The Relationship of Western Pacific Monsoon and Tropical Cyclone Activity to North Pacific and North American Climate Anomalies

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Introduction

Several seasonal extremes occurred throughout the North Pacific region during the spring and summer of 1988. During April, May, and June, North America experienced widespread drought (Ropelewski 1988). During the summer, the Asian monsoon was very active, and Japan experienced a prolonged "Baiu" season. Also, Japan experienced a very cool and wet August.

The North American drought conditions have generally been attributed to a positive Pacific-North American (PNA) circulation pattern (Wallace and Gutzler 1981) characterized by negative height anomalies over the northeast Pacific, positive height anomalies over North America, and negative height anomalies over the western Atlantic. Trenberth *et al* (1988) suggested this circulation pattern was caused by a northward shift in the intertropical convergence zone over the eastern and central tropical Pacific.

During June, July, and August, when drought conditions eased over North America, the height anomaly pattern over the Pacific region changed from a positive PNA pattern to a wavelike pattern that stretched from the subtropical western Pacific to North America (Ropelewski 1988). The placement of centers of positive and negative height anomalies was such that large negative height anomalies were centered over Japan and slightly negative anomalies were centered over central North America. Nitta (1987) described similar patterns, but with opposite phase, as atmospheric Rossby waves generated by enhanced convection over the Philippine Sea.

Although a positive sea surface temperature anomaly of about 0.5°-1.0°C was present in the Philippine Sea during August (Nitta 1990), outgoing long-wave radiation (OLR) anomalies were positive (NOAA 1988), which indicates less convection than normal. However, large negative OLR anomalies that represent enhanced convection were found between 20°N-35°N and 125°E-170°E (NOAA 1988). These positive OLR anomalies were associated with a northward shift in the western Pacific monsoon trough and tropical cyclone activity (Figure 1). The anomalous concentration of eight tropical cyclones resulted in a large anomalous heat

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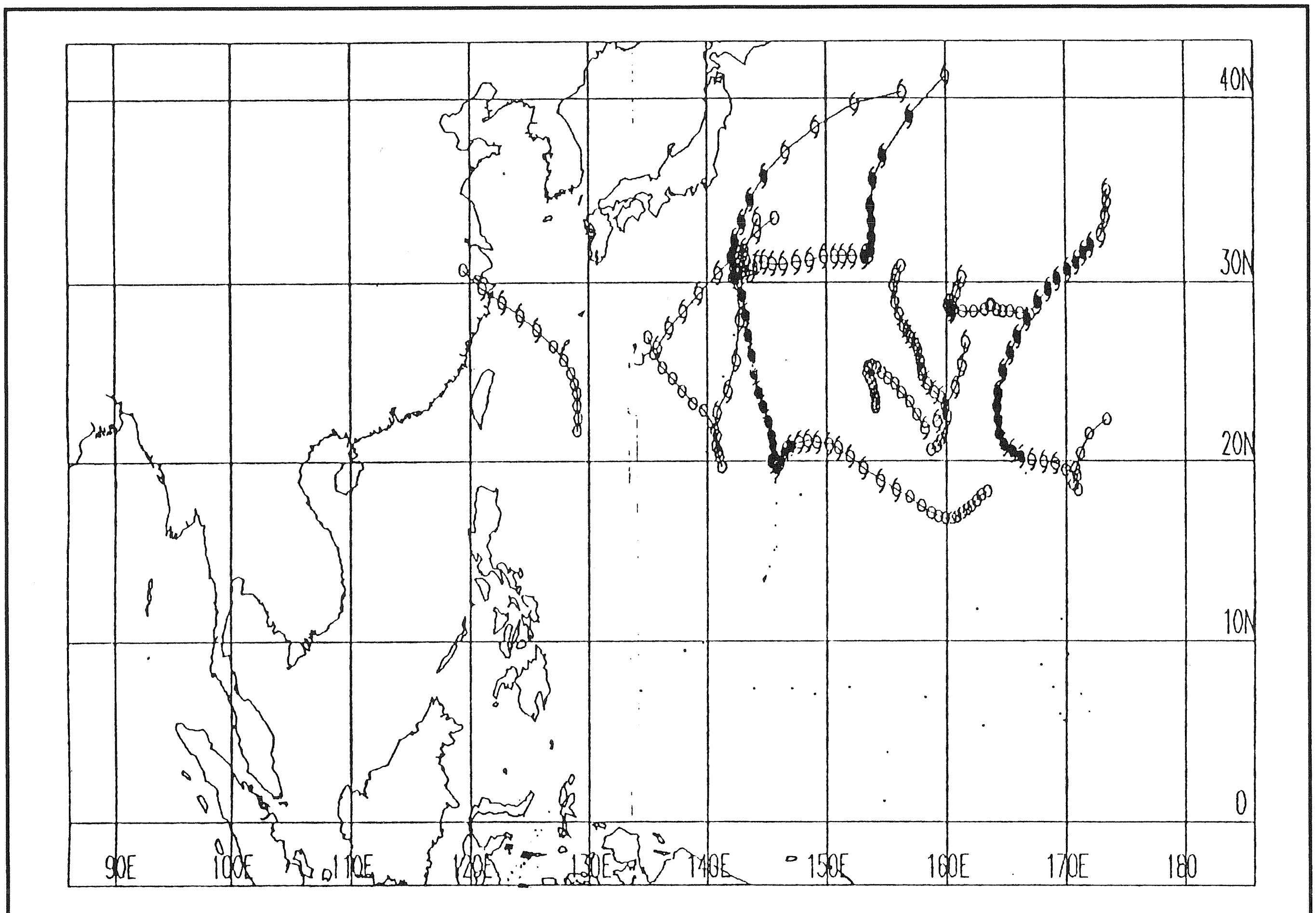

