Diurnal Temperature Change in the Atmosphere between 30 and 60 km Over White Sands Missile Range

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ABSTRACT

Diurnal temperature variations between 30 and 60 km have been determined in a series of eleven meteorological rocket soundings from 0400 MST 7 February 1964 through 0205 MST 8 February 1964 over White Sands Missile Range, New Mexico. The soundings were spaced at 2-hour intervals and temperatures were measured with thermistor type instrumentation suspended on a parachute. Minimum temperatures were recorded near 0400 to 0600 MST and maximum temperatures occurred about 1400 MST. The temperature range decreased from near 20C at 55 km to 15C at 45 km and to near 5C at 35 km. Significant non-diurnal heating was also present. Additional sets of temperature soundings made at 1400 and 1600 MST on 21 November 1964 and 0400 and 0600 MST on the 22nd over White Sands Missile Range were available for comparison. These soundings indicated a day to night variation of 15C from 63 km down to 55 km with marked dampening of variation thereafter. The November soundings may not represent the entire diurnal range since the soundings might have included large scale non-diurnal heating which was impossible to isolate.

1. Introduction

In February 1964 a series of wind and temperature soundings was conducted at White Sands Missile Range, New Mexico, in a program designed to study tidal motions between 30 km and 60 km. The series involved firing a meteorological sounding rocket every two hours for 24 hours with additional single soundings made 12 and 24 hours after the series. Wind profiles were recovered from all firings and temperature data resulted from 13 of the rocket probes. Only the temperature soundings will be considered here, the times of which are: 0400, 0600, 1000, 1200, 1405, 1600, 1800, 2000 and 2222 hours MST 7 February; 0013, 0205 and 1600 hours MST 8 February; and 0400 hours MST 9 February. Sunrise occurred at 0655 and 0654 MST on the 7th and 8th, respectively, and sunset was at 1746 MST on the 7th.

Again on 21 and 22 November 1964 a similar series of firings was conducted at White Sands Missile Range. However, although rocket wind soundings were made every two hours for 24 hours, only four temperature soundings were included and are incorporated here. The times of the temperature soundings are: 1400 and 1600 MST 21 November and 0400 and 0600 MST 22 November. Sunrise occurred at 0642 MST on the 22nd and sunset was at 1703 on the 21st.

The temperature measuring flight package was developed by the U. S. Army Electronics Research and Development Activity, White Sands Missile Range, and is designated the WSMR "Delta Model." While the "Delta" incorporates certain improvements, it is basically similar to earlier White Sands Missile Range models used in the Meteorological Rocket Network (Webb *et al.*, 1962). A rather extensive treatment of factors involved in measuring temperatures with this type thermistor instrument has been given by Wagner (1964) who also determined correction factors for the operational range of the system.

2. Discussion

Fig. 1 is a time cross section prepared from the thirteen February soundings after standard corrections, as determined by Wagner, have been applied. Data points from which this figure was constructed (as listed in Table 1) represent the temperatures averaged graphically over 2-km layers. The averaging interval was chosen such that minor fluctuations are smoothed sufficiently to allow a simplified examination of the mean conditions along the profile. Soundings are indicated in Fig. 1 by heavy vertical lines. Prominent features include a large diurnal variation in the stratopause region, an occurrence of maximum temperature near 1400 MST and minimum temperature near 0400–0600 MST, and a rapid dampening of the diurnal effect with decreasing altitude. Also the sounding at 1600 MST 8 February fits very well into the general pattern displayed on 7 February. However, the sounding of 0400 MST 9 February indicates that significant warming has occurred between 50 and 55 km.

Fig. 2 is a presentation of the temperature variation with time at 5-km intervals from 30 km to 55 km. Both the 50-km and 55-km levels exhibit a striking diurnal tendency and the dampening effect is apparent as one proceeds downward. The diurnal pattern is greatly distorted at the 45-km level by the rapid and intense warming which occurred between 2000 and 2222 MST. This warming extends downward to at least 30 km and obscures the actual diurnal range. However, it appears that the diurnal range is less than 5C at 30 km.

