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Meridional Atmospheric Teleconnections Over The North Pacific From 1950 to 1972

W. B. WHITE and A. E. WALKER—*Scripps Institution of Oceanography, University of California at San Diego, La Jolla, Calif.*

ABSTRACT—The meridional atmospheric teleconnections over the central North Pacific Ocean during winter are investigated by correlating the year-to-year fluctuations in the convective activity at the Equator, mid-latitude pressure/wind system, and subtropical pressure/wind system from 1950 to 1972. To establish fluctuations in these climatological systems, we consider the 23-yr time sequences of the maximum strength of the subtropical ridge, maximum intensity of the Aleutian Low, and strength of convective activity at the Equator, the latter inferred from the rainfall and sea-surface temperature at Canton Island (2°48′S, 171°43′W) observed by numerous authors to be representative of rainfall and sea-surface temperature over the entire central and eastern equatorial Pacific Ocean.

Upon cross correlation of these time sequences, we find that, throughout the two decades from 1950 to 1972, the intensity of the subtropical ridge and of the Aleutian Low were significantly correlated with one another (−0.50) as were the absolute magnitudes of their associated wind systems, the westerlies and northeast trades (0.83). Only during 1964–72, however, was the intensity of the Aleutian Low correlated (0.62) with fluctuations in the convective activity of the Equator. This indicates that the anomaly activity in the mid-latitude and subtropical pressure/wind systems and in the convective activity at the Equator were closely coupled during this time period. Conversely, during 1950–63, the lack of correlation between the convective activity at the Equator and the mid-latitude pressure/wind system suggests that the anomalies in these two systems were decoupled, at least in a linear way.

Bjerknes has found that fluctuations in the convective activity along the Equator in the Pacific were in association with the global tropical "southern oscillation" from 1955 to 1967. This suggests that, during the period of our study prior to 1964, the fluctuations in the mid-latitude pressure/wind system were independent of the fluctuations of sea-level pressure in the tropical latitudes of the world. However, the results of this paper together with the work of Bjerknes suggest that, after 1963, the mid-latitude pressure/wind system fluctuated in concert with the fluctuations of sea-level pressure over the tropical latitudes of the world. Speculation as to the causes for the approximate decadal variation in the meridional atmospheric teleconnections over the North Pacific is presented in terms of the decadal fluctuations found in the long-term trends of the major atmospheric systems.

1. INTRODUCTION

During the winter of different years, the atmosphere over the North Pacific Ocean experiences large-scale anomalous variations from its mean state both in the mid-latitude pressure/wind system (Namias 1959, 1963*a*, 1969) and in the equatorial thermal convective system (Bjerknes 1966, 1969). The anomalous behavior of these respective climatological systems is thought to be in quasi-equilibrium with related thermal anomalies in the upper layers of the ocean. The basic feedback process between ocean and atmosphere involves the wind-driven ocean circulation affecting the distribution of heat available for release to the atmosphere, with the heat flux distribution in turn affecting the distribution of the wind stress that directly drives the ocean.

In addition to relating the atmospheric pressure/wind anomalies to oceanic anomalous heat sources, Namias (1963*b*) and Bjerknes (1969) have presented evidence for the existence of a large-scale meridional teleconnection between the mid-latitude pressure/wind system and the equatorial convective activity. Both have found that during certain years (1950, 1958, 1964–66) a strong (weak) low-pressure system at middle latitudes was directly correlated with increased (decreased) rainfall at the Equator, the latter associated with a widespread equatorial warming (cooling) of the sea surface. In essence, they found that, when the convective activity in the vicinity of the Equator was strong, the mid-latitude pressure system was intense, and conversely. In addition, Bjerknes (1969) has noted that intense equatorial convective activity over the central North Pacific was associated with a breakdown of the zonal equatorial Walker cell, the latter fluctuating in association with the quasi-periodic "southern oscillation" first discussed by Walker and Bliss (1932, 1937).

