NOTES AND CORRESPONDENCE

Trends and Variations of Mean Temperature in the Lower Troposphere

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ABSTRACT

Deviations of the 1000–500 mb thickness from the 1949–76 mean (the period of record) and from the 1965–76 mean (a period of apparent warming in the lower troposphere) are presented for the Northern Hemisphere (25–85°N), the arctic (70–85°N), and the low-latitude belt (25–40°N). Results are compared with those obtained by other investigators from surface and upper air data.

A dramatic drop in the mean temperature of the lower troposphere to the lowest point of the record occurred between January 1975 and August 1976. This cooling followed a slow warming trend between 1965 and 1975 which was greater at low latitudes than in the arctic.

1. Introduction

Several analyses of average Northern Hemisphere surface temperature support the contention that a mean warming of about 0.6°C in the period 1880–1940 has been followed by a 0.3°C cooling (Mitchell, 1975; Reitan, 1974; Lamb, 1975; Bach, 1976; and others). A more recent warming commencing in 1965 has been reported by Budyko and Vinnikov (1976) and Angell and Korshover (1977).

There is no consensus as to the cause of the initial cooling trend, nor whether it will continue or reverse. Mitchell (1975) concludes that the present natural climatic cooling trend is more powerful than the impact of increasing CO_2 as a source of atmospheric warming. Broecker (1975), on the other hand, expects the natural cooling to bottom out soon due to the rapid increase of CO_2. This view is shared by Budyko and Vinnikov (1976) who predict a probable intensification of the warming due to an increasing concentration of CO_2 in the atmosphere, but with fluctuations due to the effect of ash from volcanic eruptions.

Evidence is presented in this paper which shows that the warming trend noted by Budyko and Vinnikov (1976), and by Angell and Korshover (1977), may already be reversing its direction.

2. Observations and data processing

The analysis uses daily values of 500 and 1000 mb geopotential heights from 28 years of data (1 January 1949 to 31 December 1976). The data set used is that of the Extended Forecast Division of the Canadian Meteorological Centre for a 5° latitude-longitude grid from 25–90°N. This data set was obtained from two quality controlled sources: 1) the United Kingdom set for the period 1949–71, and 2) the daily analysis data set of the Canadian Meteorological Centre since 1971. Data from the Pacific Ocean area are missing prior to 1965.

Daily values of 1000–500 mb thickness, obtained by subtraction of the two heights, were first averaged to obtain monthly mean thickness over the grid. A 12-month centered moving average was next applied to the monthly means at each grid point. Weighted mean values for each latitude from 25 to 85°N were then obtained and combined to give means for the zones and periods shown in Table 1.

The deviations of the 1000–500 mb thickness means from the 27-or 11-year means, respectively, are shown in Figs. 1 and 2, together with quadratic regression curves in Fig. 2 as indicators of trends. Graphs are labeled in degrees Celsius from the relation thickness (dam)/2 = °C which is based on the hydrostatic equa-

TABLE 1. Data coverage in space and time.

Zone	Period	Data
25–85°N	July 1949–June 1976	No Pacific data prior to 1965
25–85°N	July 1949–June 1976	No Pacific data
25–85°N	July 1965–June 1976	Pacific data included
70–85°N	July 1965–June 1976	Pacific data included
25–40°N	July 1965–June 1976	Pacific data included