Figure 1. Positions each 6 h of western North Pacific tropical cyclones that occurred between August 1 and September 15, 1990. Open circles represent tropical depression intensity. Open hurricane symbols represent tropical storm intensity. Closed hurricane symbols represent typhoon intensity.

source over the subtropical western Pacific. Murphree (1991) examined the extratropical atmospheric response to various locations of anomalous tropical heat sources.

This present study investigates the influence of western Pacific tropical cyclone activity as possible centers of anomalous tropical heating on the large-scale circulation over the Pacific region. The characterization of tropical cyclone activity via an index based on anomalous 700 mb zonal wind is described first. Patterns of anomalous large-scale extratropical circulation anomalies based on composites of similar periods of tropical cyclone activity are then presented, followed by general conclusions.

Tropical Cyclone Activity

Tropical cyclones over the western North Pacific occur during all months, with the peak season occurring during July to October. The tropical cyclones may be characterized according to their track type (Figure 2). Tropical cyclones following straight tracks generally move to the west or northwest. Recurving tropical cyclones begin as straight-moving storms, but then pass through north. Periods of inactivity that last at least ten days have also been observed during the peak tropical cyclone season.

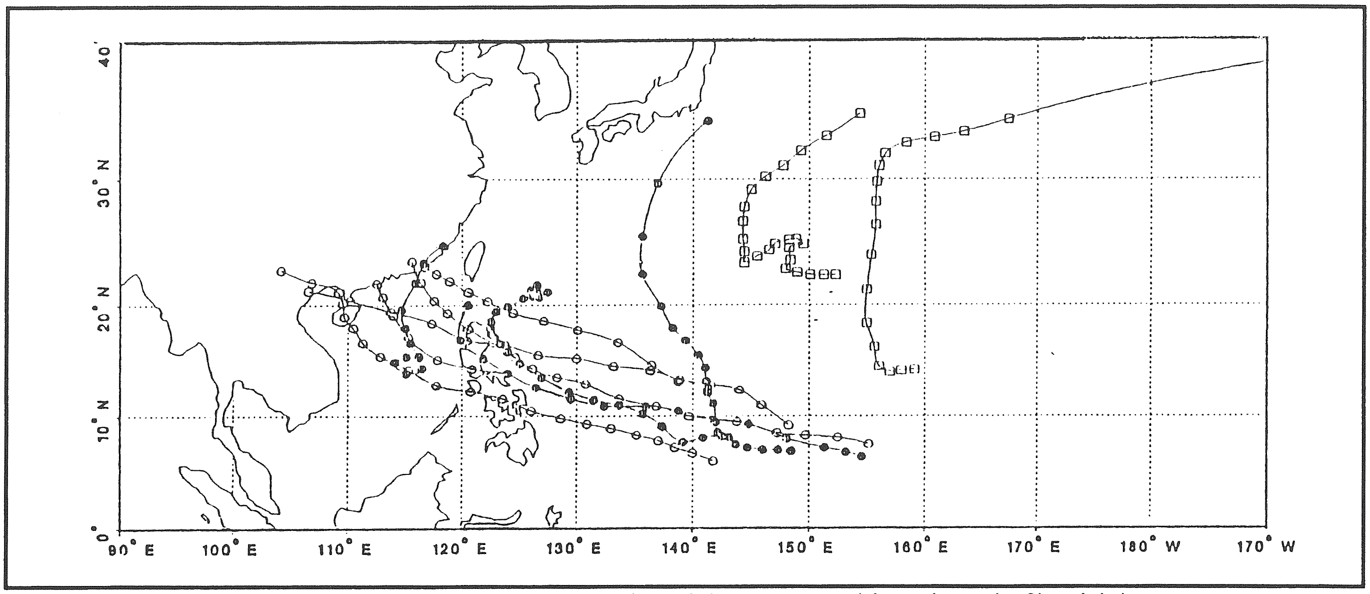

Figure 2. Representative western North Pacific tropical cyclone tracks. Open circles represent straight-moving tracks. Closed circles represent recurving-south tracks. Open boxes represent recurving-north tracks.

Based on an extensive tropical cyclone climatology, Harr and Elsberry (1991) suggested tropical cyclones that form north of 20°N or east of 150°E and north of 10°N have a climatological preference to follow a recurving track. These are labelled recurve-north in Figure 2. Recurving tropical cyclones that form in regions where there is no climatological preference between a straight or recurving track are labelled recurve-south.

Harr and Elsberry (1991) identified physically and statistically significant May-October large-scale anomalous 700-mb circulation patterns over the western North Pacific that are linked to prolonged periods of straight-moving, recurving-south and recurving-north tropical cyclones. They also identified anomalous large-scale circulations associated with inactive periods. Physically, these patterns identify anomalous lower-tropospheric winds associated with changes in monsoon trough and subtropical ridge positions and intensities.

The anomalous circulation patterns are summarized by an index composed of the 700-mb anomalous zonal wind summed between 100°E-140°E in 5-degree-latitude bands from the equator to 30°N (Figure 3). This index is used to categorize anomaly charts based on 12-h objectively analyzed wind fields into one of the four circulation types. The temporal variability of the western North Pacific anomalous tropical circulation can then be examined using time series of the resulting index categorizations.

North Pacific Circulation Anomalies

The tropical circulation index is used to identify regimes of similar tropical cyclone activity (track types) or inactivity between May and October from 1979 to 1988. A regime is identified when the circulation

