The Connection between Trends of Mean Temperature and Circulation at the Surface: Part II. Summer

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ABSTRACT

The local temperature trends in summer are not so obviously associated with advection changes as are those in winter. This appears to be due to weaker temperature contrasts at middle and high latitudes in summer combined with a smaller amplitude of the mean waves. A larger share of the total variance in the trend of sea level pressure is accounted for by the shorter waves than in winter. Local temperature changes are as big in summer as in winter in many places at middle latitudes, whereas in the arctic they are appreciably smaller. The zonally averaged trends in summer are larger at middle than at high latitudes, which is the reverse of winter. The sign of the zonally averaged temperature changes differs from one latitude belt to another as in winter, and the sign at a given latitude is not necessarily the same in both seasons. In contrast with winter, the sensible heat transport by mean waves in the sea level pressure in summer plays an insignificant part in causing trends in the zonally averaged temperature.

1. Introduction

The temperature trends at the surface over the Northern Hemisphere in winter and their relation to changes in the pressure at sea level were described in part I of this paper (van Loon and Williams, 1976; after this referred to as vLW). We found that the temperature trends were connected with changes in the circulation on the scale of long waves, so that the trends were associated with changes in advection. In the periods examined, the sign of the trend at higher latitudes determined the sign for the Northern Hemisphere, because the size of the trend was several times larger in the polar region than at middle and low latitudes, and the trends in middle and low latitudes tended to offset each other. The difference between 1900–41 and 1942–72 in the poleward transport of sensible heat by the mean eddies indicated that changes in the amount of this transport was one of the factors responsible for the large opposite trends in the arctic in the two periods. We concluded that the amplitude of the global temperature trend in the last century is still open to doubt and that one cannot be sure of its sign since 1942.

In this paper, we describe the trends of surface mean temperature and sea level pressure in summer (June, July, August) for 1900–41, 1942–72 and 1950–64. The trend is defined as the slope of the linear regression line of the quantity considered, fitted by least squares for the period chosen. The data are from the same sources as in vLW.

2. The trend of temperature

There is no study which deals with the temperature trends in summer for the whole Northern Hemisphere. Usually only annual and winter values are given, with the exception of Lysgaard (1949) who computed the trends of July before 1940 over part of the hemisphere by averages of overlapping 10-year, 30-year, or longer periods. We have divided our data into the two periods before and after 1941–42 when the trend of the annual and winter mean temperature of the Northern Hemisphere changed from upward to downward (Mitchell, 1961), and compare in addition summer and winter in 1950–64.

The number of stations over the northern oceans before World War II was too small to permit a complete areal analysis of the temperature trend. When weather ships began observing in the late 1940's such an analysis became possible in the westerlies, but the coverage over the tropical waters still leaves much to be desired.

The trend of mean temperature in summer for 1900–41 is shown in Fig. 1 as lines of equal slope. Over most of the parts where it was possible to draw the lines the trend was upward. Changes outside the polar regions were in some places as big as in winter (cf. vLW, their Fig. 10), but in the arctic they were smaller than in winter. The same was true in 1942–72 (Fig. 2). The belt of cooling in middle latitudes in 1942–72 was

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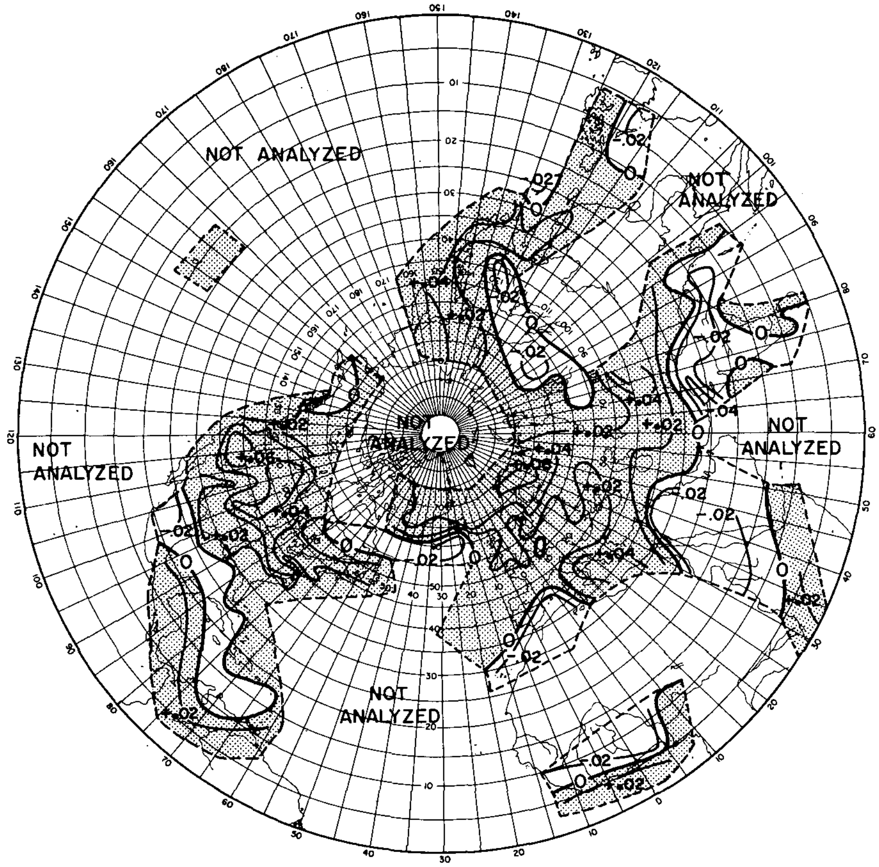

