिबंधीय उच्च क्षेत्र से संबद्ध स्थिति के कारण सुस्पष्ट जलवायविक अंतःमौसमी दोलन (सी. आई.एस.ओ.) पर निर्भर होते है। मानसून के सक्रिय होने से पूर्व तथा मानसून की वापसी की अवधियों में कई उष्णकटिबंधीय तूफानों का बनना जलवायविक अंतः मौसमी दोलन (सी.आई.एस.ओ.) पर निर्भर रहता है लेकिन मानसून के सक्रिय होने तथा प्रबलता से सक्रिय रहने के दौरान (मध्य जून से मध्य सितम्बर तक) उष्णकटिबंधीय तूफानों का बनना सी. आई. एस. ओ. पर निर्भर नहीं करता है।

**ABSTRACT.** With 20-year (1975-94) climatological data, we demonstrate that the tropical storm track over the western North Pacific (0°-40°N, 100°-180°E) exhibits prominent sub-seasonal variations on a time scale of about 40 days from May to November. The storm track variability is regulated by the conspicuous Climatological Intra Seasonal Oscillation (CISO) in the strength of the western North Pacific summer monsoon and the associated position of the western Pacific Sub-tropical High. The CISO cycle regulates the number of tropical storm formation during the Pre-Onset and Withdraw Cycles but not during the Onset and Peak Monsoon Cycles (from mid-June to mid-September).

Key words — Sub-seasonal variation, Climatological Intra-seasonal Oscillation (CISO), Outgoing Longwave Radiation (OLR), Storm track

## 1. Introduction

Harr and Elsberry (1991) demonstrated that the tropical cyclone track types exhibit evident intra-seasonal variations during the year of 1980. The straight-moving and recurving tracks occurred alternatively during that summer from June to October. Other years appear to have similar persistent periods of alternating track types. Normally, the intra-seasonal variations of tracks are subject to year-to-year variability. Therefore, it is not clear to what extent the tropical cyclone tracks have sub-seasonal variation in the climatological sense. Recently, Uedo *et al.* (1995) noticed a dramatic change in tropical cyclone tracks in late July and early August, accompanying the end of Baiu, implying that the intra-seasonal variation of tropical cyclone tracks may be phase locked to annual cycle.

In a recent paper, Wang and Xu (1996) (hereafter WX 96) have demonstrated that the Northern Hemisphere (NH) summer monsoon, especially the Western North Pacific Summer Monsoon (WNPSM), displays statistically significant climatological intra-seasonal oscillations (CISO). Four CISO cycles were identified in the NH summer monsoon domain from May to November. The extreme phases of CISO cycles characterize sub-seasonal variations of the NH summer

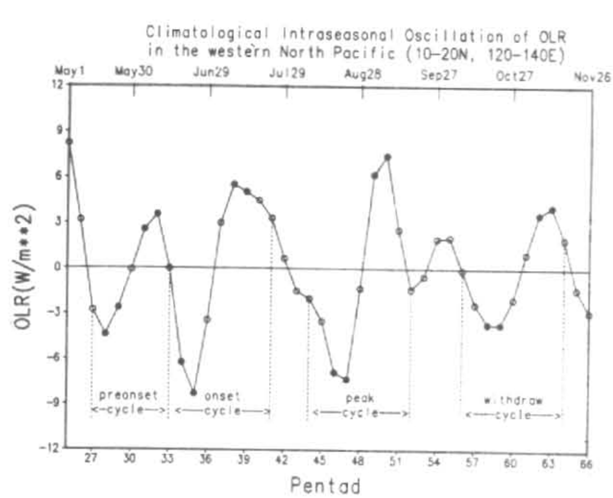



Fig. 1. The OLR Climatological Intra Seasonal Oscillation (CISO) Index for WNPSM. Each circle or solid represents climatological pentad mean OLR deviation from the smoothed annual cycle. Four major CISO cycles are indicated. The contrasting wet (negative OLR anomalies) and dry (positive OLR anomalies) phases for each cycle are marked by solids.

