# THERMAL CONDITIONS IN THE ARCTIC STRATOSPHERE NEAR 80W IN JANUARY[1]

*E. Paul McClain*

University of Chicago

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## ABSTRACT

Revised means, frequency distributions and other statistics based on ten years of January temperature observations at the 200-, 100- and 50-mb levels are presented for four arctic stations. The frequency distributions are shown to be markedly bimodal, a characteristic that becomes more pronounced with increasing height and latitude. Thermal conditions in the arctic and antarctic stratospheres are compared with the aid of recent IGY data.

## 1. Introduction

Earlier aerological investigations of the temperature field at the levels above 300 mb in the Arctic in winter have suffered from paucity of observations and from bias in the existing data. By taking advantage of the greatly increased number of soundings reaching the 100- and 50-mb levels recently, January data for the ten-year period 1950 to 1959 are used to obtain frequency distributions and other temperature statistics for four arctic stations north of the 60th parallel and near the 80th meridian west. Recent International Geophysical Year observations for Antarctica are used to obtain better comparisons with the Arctic than heretofore possible.

In the past decade or so, a number of researchers have constructed mean meridional cross sections along or near 80W—namely, Hess [1], Kochanski [2], Wege *et al* [3], and Goldie *et al* [4]. A comparison of these cross sections provided the stimulus for the present investigation. As will be seen in fig. 1, the mean January temperatures provided by these authors differ considerably. It will be shown in a later section that in large part these differences are attributable to the observational periods used and to biased samples.

## 2. Observational materials

The observations used in this investigation consisted chiefly of the daily 200-, 100-, and 50-mb temperatures for the ten Januaries 1950 to 1959 at the following stations: Coral Harbor (64°11′N, 83°22′W), Resolute (74°43′N, 94°59′W), Eureka (80°13′N, 86°11′W), and Alert (82°33′N, 62°35′W). It was necessary to use a variety of data sources [5; 6], including manuscript data provided by courtesy of the Department of Transport, Canada in order to obtain a reasonably complete set of observations. Temperatures from the 0300 GCT (0000 GCT after 1957) observation time were used when available. If the 0300 observation was

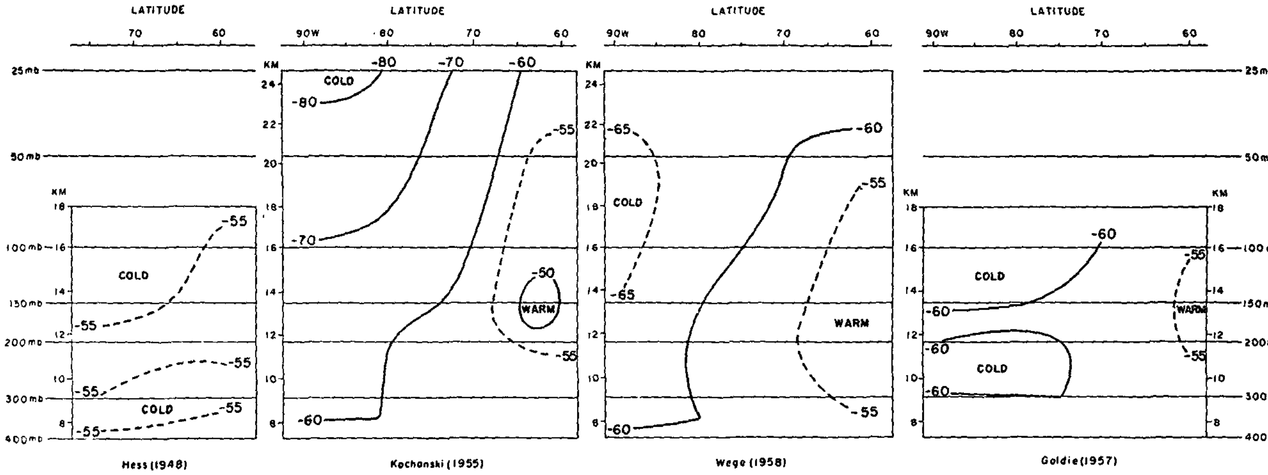

FIG. 1. A comparison of cross sections of mean temperature in the arctic stratosphere near 80W.