FIG. 1. Isopleths of the slope of the regression line of summer mean temperature (°C per year) for 1900–41.

broken by only small areas of warming which differed from winter when large areas of opposite sign alternated along the circumference.

Note that although the change was positive over the western United States and Canada west of Hudson Bay in both periods, this does not necessarily imply a steady upward trend in 1900–72 in the sense that one could add the slopes of the two periods and so arrive at a change for the whole period. This is illustrated in Fig. 3 by time series of mean temperatures at locations representative of the region where the tendency was positive in both periods. At the two southern stations (Boise and Sacramento) the temperature dropped from the mid 1930's to the mid 1940's so that although the temperature rose in 1942–72, it did so from a level considerably below the peak of the preceding years. At the end of the record, the level was therefore no higher than the peak in the 1930's. At Edmonton, however, it was appreciably higher. It is interesting that changes on the scale of several decades corresponded at the three places but that short changes seldom matched.

Zonally averaged changes from 1942 to 1972 (Fig. 4) were positive south of 30°N as far south (15°N) as our analysis goes, and negative at middle and high latitudes. The biggest differences between winter and summer were over the polar cap where the negative changes were 4–7 times larger in winter than in summer, and in 45°–50°N where the zonal mean winter temperature rose but the summer temperature fell. Another difference between the two seasons was that the changes in summer in 40°–50°N were larger than those farther north.

The average change in 1942–72 between 15° and 80°N in summer was −0.19°C, weighted by area as explained in vLW. The change was influenced mainly by the large negative values in middle latitudes, whereas the average change in winter (−0.21°C) was dominated by the trend in the arctic. The sign of the *global* trend is not necessarily the same as the one between 15° and 80°N; a rise of 0.11°C over the rest of the tropics and in the Southern Hemisphere, where it is impossible to establish a zonally averaged trend, would be enough to offset the −0.19°C between 15° and 80°N.

A zonally averaged change between 1900 and 1941 cannot be obtained by our method. Indirectly, it is possible to get an idea of its latitudinal distribution from Mitchell's (1963) zonal averages for 10° latitude belts. Mitchell's values are for winter and for the year,

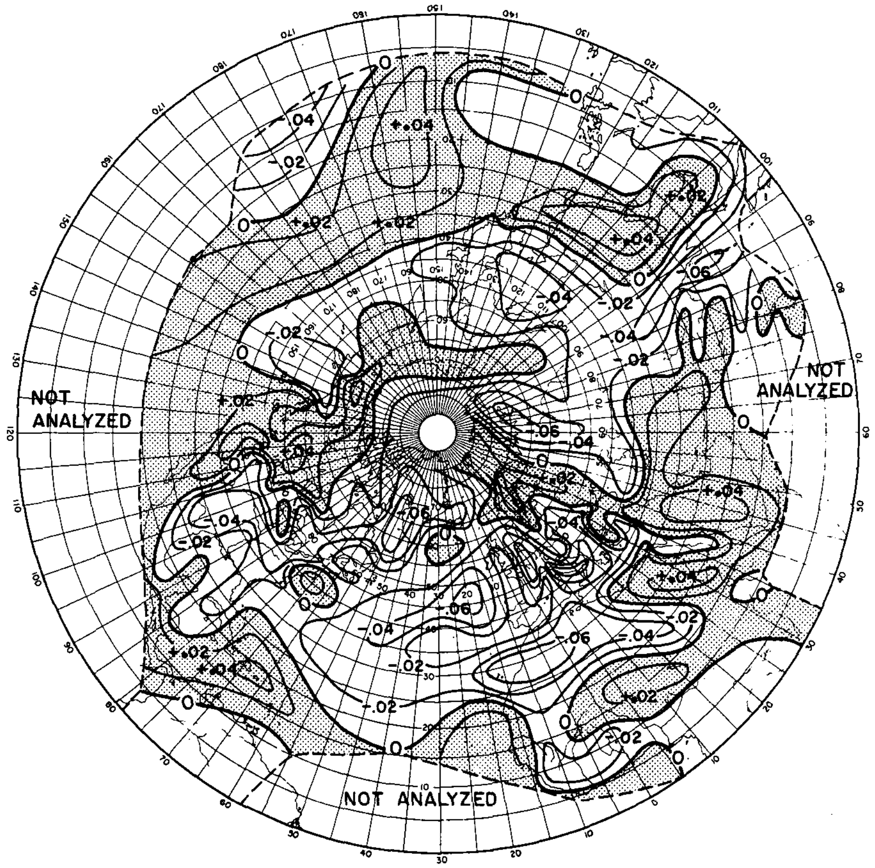

FIG. 2. As in Fig. 1, but for 1942–72.

