Seasonal Transitions in the Thermal Structure of the Mesosphere at High Latitudes

J. S. Theon and W. S. Smith

Goddard Space Flight Center, Greenbelt, Md.

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ABSTRACT

Twelve acoustic grenade experiments were conducted during the period September 1968–February 1969 from Barrow, Alaska (71N). These measurements were intended to monitor the transition in the thermal structure of the mesosphere from the persistent summertime case to the dynamic and highly variable wintertime case. The disturbed features typical of winter appeared in the high mesosphere in September, and at successively lower altitudes until December, at which time the full winter structure had been established. In early January, a warming at the stratopause began a chain of events which eventually would restore the summertime structure and thus complete the cycle.

1. Introduction

The Meteorological Sounding Rocket Program of the Goddard Space Flight Center has performed rocket-borne measurements of the mesosphere since 1960. These observations have provided a general climatology of the circulation and temperature structure of the mesosphere at sites ranging from the tropics to the arctic (Nordberg et al., 1965; COESA, 1966). In the past, a large fraction of the soundings conducted at high-latitude sites were made during either the summer or winter regimes. Consequently, the nature of the transition between the extremes of season had not been observed in detail. Barrow, Alaska (71N), was the logical location from which to conduct a series of soundings to observe this transition because, of all the sites where mesospheric soundings have been obtained, the seasonal differences between summer and winter are most pronounced there. Not only was the summer-to-winter changeover observed, but also the initial stages of the reverse process, namely, the winter-to-summer transition.

2. The experiment

Twelve acoustic grenade soundings (see Nordberg and Smith, 1964) were conducted from Barrow during the period 17 September 1968 to 4 February 1969. Initially, plans called for one pair of soundings separated by 2 hr once each month. The purpose of conducting pairs of soundings only 2 hr apart was to obtain information concerning the short-term temperature variability in the mesosphere. It was recognized that such limited information would not permit the complete resolution of seasonal and short-term effects, but the data were useful as an indication of the presence of significant short-term temperature changes. As can be seen from the list of soundings in Table 1, operational considerations did not permit the original schedule to be maintained.

3. Results and discussion

The differences in seasonal averages of the mesospheric temperature structure at Barrow are illustrated by Fig. 1. The solid curve gives the average of 10 summer profiles, and the broken curve, the average of 12 winter profiles observed at Barrow during the years 1965–67 (Smith et al., 1967, 1968, 1969). The cross-hatched area surrounding each average profile repre-

![Seasonal average temperature profiles above Barrow, Alaska (71N). The solid curve is the average of 10 summer soundings, and the broken curve the average of 12 winter soundings conducted during 1965–67. The cross-hatched areas surrounding each curve represent the total range of temperatures included in the average.](image-url)
Table 1. Date and time of the acoustic grenade soundings conducted at Barrow for this study.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time (GMT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 September 1968</td>
<td>2003</td>
</tr>
<tr>
<td>14 October 1968</td>
<td>0100</td>
</tr>
<tr>
<td>14 October 1968</td>
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<td>19 January 1969</td>
<td>0200</td>
</tr>
<tr>
<td>26 January 1969</td>
<td>0500</td>
</tr>
<tr>
<td>31 January 1969</td>
<td>0700</td>
</tr>
<tr>
<td>4 February 1969</td>
<td>2230</td>
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</table>

The total range of temperatures included in the average. The average temperature of the summer stratopause was 280K, while the average temperature of the winter stratopause was only 240K. The average temperature of the summer mesopause, 142K, is approximately 80K colder than the average temperature of the winter mesopause. The resulting average mesospheric lapse rates were 3.2K km⁻¹ for summer and 0.8K km⁻¹ for winter. Although the average profile for the summer mesosphere is quite representative of the 10 individual profiles from which it was derived, the average winter profile does not resemble the 12 individual profiles from which it was derived because of what appear to be superimposed wave-like features in them. The variability of temperature with time is quite small in summer, amounting to about ±5K at any given altitude in the mesosphere over the course of the entire summer. In the winter, however, temperature changes of 30–40K hr⁻¹ are common at 80 km (Theon, 1968). In none of the 10 summer soundings (late June to early August) included in Fig. 1 was there evidence of the wave-like structure in the mesosphere. Therefore, the presence of the wave-like features in the temperature profiles of this 1968–69 series was assumed to be an indication that the summer regime had been replaced by the winter regime.

