The Southern Oscillation. Part II: Associations with Changes in the Middle Troposphere in the Northern Winter

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ABSTRACT

We have investigated the relationship between the extremes of the Southern Oscillation and the following quantities at 700 mb in winter, 1948/1949 to 1978/1979: eddy transfer of sensible heat, temperature, geopotential height and geostrophic wind. In the phase of the Southern Oscillation when pressures are high over the tropical South Indian Ocean and low over the tropical South Pacific Ocean, in contrast with the opposite pressure distribution, the zonal mean poleward flux of sensible heat in the quasistationary waves tends to be higher in middle latitudes; the temperatures and heights tend to be lower between 30 and 60°N with the maximum difference at 45°N; the geostrophic wind tends to be stronger south of 45°N and weaker to the north; and the transfer of sensible heat by the transient waves tends to be stronger south of 45°S, and weaker to the north.

In this extreme of the Southern Oscillation the zonal mean geostrophic wind on both hemispheres is stronger in the subtropics and weaker at higher latitudes than in the other extreme when pressures are high over the tropical South Pacific and low in the tropical South Indian Ocean.

1. Introduction

In their study of the Southern Oscillation (SO) in the season December–February, van Loon and Madden (1981) defined the years from 1899/1900 to 1977/1978 when the oscillation reached extremes, and the reader is referred to that paper for a discussion of the definition. We named these extremes according to conditions in the South Pacific Ocean such that HIGH/ DRY (H/D) refers to the years when the sea level pressure was high over the central tropical South Pacific Ocean while extreme dryness reigned in the equatorial Pacific, and LOW/WET (L/W) refers to the opposite conditions over the same regions. In the following, we shall describe the association between the SO and these quantities at 700 mb on the Northern Hemisphere: eddy transport of sensible heat, temperature, pressure-height and zonal geostrophic wind, in those December–February seasons, 1948/49–1978/79, when 700 mb heights and temperature are available at gridpoints north of 20°N. In Table 1 is a list of the extreme years of the SO oscillation during this period. We have averaged the various 700 mb quantities in the 9 L/W years and in the eight H/D years since 1948/49, a procedure that enhances the SO signal, and have subtracted the H/D from the L/W averages which further amplifies the signal.

2. The Southern Oscillation at 700 mb on the Northern Hemisphere

The zonal averages of the differences, L/W − H/D, are shown in Fig. 1. Beginning at the top, the poleward transfer of sensible heat by the quasistationary waves $[\bar{v}^*\bar{T}^*]$, where the brackets denote a zonal average and the overbar a seasonal average, is larger in the L/W than in the H/D winters in the latitudes where $[\bar{v}^*\bar{T}^*]$ reaches its peak, 40–65°N (see van Loon, 1979, Fig. 3). In the latter paper the connection between $[\bar{v}^*\bar{T}^*]_{700}$ and $[\bar{T}]_{700}$ was discussed, and and it was demonstrated that in a 29-year series the correlation between $[\bar{v}^*\bar{T}^*]_{700}$ at 50°N and $[\bar{T}]_{700}$ at 40°N is −0.82, and that between the flux divergence in 35–45°N and temperature at 40°N it is −0.84 (van Loon, 1979, Fig. 10 and Table 1). It is evident from Fig. 1 that part of this close relationship between $[\bar{v}^*\bar{T}^*]_{700}$ and $[\bar{T}]_{700}$ is linked with the SO, as the temperature difference between L/W and H/D is biggest where the heat flux divergence is stronger in the L/W than in the H/D winters, that is, south of 50°N.

The meridional profile of 700 mb height changes

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TABLE 1. Northern winters-southern summers (DJF) 1948/49–1977/78 when the Southern Oscillation reached extremes. HIGH/DRY and LOW/WET refer to sea level pressure in the tropical parts and rainfall in the equatorial region of the South Pacific Ocean. The underlined years plus 1978/79 were used to obtain the 500 mb wind differences in the Southern Hemisphere in Fig. 6.