To arrive at the foregoing meridional teleconnections between the mid-latitude pressure/wind system and the convective activity at the Equator, both Namias and Bjerknes have looked at either isolated years or short time spans (∼3 yr), utilizing a number of differing data displays to illustrate their findings. It is the purpose of the present study to extend their results over a longer period of time, utilizing a common data base as the reference throughout the 23-yr period from 1950 to 1972, and to establish the different modes that the meridional teleconnection has assumed during this time period.

The data necessary to determine the variability in the mid-latitude pressure/wind system are the intensity of the Aleutian low and the magnitude of the westerly winds, the latter depending also upon the strength of the subtropical ridge. The data necessary to determine the variability in the convective activity at the Equator are the equatorial rainfall and sea-surface temperature, the latter driving the upward thermal convection and the former related to the amount of latent heat released as a result of the thermal convection.

We are concerned exclusively with monthly mean January data, the year-to-year variability of which is determined by high-pass filtering the time sequences of these data. The resulting filtered time sequences of data are then statistically correlated with one another to determine in a quantitative way the different modes that the meridional teleconnection took over specific periods within the 23-yr time span.

2. SOURCES OF DATA

The monthly mean January strength of the Aleutian Low is taken as the minimum sea-level pressure located at the center of the Low as indicated from the January monthly mean surface pressure maps provided by the National Weather Service at Suitland, Md. When the Aleutian Low is split into two smaller low-pressure systems, one in the eastern and one in the western mid-latitude North Pacific, the minimum pressure of the two secondary minima is taken. This value is always less in magnitude than when the Aleutian Low is not split. The strength of the subtropical ridge is taken as the maximum sea-level pressure between 150°W and 180° as displayed on the January monthly mean surface pressure maps provided by the Extended Forecast Division of the National Weather Service.

The strength of the January westerly winds is displayed as an index of the magnitude of the zonal wind stress averaged from 140°E to 130°W at 45°N. The initial data were calculated by Fofonoff et al. (1960–63) and Wickett (1966, 1968, 1969, 1971) from sea level pressure data provided by the Extended Forecast Division. The strength of the January northeast trade winds is displayed as an index of the magnitude of the zonal wind stress averaged from 130°E to 130°W along 17.5°N. These data had not been initially calculated by Fofonoff or Wickett; thus they were calculated here using the velocity squared drag law. The surface zonal wind velocity was calculated using a modified geostrophic relationship that was the same as that used by Fofonoff and Wickett with pressure data at 15°N and 20°N provided by the Extended Forecast Division.

The January equatorial rainfall and sea-surface temperature is approximated by that taken at Canton Island

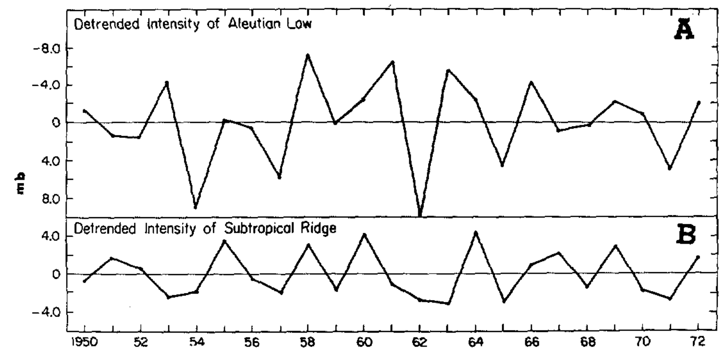

FIGURE 1.—(A) the maximum intensity of the Aleutian Low during January and (B) the maximum intensity of the subtropical ridge from 150°W–180° during January.

(2°48′S, 171°43′W). The fluctuations in sea-surface temperature at Canton Island have been shown by Bjerknes (1969) to be representative of fluctuations in the sea-surface temperature over the entire central and eastern equatorial Pacific. This is also true of rainfall at Canton Island, as established by Doberitz et al. (1967) who cross-correlated the equatorial precipitation fields across the Pacific and found strong coherence from 2.5°S to 5°N all along the Equator east of 165°E to the South American coast. These studies indicate that both the sea-surface temperature and the rainfall at Canton Island are representative of the entire eastern and central equatorial Pacific.

