Prevailing Wind in the Meteor Zone (80–100 km) over Atlanta and its Association with Midwinter Stratospheric Warming

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ABSTRACT

The wind data generated by an all sky, continuous wave radio meteor wind facility at Atlanta (34°N, 84°W) is analyzed over the period of August 1974 through July 1975. Zonal and meridional components of the prevailing wind over the height range of 80–100 km, at 2 km intervals represent 5–10 day averages where the tidal components have been removed. Large southerly wind during winter and weak northerly wind during summer at 80–100 km altitude is consistent with other observations and mesospheric circulation models.

Various phases of the 1974–75 midwinter stratospheric warming, including a pre-warming pulse during the second half of November 1974, are indicated to affect the prevailing wind in the meteor zone over Atlanta in a consistent manner, by making use of the latitudinal and vertical compensation of temperature and also the movement of pressure systems in the stratosphere and above.

1. Introduction

Based on very sparsely distributed data, in time and location, a general profile of the seasonal variations of the prevailing wind in the lower thermosphere (80–120 km) is becoming established. Minina *et al.* (1977) have analyzed the wind data from many years at heights of 80–100 km, primarily from meteor radar observations made at various Northern Hemisphere stations. During winter the cyclonic vortex centered near the pole dominates the circulation in the meteor zone at high and middle latitudes (up to at least 120 km; Groves, 1971); in summer, the anticyclonic circulation is characteristic of high latitudes (north of 65°N). The cyclonic circulation in the middle latitudes and the ring of subtropical highs exist year round. Thus, the winds in the meteor zone are shaped not only by the seasonal variations of the thermal balance at these heights, but also by the lower-lying layer of the mesosphere.

The present work investigates the imprint on the general circulation at lower thermospheric heights (80–110 km) of the very large perturbation of the high latitude winter stratosphere which occurs during a major warming event. During a warming the height of the stratopause, defined as the temperature maximum, can vary from 20 to 60 km altitude in high latitudes; the mesopause height however, seems to vary over a much narrower range, possibly from 70 to 90 km altitude. Labitzke (1972) has combined several soundings from different winters to give vertical temperature profiles for high and low latitudes for a "composite warming". Here opposite changes in temperature between stratosphere and upper mesosphere, and between high and low latitude are highlighted. The region of sign change lies between 50–55 km in this simplified scheme. Warming events are invariably associated with increased vertical flux of wave energy through the tropopause. Polar warming occurs as a result of poleward heat transport in an upward-propagating wave disturbance. The cooling in the upper mesosphere in high latitudes is explained by Matsuno's (1971) model as a result of induced upward motion due to the excess poleward heat transport in the stratosphere setting up a secondary meridional circulation.

There have been a few observations on the effect of various major stratospheric warmings on the wind pattern in the 80–100 km altitude range. For example, Hook (1972; at 65°N, 140°W) using meteor radar and Gregory and Manson (1975; at 52°N, 107°W) using partial reflection technique, observe that in association with the warming phase in the stratosphere, there was found a reversal of zonal and meridional wind in the mesopause region from westerly and southerly prevailing directions, respectively. Gregory and Manson (1975) deduce meridional