In Fig. 3 the data are plotted to show the maximum change (range) over the 24-hour period at the same 5-km levels of the previous figure. It should be recognized that this figure presents the local change and not purely the diurnal range. Thus, while the maximum temperature changes at 50 km and 55 km appear to represent the diurnal regime, the values at 30 km and 35 km are determined by some other mechanism. This is easily seen from Fig. 2.

Unfortunately, a similar treatment cannot be applied

TABLE 1. Rocketsonde temperature values (deg Centigrade) for 7, 8 and 9 February 1964.

Alt					7 Feb						8 Feb		9 Feb
(km)	0400	0600	1000	1200	1405	1600	1800	2000	2222	0013	0205	0400	1600
21	−58	−57	−58	−60	−57	−57	−58	−58	−57	−57	−55	−56	−58
23	−57	−57	−55	−58	−54	−55	−56	−55	−53	−56	−54	−54	−55
25	−55	−45	−51	−54	−52	−52	−54	−54	−51	−54	−49	−51	−52
27	−51	−48	−50	−51	−49	−50	−49	−51	−50	−49	−47	−47	−5i
29	−48	−45	−48	−49	−47	−47	−47	−47	−43	−47	−44	−43	−48
31	−41	−42	−41	−43	−40	−41	−47	−43	−41	−42	−38	−41	−43
33	−39	−35	−34	−36	−34	−38	−42	−38	−36	−38	−33	−40	−41
35	−34	−31	−30	−32	−34	−34	−38	−35	−29	−30	−30	−37	−38
37	−33	−29	−28	−26	−28	−29	−34	−33	−28	−29	−28	−32	−38
39	−33	−24	−27	−24	−24	−26	−31	−31	−28	−28	−27	−29	−34
41	−32	−21	−24	−20	−20	−23	−24	−25	−21	−25	−23	−25	−30
43	−28		−20	−20	−19	−19	−24	−22	−10	−22	−20	−20	−28
45	−19		−7	−14	−7	−11	−14	−12	−4	−10	−11	−8	−27
47	−16		−5	−9	+1	−5	−7	−9	−8	−13	−13	−5	−22
49	−18		−4	−6	+1	−5	−9	−13	−12	−17	−14	−5	−16
51	−21		−3	−6	+1	−5	−11	−14	−11	−12	−14	−4	−13
53	−20		−2	−4	+1	−5	−11	−11		−5	−13	−7	−9
55	−21		−1	−5	+1	−4	−11	−9		−9	−15	−1	−10
57	−24		0	−4				−12			−11		−18
59			+2	−6							−9		−22
61				−8									
63				−11									