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missing, the 1500 GCT (1200 GCT after 1957) was substituted whenever it was available. This substitution is permissible because radiation errors are not a factor in January at these high latitudes.

Table 1 shows the variation from year to year of the number of observations available at each station and level; the corresponding mean temperatures for each month and for the period as a whole are given also. With the exception of 1958 and 1959, it will be seen that the number of radiosondes reaching the 100- and 50-mb levels tends to be a function of the 200-mb mean temperature. Premature bursting of radiosonde balloons when they are exposed to very low temperatures was discussed briefly some time ago by Court [11; 12] and more recently by Schumacher [13]. However, as will be seen from table 1, balloon performance has improved recently; since 1957, a very high percentage of the balloons has reached the 50-mb level in spite of relatively low mean temperatures.

Another feature of table 1 is the great variability of the means for individual months at all stations and all levels. This variability makes it unlikely that one could obtain representative or stable mean values using periods of only a few years, even if no bias were present in the observations. At the 100- and 50-mb levels, part of this variability is probably due to biased sampling in the earlier years when well less than half the soundings reached these levels. Particularly striking are the very high mean temperatures in 1953 and 1955 in comparison with the ten-year mean and with the means of the neighboring years. In this connection, Belmont [14] has compared the mean January temperatures in the stratosphere above Ice Island T-3, which at that time was drifting near 86N and 95W, with the mean temperatures at nearby arctic stations, taken from published summaries [6; 7; 8; 9]. He considered it noteworthy that T-3's average 200-mb temperature of −52.7C ($N = 27$) was much higher than the January mean temperatures given for Alert, Resolute, Eureka, and Coral Harbor; however, it is evident from table 1 that the January 1953 temperatures at all of these stations were quite comparable with those at T-3.

In constructing his cross section, it was necessary for Hess to combine the January and February data of the years 1942 to 1945 in order to obtain even 45 temperature observations at the 200-mb level over his northernmost station, Arctic Bay (73°16′N, 84°17′W). It is evident from the ten-year means in table 1 that his mean temperatures in the layer from 200 to 100 mb are some 3C to 5C too high. Goldie *et al*, who used data from the published summaries cited in table 1, were

TABLE 1. Number of temperature observations ($N$) and average temperatures ($\bar{T}$) for individual Januaries and for the ten-year period 1950–59. The temperatures are in °C with the negative sign omitted. The left-hand column contains means taken from published summaries.*

