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SEASONAL TRANSITIONS IN THE THERMAL STRUCTURE OF THE MESOSPHERE AT HIGH LATITUDES

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GSFC — GODDARD SPACE FLIGHT CENTER
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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.

CONTENTS

ILLUSTRATIONS

TABLE

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 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 September 17, 1968 to February 4, 1969. Initially, plans called for one pair of soundings separated by two hours once each month. The purpose of conducting pairs of soundings only two hours 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 Figure 1. The solid curve gives the average of ten summer profiles, and the broken curve, the average of twelve winter profiles observed at Barrow during the years 1965-67 (Smith, et al., 1967, 1968, 1969). The cross hatched area surrounding each average profile represents the total range of temperatures included in the average. The average temperature of the summer stratopause was 280 K, while the average temperature of the winter stratopause was only 240 K. The average temperature of the summer mesopause, 142 K, is approximately 80 K colder than the average temperature of the winter mesopause. The resulting average mesospheric lapse rates were -3.2 K km^{-1} for summer and 0.5 K km^{-1} for winter. Although the average profile for the summer mesosphere is quite representative of the ten individual profiles from which it was derived, the average winter profile does not resemble the twelve 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 ±5 K at any given altitude in the mesosphere over the course of the entire summer. In the winter, however, temperature changes of 30-40 K hr^{-1} are common at 80 km (Theon, 1968). In none of the ten summer soundings (late June to early August) included in Figure 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, a lapse rate sign reversal (other than the expected ones at the stratopause and mesopause) was considered to be evidence of a wave-like disturbance. As can be seen in the individual temperature profiles given in Figure 2, these features appeared first in the high mesosphere in September, and at successively lower altitudes throughout the remainder of the transition period. The altitudes where the lapse rate reversals occurred were plotted as a function of date during the September-February period, as shown in Figure 3. Note that when the lowest altitudes where the waves were observed for the first eight soundings are connected, a gradually descending envelope results. The rate of descent is approximately 15 km month^{-1} initially, but 9 km month^{-1} when averaged over the entire period shown. A minor stratospheric warming altered this pattern by the 19th of January. The warming, which began 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. This phenomenon 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 Figure 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 September which is characterized by large vertical temperature gradients (warm stratopause, cold mesopause) and small temperature changes with time (also see Figure 1) at a given altitude, is gradually replaced by the typical winter thermal structure. The winter structure is, in turn, altered by the warmings at the end of the observed period. By early December, the stratopause had cooled by about 20 K and the mesopause had warmed by 30-40 K. Rapid changes in this region began to occur in late December, and by the 11th of January, the warming had spread both upward to 70 km 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 second warm center was an independent event or merely a lower extension of the first warming. This second warming, though not in the explosive category, did account for a temperature increase of almost 70 K at 43 km during a 15 day period.

Examination of the wind profiles which resulted from the twelve soundings indicates that in the region described as disturbed in Figure 3, there was considerably more wind variability both in the vertical and time coordinates. 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. Although an easterly circulation is typical of summer, the intensities of these winds were so low as to be transitional rather than wintertime in nature.

4. Conclusions

The transition from the persistent temperature structure characteristic of the summer mesosphere to the disturbed and highly variable temperature profiles typical of the winter mesosphere at Barrow, Alaska, was observed during the period September 1968 to February 1969. The breakdown of the summertime structure was observed first at 75 km in September. This disturbed 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, which began at the stratopause 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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Table 1

Date and time of the acoustic grenade soundings

conducted at Barrow for this study

Date	Time (GMT)
17 September 1968	2003
14 October 1968	0100
14 October 1968	0300
22 November 1968	0031
22 November 1968	0755
13 December 1968	0459
13 December 1968	0659
11 January 1969	1015
19 January 1969	0200
26 January 1969	0500
31 January 1969	0700
4 February 1969	2230