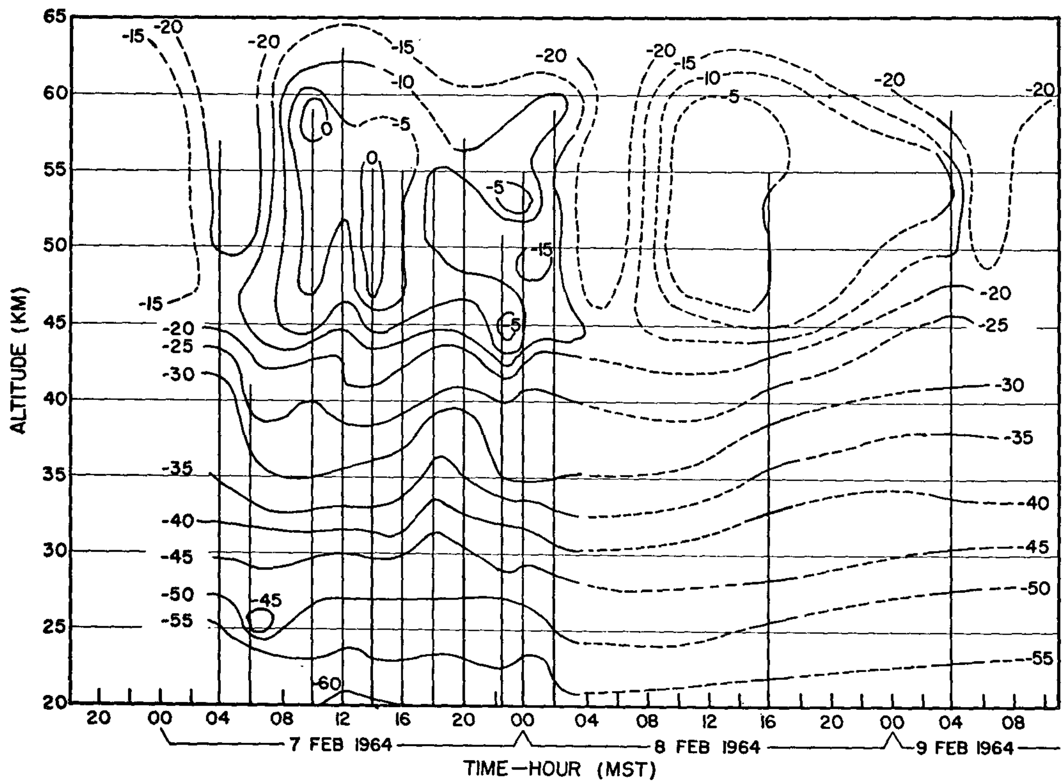

FIG. 1. Time-height cross section of temperature (deg C) for White Sands Missile Range.

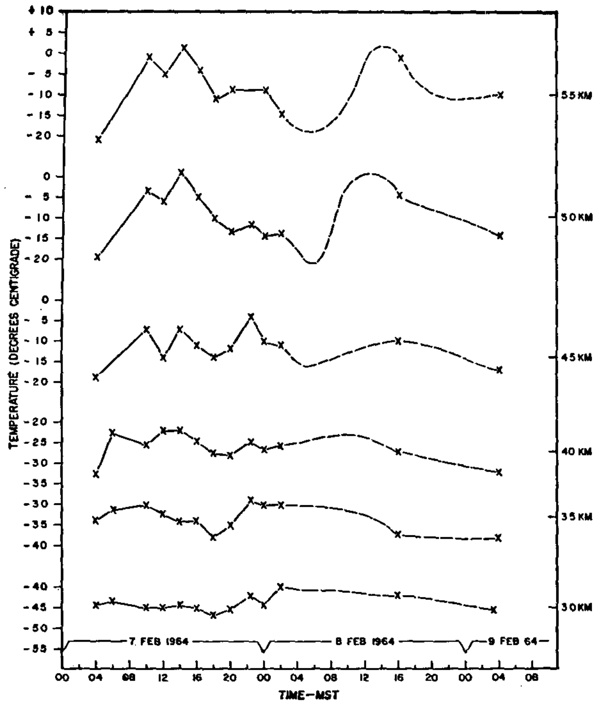

FIG. 2. Temperature variation with time at 30, 35, 40, 45, 50 and 55 km over White Sands Missile Range.

to the soundings of 21 and 22 November because of the limited number of soundings. Consequently, the 1400 and 1600 MST soundings of 21 November were averaged, as were the 0400 and 0600 MST soundings of the 22nd. These averages are plotted in Fig. 4 and marked "Day (Avg)" and "Night (Avg)", respectively. A further comparison of the two resulting profiles is made in Fig. 5(A). The temperature differences between daytime and nighttime might serve as a measure of the diurnal variation. In contrast to the February findings, there appears to be no diurnal variation at 50 km. For this November day and night, the diurnal variation appears mostly from 55 km up to the top of the data (63 km). As seen from Fig. 5, the temperature change amounts to between 11C and 15C between these levels and decreases to zero at just over 50 km. Below 50 km there is no consistent pattern. For comparison with the February findings, a similar data plot is presented in Fig. 5(B). In Fig. 5(B) the 0400 and 0600 MST soundings of 7 February were used for the night average and 1400 and 1600 MST 7 February for the day average. Since the 0600 MST sounding terminated at 41 km, it was necessary to use 0400 MST data only for the night average temperature from 41 km to 55 km. From comparison of Figs. 5(A) and 5(B), it appears that the diurnal variation extended much lower into the stratosphere for the February day than for the November case. This conclusion may not be justifiable, however, since there might have been other major forces at work