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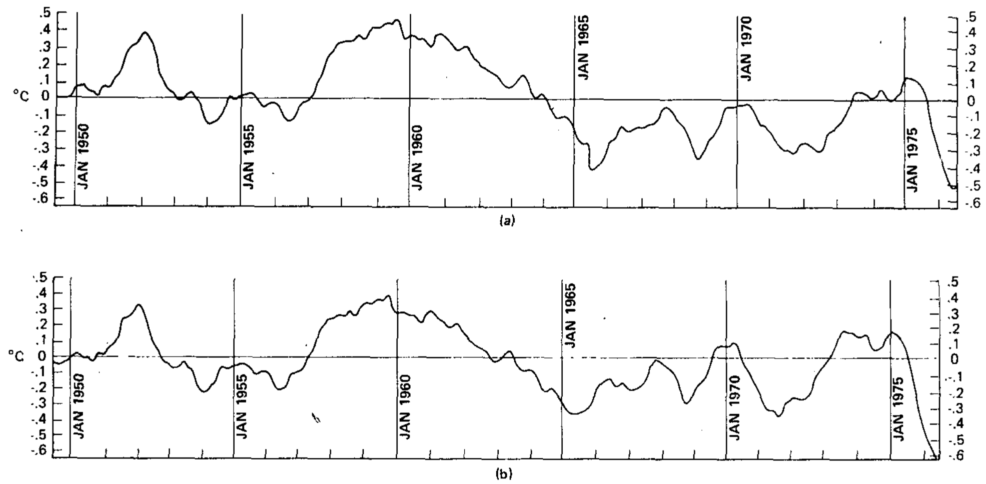

FIG. 1. Deviation of 12-month centered moving average 1000–500 mb thickness, 25–85°N, July 1949–June 1976 (temperature units): (a) no Pacific Ocean data before January 1965, (b) no Pacific Ocean data whole period. Intervals along the abscissa are yearly from January to January.

tion, and gives results accurate to within 0.01°C for the 1000–500 mb layer.

3. Results

Over the period studied, the mean temperature of the lower troposphere in the decade before 1965 was generally above average, whereas that from 1965 to 1975 was more often below average as shown in the time series in Fig. 1a. Following the general cooling from 1959 to 1965 of about 0.9°C, the record shows a slow warming trend proceeding through three oscillations of increasing magnitude. The third and largest oscillation terminates in a sharp decline of 0.7°C beginning in January 1975, such that the mean temperature over the Northern Hemisphere in late 1976 was at its lowest point since the record began in 1949. The latest running means incorporating the mean thickness to May 1977 (not illustrated) shows that the sharp decline ceased in August 1976.

A discontinuity occurs in the slope of the curve at the 1965 minimum in Fig. 1a. This is due to the fact that data from the Pacific was included in the average after that date (see Table 1). This may be compared with Fig. 1b, where Pacific data have been omitted throughout. In the latter more uniform series there is a smaller negative deviation in 1965 than before, but the magnitude of the subsequent fluctuations is not affected appreciably. The cooling from 1959–65 is now 0.73°C (cf. 0.89°C) and from January 1975 to June 1976 0.78°C (cf. 0.67°C).

Deviations of temperature from the 11-year mean for the period of apparent warming (1965–75) are shown in Fig. 2a. Negative deviations predominate during the late sixties and positive ones during the early seventies. Exclusion of the 1949–65 data has resulted in a marked increase in the magnitude of the positive deviations from the mean in the 1966–76 period due to a 0.2°C decrease of the 11-year mean (Fig. 2a) relative to the 27-year mean (Fig. 1a).

It is of interest to compare reported results of investigations into recent long-term changes in Northern Hemisphere temperatures. This is done in Table 2.

These results show that the strong cooling trend in the lower troposphere in the late fifties and early sixties indicated in Fig. 1b, and also shown by Dronia (1974), is almost twice as large as that for the troposphere as a whole found by Angell and Korshover (1977) and Starr and Oort (1973) and three times the trend at the surface given by Angell and Korshover (1977) and Mason (1976). This surface cooling in the

TABLE 2. Temperature trends in the Northern Hemisphere. Trends are given for the zone north of 25 or 30°N except those marked with an asterisk which are for the whole Northern Hemisphere.