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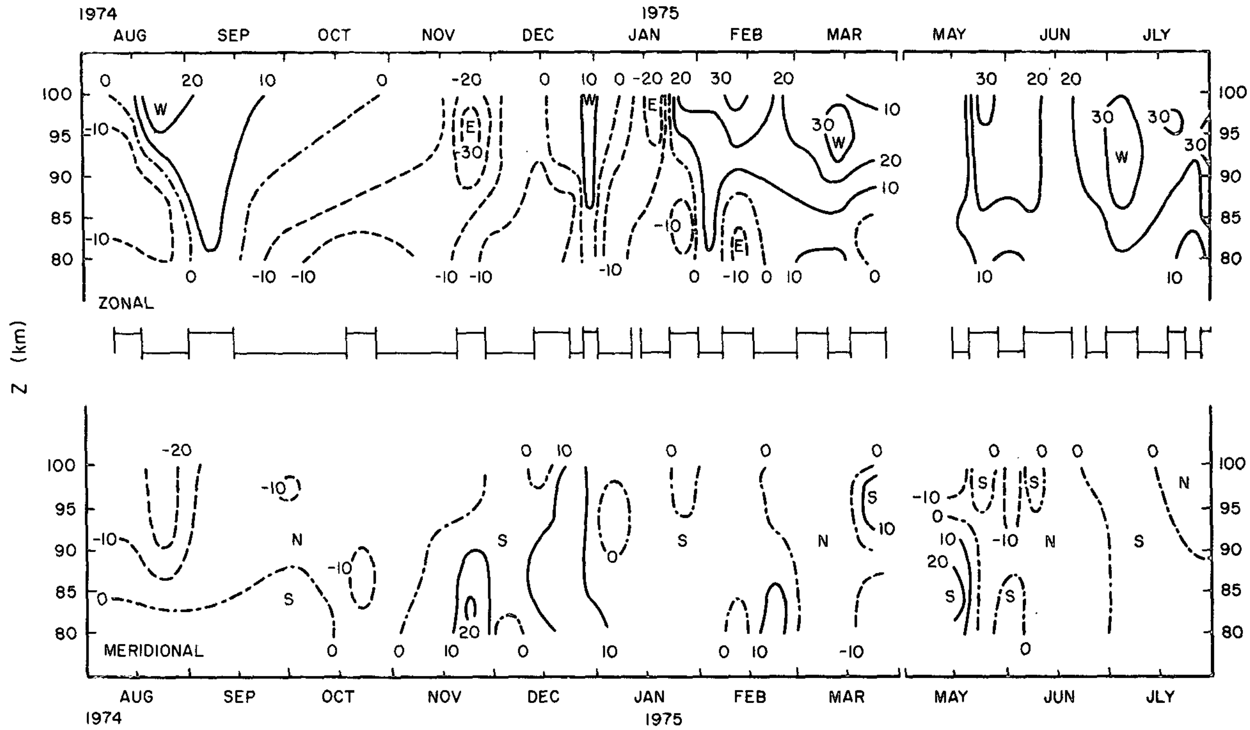

FIG. 1. Height-time variation of the prevailing wind components (m s^{-1}): August 1974–July 1975. Lines in the center indicate averaging period.

temperature gradients from their data and believe that the pattern of opposite temperature changes in the vertical as noted by Labitzke (1972) in relation to the stratospheric warmings in winter is consistent with their data. Recently, based on the satellite temperature measurements in the 40–90 km region by Nimbus 6 Pressure Modulator Radiometer (PMR), Austin *et al.* (1977) have traced a particularly large amplitude temperature wave on 7 February 1976 in the high-latitude mesopause region all the way from the lower stratosphere with an overall westward phase shift of 250°.

In the present study, the radio meteor technique has been used to obtain wind data in the height range of 80–100 km over Atlanta (34°N, 84°W). The prevailing wind regime over this height range is analyzed for the period of August 1974–July 1975. Particular emphasis is placed on the circulation changes observed at meteor heights over this low midlatitude station as related to the high-latitude midwinter stratospheric warming in 1974–75.

2. Wind observations using meteor radar

The Georgia Tech system (at Atlanta; 34°N, 84°W) has been in routine operation since July 1974. It has been designed as a continuous wave, all sky system with a capability of continuous operation 24 hours a day, seven days a week with an adequate usable echo rate (Roper, 1975). The data is processed by using a technique developed by Groves (1959) that finds a "best fit" model to represent data by generalizing the least squares solution. Third degree polynomials in height for zonal and meridional components, and a zero degree polynomial for the vertical component are found satisfactory for data that have at least 120 echoes per grouping. The fundamental period is taken as 24 h with 12 and 8 h components also computed. This choice is justified by the ample data on the presence of large tidal components (24 and 12 h) at meteor heights.