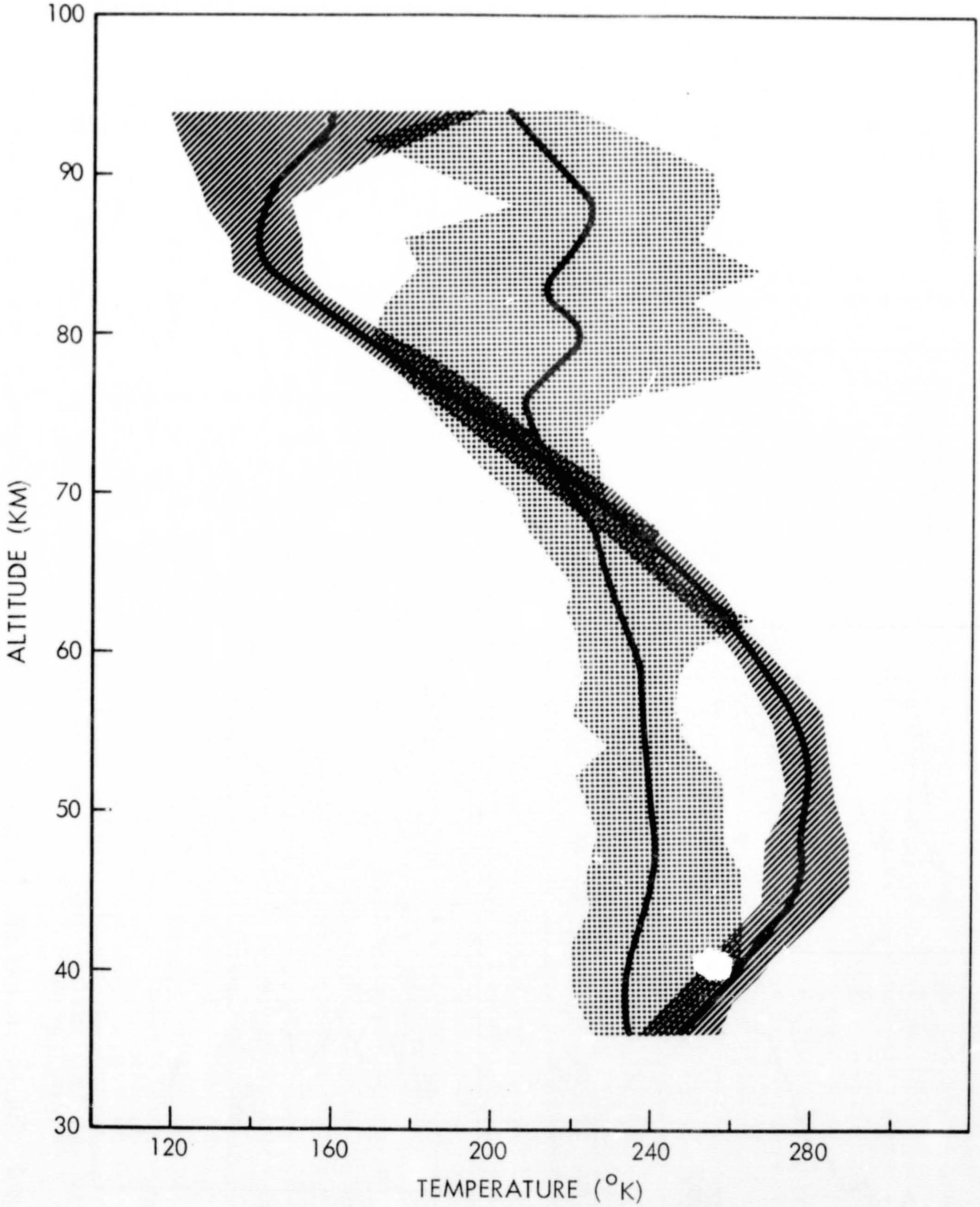

Figure 1. Seasonal average temperature profiles above Barrow, Alaska (71N). The solid curve is the average of ten summer soundings, and the broken curve the average of twelve winter soundings conducted during 1965-67. The cross hatched areas surrounding each curve represent the total range of temperatures included in the average.