| | | 1951–53[1] | 1950 | 1951 | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | 1958 | 1959 | 1950–59 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Alert | | | | | | | | | | | | | |
| 50 mb | $N$ | 18 | 0 | 0 | 0 | 16 | 0 | 21 | 0 | 5 | 23 | 29 | 94 |
| | $\bar{T}$ | 56.0 | — | — | — | 54.7 | — | 49.3 | — | 76.0 | 71.3 | 76.2 | 65.3 |
| 100 mb | $N$ | 65 | 0 | 19 | 11 | 26 | 16 | 29 | 5 | 25 | 29 | 31 | 191 |
| | $\bar{T}$ | 61.9 | — | 65.8 | 69.6 | 54.4 | 61.9 | 50.1 | 69.0 | 68.5 | 67.9 | 67.8 | 62.9 |
| 200 mb | $N$ | 88 | 0 | 26 | 24 | 27 | 26 | 31 | 31 | 27 | 30 | 31 | 253 |
| | $\bar{T}$ | 59.9 | — | 60.7 | 64.1 | 54.5 | 60.4 | 51.5 | 64.3 | 64.1 | 63.4 | 61.3 | 60.4 |
| Eureka | | 1948–50[2] | | | | | | | | | | | |
| 50 mb | $N$ | 0 | 0 | 0 | 0 | 3 | 2 | 20 | 0 | 2 | 27 | 30 | 84 |
| | $\bar{T}$ | — | — | — | — | 51.0 | 53.5 | 49.6 | — | 72.5 | 70.3 | 74.1 | 65.7 |
| 100 mb | $N$ | 4 | 2 | 3 | 12 | 15 | 13 | 31 | 17 | 25 | 29 | 31 | 179 |
| | $\bar{T}$ | 67.9 | 67.0 | 61.7 | 68.4 | 51.5 | 59.1 | 48.9 | 69.8 | 71.2 | 65.7 | 66.9 | 62.6 |
| 200 mb | $N$ | 24 | 17 | 11 | 20 | 17 | 23 | 31 | 28 | 31 | 30 | 31 | 239 |
| | $\bar{T}$ | 59.0 | 58.8 | 59.1 | 62.9 | 51.1 | 58.3 | 49.9 | 61.9 | 64.3 | 61.9 | 61.3 | 59.2 |
| Resolute | | 1948–50[3] | | | | | | | | | | | |
| 50 mb | $N$ | 0 | 0 | 0 | 0 | 9 | 8 | 29 | 4 | 8 | 19 | 28 | 105 |
| | $\bar{T}$ | — | — | — | — | 50.0 | 52.0 | 51.2 | 68.2 | 70.1 | 64.8 | 72.0 | 61.3 |
| 100 mb | $N$ | 10 | 12 | 9 | 12 | 19 | 20 | 31 | 18 | 23 | 27 | 30 | 202 |
| | $\bar{T}$ | 64.3 | 63.5 | 58.0 | 63.2 | 47.8 | 58.2 | 48.6 | 66.8 | 67.5 | 62.4 | 65.1 | 59.9 |
| 200 mb | $N$ | 33 | 24 | 18 | 27 | 27 | 26 | 31 | 30 | 31 | 31 | 30 | 275 |
| | $\bar{T}$ | 57.3 | 58.0 | 59.2 | 59.6 | 48.1 | 57.8 | 47.8 | 60.5 | 62.7 | 58.1 | 59.8 | 57.1 |
| Coral Harbor | | 1944–47[4] | | | | | | | | | | | |
| 50 mb | $N$ | 0 | 0 | 0 | 0 | 4 | 10 | 12 | 3 | 7 | 12 | 27 | 75 |
| | $\bar{T}$ | — | — | — | — | 53.2 | 59.0 | 51.6 | 73.7 | 68.8 | 64.1 | 69.0 | 63.4 |
| 100 mb | $N$ | 12 | 0 | 0 | 19 | 23 | 25 | 29 | 28 | 21 | 26 | 31 | 202 |
| | $\bar{T}$ | 59.2 | — | — | 62.7 | 48.0 | 60.0 | 48.4 | 63.8 | 64.8 | 59.3 | 63.2 | 58.7 |
| 200 mb | $N$ | 55 | 0 | 5 | 23 | 26 | 27 | 31 | 30 | 26 | 30 | 31 | 229 |
| | $\bar{T}$ | 56.3 | — | 48.8 | 56.3 | 46.8 | 58.1 | 45.8 | 59.3 | 61.9 | 55.2 | 59.0 | 54.9 |

* The superscripts 1 to 4 refer to references [6] to [9], respectively.

fortunate in obtaining short-period averages at the 200- and 100-mb levels which were within about one degree of the ten-year means. Kochanski, drawing on the same sources as Goldie, attempted to extend his mean cross section to the 30-km level by extrapolation of the mean lapse rate found in the layer from 12 to 18 km. His 50-mb temperatures near Alert differ by more than 8C from the average of the 94 observations in the period 1950 to 1959; however, as will be seen in a later section, the ten-year means at the 50-mb level are probably still several degrees too high because of the sampling bias discussed earlier. The cross section constructed by Wege *et al* was based on more observations than any of the others, but the relatively small sampling of observations above the 100-mb level makes it likely that their mean temperatures in this layer are several degrees too high also. In summary, small and unrepresentative temperature samples at the levels above about 200 mb have, in general, resulted in the various short-period means being biased toward higher temperatures. An attempt to circumvent this difficulty by extrapolation of the mean lapse rate in a lower layer where data were more plentiful appears to have resulted in mean temperatures which are too low. Although the means presented in this paper are based on more observations than any previously published ones, some observational bias is still evident at the uppermost levels. In the next section, a method is presented for removing a large part of this bias.