LOW/WET	HIGH/DRY
1952/53	1949/50
1957/58	1954/55
1963/64	1955/56
1965/66	1961/62
1968/69	1966/67
1969/70	1970/71
1972/73	1973/74
1976/77	1975/76
1977/78	

in the illustration resembles that of the temperature changes, since the heights between 30 and 60°N are on the average lower in the L/W years, with the largest difference at 40–50°N. The latitudinal distribution of the difference in 700 mb height means that the height contrast between 20 and 45°N tends to be stronger in L/W than in H/D years and that the contrast between 45 and 80°N tends to be stronger in H/D years; therefore the zonal mean geostrophic wind is stronger south of 45°N and weaker north of 45°N during the L/W years, and conversely during H/D years, which is shown in the next curve in Fig. 1. Finally, the bottom curve shows that the transfer of sensible heat by the transient waves tends to be bigger in L/W than in H/D years south of about 45°N, where the temperature contrast is sharper and the cyclonic wind shear stronger during L/W years, and to be weaker north of 45°N where both the temperature contrast and the cyclonic shear are weaker in L/W years.

The areal distribution of the difference between these quantities in the extremes of the SO is shown in Figs. 2–5, the first of which is the difference in $\bar{v}^*\bar{T}^*$. The reader should compare this map with Fig. 8 in van Loon and Williams (1980) which is a 30-year mean map of $\bar{v}^*\bar{T}^*$; from such a comparison it emerges that on the average the $\bar{v}^*\bar{T}^*$ is higher during L/W than during H/D winters in the trough-ridge system over the Pacific Ocean by an amount which is larger than the 30-year average, whereas the difference is less marked in the corresponding system over the Atlantic Ocean. The 700 mb temperature and height in the L/W winters (Figs. 3 and 4) were considerably lower over the central Pacific Ocean, the United States, and the central Atlantic Ocean, but higher over Canada–Greenland and most of the subtropics than in H/D. A similar pattern was obtained by Horel and Wallace (1980) for the correlation between 700 mb height and an index of the SO. The biggest excess of zonal geostrophic wind, L/W minus H/D, was in the subtropical parts of the oceans (Fig. 5), whereas the biggest deficit was at middle latitudes over the northeastern Pacific and the Atlantic Oceans.

3. 500 mb winds

van Loon and Madden (1981) showed that zonal means of meridional contrasts in sea level pressure on both hemispheres were stronger in L/W than in H/D at lower latitudes but weaker at higher latitudes which, of course, implies a similar behavior of the zonal mean geostrophic wind at sea level. Clearly, the wind at 700 mb on the Northern Hemisphere strengthens and weakens in the same manner, and one might expect the wind on the Southern Hemi-

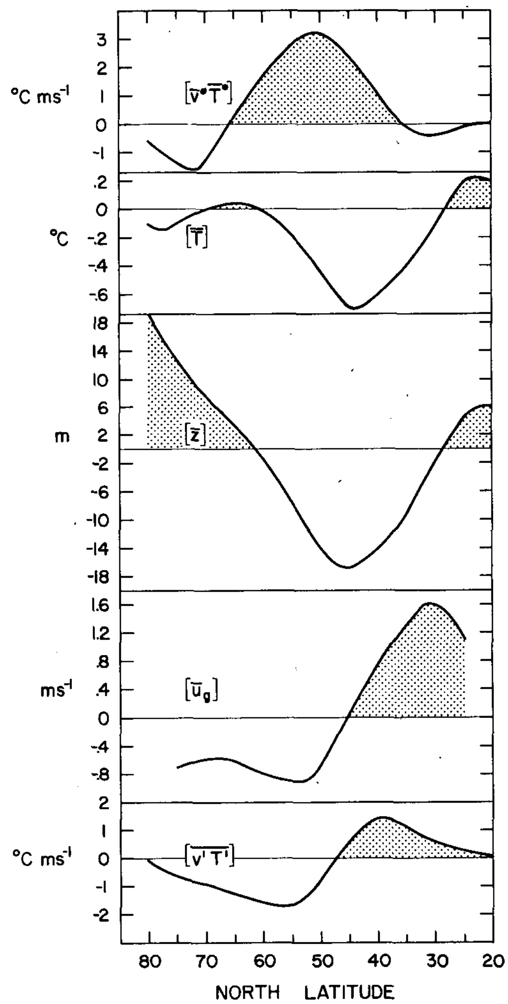

FIG. 1. The difference between extremes of the Southern Oscillation in the zonal averages of $\bar{v}^*\bar{T}^*$, the meridional transfer of sensible heat in the quasi-stationary waves; $\bar{T}$, temperature; $\bar{z}$, geopotential height, $\bar{u}$, zonal geostrophic wind; and $\overline{v'T'}$, the transfer of sensible heat in the transient eddies. All for December–February and 700 mb.