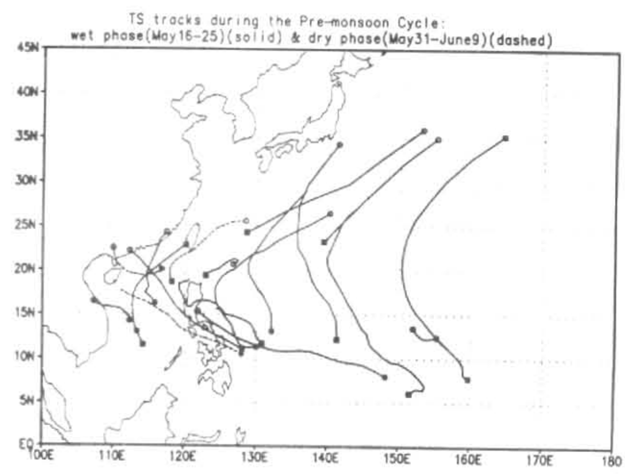



Fig. 2. Tropical Storm tracks during the wet (16-25 May) (solid) and dry (31 May-9 June) (dashed) phases of Pre-Monsoon Cycle for the period of 1975-94.

monsoon (*i.e.*, the onset, peak, and withdrawal, as well as active/break monsoon periods) and link monsoon singularities (the weather events which occur on a fixed pentad with usual regularity) at various monsoon regions: WNPSM, Indian summer monsoon, and East Asian sub-tropical monsoon.

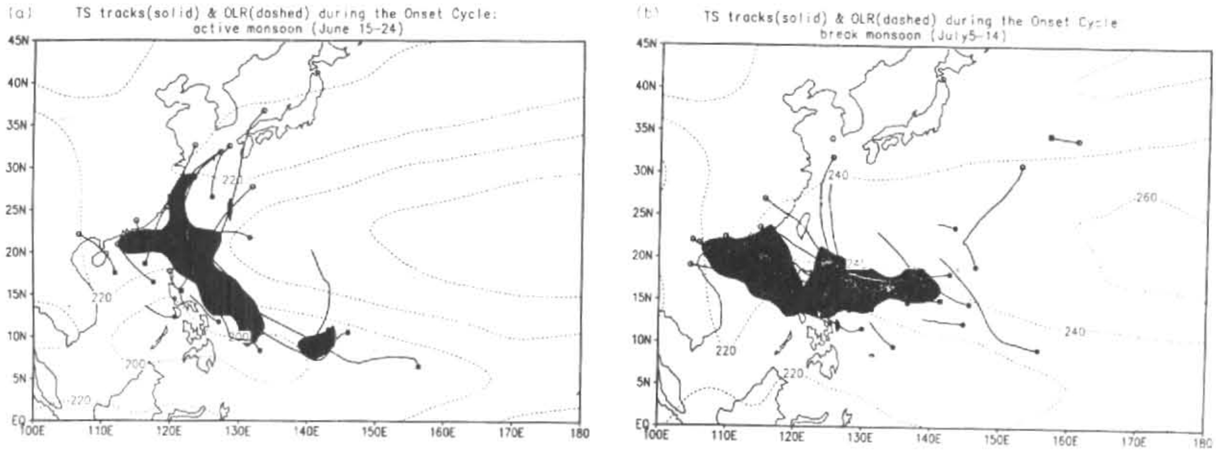
If the WNPSM has prominent climatological intra-seasonal oscillations, the corresponding circulation changes would affect tropical storm activity. The purpose of the present paper is to explore the climatological intra-seasonal variability of tropical storm activity. What we discovered is that the storm tracks indeed display significant climatological intra-seasonal variations on a time scale of about 40 days. In section 2, we briefly describe the data used for the present study. In section 3, we present evidence of the CISO of WNPSM and define four primary CISO cycles using Outgoing Longwave Radiation (OLR) pentad mean time series. In section 4, we contrast tropical storm tracks during the extremely wet and dry phases of each CISO cycle, describe the prominent changes in storm tracks, and explore how the circulation changes affect the storm tracks.