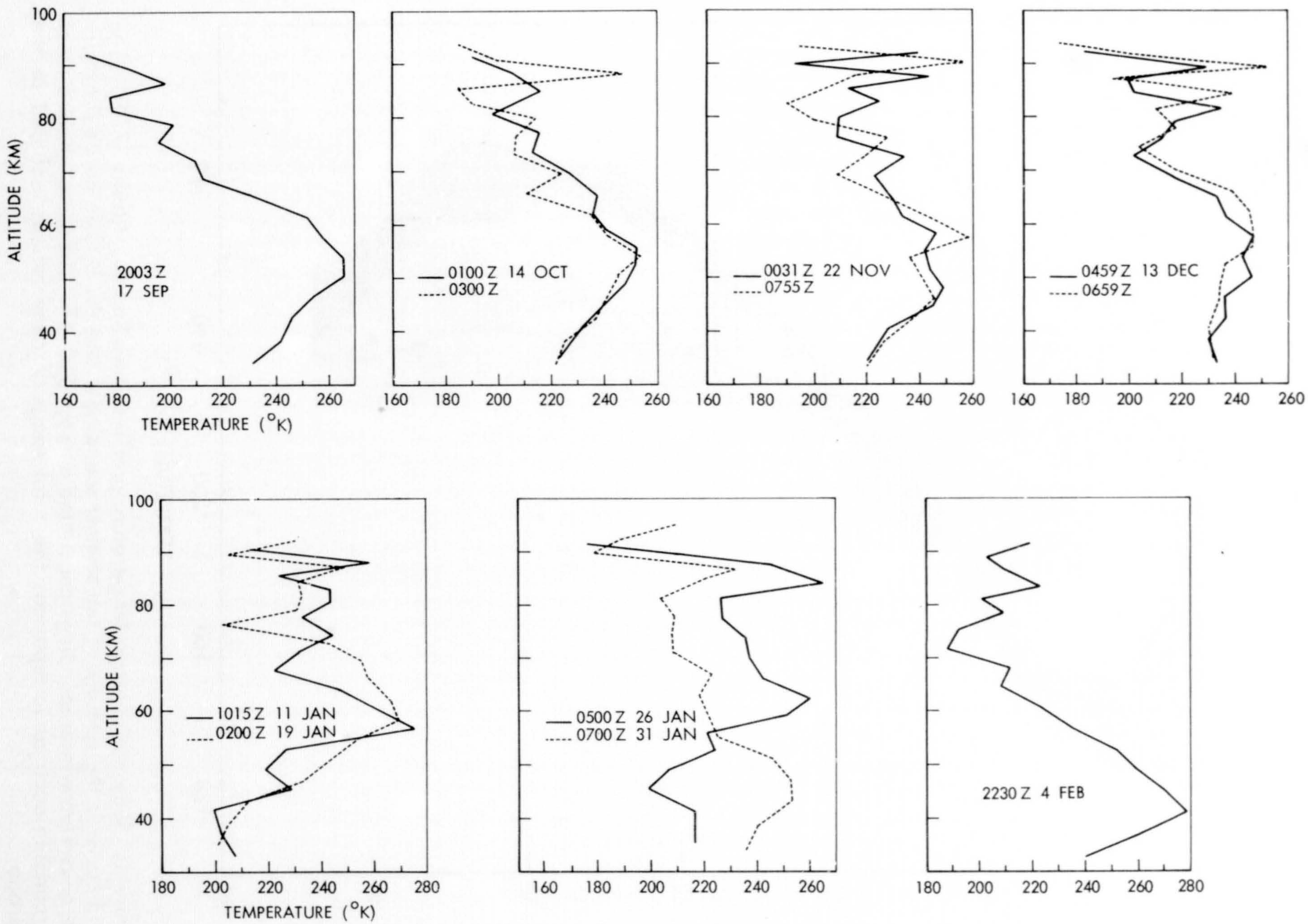

Figure 2. The twelve individual temperature profiles obtained from Barrow for the transition study.

