台灣夏季氣候年際變化與大尺度調節機制

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摘要

此研究主要目的在於探討1950-2000年期間台灣夏季(六-八月)氣候變化特性與相關大尺度調節機制，包括西北太平洋夏季季風、太平洋氣候變遷，及西北太平洋颱風活動。台灣夏季降雨和溫度年際變化大致呈現相反相位：當台灣夏季偏冷時往往對應到偏濕的型態，反之亦然。本文依據台灣溫度與降雨之變化特性，低層環流變化型態，與太平洋氣候變遷之相位，將台灣夏季氣候變化分成六大型態，其中四個型態之主要調節機制爲東西延伸低層環流所伴隨的垂直運動，此環流爲西北太平洋季風變化之主要特徵。其餘二個型態之主要調節機制爲東北-西南向環流距平外圍風場所導引之水氣傳送，此環流爲太平洋氣候變遷之主要分量。西北太平洋颱風活動對台灣夏季氣候之影響係以颱風雨變化來分析。當西北太平洋於低層爲高壓距平時，其南方之垂直風切加強，抑制颱風生成及隨後活動，使得颱風侵台機會減少，颱風雨亦減少。另一方面，當西北太平洋爲低壓距平型態時，台灣之颱風雨未必增加；有利颱風雨增加之情況爲偏多颱風於台灣東南方形成，再經由北方低壓距平導引向北偏轉接近台灣而帶來較多的颱風雨。

關鍵字：西北太平洋夏季季風、太平洋氣候變遷

1. Introduction

During the past two decades, about 40% of Taiwan's summer rainfall was caused by tropical cyclone (TC) activity, while the remaining 60% of rainfall was induced by summer monsoon and other seasonal rainfall mechanisms (Chen and Fan 2003). Both the summer monsoon and TC activity over the western North Pacific (WNP) underwent evident interannual variability. The interannual variability of the WNP summer monsoon (WNPSM) circulation features a prominent meridional wave train pattern over East Asia and the WNP in association with the variability of the WNP monsoon trough and the Pacific subtropical high (Wang et al. 2001). Variations in strength and spatial positioning of the WNP monsoon trough and the Pacific subtropical high were regarded as important factors affecting interannual variability in the WNP TC activity (e.g., Chia and Ropelewski 2002; Chu 2004). The WNP monsoon trough displaced eastward in accordance with the intensification and eastward extension of equatorial westerlies over the western Pacific caused by warm El Niño-Southern Oscillation (ENSO) conditions (e.g., Lander 1994b). TC genesis location thus shifted eastward during a warm ENSO event (Chan 2000; Wang and Chan 2002). The relationship between circulation and TC activity can be described as that areas with anomalous cyclonic (anticyclonic) flows are generally associated with enhanced (suppressed) TC activity (Lander 1994a; Chan 2000). Over the Pacific, an abrupt climate change occurred during the late 1970s (e.g., Trenberth 1990). We hereafter refer to this climate change as the Pacific interdecadal climate change (PICC). Chang et al. (2000a-b) demonstrated that, on the interdecadal time scale, tropical SST variability associated with the PICC modified EA monsoon rainfall anomalies by regulating the strength and spatial pattern of the Pacific subtropical high.

The above reviews reveal that influences of the WNPSM variability, the PICC, and the WNP TC activity on the EA summer climate are closely related to variability in the WNP monsoon trough and the Pacific subtropical high. Taiwan is adjacent to the northern edge of the WNP monsoon trough and to the western boundary of the Pacific subtropical high. Thus, Taiwan's summer climate variability should be evidently influenced by large-scale background variations relating to the WNPSM, the PICC, and the WNP TC activity. The main purposes of this study are twofold: 1) to examine the major characteristics of Taiwan's summer climate variability; 2) to investigate the influences of the WNPSM variability, the PICC, and the WNP TC activity on Taiwan's summer climate variability and associated regulating processes. Results of this study should help in facilitating the development of short-term climate prediction tasks in Taiwan.

