A Possible Relationship between Some "Severe" Winters in North America and Enhanced Convective Activity over the Tropical West Pacific

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ABSTRACT

From observations and a variety of general circulation modeling evidence, it is suggested that the exceptionally cold weather experienced over much of the United States during some recent winter months (e.g., January 1985, December 1976–February 1977) was associated with enhanced latent heat release over the tropical West Pacific. The mechanism associated with such enhancement may not be unique.

1. Introduction

As discussed in the NMC Climate Diagnostics Bulletin (Climate Analysis Center, 1985) a strong Pacific/North American (PNA) teleconnection pattern (Wallace and Gutzler, 1981) was evident in the upper flow in January 1985 associated with near record high monthly mean temperatures in Alaska, and freezing conditions in Florida. This pattern (see Fig. 1a) is associated with anticyclonic anomalies over the tropical West Pacific (well to the west of the 1982/83 El Nino position; Quiroz, 1983) and over the West Coast of North America. The pattern bears considerable resemblance (see Fig. 1b) to the seasonal circulation anomalies during the "severe" winter of 1976/77 (Arkin, 1984; Wagner, 1977), and indeed to that occurring during other unusual winters (e.g., January 1981; R. Quiroz, personal communication, 1985).

Throughout the winter of 1984/85 the Diagnostics Bulletin has been monitoring the development of the so-called 30–60 day oscillation in tropical outgoing longwave radiation (OLR), which for this winter was particularly well defined. In November 1984 negative OLR anomalies were observed over the Indian Ocean progressing steadily eastward with time, arriving over the tropical West Pacific (TWP) towards the end of the year. Figure 12 of the January 1985 Diagnostics Bulletin shows negative monthly mean OLR anomalies in excess of 30 W m^{-2}, between about 120°–160°E, and 5°–20°N. In the first half of January, negative values exceeded 40 W m^{-2}. According to Arkin (1984), over the central equatorial Pacific, seasonally averaged OLR anomalies of this magnitude would be associated with anomalous seasonal rainfall rates of about 7 mm/day.

For January 1985, sea surface temperature (SST) anomalies in the TWP were small, and generally less than 1 K (see Fig. 1 of the Climate Diagnostics Bulletin), while for January 1977 they were somewhat larger, certainly in excess of 1 K in some parts of the TWP (see Palmer and Mansfield, 1984).

However, irrespective of the mechanism with which enhanced latent heating over the TWP may be associated, we suggest as a result of a variety of modeling evidence discussed below, that there is a systematic relationship between the type of atmospheric circulation anomaly shown in Fig. 1, and enhanced rainfall over the TWP.

2. General circulation model results

The numerical experiments described below were integrated on the U.K. Meteorological Office 11-layer general circulation model (GCM) with 2½° × 3¾° latitude/longitude resolution. The model is a version of that used by Slingo (1985) and is based on the five-layer model described by Corby et al. (1977) and retains their "climatological" radiation scheme. It uses an envelope orography (Wallace et al., 1983) which improves the simulation of the Northern Hemisphere winter circulation.

a. Correlation between 30-day mean tropical rainfall and the general circulation

A 540 day integration with climatological sea surface temperature (SST) was run in perpetual January mode. Details of this integration are given in Palmer and Mansfield (1986a). From this integration, synchronous correlation coefficients were calculated between the 18 nonoverlapping 30-day mean values of convective rainfall, averaged over a predetermined area, and 30-day mean grid point values of 200 mb streamfunction.

Figure 2a shows these correlation coefficients when rainfall was averaged over the area 0°–15°N, 150°–165°E. The similarity between the patterns in Figs. 1a, b and Fig. 2a over the North Pacific and North America

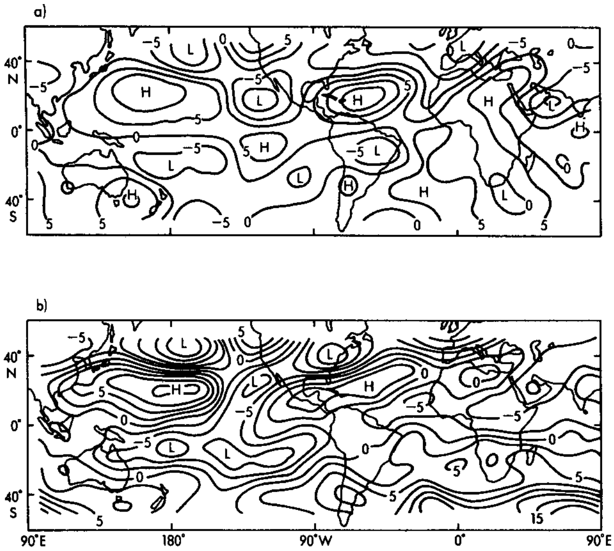

FIG. 1. 200 mb streamfunction anomaly from Climate Diagnostic Center analyses. (a) January 1985. Contour interval 5×10^6 m^2 s^{-1}. (b) December 1976–February 1977. Contour interval 2.5×10^6 m^2 s^{-1}.

is self-evident: centers over the tropical West Pacific, south of the Aleutian Islands, over northwest Canada (where the central value of 0.6 occurs at about 65°N), and east of the Caribbean have counterparts in both figures. Elsewhere, particularly in other parts of the tropics, agreement is not so good.