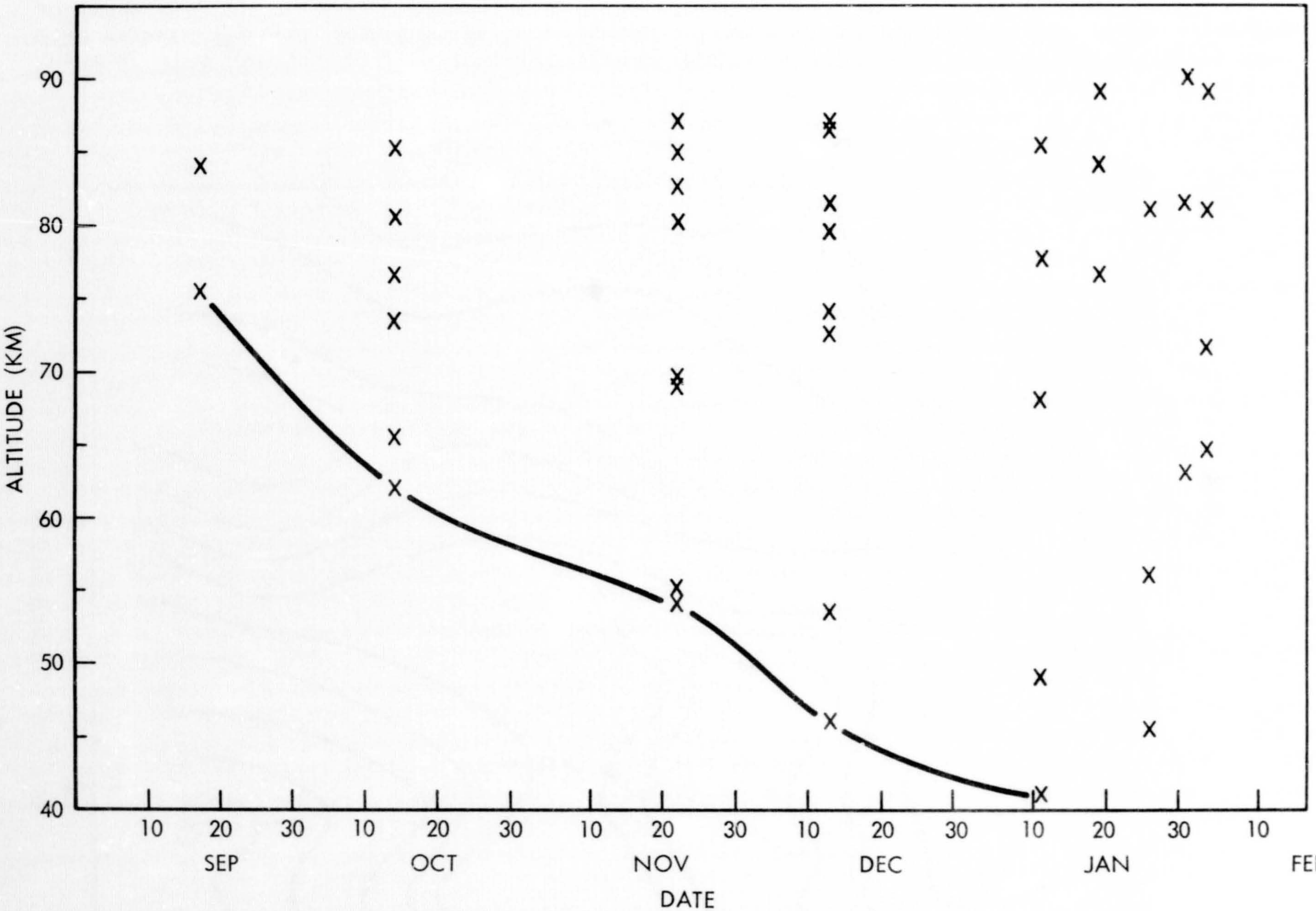

Figure 3. The altitude of each lapse rate sign reversal (except the normal stratopause and mesopause reversals) during the transition period.