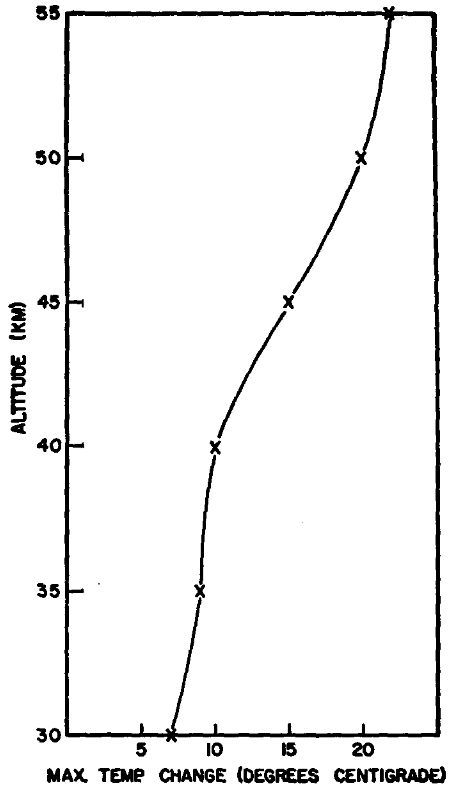

FIG. 3. Maximum 24-hour temperature change during the period 0400 MST 7 February through 0400 MST 8 February 1964 at 30, 35, 40, 45, 50 and 55 km over White Sands Missile Range.

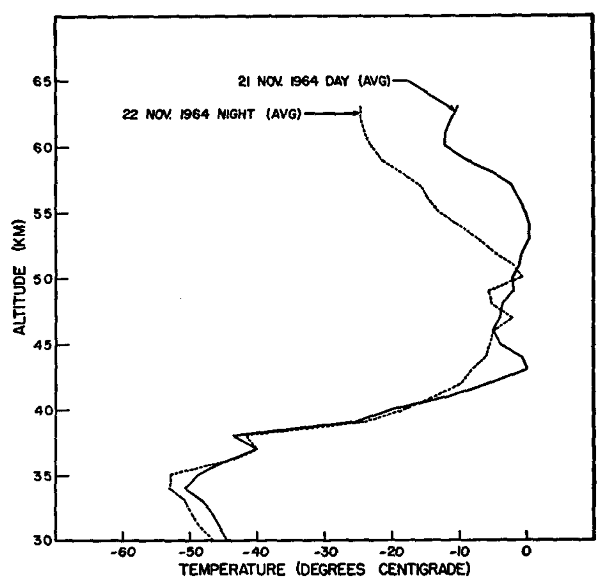

FIG. 4. Average temperature profiles over White Sands Missile Range computed from 1400 and 1600 MST 21 November 1964 (day) soundings and 0400 and 0600 MST 22 November 1964 (night) soundings.