The prevailing wind then, is the meteor wind averaged over a period of 5 to 10 days from which tidal components have been removed. The 5-day averaging is carried out to eliminate the 5-day wave present in the meteor wind over Atlanta (Salby and Roper, 1980) along with the necessity to smooth out large day-to-day variability of the tidal components in the meteor wind data. Generally low echo rate at the Atlanta facility (100 usable meteor echoes per day are desirable for synoptic-scale analysis) dictates the period of averaging over 5 days.

Fig. 1 gives the height-time plot of the zonal and meridional components of the prevailing wind for the period of August 1974 through July 1975. There are no data available over the period of 28 March–

14 May 1975. In this figure, isotachs are plotted at 10 m s^{-1} intervals. The continuous lines represent westerly and southerly winds (taken positive) on the zonal and meridional plots, respectively. The variance of the wind data over the entire period is season dependent, with larger values during winter. The standard deviation is computed to be ~20% of the wind magnitude by the Groves (1959) technique employed here. In Fig. 1, the height range is 80–100 km, with the height resolution of 2 km.

3. Results and discussion

a. *Prevailing wind, August 1974 through July 1975*

1) Zonal component

The zonal circulation is characterized by mostly easterly wind during fall through mid-winter. Westerlies are present during late winter and through the summer months (Fig. 1). The slope of the zero isotach during August 1974 indicates a downward progression of the westerly regime. The westerlies reach the 80 km level during the first week of September and appear to weaken while descending. From mid-September, easterlies reestablish beginning from lower levels, so that by the last week of October, the easterly wind takes over the entire 80–100 km height range. The easterlies gradually intensify until a maximum is reached by the fourth week of November 1974 near 95 km; a peak value of greater than -30 m s^{-1} is recorded.

Toward the end of November, easterlies start to weaken until a reversal begins in the third week of December 1974. The slope of the zero isotach, again, suggests a downward progression from 100 to 80 km. The easterly wind reestablishes, starting at lower heights by the beginning of January 1975, and intensifies to a peak value of more than -20 m s^{-1} above 90 km during mid-January. Subsequent reversal to a westerly regime during the last week in January 1975 appears to have started from higher levels. Throughout February and March 1975, the zonal circulation is such that the westerly wind strengthens with increasing height, while below 85 km, a weak and variable wind regime persists.

2) The meridional component

Compared to the east-west component, the north-south wind is weak and variable in strength. The zero isotach located below 85 km divides the northerly wind, above, from the southerly wind, below, during August through mid-October 1974. During November, the zero isotach shows a progressive establishment of southerly wind over the entire 80–100 km height range, starting at 80 km. The southerly wind persists through the last week in February 1975, with a few reversals to northerly wind. During March 1975, the wind is northerly and around the last week of March, there is a strong reversal ($u > 10$ m s^{-1}) to southerly wind above 90 km.

3) The mean meridional temperature gradients

Vertical shear in the geostrophic wind implies the presence of a horizontal temperature gradient. The thermal wind, which is the vector difference between the geostrophic wind at two pressure levels, cannot strictly be applied in relation to the meteor wind between the 80–100 km altitude range. However, qualitative information about the mean meridional temperature gradients can be inferred from the height-time plot in Fig. 1. Thus, the zonal wind field shows that from mid-August 1974 through July 1975, the meridional temperature gradient is negative, implying cooler latitudes north of Atlanta, with two significant reversals. During the period of the second half of November 1974 and later on around mid-January 1975, warmer northern latitudes are indicated.

b. *The circulation changes in the meteor zone related to the stratospheric circulation system*

We now proceed to analyze the prevailing wind field in the meteor zone (Fig. 1) in relation to the pressure and temperature regimes in the upper stratosphere. In Fig. 2 are plotted temperature traces on Atlanta longitude (84°W) at 35 and 60°N, at 0.4 and 5 mb levels, the temperature values being read from the synoptic charts produced by the Upper Air Branch of the National Meteorological Center (Staff, 1977). The values are approximate and it is also necessary to keep in mind that the thermal systems in the atmosphere generally change in intensity and position with changes in altitude.