## 2. Data

Our analysis focuses on the western north Pacific region (0°-45°N, 100°-180°E). The original tropical storm (defined as the tropical cyclones with maximum wind speed exceeding 17 m/s) track data were obtained from the Joint Typhoon Warning Center (JTWC) at Guam. The data contains a summary of the best-track position and the maximum sustained wind at 6 h intervals for the tropical storms from 1945 to 1994. It is found that at the formation time, the maximum sustained wind of some storms before 1973 is much larger than 17 m/s. This may add uncertainty to the formation positions. We made a tropical storm track climatology using 20 years of data from 1975-94. The reason for choosing this period are three-fold. First, during this period the track data are most reliable. Second, the CISO revealed by WX 96 used OLR observations for the same period and European Centre of Medium-range Weather Forecast circulation data from 1979-94. Third, there was a notable interdecadal shift of the climate in the Pacific SST after 1976 (Nitta and Yamada 1989, Trenberth 1990) which have affected El Nino (Wang 1995) and rainfall in the east Asia. The 1975-94 period are not affected by this interdecadal climate shift.

## 3. Climatological intra-seasonal oscillation (CISO) cycles in the western North Pacific

The WNPSM is characterized by heavy rainfall and southwesterlies associated with the monsoon rains. WX 96 used climatological pentad mean OLR averaged over the core region of WNPSM (10°-20° N, 120°-140°E) to represent the intensity of the WNPSM. They have shown that this climatological pentad mean




**Figs.3(a&b).** Tropical storm tracks during (a) the wet phase (14-23 June) and (b) the dry phase (5-14 July) of the Monsoon Onset Cycle for the period of 1975-94. The shading indicates areas where the frequency of TS occurrence exceeds 2.4 with an interval of 2.0. The dashed contours are climatological mean OLR which outline the locations of the deep convection (< 200 W/m$^2$) and Sub-tropical High (> 240 W/m$^2$).

OLR can be decomposed into a smoothed annual cycle (the sum of the first three Fourier harmonics) and a CISO component which reflects variations on a time scale of 20-72 days. They have demonstrated the significance of the CISO by using three statistical tests and by checking the physical consistence between OLR and circulation. This CISO component was used as an index to measure the intensity change of WNPSM. We will use this CISO index of WNPSM to define sub-seasonal cycles and associated wet and dry phases.