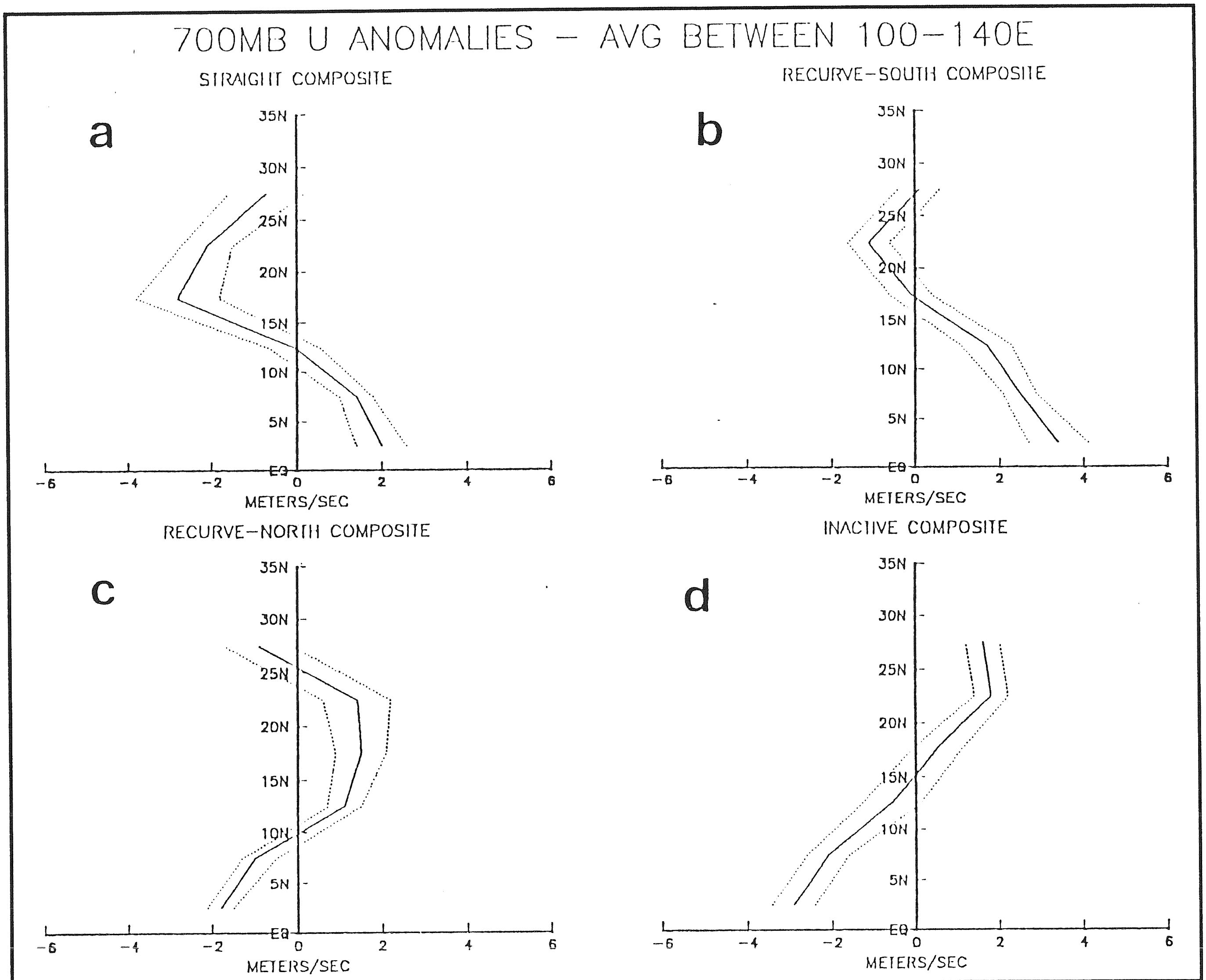

Figure 3. Latitudinal profiles of 700 mb zonal wind component anomalies for each tropical cyclone track-type category and inactive category. Positive values indicate westerly anomalies, and negative values indicate easterly anomalies. The dotted lines represent plus/minus one standard deviation.

index does not change for 7 consecutive days. Time periods meeting this criterion are combined to form 700-mb composite extratropical circulation patterns associated with tropical cyclone activity or inactivity.

In Harr and Elsberry (1991), inactive periods are defined as periods with no tropical cyclones. Their analysis indicated that during these periods, the monsoon trough is displaced far to the north of its climatological position in the Philippine Sea. The inactive and recurving-north regimes identified by easterly anomalies between the equator and 10°N (Figure 3) are combined into one group, which represents conditions with tropical cyclone activity when the monsoon trough is displaced north of the Philippine Sea. During this regime, the 700-mb height anomalies across the North Pacific consist of alternating cyclonic and anticyclonic anomalous circulations (Figure 4). A large anticyclonic anomaly over the Philippine Sea is associated with the northward displacement of the monsoon trough and tropical cyclone activity. There are cyclonic anomalies over