1) The effect of a strong warming pulse felt during November of 1974

The upper air synoptic charts (Staff, 1977) indicate that during the second half of November 1974, a warming pulse was strongly felt in the upper stratosphere. Polar latitudes at 0.4 mb (~55 km) are warmer by about 35°C on 20 November 1974 than on 6 November 1974. This can be seen from Fig. 3, where temperature traces at 70°N latitude are plotted for 6 and 20 November and 11 December 1974 from 0.4 mb maps. A warm cell has moved over the Asian land mass to a position near 90°E within the Arctic Circle during November 1974. Fig. 2 shows a warming of about 10°C during the third week of November 1974 at the 0.4 mb level for Atlanta's longitude. Also note the strong negative meridional temperature gradient (35 to 60°N) at the 5 mb level (~35 km).

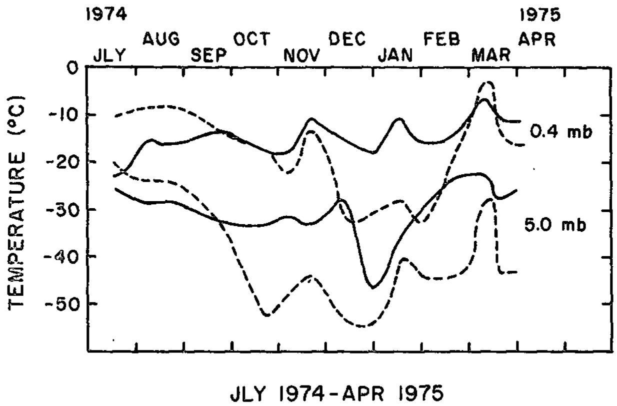

FIG. 2. Temperature traces on Atlanta longitude (84°W), at 35°N (solid line) and 60°N (dashed line), at 5 and 0.4 mb levels: July 1974–April 1975.

At meteor heights during the second half of November 1974 (Fig. 1), the easterlies strengthen above 90 km. The wind shear implies warmer northern latitudes. The meridional wind is from the north above 92 km. It is then probable that the warming pulse that was felt strongly near the stratopause, extended upward and westward (from 90°E location at ~55 km) into the mesopause region, severely weakening the stratospheric cyclonic circulation system that extends at least up to 100 km in stable winter conditions. Below 40 km altitude, there is some cooling in higher latitudes during the second half of November 1974 (Fig. 2) on Atlanta longitude, indicating opposite temperature changes in the vertical.

2) THE EFFECT OF THE MIDWINTER WARMING OF 1974–75

The reversal to westerly wind toward the end of December 1974 and return of easterlies in January 1975 leading to an intensification during the third week, are the principal zonal circulation features at 80–100 km over Atlanta (Fig. 1) that appear to be directly linked to the various phases of the 1974–75 midwinter warming of the stratosphere. This warming satisfied all but one criterion required to be classified as major; that is the mean westerly

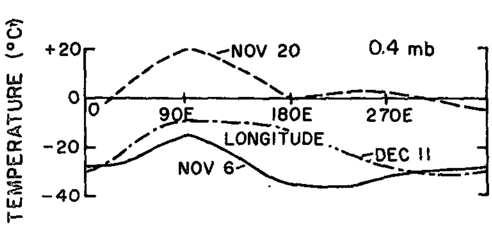

FIG. 3. Temperature traces at 70°N latitude on 0.4 mb (~55 km) pressure surface during November–December 1974.