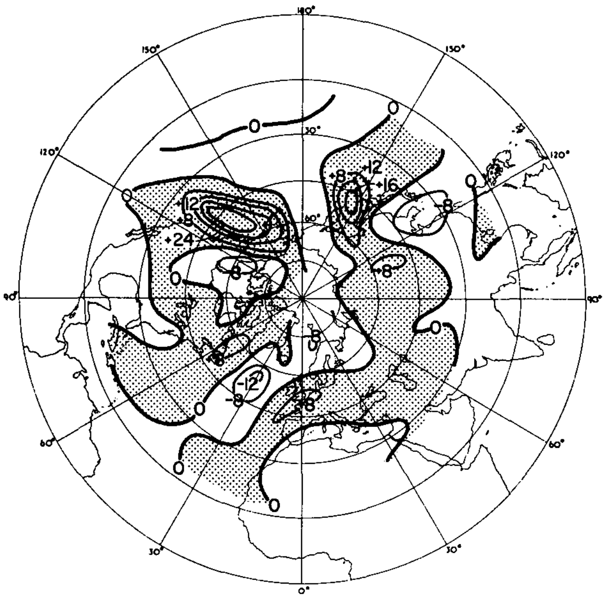

FIG. 2. As for $\bar{v}^*\bar{T}^*$ in Fig. 1, but distributed in space.

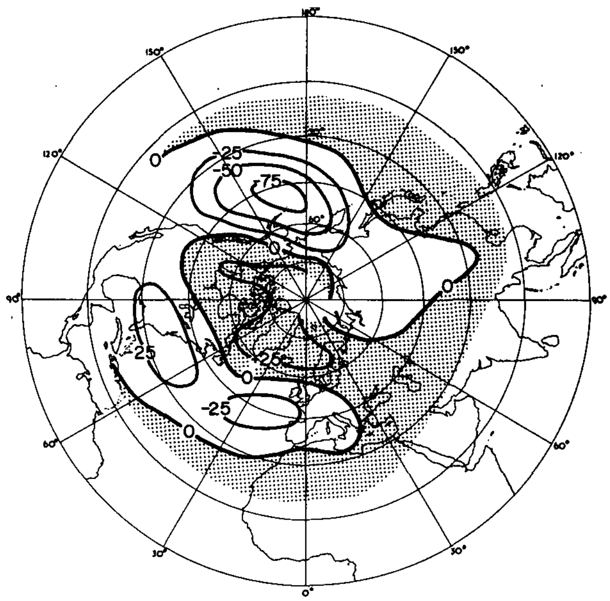

FIG. 4. As for $\bar{z}$ in Fig. 1, but distributed in space.

sphere to do so too. There are few years with analyses of the mid-tropospheric pressure-heights on the Southern Hemisphere: only four L/W and three H/D (Table 1) are available for comparing the $[\bar{u}_g]$ differences at 500 mb with those of nine L/W and eight H/D winters on the Northern Hemisphere, at 700 mb there are even fewer. Although the results in Fig. 6 are thus necessarily preliminary, it is obvious that on the average, the mid-tropospheric wind on both hemispheres is stronger equatorward of about 45° in L/W than in H/D seasons and weaker poleward of 45°. It is conceivable, therefore, that the storm tracks tend to behave in the same way: moving equatorward in L/W seasons and poleward in the H/D seasons.