but on the assumption that the year ≈ (winter + summer)/2, one can get pseudo-summer values for the temperature difference (1920–1949)—(1890–1919). The curve in Fig. 5 which represents these values should not be regarded as quantitatively right; it is, for example, fair to assume from Fig. 1 that the trend was positive at least as far north as 70°N, yet the pretended summer curve in Fig. 5 shows a downward trend north of 50°N. This could be the result of too large values for winter in Mitchell's data, or too small values for the year, or both. However, what is interesting is the fact that the largest rises in summer took place in middle latitudes, in contrast with winter when they were largest in the arctic. The zone in the Northern Hemisphere which determined the sign of the change in the average temperature of the hemisphere in summer during the period we have examined is thus 35° to 55°N.

As mentioned in vLW, we divided the record into overlapping 15-year periods of which one, 1950–64, was discussed. The trend in summer for this period is shown in Fig. 6. A comparison with Fig. 5 in vLW indicates that one major change from winter to summer was that the large rises in 1950–64 over northern Asia in winter were replaced by falls in summer. Over wide areas there was no change of sign from winter to summer but the amplitudes of the local changes were in many places smaller in summer. The zonally averaged change for 1950–64 in summer is drawn as a solid line in Fig. 7, and the change in winter as a dashed line. It is immediately clear that the zonally averaged trend was not necessarily the same in winter as in summer, which was also true for 1942–72. The average change in 1950–64 for the belt 15° to 80°N was −0.04°C in summer and +0.39°C in winter, and the difference can be ascribed mainly to the reversal of the trend over northern Asia. The largest zonally averaged change in summer in 1950–64 was, as in 1942–72, in middle latitudes. As stressed for 1942–72, the drop of 0.04°C over the region between 15° and 80°N does not indicate that the global trend was downward. A rise of 0.025°C over the incompletely covered regions between 15°N and the South Pole could counterbalance the −0.04°C.

3. The trend of pressure

The pressure trends in 1900–41 and 1942–72 are shown in Figs. 8 and 9. In a recent paper, Madden (1976) has outlined the areas with dubious pressure data in this series, which include in July most of Asia south of 45°N, most of North Africa, and the arctic before 1940. Fig. 10 has been prepared from Madden's data to illustrate the types of problem one encounters

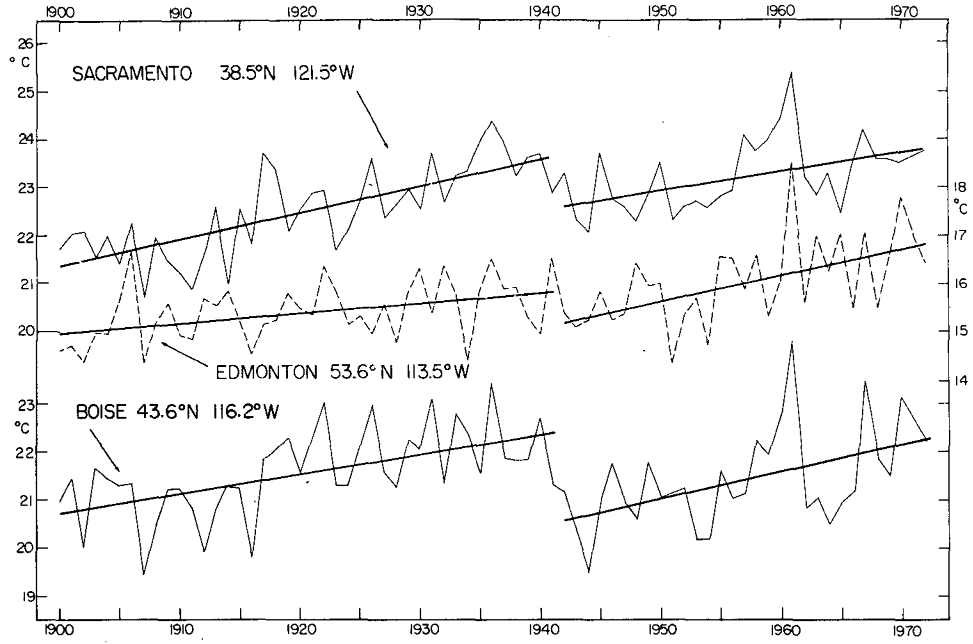

Fig. 3. Time series of summer mean temperature, and the regression lines for 1900–41 and 1942–72.