Correlations of 200 mb streamfunction with rainfall over the area 0°–15°N, 135°–150°E (not shown) are similar to those in Fig. 2a. However, we were not able to find another 15° × 15° area in the tropics where rainfall was so strongly correlated with this positive PNA pattern.

If the rainfall and streamfunction values are normally distributed, and the 18 values are assumed to be independent, then the statistical significance of the correlation coefficient r can be assessed as follows (Panofsky and Brier, 1958): If $|r(n-2)^{1/2}| \geq 1.6$, 2.0 or 2.6, with $n = 18$, then r is significant at the 10, 5 or 1% level, respectively. Thus, for example, values of $r \geq 0.5$ are significant at the 5% level. In practice, however, the assumptions of the statistical test cannot be rigorously justified and these estimates of significance should be treated with caution.

It is worth remarking that in calculations of the correlation between rainfall in the TWP and 200 mb geopotential height (rather than streamfunction), the positive center in the northern tropics was positioned just *east* of the dateline—in the position associated with Wallace and Gutzler's (1981) observations with 500 mb geopotential height. The reason for the different longitudinal positions between height and streamfunction centers is related to the failure of geostrophic balance, and is discussed in Palmer and Mansfield (1986a).

A linear regression analysis of the form $S = \alpha P + \beta$ was carried out on the 30-day mean model rainfall fields P, and streamfunction fields S. Values of α are shown in Fig. 2b for rainfall averaged over 0°–15°N, 150°–165°E. The figure shows the change in 200 mb streamfunction for a change of 1 mm day^{-1} in this area of the TWP. The PNA pattern is again clearly visible as with the correlation map. Elsewhere in the tropics and in the Southern Hemisphere (where the correlation coefficients were not in good agreement with observations) the regression coefficient is relatively weak.

Whether the 11-layer model exhibits 30–60 day tropical oscillations is at present under investigation; however, it is clear from the above that within an integration with climatological SST, intrinsic variability in rainfall over the TWP is strongly correlated with the observed PNA teleconnection patterns shown in Fig. 1.

b. The response to a "weak" SST anomaly in the TWP

In order to test further the hypothesis that the PNA pattern can be excited by rainfall anomalies in the TWP, two additional numerical experiments have been run. In one, the SST field illustrated in Fig. 3a was added to climatological values and the model was again integrated for 540 days in perpetual January mode. The SST anomaly has a maximum of 1.5 K which, although weak compared with some El Niño events, is probably as large as any observed anomaly in the TWP (see Palmer and Mansfield, 1984). The magni-

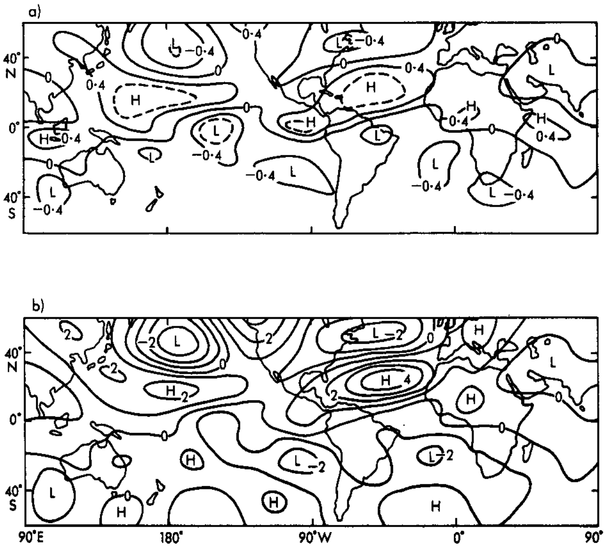

FIG. 2. (a) Correlation between 30-day mean convective rain averaged over 0°–15°N, 150°–165°E and global 30-day mean 200 mb streamfunction, from 540-day perpetual January GCM run with climatological SSTs. The statistical significance of this correlation is discussed in the text. (b) Linear regression coefficient expressing the change in 30-day mean 200 mb streamfunction for a change of 1 mm day^{-1} of 30-day mean convective rain falling in the area 0°–15°N, 150°–165°E. Contour interval 1×10^6 m^2 s^{-1} mm^{-1} day.