1. Summer climate variability in Taiwan

The 1950-2000 time series of summer total rainfalls (*P*, solid line) and mean temperature (*T*, dashed line) averaged from the 10 meteorological stations are shown in Fig. 1. Both the summer *P* and *T* time series exhibit noticeable interannual variations and their variations tend to be opposite in sign with a simultaneous correlation coefficient of –0.56. The fundamental variability types appear as anomalous cold-wet and anomalous warm-dry conditions. In this study, the period 1950-1977 is defined as interdecadal period 1 (IP1) and the period 1978-2000 as interdecadal period 2 (IP2). In these two decades, we find six major climate variability types, three in IP1 and three in IP2 (Table 1). These are denoted as IP1(Wd-H), IP1(Cw-H), IP1(Cw-L), IP2(Wd-H), IP2(Wd-L), and IP2(Cw-L), where the notation W represents for anomalous warm, C for anomalous cold, d for anomalous dry, w for anomalous wet, H for anomalous high, and L for anomalous low. For the six variability types, their composite *P* and *T* anomalies tend to exhibit an island-wide pattern, implicating a close relation to large-scale background variations (e.g., Chen et al. 2002; Chen and Fan 2003).

2. Influences of the WNPSM variability and the PICC

Composite S850 anomalies of Taiwan's six summer climate variability types exhibit spatial features resembling either those of the WNPSM variability or those of the PICC. Major regulatory mechanisms imposed by the WNPSM variability and the PICC on Taiwan's summer climate variability are illustrated by schematic diagrams in Fig. 2. For the WNPSM-related types (Wd-H, Cw-L), Taiwan lies under and near the center of an east-west elongated low-level circulation anomaly. A strong upward (downward) motion anomaly over the central region of an anomalous low (high) causes increased (decreased) rainfall and an anomalous wet (dry) summer in Taiwan. Anomalous vertical motion appears as the major mechanism induced by the WNPSM variability to regulate Taiwan's summer climate variability. For the PICC-related types (Wd-L, Cw-H), Taiwan is located over the western boundary of a southwest-northeast oriented low-level circulation anomaly over the WNP. Anomalous southwesterly (northeasterly or northerly) moisture transport driven by outer flows of an anomalous high (low) results in increased (decreased) rainfall and an anomalous wet (dry) summer in Taiwan. Anomalous moisture transport becomes the major mechanism imposed by the PICC modulating Taiwan's summer climate variability.

3. Influences of the WNP TC activity

In Taiwan, an official TC warning is issued for the coming of tropical storms or typhoons (i.e., maximum sustained wind speed $\geqq 17$ knots). Thus, TC activity analyzed in this study only includes those associated with tropical storms and typhoons. Conventionally, a TC event in Taiwan includes both the TC warning period and the immediate post-TC warning period if it has noticeable rainfalls. Hence, we define a TC period as the duration from the day of a TC's first appearance in the 117.5^0-124.5^0E, 19.5^0-27.5^0N region to the third day after the TC's departure from this region. Rainfall occurring in Taiwan during the TC period is referred to as TC rainfall, while that occurring in the remaining periods is mainly caused by seasonal rainfall mechanisms and referred to as seasonal rainfall. Influence of the WNP TC activity on Taiwan's summer climate variability is evaluated in terms of the variability of TC rainfall.

For TC, seasonal, and total rainfalls, their variations with respect to rainfall amounts and the number of rainy days in Taiwan's six variability types are shown in Table 2. These anomalous values are averaged from 10 Taiwan stations and most of them are statistically significant at 10% level. For the three anomalous dry types [IP1(Wd-H), IP2(Wd-L), IP2(Wd-H)], their TC rainfall and seasonal rainfall both decrease, indicating a general suppression in rainfall activity. For the three anomalous wet types [IP1(Cw-H), IP1(Cw-L), IP2(Cw-L)], seasonal rainfall increases in all three types, but TC rainfall only increases in one type and decreases in the other two types. Seasonal rainfall makes the major contribution to excessive rainfall in anomalous wet summers. Table 2 also shows that variability of rainfall amounts is in phase with variability in the number of rainy days in all six types. This relationship may be interpreted as seasonal rainfall variability being largely affected by the strength of the seasonal rainfall mechanism, while TC rainfall variability is likely modulated by the frequency of TC passage in the vicinity of Taiwan.