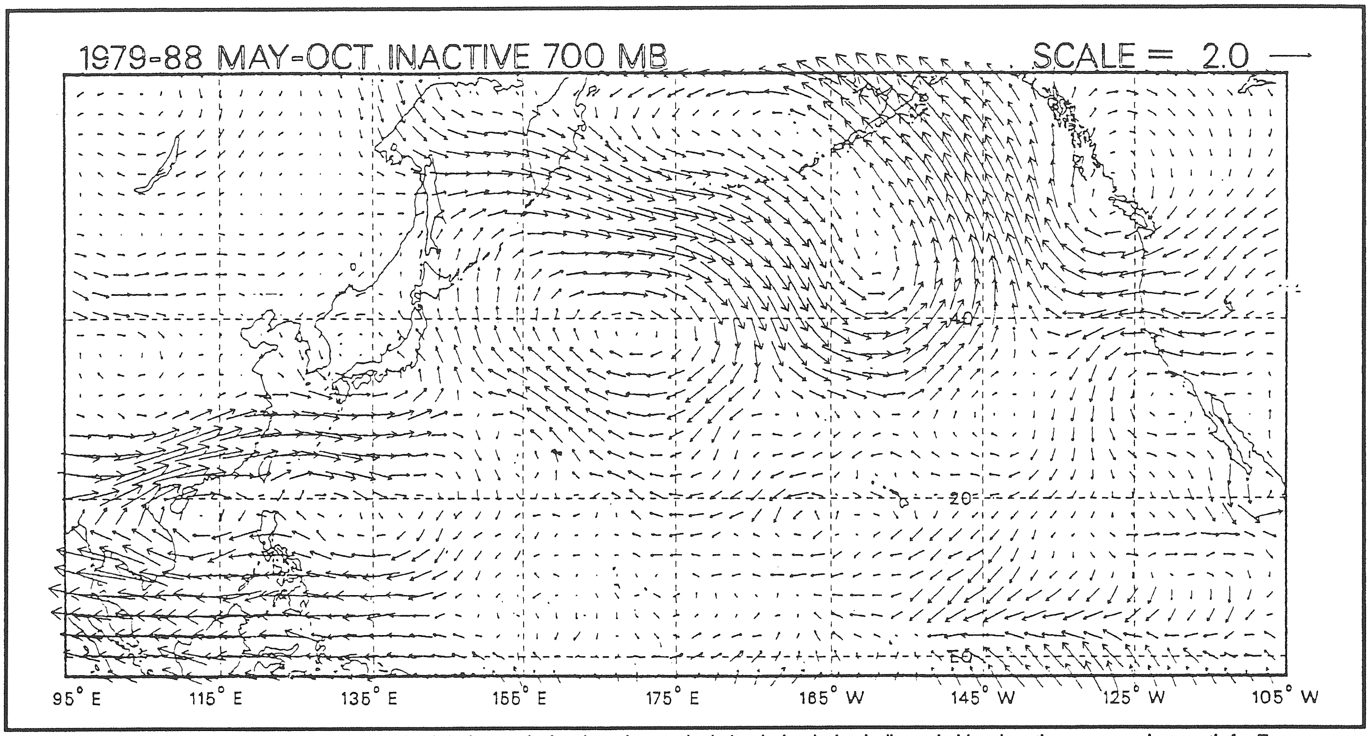

Figure 4. Anomalous 700-mb winds composited during periods when the tropical circulation index indicated either inactive or recurving-north for 7 consecutive days. In this composite, 714 fields were used. Units are meters per second.

Japan and anticyclonic anomalies over northwestern North America. This anomaly pattern is similar to the anomalous circulation during August 1988, when the tropical cyclone activity was shifted northward (Figure 1).

The recurving-south regime is associated with an active monsoon trough throughout the South China Sea and northern Philippine Sea (Harr and Elsberry 1991). During this regime, alternating cyclonic and anticyclonic anomalous circulations also stretch across the North Pacific (Figure 5). However, these circulations are nearly opposite in phase to those associated with the recurving-north and inactive regimes (Figure 4). The recurving-south circulation pattern contains large westerly anomalies throughout the tropical western Pacific, which suggests the monsoon trough is very active throughout the Philippine Sea. Cyclonic anomaly centers oriented southwest-northeast between 20°N-30°N and 120°E-155°E enhanced tropical cyclone activity over that region. Farther downstream, a large cyclonic circulation anomaly exists over the Gulf of Alaska.