TABLE 2. Regression statistics for four arctic stations.

| Station | Levels (mb) | $r$ | Regression eq. (°C) | RE (°C) | $N$ |
|---|---|---|---|---|---|
| Alert | 100/50 | 0.97 | $T_{50} = 13.5 + 1.30\, T_{100}$ | 3.3 | 94 |
| | 200/100 | 0.90 | $T_{100} = 10.9 + 1.25\, T_{200}$ | 3.8 | 186 |
| Eureka | 100/50 | 0.97 | $T_{50} = 1.9 + 1.12\, T_{100}$ | 3.1 | 84 |
| | 200/100 | 0.91 | $T_{100} = 6.3 + 1.18\, T_{200}$ | 4.1 | 175 |
| Resolute | 100/50 | 0.95 | $T_{50} = 0.9 + 1.10\, T_{100}$ | 3.6 | 105 |
| | 200/100 | 0.91 | $T_{100} = 7.4 + 1.19\, T_{200}$ | 4.0 | 191 |
| Coral Harbor | 100/50 | 0.91 | $T_{50} = -7.5 + 0.96\, T_{100}$ | 3.5 | 67 |
| | 200/100 | 0.92 | $T_{100} = -6.6 + 0.95\, T_{200}$ | 3.1 | 198 |

## 3. Regression estimates

Table 2 contains linear correlation coefficients ($r$) and regression equations relating the 200- and 100-mb levels and the 100- and 50-mb levels, together with the residual errors (RE) and the number of observation pairs (N), for the stations Alert, Eureka, Resolute, and Coral Harbor. It is seen that neighboring levels are well correlated and, with the exception of Coral Harbor, the degree of correlation increases upward. The "error of prediction" of the temperature at the upper level from that at the lower level (*i.e.*, the "residual error" defined by Brooks and Carruthers [15]), is everywhere four degrees or less and, with the exception of Coral Harbor, decreases with height.

TABLE 3. Comparison of mean temperatures (°C) based on actual observations and on actual plus derived observations.

| | | Actual observations | | Actual plus regression estimates | |
|---|---|---|---|---|---|
| Stations | Level (mb) | Mean | $N$ | Mean | $N$ |
| Alert | 50 | −65.3 | 94 | −68.5 | 189 |
| | 100 | −62.9 | 191 | −64.2 | 252 |
| Eureka | 50 | −65.7 | 84 | −67.6 | 178 |
| | 100 | −62.6 | 179 | −63.5 | 239 |
| Resolute | 50 | −61.3 | 105 | −65.0 | 199 |
| | 100 | −59.9 | 202 | −60.8 | 275 |
| Coral Harbor | 50 | −63.4 | 75 | −64.2 | 190 |
| | 100 | −58.7 | 202 | −58.7 | 229 |

Making use of these regression relationships, 100-mb-temperature estimates were made for each day when the balloon reached 200 mb but failed to reach 100 mb. Likewise, estimates of the 50-mb temperature were made for days when the 100-mb level was reached but the 50-mb level was not. Table 3 presents a comparison of the ten-year means from table 1 and means based on the actual observations *plus* the estimates obtained from the regression equations. Comparison of the two sets of means bears out the contention that the observations at the uppermost levels are biased in favor of the warmer periods. The revised means at the 100-mb level are of the order of one degree lower than the means based on actual observations only; those at the 50-mb level are about one to four degrees lower.

TABLE 4. Comparison of mean temperatures (°C) at arctic and antarctic stations.

| | 200 mb | | 100 mb | | 50 mb | |
|---|---|---|---|---|---|---|
| Station and period | $\bar{T}$ | $N$ | $\bar{T}$ | $N$ | $\bar{T}$ | $N$ |
| Eureka (80°13′N)<br>1950–59 | −59.2 | 239 | −63.5 | 239 | −67.6 | 178 |
| Little America (78°34′S)<br>1940, 1957–58 | −70.8 | 83 | −77.3 | 58 | −84.1 | 47 |
| Resolute (74°43′N)<br>1950–59 | −57.1 | 275 | −60.8 | 275 | −65.0 | 199 |
| Maudheim (71°03′S)<br>1951–52 | −73.2 | 52 | −77.3 | 27 | — | — |
| Argentine I. (65°15′S)<br>1954–56 | −67.1 | (?) | −70.3 | 57 | — | — |
| Coral Harbor (64°11′N)<br>1950–59 | −54.9 | 229 | −58.7 | 229 | −64.2 | 190 |

Numerous comparisons of mean thermal conditions in the arctic and antarctic stratospheres in midwinter appear in the literature. All of them, even the most recent [13; 15; 16], have used observations at such stations as Coral Harbor, Eureka, and Arctic Bay for years in the period 1944 to 1950. Table 4 gives a