in the sea level pressures. The ordinate in the figure is expected standard deviation of monthly means, which is a standard deviation associated with the estimated natural variability as defined by Madden. At 20°N, 40°E (Fig. 10) some values at the beginning of the series are obviously too low and will amplify the upward trend of the first period (1900–41); a break in the record occurs in the early 1940's after which the level of the pressure is lower, but the second period (1942–72) begins before the break and as a result the higher values of the first two years diminish the upward trend in the period. In the arctic, where few observations were available in the earlier part of the century, analysts tended to draw a semi-permanent high with the result that a fictitious downward trend was created (Fig. 10, bottom curve). The latter flaw would affect Fig. 8, and the former flaw would affect both Figs. 8 and 9.

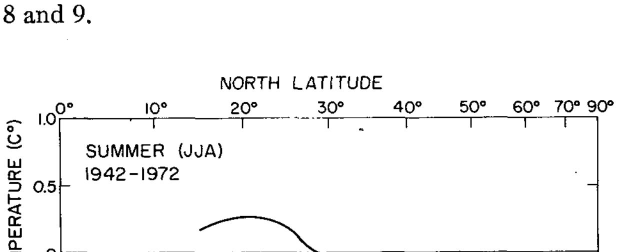

Fig. 4. Meridional profile of the 1942–72 change of zonal mean summer temperature. Computed from Fig. 2.

In winter (vLW) there were numerous examples where a change in pressure (wind) was compatible with the change in mean temperature, and temperature trends could fairly be said to be connected with changes in advection. But if one compares the pressure trends in Figs. 8 and 9 with the corresponding temperature trends in Figs. 1 and 2, the connection between changes in advection and temperature in summer is not always immediately visible. In 1900–41, for instance, the temperature rose over North America and the changes in pressure were such that the component of change in the geostrophic wind would be southerly in the eastern and western parts of the continent and northerly in the central part where, however, the rise of temperature was biggest. In most other places the relation between change in temperature and pressure in 1900–41 was similarly ambiguous. In 1942–72 (cf. Figs. 2 and 9) the trends in the two elements were better related. For instance, the warming over Alaska and the western part of Canada and the United States occurred in an increasing southerly (decreasing northerly) flow, and the cooling east of that area and over Greenland was associated with increasing northerly (decreasing southerly) flow. Several other examples may be found, but often the association between changes in advection and temperature changes was not so visible in summer as in winter.

A comparison of Fig. 8 with Fig. 13 in vLW, the pressure trends for 1900–41 in summer and in winter, shows that local pressure changes are not necessarily of the same sign or size in two different seasons during the same period.

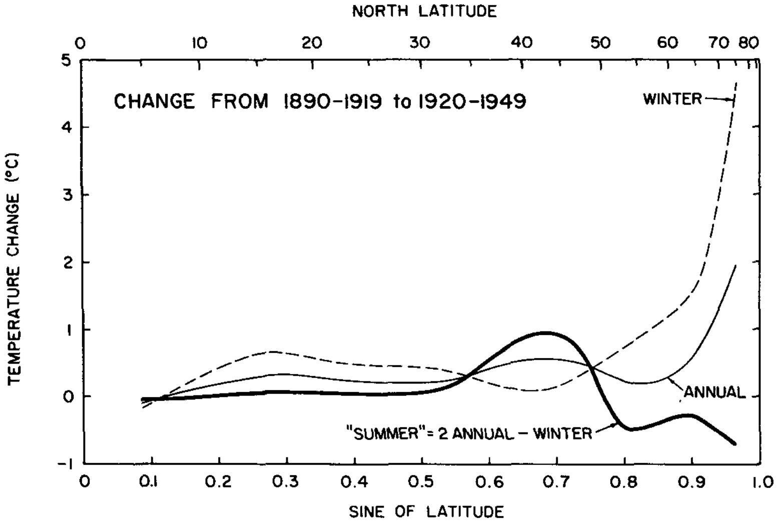

Fig. 5. Change of zonally averaged 30-year mean temperature from 1890–1919 to 1920–1949: broken line, winter; thin solid line, annual; heavy line, 2 annual minus winter. Based on data from Mitchell (1963).