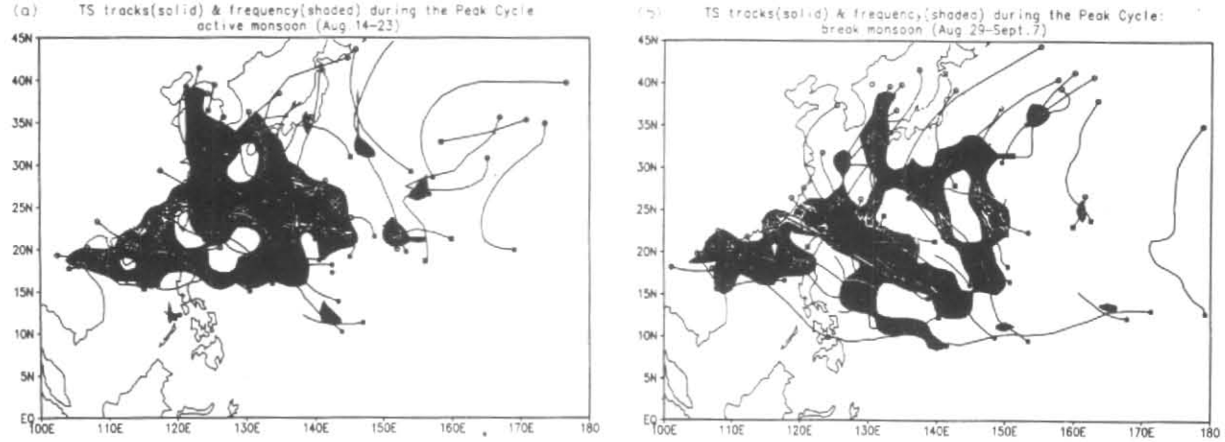
Fig. 1 presents the OLR, CISO index for WNPSM. Obviously, there are four apparent cycles with contrasting wet and dry phases as shown on the figure. The first cycle spanning from 11 May to 14 June is termed as Pre-Monsoon Cycle. Its wet phase (Pentad 28-29 or 16-25 May) marks the onset of the South China Sea summer monsoon, while its dry phase (P 31-32, 31 May - 9 June) characterize pre-monsoon dry weather over the vast area of the western North Pacific. The second cycle lasting from 15 June to 24 July is called Onset Cycle because during its wet phase (P 34-35, 15-24 June) the WNPSM begins. Its dry phase (P 38-39, 5 to 14 July) represents the first break monsoon after the onset of WNPSM. During the wet phase of the cycle III (P 46-47 or 14-23 August), the WNPSM reaches its height and for this reason we call it Peak Cycle. The dry phase of the Peak cycle (P 49-50, or 29 August 7 - September) indicates the second, also the strongest break monsoon. The fourth major cycle consists of a wet phase (P 58-59, or 13-22 October) that corresponds to the last wet spell of the WNPSM and a dry phase (P 62-63, or 2-11 November) which marks the withdraw of the WNPSM. In between Cycle II and III there is a short special transitional period. So is in between Cycle III and IV. We will not discuss these two special transition periods in the present paper.

WX 96 have shown that the occurrence of each of the wet or dry phases are accompanied by abrupt changes in OLR and large-scale circulation systems. The transitions between wet and dry phases are in a discontinuous manner. They are relatively quick adjustment between two relatively steady evolution stages.

## 4. Sub-seasonal variations of the tropical storm tracks

### (a) *The pre-monsoon cycle (11 May - 14 June)*

Fig. 2 shows the Tropical Storm (TS) tracks for the wet (16-25 May) (solid) and dry (31 May - 9 June) (dashed) phases. Evidently, the TS activity is concentrated in the wet phase. The number of TS drops sharply from wet to dry phases regardless of the fact that the seasonal march should favour the formation of TS in the latter period (the dry phase). This indicates a prominent regulation of TS activity by CISO. It is worthy of mention, however, that the significant CISO regulation on TS formation occurs only in Pre- Monsoon and Withdrawal Cycles of the WNPSM. During the Onset and Peak Cycles from mid-June to mid-September the number of formation of TS does not depend on the wet or dry phases of the CISO.




**Figs. 4 (a&b).** Tropical storm tracks during (a) the wet phase (14-23 August) and (b) the dry phase (29 August - 7 September) of the Peak Monsoon Cycle for the period of 1975-94. The shading indicates areas where the frequency of TS occurrence exceeds 2.4 with an interval of 2.0.

From Fig. 2 it is also evident that the TS in wet phase tend to recurve around 20°N. During that period (16-25 May), South China Sea Summer monsoon starts, and Taiwan and Okinawa rainy seasons also begin. The western North Pacific convection and western Pacific sub-tropical High suddenly advances northward just before the wet phase started. The recurving tracks are result of the steering flows between the sub-tropical ridge and mid-latitude trough associated with the quasi-steady pre-Meiyu (Baiu) front.