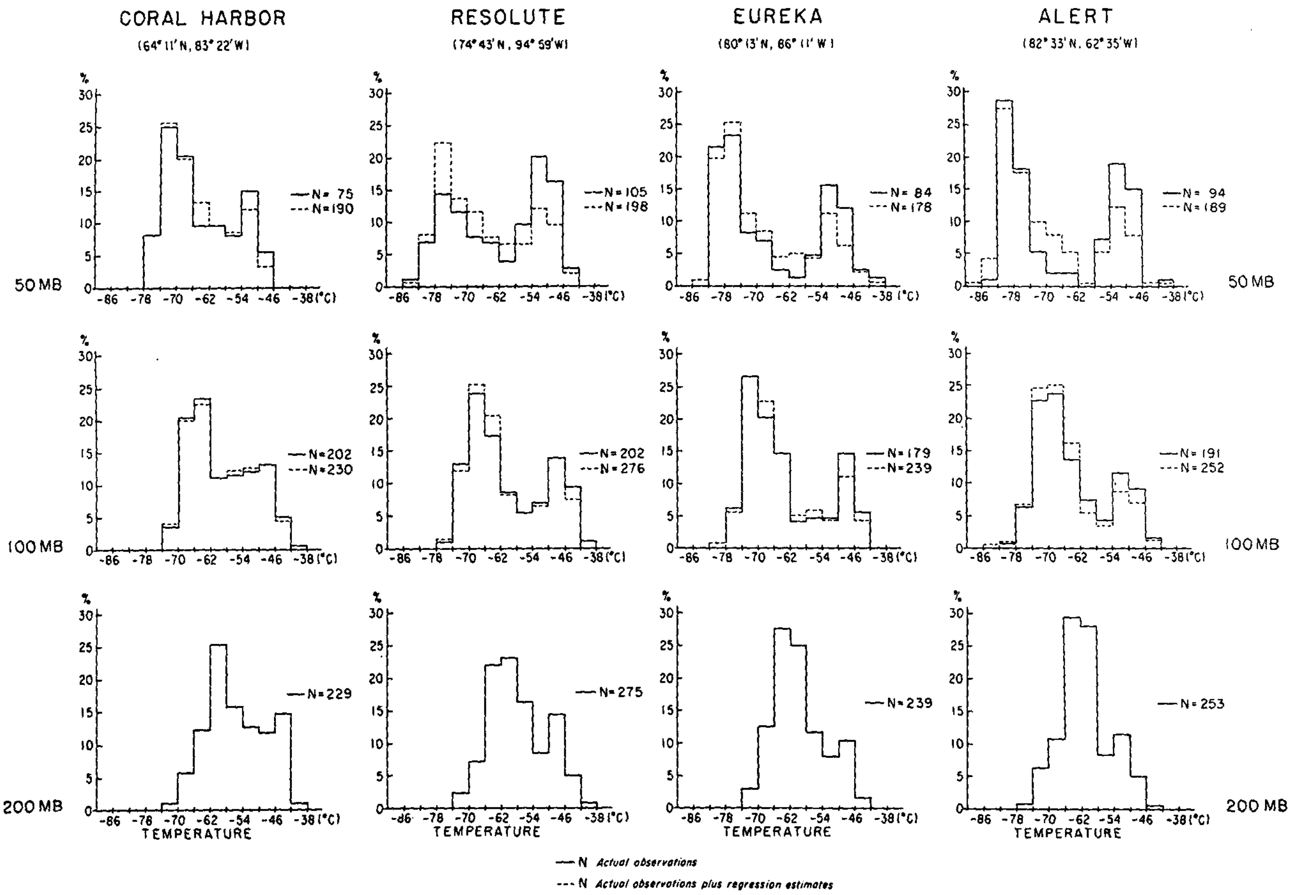

FIG. 2. Frequency distributions of January temperature at the 200-, 100-, and 50-mb levels for several arctic stations.

considerably more up-to-date comparison of stations in the two areas. The arctic stations Eureka, Resolute, and Coral Harbor are shown together with three antarctic stations at similar latitudes. The July mean values for Maudheim and Argentine Island were obtained from [13] and [16], respectively; those for Little America were computed from observations published by Court [12] and from manuscript data furnished by the U. S. Weather Bureau. There has been little doubt in the past that the antarctic stratosphere is, in the mean, colder than the arctic, but there has been doubt as to the magnitude of the difference. It is seen from table 4 that the mean antarctic temperatures range from 12C lower at the 200-mb level to as much as 18C lower at the 50-mb level.