The distribution over the Southern Hemisphere of the differences in 500-mb zonal geostrophic wind between the two extremes of the SO is given in Fig. 7. The pattern is as one would expect, more zonally symmetric than on the Northern Hemisphere (cf. Fig. 5). The negative correlation between the temperature gradients (thermal winds) in low and high latitudes which is implied in the pattern is not associated with the transport of sensible heat in the

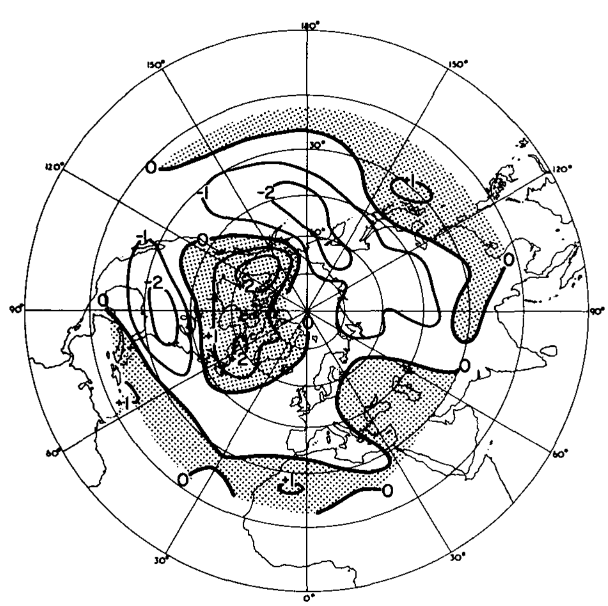

FIG. 3. As for $\bar{T}$ in Fig. 1, but distributed in space.

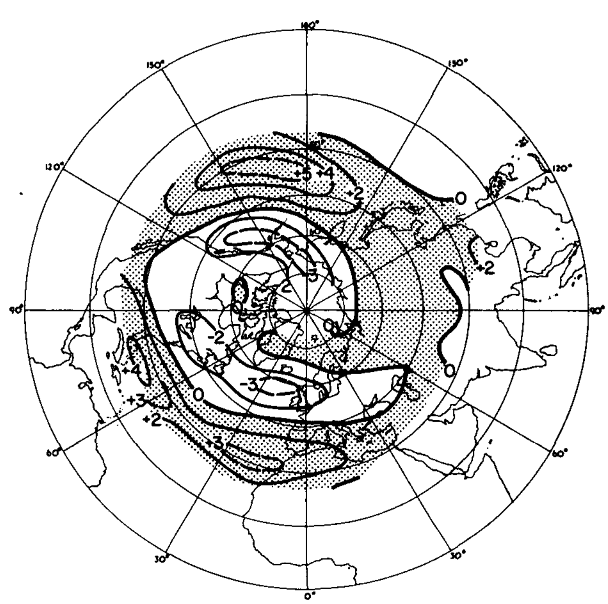

FIG. 5. As for $\bar{u}_g$ in Fig. 1, but distributed in space.

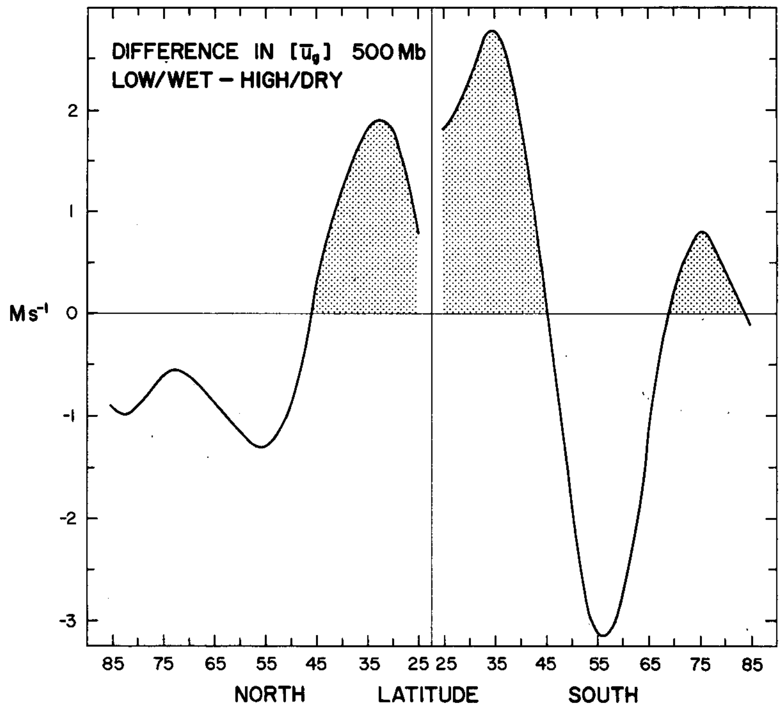

FIG. 6. The difference in 500 mb zonally averaged geostrophic wind between extremes of the Southern Oscillation in December–February. The years used for the Southern Hemisphere are underlined in Table 1.

quasistationary waves but with that in the transient waves, in contrast with conditions on the Northern Hemisphere (van Loon, 1979, Section 6).