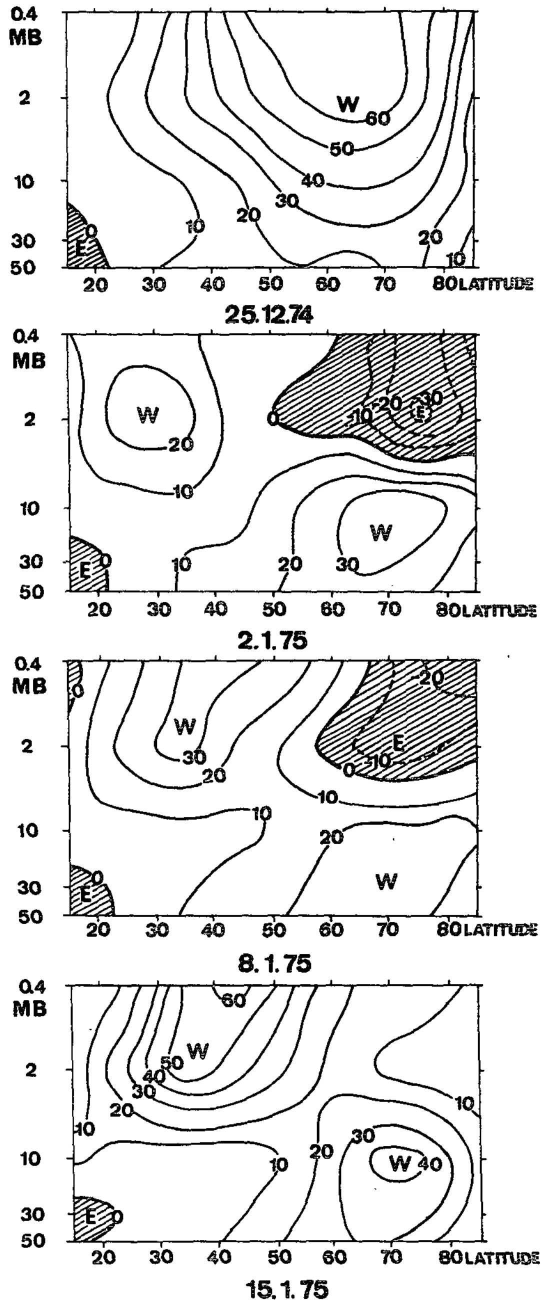

FIG. 4. Mean zonal wind associated with the midwinter warming of 1974–75 (after Klinker, 1977).

circulation poleward of 60°N did not reverse to easterly at 10 mb level. Figs. 4 and 5 (after Klinker, 1977) which plot mean zonal wind and temperature respectively, illustrate various phases of this warming at middle and upper stratospheric heights: on 2 January 1975 at 2 mb level we find easterlies north of 55°N and there is warming by about 40°C north of 70°N. On the 70°N latitude circle (Fig. 6), the crest of the warming is located over Siberian Arctic on 2 January 1975 in an apparent wavenumber