## 4. Frequency distributions

Fig. 2 contains frequency distributions of the January temperatures at the 200-, 100-, and 50-mb levels for the stations Alert, Eureka, Resolute, and Coral Harbor. The most notable feature of these distributions is that they are distinctly bimodal; moreover, they become more so with increasing height and latitude. It is of interest that although the warmer mode falls within the same temperature interval (−50C to −54C) at nearly all the stations and levels, the colder mode occurs at increasingly lower temperatures with increasing altitude and latitude. The additional temperature estimates obtained from the regression relations were also used to revise the frequency distributions (see fig. 2). The most substantial changes in the distributions appear at the 50-mb level and at the northernmost stations. In general, the warmer mode was diminished, and the colder mode was somewhat enhanced; the overall bimodal character of the distributions was preserved.

The bimodal nature of these distributions is the more interesting in light of the fact that Goldie [5] found that, in general, upper-air temperature distributions at all levels from 700 mb to 100 mb are unimodal and symmetrical and that normality may be assumed with very little error. He did state, however, that exceptions occur when two or more distinct temperature regimes prevail at a particular level—for example, when tropopause fluctuations result in a level being part of the time in the troposphere and part of the time in the stratosphere. There is evidence that the high arctic stratosphere is, in fact, dominated by two distinct thermal regimes. Wexler and Moreland [17] have described certain slowly moving, large cold cyclones and warm anticyclones at the 50-mb level which seem to have little or no connection with lower-level pressure systems and which tend to shift their prevailing locations from one year to the next. Characteristic minimum temperatures associated with the upper cyclones were in the range −70C to −80C; typical maximum temperatures associated with the upper anticyclones were in the range −40C to −55C. These temperature values correspond closely to the 50-mb modal temperatures of the frequency distributions of fig. 2. The association between the 50-mb heights and temperatures is further corroborated by the *clustering* of the frequency distributions for Alert shown in table 5 and by a very high linear correlation (0.88 with $N = 92$) between the heights and temperatures. Godson and Lee [18] have produced graphs of 10-day running mean temperatures at the 100-mb surface and pressure-time cross sections of temperature, extending from 500 mb to 20 mb, at several stations to illustrate the thermal structure of the arctic stratosphere in three autumn, winter, and spring seasons. They described and discussed periods of rapid warming which took place one year as early as the first part of January, in another year as late as the last part of March. Temperatures were observed to increase from below −70C to above −50C in about five days time; these marked variations were essentially confined to the levels 100 mb and higher. This investigation also tended to confirm the existence of the 50-mb circulation systems described by Wexler and Moreland.

Table 5. Frequency distributions of 50-mb heights (gpm) and temperatures (°C) for Alert in January (1951–59).

| Height/temp. | 34–41 | 42–49 | 50–57 | 58–65 | 66–73 | 74–81 | 82–88 | Totals |
|---|---|---|---|---|---|---|---|---|
| 18,650–18,949 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 5 |
| 18,950–19,249 | 0 | 0 | 0 | 0 | 1 | 11 | 1 | 13 |
| 19,250–19,549 | 0 | 0 | 0 | 0 | 3 | 22 | 0 | 25 |
| 19,550–19,849 | 0 | 0 | 2 | 0 | 3 | 4 | 0 | 9 |
| 19,850–20,149 | 0 | 5 | 16 | 2 | 0 | 0 | 0 | 23 |
| 20,150–20,449 | 1 | 8 | 8 | 0 | 0 | 0 | 0 | 17 |
| 20,450–20,749 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Totals | 1 | 13 | 26 | 2 | 7 | 42 | 1 | 92 |

Table 6. Frequency distributions (per cent) of July temperatures (°C) at Little America (1940, 1957–58).