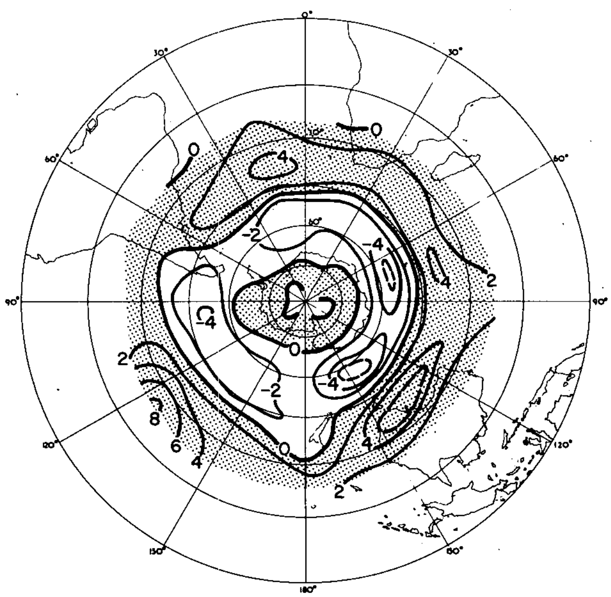

FIG. 7. The difference between extremes of the Southern Oscillation in the zonal geostrophic wind (m s⁻¹) at 500 mb on the Southern Hemisphere: 4 LOW/WET minus 3 HIGH/DRY.

4. Trends

There is possibly a connection between trends in the SO and trends in the winter circulation over the Northern Hemisphere. Unfortunately, our 31-year series of 700 mb is too short to provide adequate tests of the association between the trends in the various quantities shown, and our conclusions are therefore conditional. It was noted by van Loon and Williams (1980, Figs. 1 and 2) that there was a substantial downward trend of $[\bar{T}_{700}]_{40°N}$ from the beginning of the record in the winter of 1948/49 till the late 1960's after which the temperature rose for six years until the winter of 1974/75. As shown by van Loon (1980),[2] the trend of $[\bar{v}^*\bar{T}^*_{700}]_{50°N}$ during the same period was opposite to that of $[\bar{T}]$, the correlation between the two 31-year series being -0.82. The two time series are plotted in the lower half of Fig. 8, and on top of the illustration is the time series of seasonal (DJF) sea level mean pressure at Tahiti (17°S, 150°W). It is remarkable that Tahiti's pressure became increasingly lower from the beginning of the period until the late 1960's after which its value

[2] van Loon, H., 1980: Trends of 700-mb temperature in winter and their connection with changes in stationary-eddy heat fluxes. *Proc. Fourth Annual Climate Diagnosis Workshop,* Madison, October 1979, NOAA, 220–225.

rose till 1974/75; in the drawing the trend has been accentuated by our using a curve drawn through the troughs of Tahiti's pressure for comparison with the temperature and heat flux curves. There was, in other words, a trend in the pressure in the central South Pacific Ocean which paralleled the trend in the zonal mean 700 mb temperature at 40°N and was opposite of that in the stationary-eddy flux at 50°N. We suggest, with reference to Fig. 1, that at least during this period the intensity and position of the South Pacific high were associated with the amount of baroclinity, and the activity of the quasi-stationary waves on the Northern Hemisphere.