3. CORRELATION PROCEDURES

Each of the aforementioned time sequences are high-pass filtered by detrending with a least squares, best fit, fifth degree polynominal extending over the 23-yr period. The reason for doing this is to be able to correlate the year-to-year variability between the various time sequences without contamination from the longer period (~20-yr) fluctuation upon which the yearly fluctuations are superimposed. The resulting detrended time sequences of data are then statistically correlated over three principal time periods, 1950–63, 1964–72, and 1950–72. The level of statistical significance at the 90-percent (95-percent) confidence level is 0.55 (0.63) for 10 pairs of observations and 0.35 (0.41) for 23 pairs of observations (Young 1962).

The choice of time periods over which to correlate the time sequences is obtained by optimizing the degree of correlation between the equatorial time sequence and that at middle latitudes, wherein the meridional teleconnection appeared to be present over the time span 1964–72 and absent over 1950–63 (as will be shown subsequently).

4. FLUCTUATIONS IN THE MID-LATITUDE AND SUBTROPICAL PRESSURE/WIND SYSTEMS

Before establishing the meridional teleconnection between the mid-latitude pressure/wind system and the convective activity at the Equator, we want to determine the

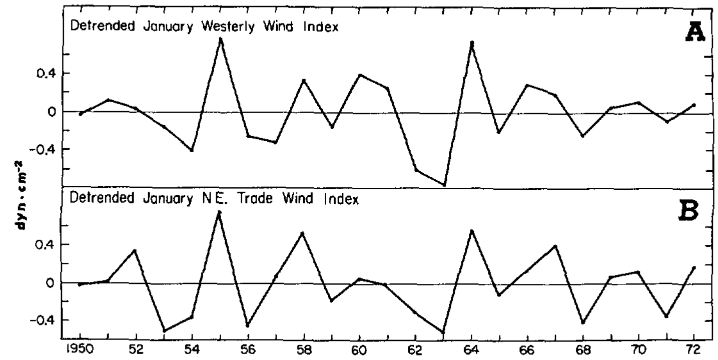

FIGURE 2.—(A) the absolute magnitude of the mean zonal westerly wind stress index averaged along 45°N from 140°E to 130°W during January and (B) the absolute magnitude of the mean zonal northeast trade-wind stress index averaged along 17.5°N from 130°E to 130°W.

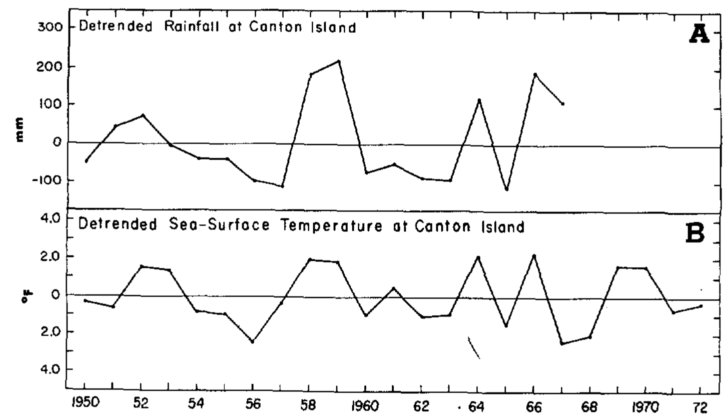

FIGURE 3.—(A) the January mean rainfall and (B) the January mean sea surface temperature at Canton Island.

meridional relationship between the mid-latitude and the subtropical systems. This also leads to an understanding of how fluctuations in the pressure system influence those in the wind system. To begin to see this, consider figures 1A and 1B wherein the detrended time sequence of the intensity of the Aleutian Low and that of the subtropical ridge over the central North Pacific are presented. Correlating these two time sequences over the 23-yr period yields a coefficient of −0.50, which is significant at the 95-percent confidence level. (Note that the ordinate scales are opposite in sign.) The lack of better correlation is hampered by the background noise contained in the intensity of the subtropical ridge, which had fluctuations only barely above the measurement error (±1–2 mb). Even so, this correlation illustrates the close relationship between the semipermanent centers of action of the mid-latitude and subtropical North Pacific.