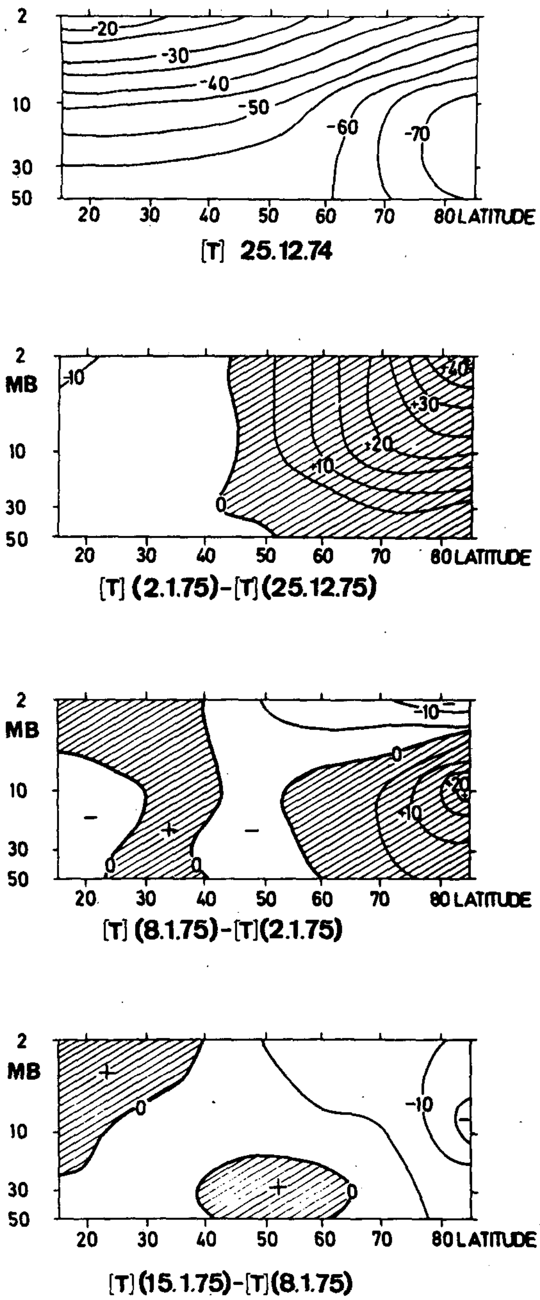

FIG. 5. Mean zonal temperature associated with the mid-winter warming of 1974–75 (after Klinker, 1977).

one pattern. The temperature traces for Atlanta longitude toward the end of December 1974 (Fig. 2) show cooling at 35°N in the upper stratosphere—also noticeable on the mean zonal temperature plot for 2 January 1975 at lower latitudes (Fig. 5). From Fig. 6 we also notice that the warm stratopause has descended to about 35 km in high latitudes during this period.

What are the implications of this amplification stage of the warming to the circulation in the meteor zone over Atlanta? At meteor heights we find westerlies strengthening with increasing altitude during this period (a reversal from easterly wind). The meridional wind is southerly and more intense during the second half of December 1974 (Fig. 1). The inferred thermal wind indicates that the northern latitudes are cooler. This situation, in principle, corresponds to a schematic profile of vertical temperature structure where in response to the warming in the stratosphere, a very cold mesopause near 80 km in higher latitudes is indicated by Labitzke (1972); and also a warmer mesopause in tropical latitudes. Direct observational evidence of cold mesopause in latitudes north of about 30°N coincident with a strong warming pulse felt in the upper stratosphere during early January 1976 has been given by Hirota and Barnett (1977), based on the Nimbus 6 PMR radiance data from the altitude of 40 to 90 km.

We have so far considered this warming primarily in the zonal mean state. Even though an important zonal mean temperature increase is associated with the warmings in the stratosphere and lower mesosphere, the presence of strong planetary thermal waves gives the warmings a local character. On 1 January 1975 the pressure system in the upper stratosphere is in predominantly zonal wavenumber one pattern (Staff, 1977; also the thermal regime, Fig. 6). For upward propagation of energy, the planetary waves tilt westward with increasing altitude and also with decreasing latitude. The low in high latitudes indeed moved westward from ~75°N, 0°W at 5 mb (~35 km) to ~65°N, 30°W at 0.4 mb (Staff, 1977). It is then possible that this low was over North America near the mesopause, more intense in view of the high latitude cooling indicated earlier. This would then explain the reversal to westerly wind (and the strong southerly component) in the meteor zone over Atlanta in association with the warming in high-latitude upper stratosphere. There is, however, no observational data available to confirm this.

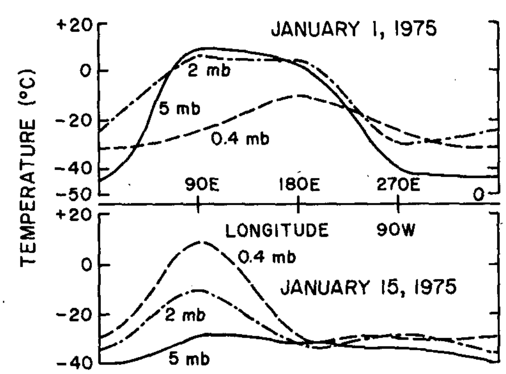

FIG. 6. Temperature traces at 70°N latitude in the upper stratosphere on 1 and 15 January 1975.