(b) *The onset cycle (15 June to 24 July)*

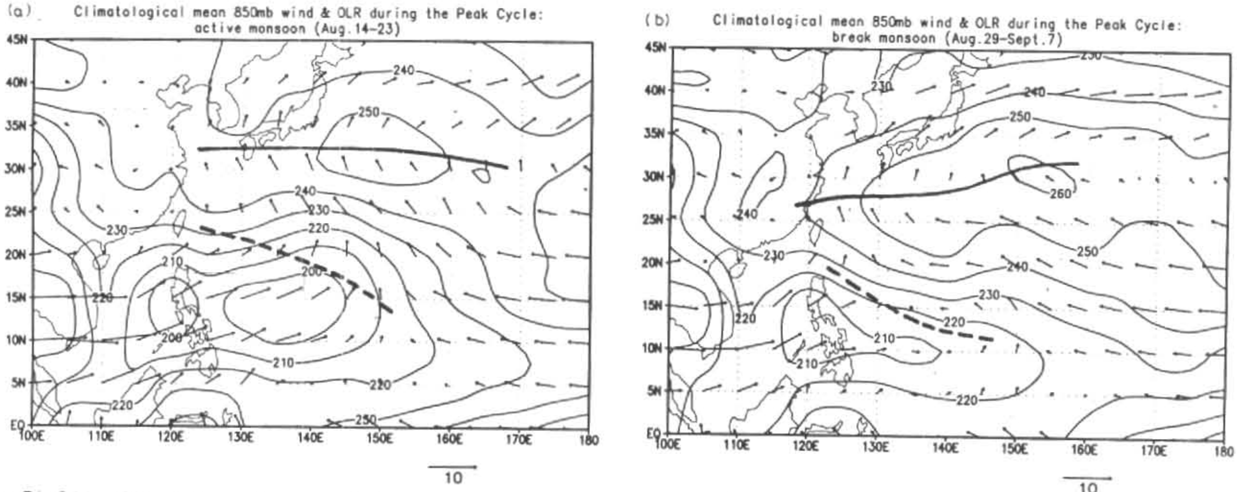
Figs. 3(a & b) contrast the TS tracks at the wet and dry phases of the Onset Cycle. In the wet phase (15-24 June, the dominant track is a recurvature from southern Philippine Sea northwestward and turning northeastward near Taiwan (25°N). In sharp contrast, the dry phase (5-14 July) tracks have only one recurvature. The majority of the TS move straight westnorthwestward from northern Philippine Sea to northern South China Sea with about 2/3 of TS landed southeast China.

The change of tracks are caused by changes of large-scale steering flows. The OLR contour of 240 $w/m^2$ may be used as an indicator of the western Pacific Sub-tropical High Fig. 3, dashed contours). During the wet phase the Sub-tropical High is located east of 130°E with ridge line at about 22°N. This circulation pattern favours recurvature of tropical storms. On the other hand, during the dry phase, the Sub-tropical High extends westward to 115°E. The enhanced easterlies south of the Sub-tropical High steer tropical storms westward. In addition, the beta-drift contributes a northwestward component.

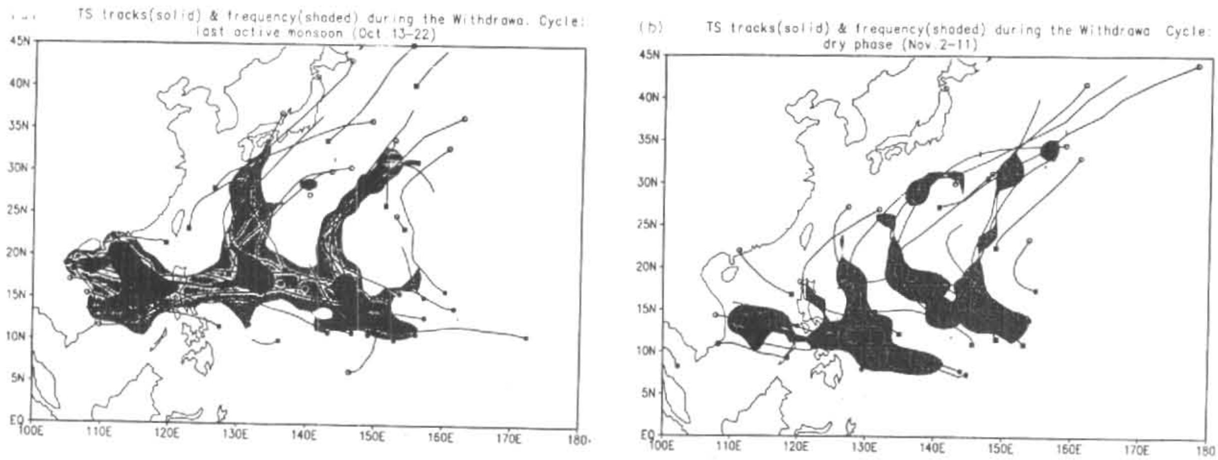
(c) *The peak cycle (4 August-17 September)*