5. Conclusions

We have demonstrated that in the December–February seasons, 1948/49–1978/79, when the Southern Oscillation reached the extreme when the pressure is low over the tropics of the South Pacific Ocean (L/W), the northward transport of sensible heat in the quasistationary eddies on the Northern Hemisphere was larger than when the Oscillation was in its opposite extreme (H/D). In the L/W seasons, the 700 mb temperatures and geopotential heights were higher in the mean than in the H/D seasons over most of the subtropics and the Canadian side of the arctic but lower in middle latitudes; and the geostrophic west wind in L/W seasons was stronger at lower latitudes and weaker at higher latitudes than in H/D seasons. The transfer of sensible heat by the transient waves in general increased where the temperature contrast increased from H/D to the L/W extreme, particularly from eastern Asia southeastwards across the Pacific and from Mexico into the Mediterranean, whereas it decreased where the temperature contrast diminished (cf. Figs. 3 and 9). Finally, the indications are that the zonally averaged geostrophic wind in the troposphere of *both* hemispheres varies in phase from one extreme of the SO to the other; that is, the zonally averaged west wind in the L/W extreme is stronger in the subtropics and weaker at middle and high latitudes of both hemispheres than in the H/D extreme. Judged by these effects, the influence of the SO on the general circulation in the northern winter seems, *as a hypothesis,* to be a modulation of the zonally averaged, mean meridional circulation cells, accompanied by a modulation of the quasi-stationary waves.

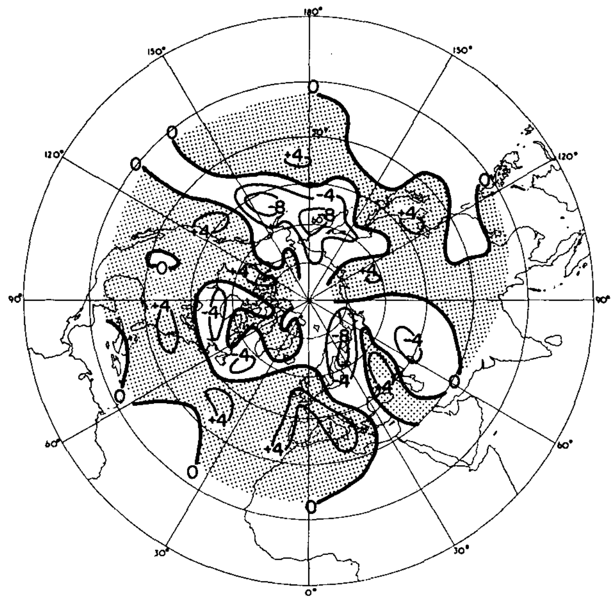

FIG. 9. As for $\overline{v'T'}$ in Fig. 1, but distributed in space.

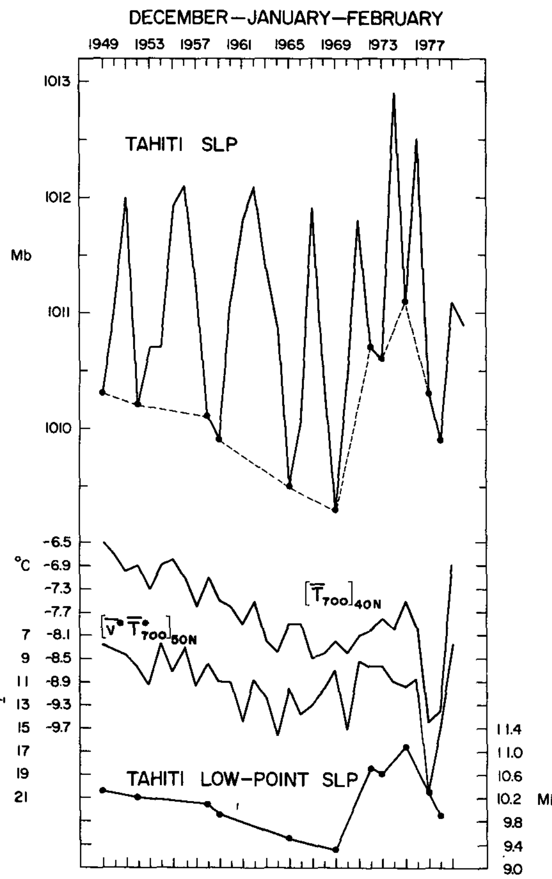

FIG. 8. The upper curve is a time series of sea-level pressure in December–February at Tahiti (17°S, 150°W); a dotted line connects the troughs (dots) in the series. The lower time series are for zonally-averaged temperature at 40°N and transfer of sensible heat in the quasistationary eddies at 50°N, both at 700 mb; the lowest curve is a repetition of the line connecting the troughs in the time series for Tahiti.

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