An even better correlation is obtained when the magnitude (absolute value of the stress vector) of the westerly wind stress index and that of the northeast trade winds are compared (figs. 2A and 2B). Over the 23-yr period, these two detrended time sequences are correlated to 0.83, significant at the 99-percent confidence level.

Upon cross correlating the wind stress time sequences with the pressure time sequences in figure 1, we find that when the northeast trade winds fluctuated, it was chiefly in response to the changes in the intensity of the subtropical ridge, with little or no effect from changes in either the equatorial sea-level pressure (not shown here) or in the latitudinal position of the subtropical ridge (also not shown). The fluctuations in the westerly wind stress were found to be chiefly due to changes in the pressure difference between the Aleutian Low and the subtropical ridge, the pressure fluctuations of the latter dominated almost completely by that of the former, with little influence by the relative latitudinal positions (not shown here) of these pressure systems.

Note that, from 1950 to 1972, a peak in the magnitudes of both the northeast trade winds and the westerlies occurred every 3–4 yr. The reason for this quasi-periodic fluctuation is not clear.

5. FLUCTUATIONS IN THE CONVECTIVE ACTIVITY AT THE EQUATOR

Bjerknes (1969) has found that the strength of the convective activity (as indicated by rainfall) at the Equator in the central and eastern Pacific depends heavily upon the sea-surface temperature in that part of the ocean and that both are direct indicators of the strength of the local Hadley/Walker circulation over the Pacific Ocean.

This result follows from the ocean/atmosphere climatology of the central equatorial Pacific as Bjerknes describes it. During most years, a tongue of cold water extends along the Equator westward from the South American coast to near 180°. During these times, the sea surface temperature maximum at the thermal Equator is well developed between 5° and 10° north of the Equator. This situation is also associated with a strong zonal Walker cell with ascending convective activity in the western equatorial Pacific and some subsidence in the central and eastern equatorial Pacific; the quasi-meridional Hadley cell in the latter region is relatively weak.

In other years, however, the equatorial cold-water tongue recedes to a longitudinal position near the Galapagos Islands (120°W), or it disappears altogether, in which case the Hadley cell in the eastern and central equatorial Pacific becomes much stronger, while the Pacific Walker cell becomes relatively weaker. In this situation, the strongest convective activity is still restricted to the western equatorial Pacific, but convection extends in varying degrees along the Equator from Indonesia to Ecuador in association with the high equatorial sea-surface temperature (Krueger and Gray 1969). The high sea-surface temperature developed because of a reduction in the southeast trade winds along the Equator, leading to a reduction in equatorial upwelling and/or a reduction in the advection of cold water from the eastern boundary region by the south equatorial current.

TABLE 1.—*Summary of correlation coefficients*

Parameters	Time interval	Correlation coefficient	Significance level (%)
Magnitude Aleutian Low-magnitude subtropical ridge	1950–72	−0. 50	>95
Magnitude westerly wind-magnitude northeast trades	1950–72	. 83	>99
Sea-surface temperature (Equator)-rainfall (Equator)	1950–72	. 85	>99
Sea-surface temperature (Equator)-magnitude Aleutian Low	1950–63	− . 30	None
	1964–72	. 62	95

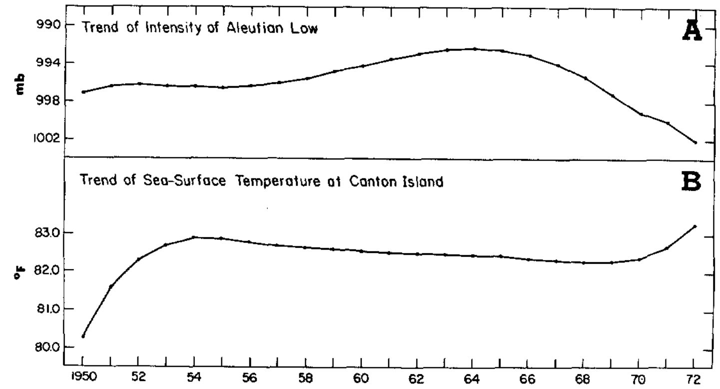

FIGURE 4.—(A) the fifth-degree polynomial trend of the intensity of the Aleutian Low during January and (B) the fifth-degree polynomial trend of sea-surface temperature at Canton Island.