4. The zonal harmonic waves

Fig. 11 contains the percentage that each of the first four waves at 55°N contributed to the total spatial variance in the pressure trends of ten 15-year periods in summer, plus the percentage explained by the remaining waves; as in winter, there is no single wave or combination of waves in which the pressure pattern preferably changed. The share of the variance con-

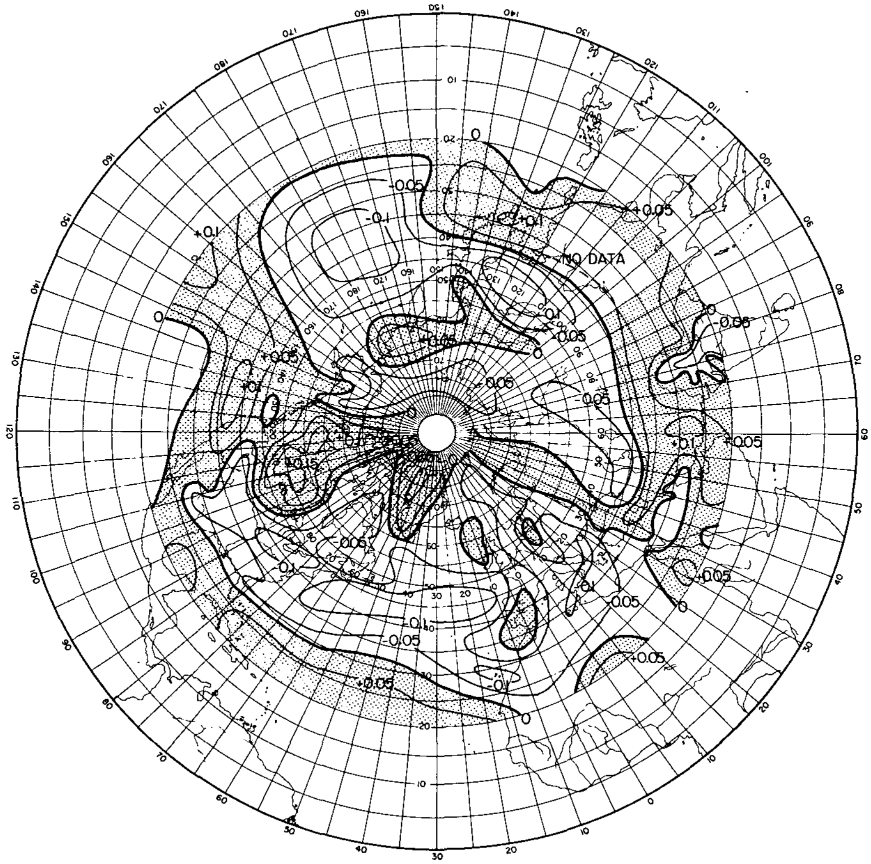

Fig. 6. As in Fig. 1 but for 1950–64.

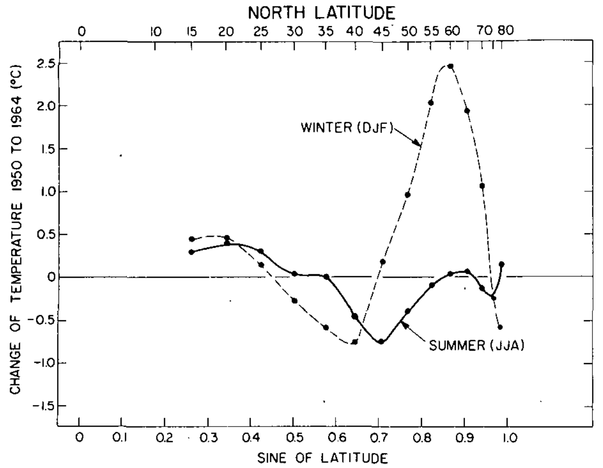

FIG. 7. Meridional profiles of the 1950–64 change of zonally averaged temperature: solid line, summer, computed from Fig. 6; broken line, winter, from van Loon and Williams (1976).

TABLE 1. Amplitude (mb) of the first four mean zonal harmonic waves in the sea level pressure. Winter (DJF) and summer (JJA) at 55°N.

	Wavenumber			
	1	2	3	4
A_{summer}	2.1	2.3	0.6	0.3
A_{winter}	8.2	9.7	4.3	1.5

tributed by the wavenumbers >4 was larger in summer than in winter. The mean waves themselves were smaller in summer than in winter; e.g., at 55°N waves 1–4 in summer were only one-fourth to one-seventh of their size in winter (Table 1). The generally weaker temperature contrasts at middle and high latitudes in summer than in winter, the larger share of the variance explained by the higher wave numbers in summer, and the smaller amplitudes of the low wavenumbers are probably the reason why it is more difficult directly to see an effect of advection changes in summer by comparing the maps of temperature and pressure.