Reference	Period of warming or cooling	Layer	Temperature trend (°C)
Angell and Korshover (1977)	1959–64	sfce—100 mb	−0.34
Angell and Korshover (1977)	1959–64	surface	−0.22*
Dronia (1974)	1959–64	1000–500 mb	−0.6
Mason (1976)	1958–63	surface	−0.2*
Starr and Oort (1973)	1958–63	M.S.L.–75 mb	−0.39
Fig. 1b	1959–65	1000–500 mb	−0.73
Angell and Korshover (1977)	1964–74	sfce—100 mb	−0.08
Angell and Korshover (1977)	1964–74	surface	+0.02*
Brinkmann (1976)	1965–73	surface	+0.02*
Budyko and Vinnikov (1976)	1964–75	surface	+0.3 (10 year)$^{-1}$
Dronia (1974)	1964–73	1000–500 mb	+0.11
Fig. 2a	1965–75	1000–500 mb	+0.19

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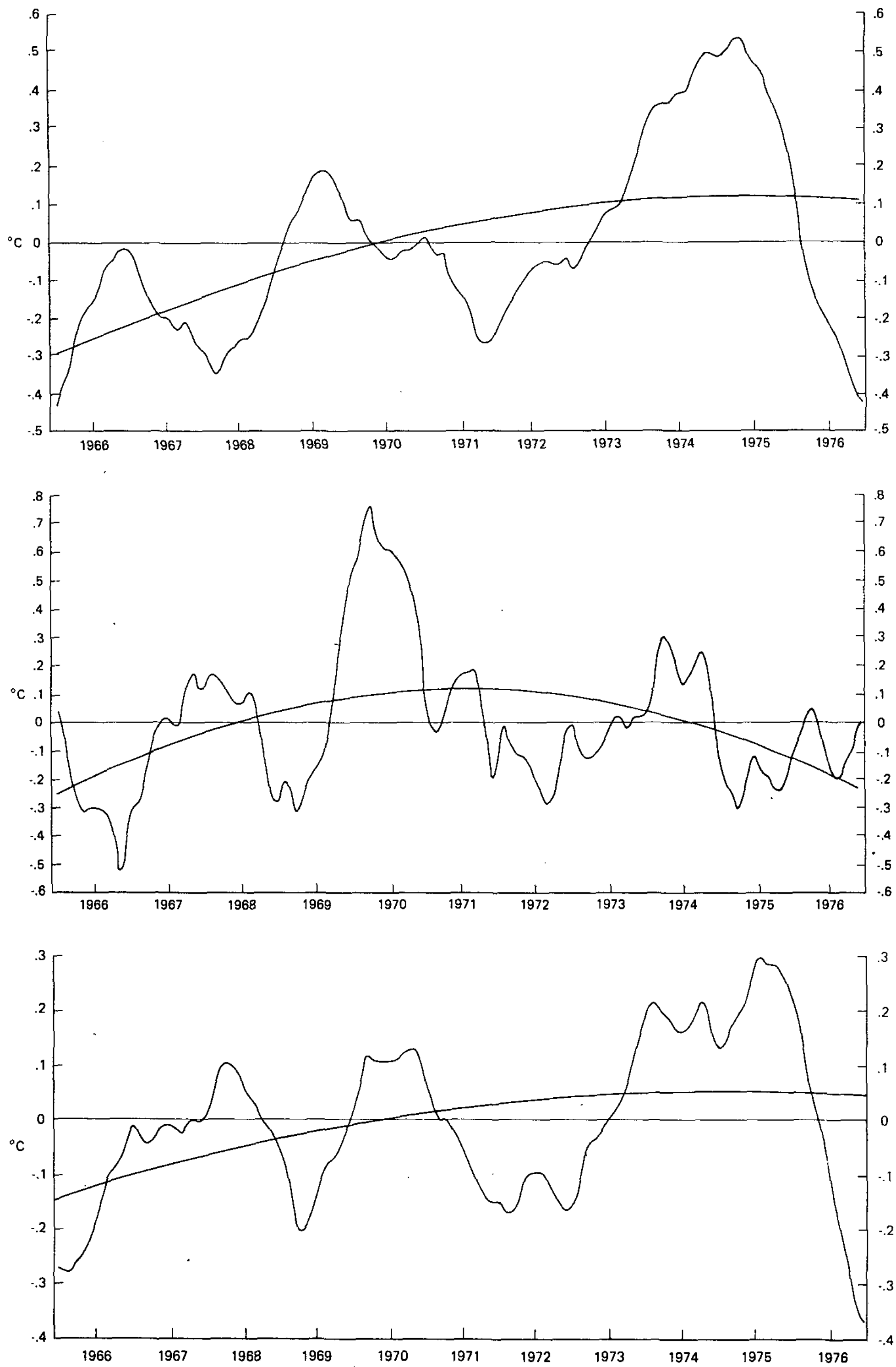

FIG. 2a. As in Fig. 1a except for July 1965–June 1976. The smooth curve is a quadratic regression line of best fit.
FIG. 2b. As in Fig. 2a except for 70–85°N.
FIG. 2c. As in Fig. 2a except for 25–40°N.