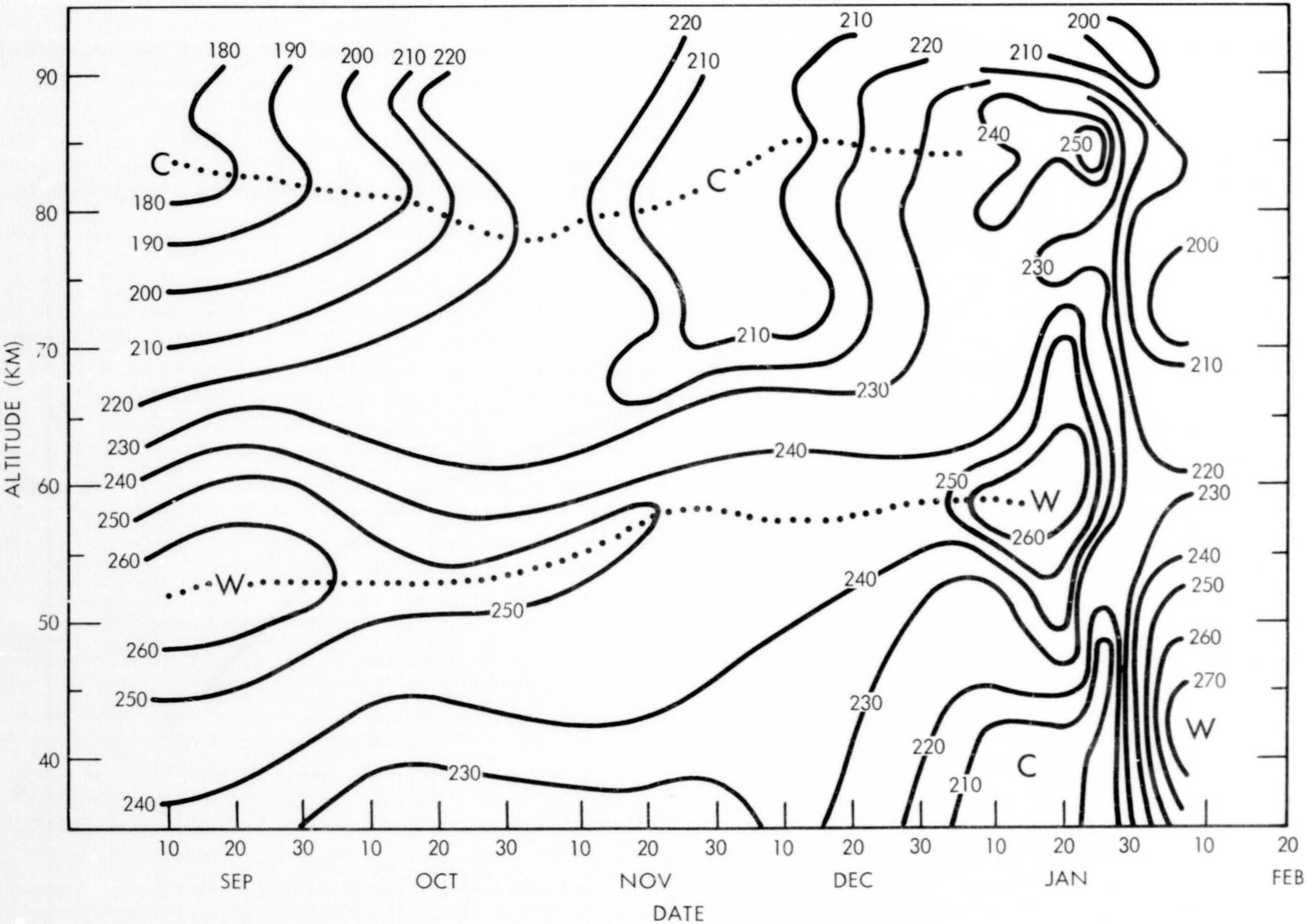

Figure 4. Time cross-section of the temperature structure between 35 and 95 km over Barrow during the transition period. The upper dotted line is the mesopause and the lower dotted line, the stratopause. Isotherms are in °K.