5. Sensible heat transport by quasi-stationary waves in the sea level pressure

The amount of zonally averaged sensible heat transported by the mean waves across middle and high latitudes at sea level in summer (Fig. 12, top) was not only much smaller than in winter (cf. vLW, their Fig. 17), but it went in the opposite direction: equator-

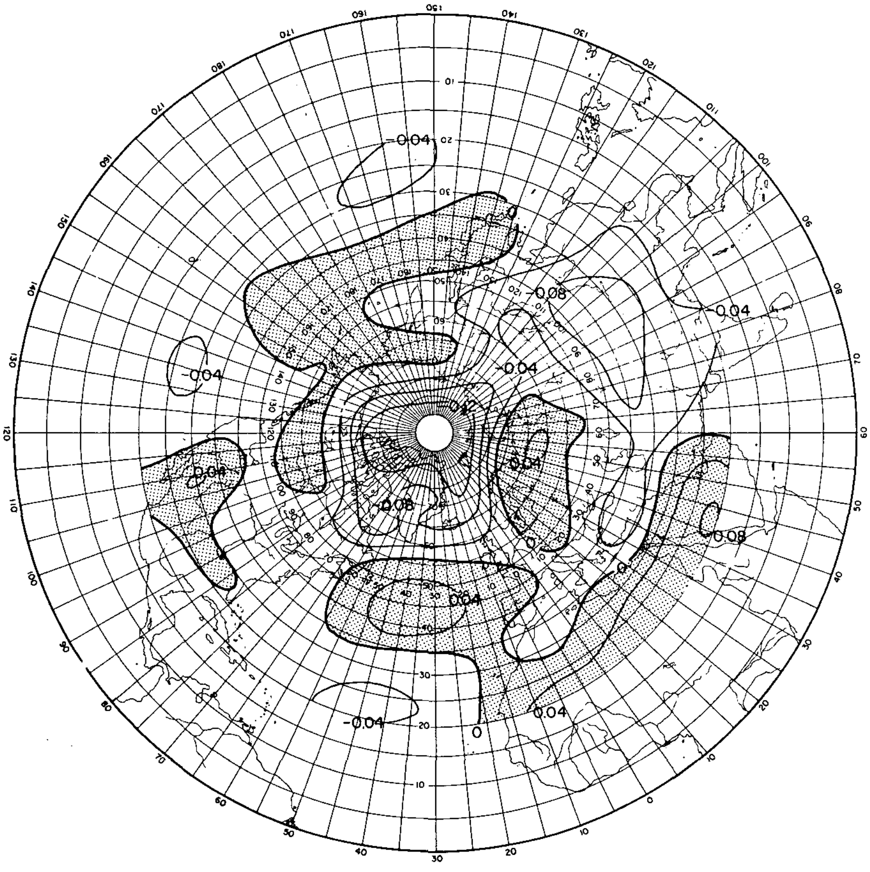

FIG. 8. Isopleths of the slope of the regression line of sea level mean pressure in summer for 1900–41. (Compare with Fig. 1.)

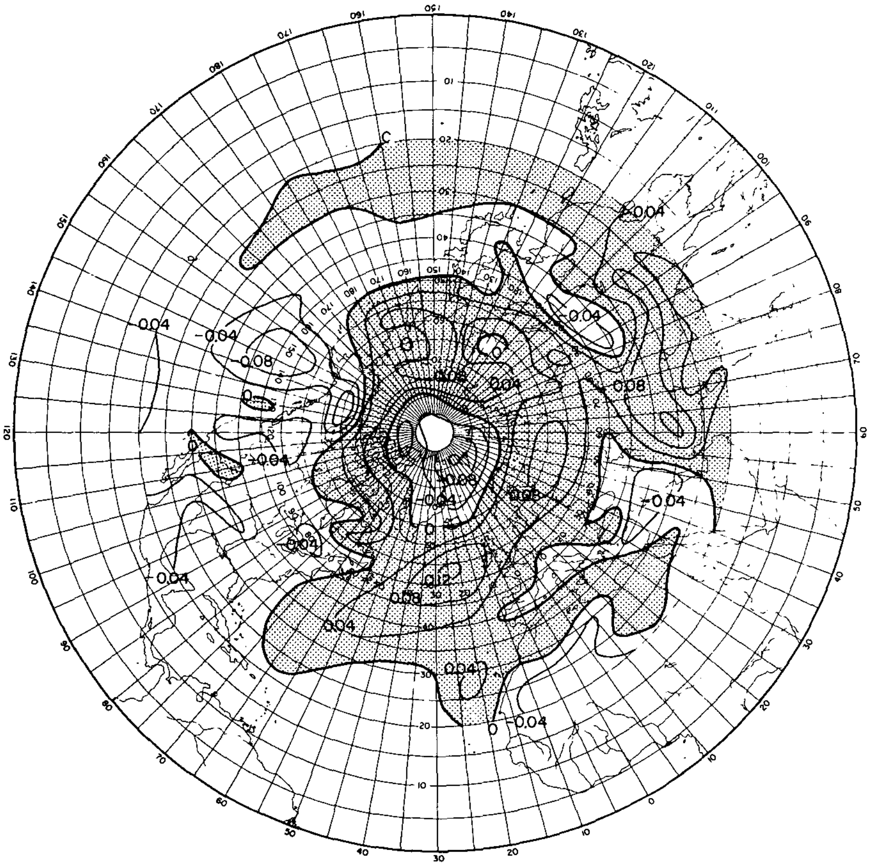

FIG. 9. As in Fig. 8 but for 1942–72. (Compare with Fig. 2.)