Northern Hemisphere has also been noted by Yamamoto and Iwashima (1975).

The warming trend in the lower troposphere between 1965 and 1975 shown in Fig. 2a (+0.19°C) agrees reasonably well with that obtained from Fig. 3 of Dronia (1974). This latter value (+0.11°C) was

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obtained by fitting a straight line to his values by least squares. According to Budyko and Vinnikov (1976), the warming trend at the surface is, on the average, about twice as large as these values (0.3°C per decade), but Angell and Korshover (1977) and Brinkmann (1976) gave a surface warming of only +0.02°C for the hemisphere as a whole. In contrast, Angell and Korshover (1977), show a cooling trend of −0.18°C for the whole troposphere during this period. A possible connection between the marked temperature decrease in the troposphere and at the surface in the Northern Hemisphere in the 1963–65 period and the eruption of Mt. Agung in 1963 has been noted by Angell and Korshover (1977), Budyko and Vinnikov (1976) and Yamamoto and Iwashima (1975).

A strong cooling trend began in the lower troposphere in 1975 and is one of the most dramatic features of the record (Fig. 1).

Marked differences are evident between the fluctuations and trends in temperature in the lower troposphere for the arctic and low latitudes in Figs. 2b and 2c. The largest amplitude fluctuation in the arctic zone (70–85°N), occurred between 1969 and 1970 and were followed by small fluctuations with decreasing temperature trend (see Fig. 2b). The quadratic regression curve shows a warming trend of about +0.37°C between 1965 and 1970 with an almost equal cooling of −0.35°C from 1970–76. A slight upward trend apparently began in 1974. There is no evidence in the thickness record of a strong temperature rise between 1965 and 1975 in the arctic to compare with the mean surface temperature increase of +0.9°C per decade reported by Budyko and Vinnikov (1976). Without the large positive oscillation in 1969–70 (also indicated by Dronia) there would be practically no trend in this zone.

Three distinct fluctuations of increasing amplitude may be observed in the mean temperature anomaly for low latitudes (25–40°N), in the time series shown in Fig. 2c, with the most recent terminating with a precipitous drop of 0.9°C in 18 months from its January 1975 high. The quadratic regression curve shows a warming trend of +0.42°C which ceases in 1974. Figs. 2b and 2c imply that the warming trend in the lower troposphere since 1965 was greater at lower latitudes than in the arctic. This is in contrast to the indications of the surface temperature where, according to Budyko and Vinnikov (1976), the opposite is the case.

4. Conclusions

The record of 1000–500 mb thickness over the Northern Hemisphere from 25–85°N shows a general rise in mean temperature in the late fifties to a maximum in 1959. This rise has been observed in other studies. A decreasing trend of −0.7°C then took over which reached a minimum in 1965. Mean temperatures thereafter show a slow rise (+0.2°C), in a series of three oscillations of increasing amplitude which terminate in a dramatic drop in 1975 and 1976 of −0.8°C.

A warming trend is also shown in the record for low latitudes (25–40°N) between 1965 and 1975, in contrast to the arctic (70–85°N), where the warming trend is negligible. This contradicts evidence from the surface temperature record reported by Budyko and Vinnikov (1976).

A dramatic drop in mean temperature in 1975 and 1976 has apparently reversed or, at least, interrupted the apparent rising trend of the late sixties and early seventies, which perhaps supports the view of Mitchell (1975) that the natural climatic cooling is more powerful than the impact of increasing CO_2.

This unexpected feature of the temperature curve demonstrates once again how difficult it is to draw any general conclusions about long-term climatic trends from particular trends in a portion of the temperature record.

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