In order to make identification of the wave-like features in the temperature profiles as objective as possible, the authors chose to use a lapse rate sign reversal (other than the expected ones at the stratopause and mesopause) as evidence of a wave-like disturbance. As can be seen in the individual temperature profiles given in Fig. 2, these features appeared first in the high mesosphere in September, and at successively lower altitudes throughout the remainder of the transition period. The lowest altitudes in the mesosphere (and upper stratosphere) where the lapse rate reversals occurred are given by the curve as a function of date.
Fig. 3. The altitude of the boundary separating the disturbed region (above curve) from the undisturbed region as a function of date. The curve is the boundary chosen by the authors, while the symbols are points chosen by independent observers. One observer chose several points (triangles), while other observers chose some points below the level of the grenade data.

during the September–February period in Fig. 3. This boundary for the first eight soundings forms a gradually descending envelope. The rate of descent is approximately 15 km month$^{-1}$ initially, but 9 km month$^{-1}$ when averaged over the entire period shown. At the suggestion of R. S. Quiroz, three of his colleagues also identified the lower boundary of the disturbed region as shown by the symbols in Fig. 3. Several of the points

Fig. 4. Time cross section of the temperature structure between 35 and 95 km over Barrow during the transition period. The upper dotted line is the mesopause and the lower dotted line, the stratopause. Isotherms are in °K.
were at altitudes <40 km and were omitted since the
grenade data available did not extend below 33 km.
Note that all three independent observers also found a
descending disturbed region.

A minor stratospheric warming altered the descending
pattern by 19 January. The warming, which appeared
to begin in early January at approximately 60 km,
reached the 50-km level by mid-January, where it
either masked or prevented the formation of the wave-
like structure. Note is also taken of the 20K increase
in temperature during December at 80 km, but the relation-
ship between this gradual warming and the one
mentioned in the foregoing, if any, is not clear. Thus,
the warmings marked the beginning of the process by
which the winter regime breaks down and is eventually
replaced by the stable structure of summer (see Theon
et al., 1967).

The warming is clearly evident in Fig. 4, a time
cross section of the temperature structure over Barrow.
Where pairs of profiles were observed on a single day,
they were averaged and some minor smoothing was
performed so that only well-defined and persistent
features were retained. Note that the simple and well-
ordered summer thermal structure present in Septem-
ber, which is characterized by large vertical temperature
gradients (warm stratosopause, cold mesopause) and
small temperature changes with time (also see Fig. 1)
at a given altitude, is gradually replaced by the typical
winter thermal structure. The winter structure is, in
turn, altered by several warmings at the end of the
observed period. Between mid-September and early
December, the stratosopause had cooled by about 20K
and the mesopause had warmed by 30–40K. Rapid
changes in this region began to occur in late December,
and by 11 January, the warming centered at 60 km
had spread both upward to 70 and downward to 50 km.
Cooling had set in at 75 km by late January, and a
second warm center occurred near 43 km. It cannot
be ascertained from the data available whether the
several warm centers were independent events or
merely a lower extension of the first warming. The late
January warming, though not in the explosive category,
did account for a temperature increase of almost 70K
at 43 km during a 15-day period. The warm mesopause
observed in late October, followed by the cooling in
November, follows a pattern interpreted as a possible

Examination of the wind profiles which resulted from
the 12 soundings indicates that in the region described
as disturbed in Fig. 3, there was considerably more
wind variability both in the vertical and time coordi-
nates. In the undisturbed region, the winds were more
uniformly westerly. In other words, the wave-like
features in the temperature profiles were accompanied
by large wind shears.

4. Conclusions

The transition from the persistent temperature struc-
ture characteristic of the summer mesosphere to the
disturbed and highly variable temperature profiles
typical of the winter mesosphere at Barrow was ob-
served during the period September 1968 to February
1969. The breakdown of the summertime structure
was observed first at 75 km in September. This dis-

turbed region propagated downward with time at the
rate of approximately 9 km month⁻¹ until early January,
although the thermal state of the mesosphere could be
categorized as typical of winter by late November.
A warming trend, observed at the stratospause in early
January, marked the beginning of the breakdown of the
wintertime regime, thus initiating the final portion of
the seasonal cycle.

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