| Level (mb) | Temperature 58–61 | 62–65 | 66–69 | 70–73 | 74–77 | 78–81 | 82–85 | 86–89 | 90–93 | $N$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 50 | | | | 0.0 | 6.4 | 12.8 | 40.4 | 40.4 | 0.0 | 47 |
| 100 | | 0.0 | 1.7 | 8.5 | 35.6 | 52.5 | 1.7 | 0.0 | | 59 |
| 200 | 1.2 | 7.2 | 21.7 | 53.0 | 14.5 | 2.4 | 0.0 | | | 83 |

It is noteworthy that frequency distributions of midwinter temperatures at Little America, shown in table 6, give no indication of a secondary warm mode like that found at arctic stations. A smaller sample of 27 observations from Maudheim [13] also exhibits a simple unimodal distribution at the 100-mb level. If these rather small samples are representative, it appears that warm anticyclones of the type found in the high stratosphere of the arctic area are seldom if ever present in the Antarctic. The increasing skewness of the Little America temperature distributions with increasing elevation, culminating in the marked *cut-off* of about −89C at the 50-mb level, might indicate that the sample, which is quite small, is biased against extremely low temperatures.

Table 7. Standard deviations of temperature (°C) at arctic and antarctic stations.

| Station and period | Level (mb) 200 | 100 | 50 |
|---|---|---|---|
| Alert (1951–59) | 6.2 | 8.2 | 13.4 |
| Eureka (1950–59) | 7.2 | 9.9 | 13.3 |
| Resolute (1950–59) | 7.0 | 9.6 | 11.5 |
| Coral Harbor (1951–59) | 7.4 | 8.0 | 8.5 |
| Little America (1940, 1957–58) | 3.6 | 3.0 | 3.5 |
| Maudheim (1951–52) | 3.6 | 2.7 | — |

## 5. Standard deviations

The bimodal character of the arctic temperature frequency distributions is reflected in the very large standard deviations given for the arctic stations in table 7. As might be expected from the variation of the temperature interval separating the modes, the magnitude of the standard deviations increases with both altitude and latitude. The deviations found in this study are larger than those computed by Goldie *et al* [4] for the same area: at both 200 and 100 mb, they found a maximum of about 6.5C near 65N, the values decreasing to less than 5C near 90N. The standard deviations given by Schumacher [13] for Maudheim and those computed for Little America[2] were much smaller than those for the arctic stations at all levels, and they exhibited no tendency to increase with height.

Table 8. Percentage of days on which warm regimes prevailed at various levels over Resolute in January.

| | 200 mb % | $N$ | 100 mb % | $N$ | 50 mb % | $N$ |
|---|---|---|---|---|---|---|
| 1950 | 0.0 | 24 | 0.0 | 24 | 0.0 | 11 |
| 1951 | 5.6 | 18 | 27.8 | 18 | 22.2 | 9 |
| 1952 | 0.0 | 27 | 3.7 | 27 | 8.3 | 12 |
| 1953 | 96.3 | 27 | 100.0 | 27 | 100.0 | 19 |
| 1954 | 23.1 | 26 | 26.9 | 26 | 35.0 | 20 |
| 1955 | 83.9 | 31 | 87.1 | 31 | 93.5 | 31 |
| 1956 | 0.0 | 30 | 0.0 | 27 | 0.0 | 18 |
| 1957 | 0.0 | 31 | 0.0 | 31 | 0.0 | 23 |
| 1958 | 22.6 | 31 | 22.6 | 31 | 23.1 | 26 |
| 1959 | 0.0 | 30 | 3.3 | 30 | 13.3 | 30 |
| 1950–59 | 24.0 | 275 | 27.6 | 272 | 34.2 | 199 |

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[2] Manuscript data for July 1957 and 1958 were provided by the Polar Meteorological Research Unit of the U. S. Weather Bureau.

## 6. Other aspects of the thermal regimes in the arctic stratosphere

Considerable evidence has been presented that two distinct thermal regimes prevail in the high arctic stratosphere. Table 8 was constructed by splitting the temperature observations into two parts according as the temperature was higher or lower than the antimodal value at that level. This table thus gives the relative frequency of warm regime days during the individual Januaries and during the 1950 to 1959 period as a whole. Resolute was chosen for this purpose because it had the largest number of observations at the highest levels. It is seen from table 8 that some Januaries had no warm regime days, others had no cold regime days, and some experienced both types of regimes. For the period as a whole, warm regimes prevailed about one fourth of the time at the 200-mb level but about one third of the time at the 50-mb level. Restriction of this study to a single midwinter month did not permit construction of frequency distributions of the duration of individual cold or warm spells. However, inspection of the daily temperature sequences indicated that the minimum duration of such regimes at particular stations is of the order of five to seven days.