Using the 6-hr records of the JTWC best track data, TC passage frequency is estimated by the count of TC appearance in every 3^0x3^0 box throughout the summer season. Composite anomalies of TC passage frequency related to Taiwan's six variability types are shown in Fig. 9. In the vicinity of Taiwan, TC passage frequency anomaly is positive for the IP2(Cw-L) type and negative for the other five types. The positive (negative) anomaly corresponds to increases (decreases) in TC rainfall and TC-induced rainy days in Table 2, revealing the important role of the TC passage frequency in regulating Taiwan's TC rainfall.

Our analyses have demonstrated that TC rainfall over Taiwan tends to decrease in company with inactive TC activity over the WNP suppressed by the overlying low-level anomalous high. However, active TC activity enhanced by the WNP low-level anomalous low does not necessarily bring more TC rainfalls into Taiwan. Variability of Taiwan's TC rainfall depends on two TC characters: genesis location and movement track. The former is closely related to variability of vertical wind shear and the latter is mainly regulated by the low-level circulation anomaly over the WNP. A favorable condition for TC rainfall to increase in Taiwan occurs when more TCs form in a region southeast of Taiwan (120^0-135^0E) and are later steered by the low-level anomalous low over the WNP to recurve northward toward Taiwan.

5. Concluding remarks

During the period 1950 to 2000, Taiwan's summer rainfall and temperature anomalies tend to vary in opposite phase. The fundamental variability types appear as anomalous cold-wet and anomalous warm-dry conditions. As shown in our analyses, variability features of Taiwan's summer rainfall may be summarized according to four types of spatial relations between Taiwan and the low-level circulation anomaly over the WNP. First, when Taiwan is located near the center of an anomalous high, anomalous strong downward motion and suppressed TC activity result in decreases in seasonal and TC rainfalls and an anomalous dry summer. Second, when Taiwan is located near the center of an anomalous low, anomalous strong upward motion induces more seasonal rainfall, but TC rainfall tends to increase (decrease) if more TCs form in the region southeast (southwest) of Taiwan. Third, when Taiwan is located on the western edge of an anomalous high, TC rainfall decreases due to suppressed TC activity, but seasonal rainfall increases due to the enhanced moisture transport from the South China Sea into Taiwan driven by outer flows of the anomalous high. Fourth, when Taiwan is located on the western edge of an anomalous low, seasonal rainfall is reduced because moisture transport from the South China Sea into Taiwan is weakened by outer flows of the anomalous low. This study concludes three major regulating mechanisms for Taiwan's summer climate variability: anomalous vertical motion associated with the WNPSM variability, anomalous moisture transport associated with the PICC, and TC activity regulated by the low-level circulation anomaly over the WNP.

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Table 1: Six major types of Taiwan's summer climate variability during the 1950-2000 and their associated member years, temperature and rainfall anomalies averaged from 10 Taiwan stations, and the pattern of the overlying 850 mb circulation (S850) anomaly.

Interdecadal period	Temp. anomaly	Year	Taiwan ? *T*(?)	Taiwan ? *P*(mm)	S850 anomaly	Variability type
IP1 (1950-1977)	warm	1954	0.4	-205	high	IP1(Wd-H)
		1956	0.36	-256	high	
		1971	0.33	-323	high	
	Cold	1951	-0.63	168	high	IP1(Cw-H)
		1955	-0.75	316	high	
		1973	-0.46	180	high	
		1950	-0.8	67	low	IP1(Cw-L)
		1968	-0.38	132	low	
		1972	-0.57	495	low	
		1974	-0.43	82	low	
IP2 (1978-2000)	warm	1980	0.89	-510	high	IP2(Wd-H)
		1983	0.59	-330	high	
		1988	0.7	-109	high	
		1996	0.6	-162	high	
		1998	0.78	-51	high	
		1978	0.34	-208	low	IP2(Wd-L)
		1987	0.33	-127	low	
		1989	0.4	-251	low	
		1991	0.72	-69	low	
		1993	0.53	-358	low	
	cold	1982	-0.34	188	low	IP2(Cw-L)
		1985	-0.45	101	low	
		1997	-0.4	264	low	