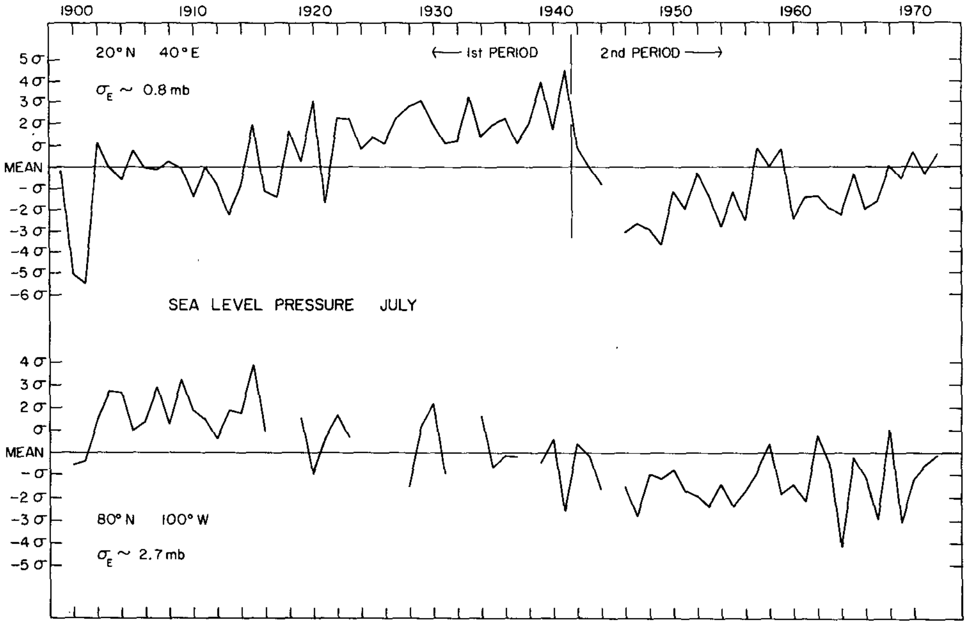

FIG. 10. Time series of sea level pressure (mb) at 20°N, 40°E and 80°N, 100°W in July. The ordinate is the expected standard deviation (see text). From Madden (1976).

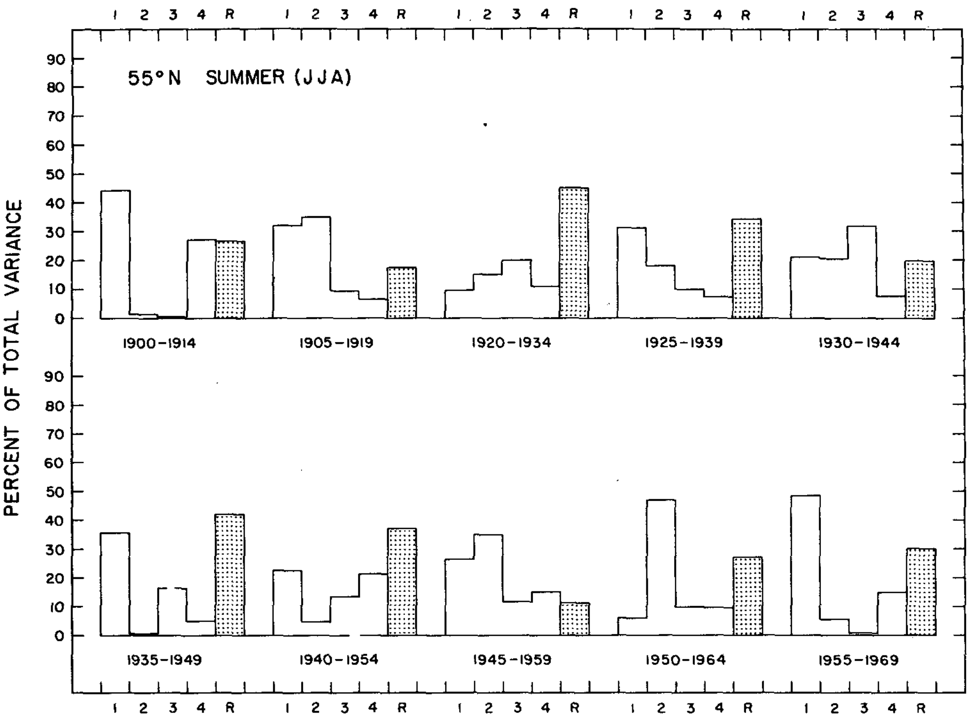

Fig. 11. The percentage of the total variance in the 15-year sea level pressure trends at 55°N in summer which is explained by each of the first four zonal harmonic waves, and by the rest of the waves (shaded columns).

ward.[2] The convergence of sensible heat transported by the mean waves took place between 30° and 45°N (Fig. 12) but in these, as in most latitudes, the transport during the cooling was only slightly below that during the warming. The small difference is furthermore in the level of noise due to the use of the same T^* for the calculations of v^*T^* in both periods (see vLW, Section 5) and to flawed pressure data. It is therefore improbable that the mean waves played a perceptible role in producing a trend in the zonal mean summer temperatures at middle and high latitudes. This is unlike winter when the mean waves had an important share in the differences of poleward heat transport which were associated with the different temperature trends in the arctic in the two periods (vLW). In winter other factors (transport of sensible heat by transient waves, ocean transports, etc.) must then have worked in the same sense as the mean waves, or if they worked in the opposite sense they were not strong enough to counterbalance the influence of the mean waves.