Figs. 4 a&b compare the TS tracks for the wet and dry phases of the Peak CISO Cycle. The primary differences in the two track patterns lie in the region north of the 30°N. In the wet phase (14-23 August), the tracks are more northward oriented whereas during the dry phase (29 August-7 September), the prevailing direction of the tracks is toward northeast, In addition, the northward tracks in the wet phase are concentrated in the longitude band between 120°E and 140°E, while the northeastward tracks in the dry phase shift eastward and are located in the longitude band between 130°E and 150°E. The eastward shift of the tracks results in a marked difference in the number of TS invading Yellow Sea and Korea. In the wet phase there are ten TS intruding into this area, while during the dry phase, only three are affecting this area. Another area of large difference is (30°-40°N, 140°-150°E): during the wet phase only three TS visited while during the dry phase nine TS were seen.

Again, the difference in storm tracks is caused by the contrasting convection and circulation patterns between the wet and dry phases. During the peak monsoon at P 46-47, vigorous convection over the Philippine Sea reaches its maximum strength (Fig. 5a). Accordingly, the monsoon southwesterlies and the monsoon trough extend to the most northeast position. The western Pacific Sub-tropical High also reaches its northern most position centered at 33°N and 150°E. The northward flows west of the Sub-tropical High provide prevailing steering flows for TS moving




Figs.5(a&b). Climatological mean OLR (contour interval is 20 W/m$^2$) and 850 hPa winds during (a) the wet phase (14-23 August) and (b) the dry phase (29 .August - 7 September) of the Peak Monsoon Cycle. The thick solid and dashed liines indicate the locations of the Sub-tropical Ridge and Monsoon Trough.




Figs.6(a&b). Tropical storm tracks during (a) the wet phase (13-22 October) and (b) the dry phase (2-11 November) of the Withdrawal Cycle for the period of 1975-94. The shading indicates areas where the frequency of TS occurrence exceeds 2.4 with an interval of 2.0.

northward toward Korea and southwest Japan. On the other hand, during the dry phase of the Peak CISO cycle, monsoon convection is much suppressed, and both the monsoon trough and the Sub-tropical High retreat southward by more than 5$^o$ latitude (Fig. 5b). The retreat of the sub-tropical ridge between 120$^o$-140$^o$E yields a large-scale southwesterly steering flow north of 30$^o$N, which is responsible for the prevailing northeastward TS tracks north of 30$^o$N during this period. Also, because of the eastward retreat of the Sub-tropical High, the TS tracks shift eastward accordingly from wet to dry phases. The tracks southward of the Sub-tropical High, however, appear to be little affected.

(d) *The withdrawal cycle (3 October - 20 November)*

The pattern of the TS tracks during CISO Withdrawal Cycle experience drastic changes [Figs. (6a&b)]. Although tracks on both the wet and dry phases exhibit two types of co-existing tracks (the recurvers and westward straight movers), their locations are very different. During the wet phase (13-22 October) the westward moving tracks is located more northwards than their counterparts in the dry phase (2-11 November). This is clear if one compares the number of TS invading northern part of the South China Sea (north of 15$^o$N). The ratio is 10 to 2. The mean recurvature latitude in the wet phase (22°-25°N) is also significantly higher than that in the dry phase (17°-20°N). Furthermore, the recurving tracks tend to be more westward in the wet phase than in the dry phase.