To verify that the sea-surface temperature at the Equator is directly related to rainfall, consider the detrended time sequences of these two parameters at Canton Island shown in figure 3. Cross correlating these two time sequences yields 0.85, significant at the 99-percent confidence level. As stated earlier, Doberitz et al. (1967) have shown that the precipitation at Canton Island is representative of the entire central and eastern equatorial Pacific from 165°E to the coast of South America; it follows, therefore, that both the sea-surface temperature and the rainfall at Canton Island are indicative of the convective activity over this entire stretch of ocean.

6. RELATIONSHIP BETWEEN THE CONVECTIVE ACTIVITY AT THE EQUATOR AND THE MID-LATITUDE PRESSURE/WIND SYSTEM

In section 4, we found that the mid-latitude and subtropical pressure/wind systems fluctuated in unison from year to year. The question now remains—how do fluctuations in this mid-latitude and subtropical pressure/wind system relate to fluctuations in the convective activity at the Equator in the central and eastern Pacific Ocean? The studies of Namias (1963*b*) and Bjerknes (1969) found that, when the sea-surface temperature at the Equator was high, the convective activity at the Equator was intense and was associated with a strong Aleutian Low. Alternately, they found that, when the sea-surface temperature at the Equator was low, the convective activity was weak and was associated with a weak Aleutian Low.

Therefore, to establish if the meridional atmospheric teleconnections of Namias and Bjerknes extended over more years than they considered (i.e., 1950, 1958, 1964–66), we correlate the strength of the convective activity at the Equator, as represented by the sea-surface temperature at Canton Island (fig. 3), with the intensity of the Aleutian Low (fig. 1). Over the 23 yr from 1950 to 1972, the correlation was insignificant, indicating that the meridional teleconnection put forth by Bjerknes and Namias did not operate consistently over this time period. Upon optimizing the correlation for different year groups, however, we find that the teleconnection did operate from 1964 to 1972, with a correlation coefficient of 0.62, significant to the 95-percent confidence level. Prior to this time for the period 1950–63, the correlation coefficient was −0.30, indicating that the teleconnection did not operate consistently—although for a few individual years (like 1950 and 1958), it did.

Therefore, over the latter part of the decade of the sixties and into the early seventies, the strength of the convective activity at the Equator and the strengths of the subtropical and mid-latitude pressure/wind systems consistently fluctuated in phase with each other. On the basis of this correlation, little can be said about the origin of the anomaly activity. However, Bjerknes (1969) has found that, over the years 1955–67, the convective activity at the Equator fluctuated as part of the southern oscillation, which is a statistical relationship between sea-level pressure records observed at various locations around the tropical latitudes of the world. This indicates that flucations in the mid-latitude pressure/wind systems in the North Pacific were coupled with those in tropical sea-level pressure from 1964 to 1967.

Over the decade of the fifties and into the early sixties (1950–63), the meridional teleconnection that existed in the latter part of the sixties was not present. Yet Bjerknes found that, at least over part of the period 1955–63, the convective activity at the Equator fluctuated in phase with the southern oscillation. This indicates that, on the average, the anomaly activity in the mid-latitude and subtropical pressure/wind systems during this time was *decoupled* (at least in a linear way) from the anomaly activity in tropical sea-level pressure over the rest of the world.

A summary of the correlation coefficients quoted in the previous discussions is presented in table 1.