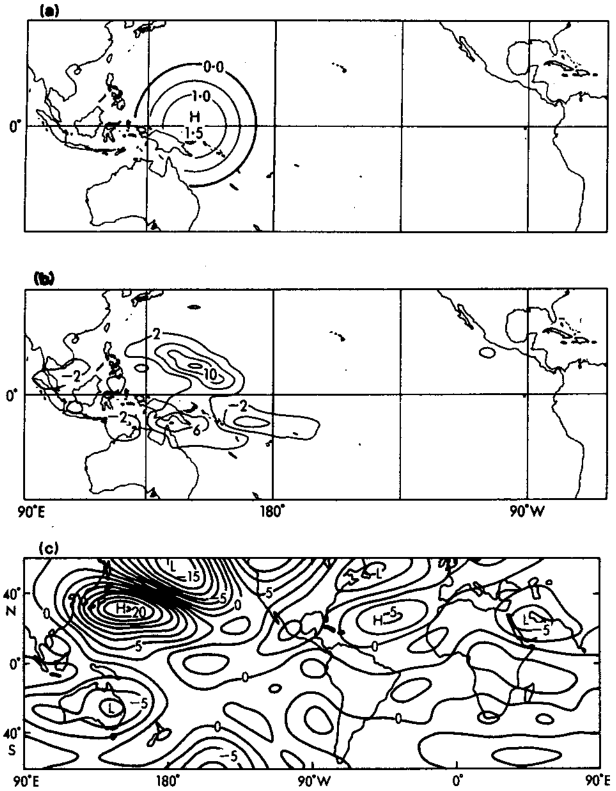

FIG. 3. (a) SST anomaly (K) used in a 540-day perpetual January integration. (b) 540-day mean convective rainfall anomaly (mm/day). (c) 540-day mean streamfunction anomaly at 200 mb. Contour interval 2.5×10^6 m^2 s^{-1}.

tude of the anomaly was certainly larger than the one which occurred in January 1985; however, the integration should be seen in the context of an attempt to induce in the model anomalous convection over the TWP which, in the atmosphere during January 1985, may have been associated with mechanisms not related to enhanced SST.

Convective rain averaged over the 540 days is enhanced over the TWP with an area (mainly contained within 0°–15°N, 135°–165°E) to the north of the equator where anomalous rainfall exceeds 10 mm day^{-1} (Fig. 3b). The 540-day mean 200 mb streamfunction anomaly over the Pacific and North America is shown in Fig. 3c, and again clearly shows the same pattern over the North Pacific and North America exhibited in Figs. 1 and 2. The strengths of the anticyclone to the north of the SST anomaly and the cyclone over the Aleutian Islands are both excessive compared with observations, but this is consistent with the fact that anomalous rainfall over the tropical West Pacific in this integration was probably larger than observed.

The hypothesis that the GCM anomaly fields are significantly different from zero has been tested with a Student t-test using the six 90-day mean fields that constitute each integration, as independent samples. As discussed in Palmer and Mansfield (1986b), geopotential height anomalies associated with the anticyclonic centers over the West Pacific and North America, and the cyclonic center near the Aleutian Islands are significant at the 1% confidence level. The height anomalies in this experiment are also significantly different at the 1% level, over the PNA area, from those resulting from forcing by a composite El Niño SST anomaly. In the latter case, the height centers over the North Pacific and North America are positioned further east compared with Fig. 3.

c. A change to the convective rainfall parameterization

A 90-day perpetual January integration was run where the constant describing rate of evaporation of falling rain in the convection parameterization was increased by 300%. This resulted in a moistening of the atmosphere and an increase in 90-day mean rainfall, up to 20 mm day^{-1}, mainly over the TWP. Associated with this, an enhanced PNA pattern of the type described above, was evident in the 90-day mean heights. For brevity we shall not show results here.

3. Conclusions

We have attempted to show that the anomalous circulation pattern observed over the North Pacific and North America during some severe winter months in North America is similar to one of the intrinsic modes of variability in a perpetual January GCM integration. Variability of this mode is strongly correlated with variability of rainfall over the tropical West Pacific (TWP). An experiment with enhanced SST in the TWP preferentially excites this mode—as does a further experiment enhancing convective rain through a change in its parameterization. Enhanced rainfall over the TWP may not arise exclusively from one mechanism: it was enhanced in January 1985 as a result of a pronounced 30–60 day oscillation in tropical cloudiness, whereas in 1976/77 it may have been associated with a persistent positive SST anomaly in the TWP area.

The GCM result that weak forcing over the TWP excites an internal mode of the model's climatological flow is in agreement with the simple barotropic model results of Simmons et al. (1983).

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