Variability type	Variability of rainfall amounts (unit: mm)			Variability of number of rainy days (unit: day)		
	TC rainfall	seasonal rainfall	total rainfall	TC rainfall	seasonal rainfall	total rainfall
IP1(Wd-H)	-188	-71	-259	-5.5	-0.6	-6.1
IP1(Cw-H)	-60	282	222	-2.7	11.1	8.4
IP1(Cw-L)	-67	261	194	-1.8	9.9	8.1
IP2(Wd-H)	-111	-120	-231	-1.7	-5.9	-7.6
IP2(Wd-L)	-148	-54	-202	-3.1	-3.0	-6.1
IP2(Cw-L)	97	88	185	3.2	1.2	4.4

Table 2: Variability of rainfall amounts and number of rainy days associated with TC, seasonal, and total rainfalls for the six types of Taiwan's summer climate variability. Composite anomaly significant at the 10% level is underlined.

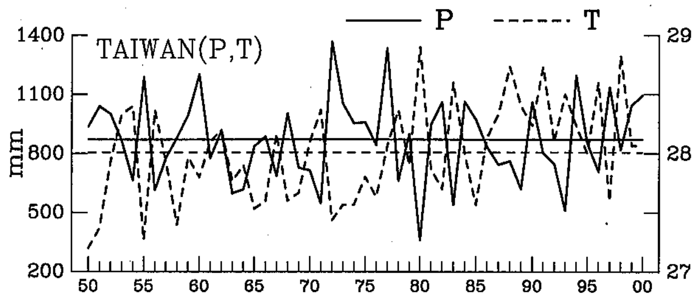

Figure 1: The 1950-2000 time series of summer (June-August) total rainfall (solid line) and mean temperature (dashed line) averaged from 10 meteorological stations in Taiwan. The superimposed horizontal lines indicate their long-term means.

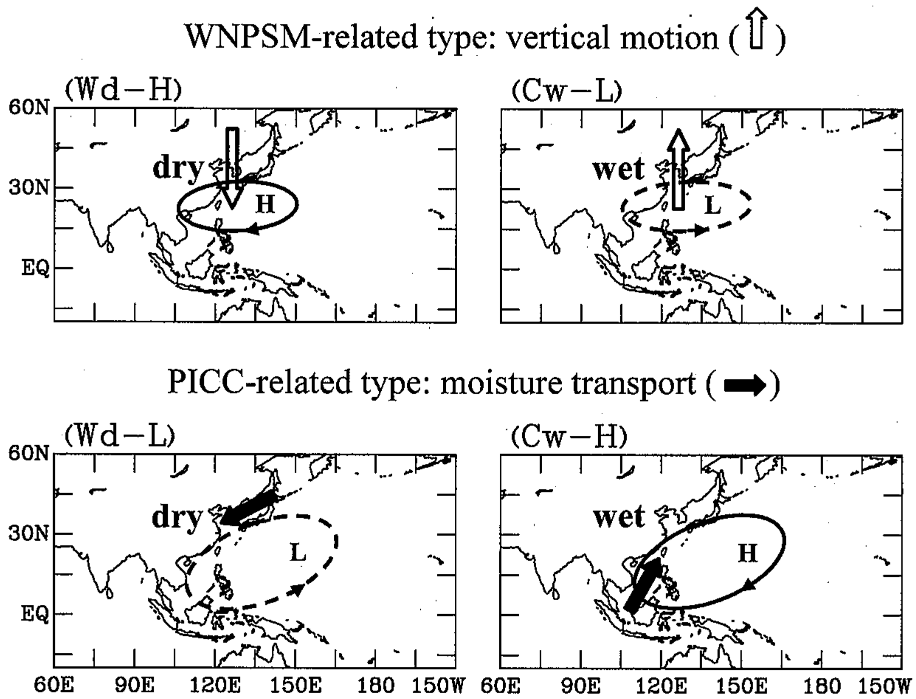

Figure 2: Schematic diagrams used to illustrate the major regulating processes imposed by the WNPSM variability and the PICC on Taiwan's summer climate variability. The direction of vertical motion (moisture transport) in the upper (lower) panels is indicated by the empty (solid) arrow.