During the straight-moving regime, the western Pacific monsoon trough is active, and tropical cyclones move toward the west or northwest under the influence of a strong subtropical ridge that exists over the East China Sea (Harr and Elsberry 1991). The wavelike features in the extratropical anomalous circulation pattern are weaker and do not seem to be associated with the tropical circulations during the straight-moving regime (Figure 6). It is hypothesized that the subtropical ridge, which prevents both the monsoon trough and tropical cyclones from moving into the subtropics, prevents the anomalous heating associated with these

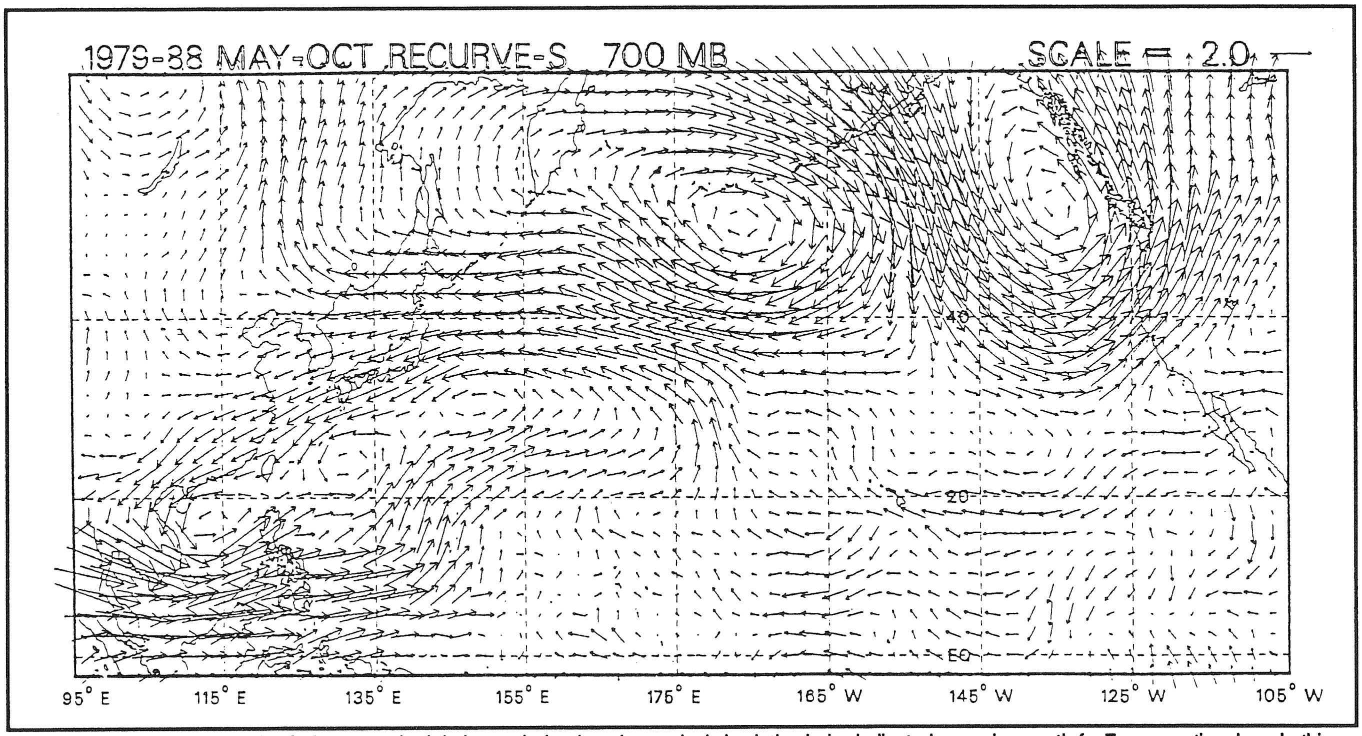

Figure 5. Anomalous 700-mb winds composited during periods when the tropical circulation index indicated recurving-south for 7 consecutive days. In this composite, 341 fields were used. Units are meters per second.