7. EFFECT OF LONG-TERM FLUCTUATIONS UPON THE TWO MODES OF MERIDIONAL TELECONNECTIONS

Over the time span 1950–72, the meridional teleconnection between the Equator and middle latitudes formed two different modes. During the period from 1964 to 1972, the strength of convective activity at the Equator over the central and eastern Pacific Ocean was closely coupled with the fluctuations in the mid-latitude and subtropical pressure/wind systems. Prior to this period however, the mid-latitude and subtropical pressure/wind systems seemed to be decoupled from the strength of the convective activity at the Equator.

To help understand why this shift in mode may have occurred on or about 1963, consider figure 4A where the best fit fifth-degree polynomial trend of the intensity of the Aleutian Low shows a nearly steady increase from 1950 to 1964, thereafter diminishing through the late sixties to an endpoint minimum in 1972. On the other hand, no similar long-term (decadal type) fluctuation can be observed in the best fit fifth-degree polynomial trend of sea-surface temperature at Canton Island (fig. 4B). This suggests that the change in mode of the meridional teleconnection may have been initiated at the middle latitudes, with the meridional teleconnection operating over a period of time (1964–72) when the Aleutian Low was steadily weakening and absent when the Aleutian Low was steadily strengthening.

Of further interest concerning the relationship between the long-term fluctuation in the strength of the Aleutian Low and the year-to-year variability is the fact that the amplitude of the annual fluctuating component was large during the late fifties and early sixties (fig. 1), diminishing in size during the middle and late sixties. From the long-term fluctuation in the intensity of the Aleutian Low in figure 4A, it appears that the amplitude of the annual fluctuating component was large when the Aleutian Low was steadily intensifying and small when the Aleutian Low was steadily weakening.

We also want to note that the peak in the long-term fluctuation of the strength of the Aleutian Low and the change in meridional teleconnection mode occurred at the same time as one of the most anomalous winters on record over the eastern half of the United States (Andrews 1964). As can be seen from figure 2, this year (i.e., 1963) had an extreme wind stress value over the North Pacific as well.

8. SUMMARY

Bjerknes (1969) has found good agreement between convective activity over the equatorial central and eastern Pacific Ocean and the mid-latitude pressure/wind system during the period from 1964 to 1966. In addition, Namias (1963*b*) has found a similar meridional teleconnection in 1950 and 1958. From the results presented here, the meridional teleconnection of Bjerknes and Namias is confirmed for 1964–72. However, over most of the period from 1950 to 1963, a consistent coupling of this type between the mid-latitude pressure/wind system and the intensity of convective activity at the Equator was not found. On the average during this latter time period, the two climatic systems in each latitudinal band were fluctuating independent of one another.

Bjerknes (1969) has also found that the convective activity at the Equator fluctuated from 1955 to 1967 in concert with the southern oscillation, which is a fluctuation in sea-level pressure about the tropical regions of the world. The results presented here, however, indicate that only during the period from 1964 to 1972 was the North Pacific mid-latitude pressure/wind system coupled with the strength of convective activity at the Equator and hence with the global tropical pressure fluctuation. Over most of the period from 1950 to 1963, the North Pacific mid-latitude pressure/wind system seemed to have been decoupled (in a linear way) from the convective activity at the Equator and the global tropical pressure fluctuation.

Associated with this change during 1963–64 in the way the convective activity at the Equator and the mid-latitude pressure/wind system were teleconnected, the long-term fluctuation in the intensity of the Aleutian Low reached a peak. Over the decade of the fifties (1950–63), there occurred a nearly steady increase in the intensity of the Aleutian Low; whereas over much of the decade of the sixties (1964–72), the Aleutian Low steadily weakened. Associated with the strong Aleutian Low in the late fifties and early sixties were large-amplitude fluctuations from year to year; during the late sixties, the amplitudes were small.

These results suggest that the large amplitude year-to-year fluctuations in the strength of the Aleutian Low during 1950–63, when the Aleutian Low steadily gained in strength, were generated independently of the convective activity at the Equator. On the other hand, the small amplitude year-to-year fluctuation in the strength of the Aleutian Low during 1964–72, when the Aleutian Low steadily weakened, was closely related to the convective activity at the Equator and with sea level pressure variations over the tropical regions of the world.

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