Over the northern Philippine Sea region (130°-160°E, 10°-17°N) there are 20 TS formed during the wet phase while only 3 TS formed during the dry phase. As mentioned before, the CISO cycle effectively regulates the TS formation in the pre-monsoon and Withdrawal Cycles, but not in the Onset and Peak cycles from mid- June to mid-September. This indicates that during off- onset and peak seasons the intensification of the tropical cyclones are strongly affected by the intra-seasonal variation of the western Pacific convective activity. Active convection provides a favourable environment for the intensification of tropical cyclones.

**5. Conclusions**

With 20-year (1975-94) climatological data, we have demonstrated that the tropical storm track over the western North Pacific (0°-40°N, 100°-180°E) exhibits pronounced sub-seasonal variations on a time scale of about 40 days. From mid-May to mid-November there are four distinct Climatological Intra Seasonal Cycles (CISOs), each with contrasting storm track patterns are revealed.

During the pre-monsoon cycle, the TS activity concentrated in the wet phase (15-24 May) with recurvature track dominant (recurving latitude is about 20°N) (Fig. 2). Little activity occurs in the dry phase (31 May - 9 June). During the Onset Cycle, the wet phase (15-24 June) is characterized by recurving tracks with a recurvature latitude at 25°N, whereas the dry phase (5-14 July is dominated by northwestward straight movers (Fig. 3). During the Peak Cycle, although the track difference south of 30°N are not apparent, the tracks north of 30°N have striking patterns between the wet and dry phases (Fig. 4). The wet phase (14-23 August) tracks are predominantly northward and concentrated in the longitude band between 120°-140°E, whereas the dry phase (29 August- 7 September) tracks are primarily northeastward and shifts eastward by about 10° longitudes. During the Withdrawal Cycle, the tracks exhibit co-existence of recurver and westward straight movers, but the wet phase (13-22 October) recurvature occurs at about 22°-25°N and more westward while the dry phase recurvature occurs at 17°-20°N and more to the east. Moreover, the wet phase straight tracks are located more northward than their counterparts in the dry phase, resulting a notable difference in the number of TS invading northern South China Sea.

The storm track variability is regulated by the conspicuous Climatological Intra Seasonal Oscillations (CISO) in the strength of the western North Pacific summer monsoon and the associated changes in the position of the western Pacific Sub-tropical High. The CISO cycle regulates the number of tropical storm formation during the Pre-Onset and Withdrawal Cycles but not during the Onset and Peak Monsoon Cycles (from mid-June to mid-September).

*Acknowledgements*

This research is supported by the Marine Meteorology Program of the Office of Naval Research under the grant N00014-96-1-0796. This is the School of Ocean and Earth Science and Technology publication number XXXX.

**References**

Harr, P.A. and Elsberry, R.L., 1991, "Tropical cyclone track characteristics as a function of large-scale circulation anomalies", *Mon. Wea. Rev.*, **119**, 1448-1468.

Nitta, T. and Yamada, S., 1989, "Recent warming of tropical surface temperature and its relationship to the Northern Hemisphere circulation", *J. Meteor. Soc. Japan*, **67**, 375-383.

Trenberth, K.E., 1990, "Recent observed interdecadal climate changes in the Northern Hemisphere", *Bull. Amer. Meteor. Soc.*, **71**, 988-993.

Ueda, H., Yasunari, T. and Kawamura, R., 1995, "Abrupt seasonal change of large-scale convection activity over the western Pacific in northern summer", *J. Meteor. Soc., Japan*, **73**, 795-809.

Wang, B., 1995, "Interdecadal changes in El Nino onset in the last four decades", *J. Climate*, **8**, 267-285.

Wang, B. and Xu, X., 1996, "Northern Hemisphere summer monsoon singularities and climatological intra-seasonal oscillation", submitted to *J. Climate*.