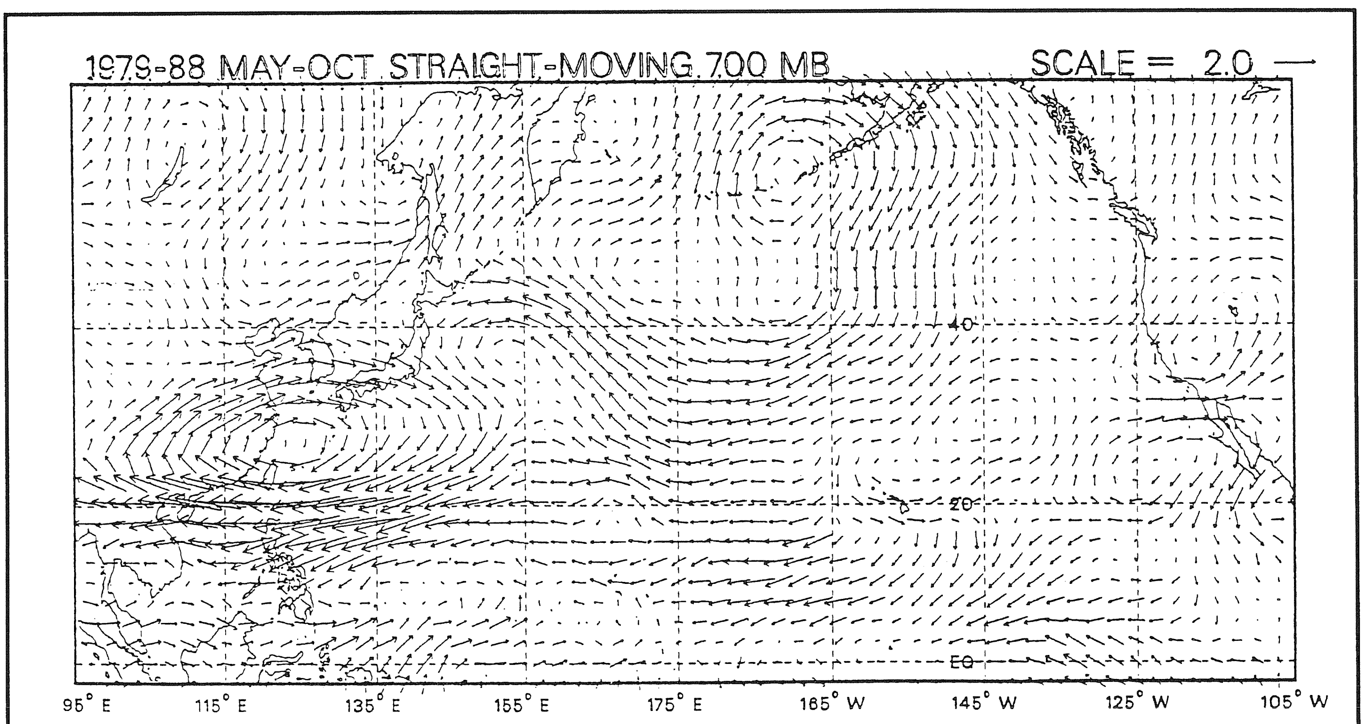

Figure 6. Anomalous 700-mb winds composited during periods when the tropical circulation index indicated straight-moving for 7 consecutive days. In this composite, 335 fields were used. Units are meters per second.

features from reaching a region that can influence the extratropics. This effect was investigated further by defining a new composite that omits recurving-south time periods when tropical cyclones moved north of 20°N (Figure 7). The anomalous westerlies over the South China Sea and Philippine Sea are larger than in the recurving-south composite because