It is interesting to observe that the descent of westerlies from above 100 km during late December 1974 (Fig. 1) appears comparable to the descent of easterlies (or warming; Figs. 4 and 5) in the high latitude upper stratosphere, with the westerlies descending (implying gradual cooling) about a week earlier. It may well be that the lower thermospheric response to circulation changes in the stratosphere also reflects the phase lag observed in the radiance maxima from low to high latitude during a stratospheric warming (Fritz and Soules, (1972); observed for 1969–70 midwinter warming, weighting function in middle stratosphere).

Now taking up the late phase of the warming, the zonally averaged temperature values (Fig. 5) indicate that the warming in higher latitudes is considerably reduced by 15 January 1975 and the low latitude warming is evident in the upper stratosphere. On Atlanta's longitude, there is warming at 35 and 60°N all through the 5 to 0.4 mb (~35 to 55 km; Fig. 2) height range. Fig. 6 shows warming with increasing height at 70°N, with the warm cell near 90°E. And as Fig. 4 indicates, by 15 January 1975, mean zonal westerlies appear at all latitudes with a strong jet centered near 40–45°N at stratopause height.

If this situation, in principle, corresponds to the late stage of a major warming, we then expect that at mesopause altitude, as projected by Labitzke (1972), there will be a warm mesopause at higher latitudes—favorable to anticyclonic circulation at those heights. The observed changes in the zonal wind at meteor heights over Atlantic around mid-January (Fig. 1) appear to support the preceding remarks. The easterlies reappear in January 1975, ascending from below, and intensify during the third week above 90 km (>20 m s^{-1}). The inferred thermal wind implies warmer northern latitudes. The southerly component has weakened in strength through January 1975.

The establishment of westerly wind toward the end of January 1975 (Fig. 1) from higher heights (i.e., from above 100 km) is the return of the normal circulation at meteor heights after the complete dissipation of the warming. The cyclonic circulation in the upper stratosphere is well established [notice the strong negative temperature gradient on Atlanta's longitude, Fig. 2; Staff (1977)] and governs the circulation in the meteor zone.

3) The summer of 1975

The stratospheric circulation during summer is governed by the relatively stable circumpolar anticyclone with easterly wind over much of the Northern Hemisphere. At meteor heights over Atlanta however, the zonal winds follow the thermal balance. Westerlies are present at 80–100 km (June through early August) with weaker winds at lower heights. Positive thermal wind implies a colder higher latitude mesopause.

4. Concluding remarks

In the present study, synoptic scale variations in the prevailing wind over Atlanta (34°N, 84°W) at 80–100 km are interpreted in the context of the stratospheric circulation system. It has been shown that strong warming pulses felt in the winter stratosphere can influence the wind regime in the meteor zone. Various phases of the midwinter warming felt strongly in the high-latitude upper stratosphere during 1974–75 are indicated to affect the prevailing wind in the meteor zone over Atlanta in a consistent manner, by primarily making use of the latitudinal and vertical temperature compensation criteria and also the movement of pressure systems in the stratosphere and above.

The wind shear in the meteor zone points to colder mesopause at latitudes north of Atlanta during summer. This observation, and the presence of weak northerly wind in summer and strong southerly wind in winter are consistent with other observations and mesospheric models (e.g., Leovy, 1964). Satellite observations indicate that the high latitude mesopause in winter is warm. The meteor wind shear data from Atlanta implies reversals to equatorward temperature gradients, at least for mid-latitudes, in association with warming events in the stratosphere. This interaction will depend on the dynamics of the particular warming event, and specifically on the extent of upward penetration of the planetary waves from the stratosphere and below.

Finally, even though the Atlanta meteor wind data is representative of a very large region (considering the altitude range (80–100 km) and the synoptic scale presentation), the conclusions reached by this study are tentative and obviously a far wider data base is required, particularly at mesopause heights, for a more complete analysis.

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