TABLE 9. Comparison of January lapse rates ($\gamma$) for different temperature regimes.

| Station | Layer (mb) | Cold regimes | | Warm regimes | |
|---|---|---|---|---|---|
| | | 100 mb mode (°C) | $\gamma$ (°C/km) | 100 mb mode (°C) | $\gamma$ (°C/km) |
| Alert | 100/50 | −69 | 1.8 | −51 | 0.4 |
| | 200/100 | | 1.2 | | 0.3 |
| Eureka | 100/50 | −71 | 1.6 | −48 | 0.9 |
| | 200/100 | | 1.3 | | 0.4 |
| Resolute | 100/50 | −67 | 2.0 | −48 | 0.9 |
| | 200/100 | | 1.1 | | 0.3 |
| Coral Harbor | 100/50 | −65 | 1.2 | −49 | 1.2 |
| | 200/100 | | 0.8 | | 1.0 |

The characteristic lapse rate in these high layers varies according as a warm or a cold regime is present. In table 9, the temperature difference between the 200- and 100-mb levels and between the 100- and 50-mb levels were computed from the regression equations in table 2 by using the 100-mb modal temperatures associated with each type of thermal regime. It is evident that lapse rates are larger during cold periods than during warm ones, the magnitude tending to increase with both altitude and latitude.

## 7. Summary and conclusions

Up-to-date means, standard deviations and frequency distributions for the 200-, 100-, and 50-mb levels have been presented for four arctic stations; these temperature statistics are based on ten years of January observations. The means and frequency distributions were adjusted by adding temperature estimates obtained from regression relationships; this increased the sample size and removed a portion of the bias present in the original temperature observations. The frequency distributions proved to be distinctly bimodal, a characteristic which is more pronounced at the higher-latitude stations and at the higher levels. Warm-regime conditions appear to prevail about one fourth to one third of the time in the high arctic stratosphere. The lapse rate tends to be steeper during cold regimes than during warm ones. The antarctic stratosphere averages about 15C colder than the arctic in the layer from 200 mb to 50 mb; moreover, antarctic temperatures are not distributed in a bimodal fashion.

Previous mean soundings, charts, and cross sections have been based on small and unrepresentative temperature samples at these high levels in the arctic stratosphere. In substantiation of the cautionary statements made by Wexler and Moreland and by Godson and Lee, this study clearly shows the danger of attaching long-term significance to statistics derived from such data samples. It is particularly unfortunate in this connection that the frequency distributions are bimodal, for this type of distribution is difficult to handle even when the observations are adequate in number and are unbiased. The bimodal character of the temperature distributions actually results in the arithmetic average being very nearly a ***least-likelihood*** estimate of the temperature; in addition, the standard deviation becomes difficult to interpret properly. In such situations, it is probably better to characterize the distribution by specifying the modes and then computing two standard deviations, one with respect to each mode. This was done for the 50-mb temperatures at Alert, the distribution being split at the antimodal class. The deviations with respect to the warm and cold modes turned out to be 4.3C and 4.2C, respectively.

The excellent linear correlations which were found between temperatures at neighboring pressure levels suggests that regression relations of the type used in this study would be useful in daily chart analyses at these levels. A desirable extension of this investigation would be a similar analysis for yet higher levels in the stratosphere, for other winter months, and for other parts of the Arctic. Although some soundings in the polar regions have begun to reach the 25-mb level in recent winters, the samples are still too small for meaningful statistical treatment; thus, it appears that extension to higher levels must await the accumulation of considerably more data. A preliminary data survey of the Eurasian sector of the Arctic indicates much poorer altitude performance on the part of the radiosondes there compared with those in the North American sector. The number of soundings reaching beyond the 200-mb level is so small, particularly at the Russian stations, that there is some doubt whether even the 100-mb temperature observations are plentiful enough to justify analysis. On the other hand, there should be no particular difficulty in obtaining adequate data for any winter month at other North American stations, at least up to the 100-mb level.

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