The trend of sensible heat transport by the mean waves at sea level is shown on the bottom of Fig. 12. Although the total transport in both periods was the same, the trend was mainly downward during the first period and upward during the second one. As in winter, the trend of the transport (°C m s^{-1} $year^{-1}$) was two orders of magnitude smaller than the total transport itself.

6. Conclusions

1) The local temperature trends in the Northern Hemisphere in summer are not so clearly associated with changes in advection as those in winter. The combination of weaker temperature contrasts, larger role played

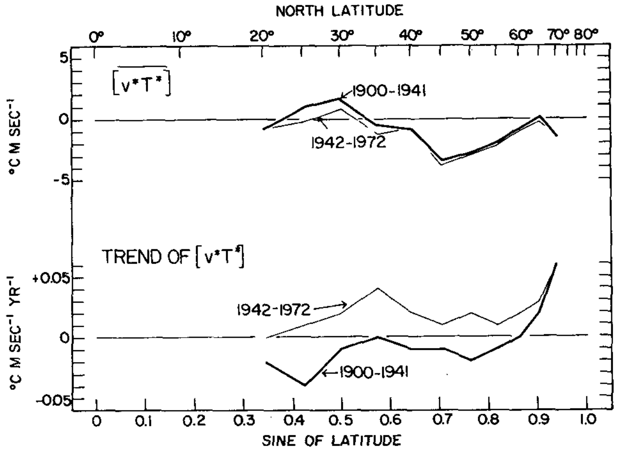

Fig. 12. The zonally averaged meridional transport of sensible heat for 1900–41 and 1942–72 by the mean waves in the sea level pressure in summer (top) and the trend of the same quantities (bottom).

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[2] The transport by the transient waves in summer is bigger in middle latitudes than that by the mean waves and is directed poleward so that the net transport by the waves becomes poleward (Oort and Rasmusson, 1971, pp. 286–289).

by the shorter waves, and the smaller amplitude of the longer waves in middle and high latitudes in summer are the likely reasons why it is difficult directly to see an effect of advection changes.

2) The sign of the zonally averaged temperature trend is not the same at all latitudes; and it is not necessarily the same in summer as in winter at a given latitude.

3) In contrast with winter, changes in the convergence of sensible heat transported by the mean waves in summer play an insignificant part in causing trends in the zonally averaged temperature over the latitude belt where the zonal trends are biggest.

4) The largest zonally averaged trends of temperature in summer are in the zone 35° to 55°N, whereas in winter the largest values are north of 50°N. In summer the sign of the mean trend of the Northern Hemisphere is therefore decided by the trend in middle latitudes.

One might speculate that the bigger zonally averaged trends of surface temperature in the polar region than in other latitudes in winter, and also the tendency in middle latitudes toward larger trends over land than over sea in winter, are associated with the inversion of temperature over surfaces of land and ice. When such an inversion is destroyed during a period of cyclonic activity with the accompanying strong winds, cloudiness and advection of warmer air, the surface temperature will rise notably more than it could over an open ocean surface without an inversion. If therefore there is a period of several years during which cyclonic activity generally increases (or anticyclonic circulation decreases), the increasing frequency with which the inversion would weaken or disappear would bring about a rising trend in the surface temperature which would be larger than the trend over an ocean. The converse holds when the cyclonic activity abates or anticyclonic conditions become more frequent. Logically, this process must be associated with trends over comparatively short periods (less than one century), as it does not seem reasonable to assume that cyclonic activity would continue to change in the same sense for centuries.

In summer, the main stable vertical temperature distribution is not in the atmosphere near the ground but in the surface layer of the ocean. Increasing cyclonic activity (or decreasing anticyclonic conditions) over a number of years in summer would not only lower the water surface temperature from one summer to the next (either because of vertical mixing or because of surface divergence and upwelling), but the concomitants of cyclonic activity (wind and clouds) would in addition lower the surface temperature by increasing the heat loss through evaporation and flux of sensible heat and by decreasing the incoming shortwave radiation at the surface. Thus a trend of increasing cyclonic activity over the ocean in summer might induce a downward temperature trend, and conversely for decreasing cyclonic activity (or increasing anticyclonic circulation) in the latitudes where a strong seasonal thermocline as well as cyclonic activity are possible in summer.

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