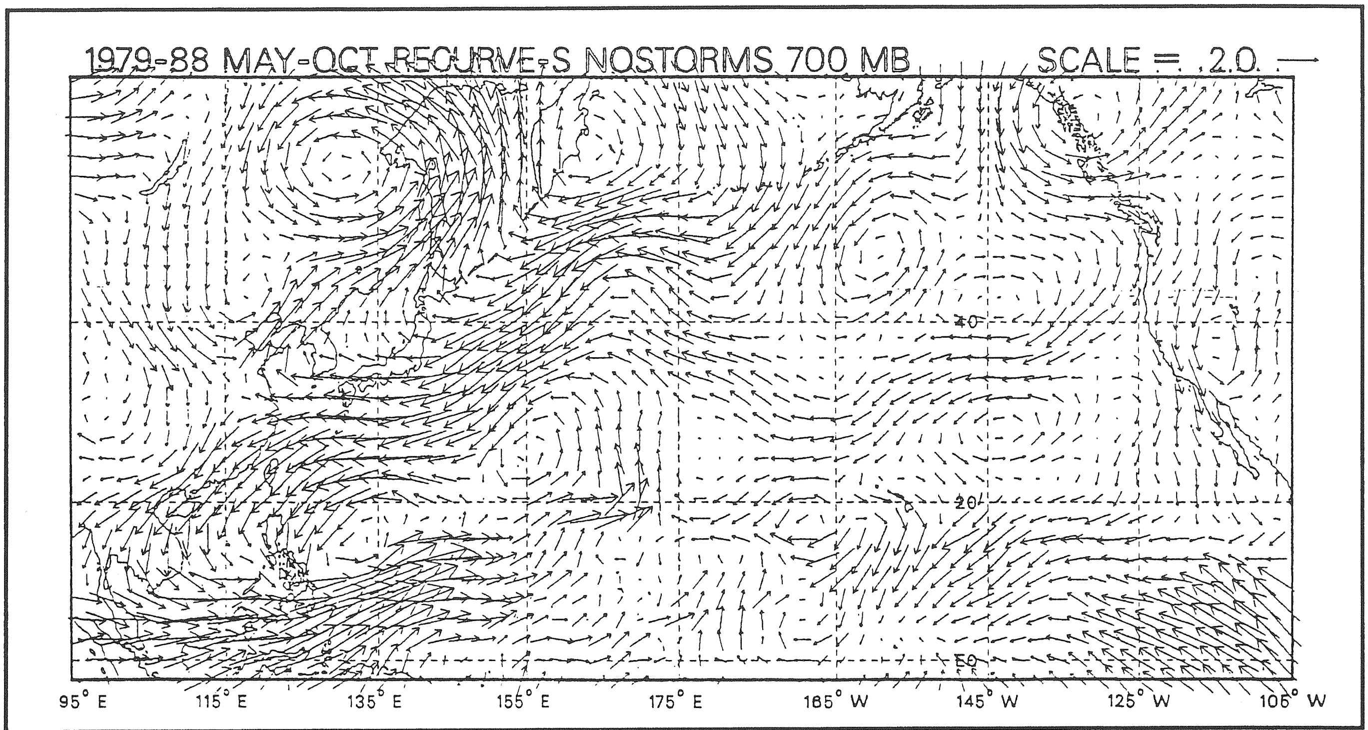

Figure 7. Anomalous 700-mb winds composited during periods when the tropical circulation index indicated recurve-southth and the tropical cyclones were south of 20°N. In this composite, 105 fields were used. Units are meters per second.

this composite highlights periods when tropical cyclones are moving over the Philippine Sea before they recurve into subtropical latitudes. Over the extratropical regions, there no wave-train anomaly features as in Figure 5. When the effect of the tropical cyclones is limited to south of 20°N, no coherent anomaly patterns extend across the North Pacific.

These composite analyses have been subjected to statistical significance tests defined by Livezey and Chen (1983). The large-scale circulation anomalies over the central and eastern North Pacific that are part of the inactive and recurve-south patterns are statistically significant. No significant anomalies are found north of 20°N in either the straight-moving or abbreviated recurve-south composites.

Discussion

Extratropical wavelike anomalous circulations across the North Pacific Basin have been identified with anomalous western North Pacific tropical circulation regimes. The tropical circulation regimes were identified with reference to western North Pacific monsoon and tropical cyclone activity. The extratropical anomaly patterns are similar to those defined by Nitta (1987) as atmospheric Rossby waves associated with tropical convection. The anomalies are also similar to results of model analyses of extratropical responses to anomalous tropical heating (Murphree 1991).

The inactive composite anomaly pattern is similar to the height anomalies of August 1988, when tropical cyclone activity shifted northward. This suggests periods of persistent tropical cyclone activity north of 20°N or inactivity can provide a mechanism for generation of anomalous tropospheric heating that can influence atmospheric circulation across the North Pacific to North America. By contrast, no coherent extratropical anomalies are found if tropical cyclone activity is confined to south of 20°N.

This analysis has also been performed with 200-mb data, and results were similar. The extratropical anomalies exhibit a barotropic structure.

These results raise additional questions to be addressed in future analyses. These include identification of the response time of the extratropics to the persistent tropical anomalies. Also, previous investigations of tropical/extratropical relationships concentrated on interannual and intraseasonal time scales. However, these results suggest shorter time scales may also be important. Finally, these results apply to the Northern Hemisphere summer season, when it has generally been thought that tropical/extratropical relationships were at a minimum.

Acknowledgment

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