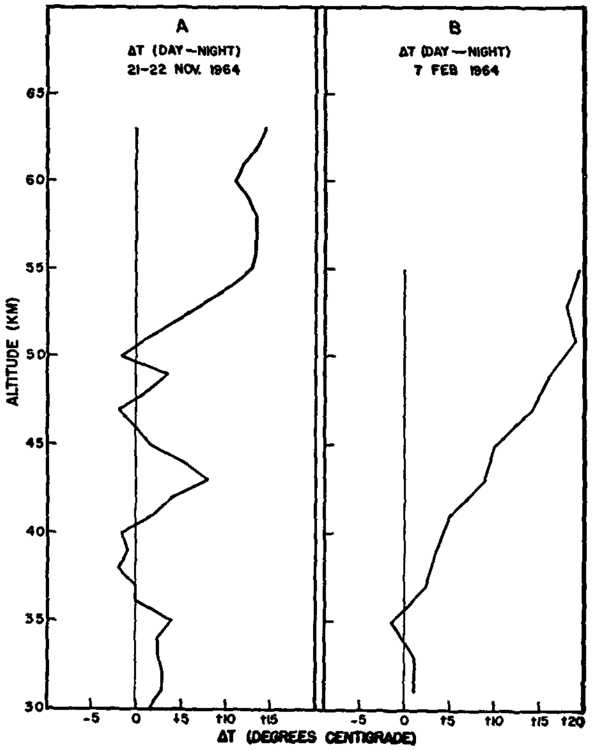

Fig. 5 (A). Temperature difference (average day minus average night) over White Sands Missile Range for 21–22 November 1964. (B). Temperature difference (average day minus average night) over White Sands Missile Range for 7 February 1964.

which obscured the actual diurnal variation of the November case particularly between 40 km and 55 km. That is, perhaps a non-diurnal warming (such as was pointed out in the 2000 and 2222 MST soundings of 7 February) has eliminated the diurnal temperature range. Without additional soundings, one can only speculate as to how representative the data of Fig. 5(A) really are, particularly below 55 km.

In any event, if the diurnal change measured on either of these two days is representative at any altitude level, then a large discrepancy exists between actual and theoretical diurnal temperatures. Although some of the earlier investigators such as Gowan (1947) and Karandikar (1946) calculated diurnal ranges of 30–35C, there has been general agreement among more recent investigators such as Johnson (1953), Pressman (1955) and Leovy (1964) that the maximum diurnal range near the stratopause, resulting from photochemical-radiative equilibrium calculations, amounts to only 4–5C.

Because of this discrepancy, those factors which might contribute to a pseudo-diurnal change have been re-examined. However, it appears that the only two known factors which fall into this category do not diminish the observed diurnal change. Conversely, the net result of the re-examination is a slightly greater actual diurnal range.

One obvious factor is the effect of direct solar radiation on the bead during daylight hours only. However, upon re-examining Wagner's treatment and the results of this factor, it is clear that it is small, amounting to an error of only 1–2C between 40 and 50 km. Further, this radiation effect is actually observed on the temperature recording and appears as periodic "spikes" resulting from the alternate shading and direct exposure of the bead to solar radiation as the parachute instrument system oscillates in a pendulum-like manner. This is demonstrated in Figs. 6 and 7 which are reproductions of two of the recordings made during the series. The data in Fig. 6 were taken during daylight hours, and the periodic "spikes" occurred at 5–7 sec intervals. The data in Fig. 7 were taken during darkness and the fluctuations are absent. It has been determined from signal strength recordings from both radar and GMD-1 ground receivers that the usual period of oscillation of the parachute-instrument system is 5–7 sec. Thus one would also expect that the shading, non-shading period would also be 5–7 sec. The magnitude of the daytime "spikes," upon being converted through instrument calibrations to temperature values, do indeed verify Wagner's predicted values. Thus the "spikes" are not incorporated in the temperature reduction process.

A secondary radiation factor which is included in Wagner's general correction is the amount of terrestrial reflection and scattering from below the bead. The variability of cloudiness can also account for some small deviation from Wagner's correction, and with the occurrence of an extensive highly reflective cloud deck below the bead, a slight heating effect on the bead would occur. Calculations show this to amount to only 1C or less and, further, only clear sky conditions were observed over the entire 24-hour period from 0000 MST 7 February to 0000 MST 8 February and only thin scattered clouds were present during the period of the 1400 and 1600 MST soundings on 21 November.

The other factor which would modify an actual diurnal change is the actual existing temperature structure itself. That is, the bead cools to near ambient atmospheric temperatures at 50 km as it descends from 65 to 75 km where it had been initially deployed from the rocket at a much higher temperature. Thus it would more closely approach a warmer stratopause value than a cold stratopause value. Consequently the bead is effectively dampening the diurnal range. According to calculation by Wagner, an observed 20C diurnal temperature spread would be increased to 24C.

3. Conclusions

The series of temperature soundings for February shows the upper stratosphere to be a region of vigorous activity. A large diurnal temperature regime and other temperature variations with shorter periods, but nearly

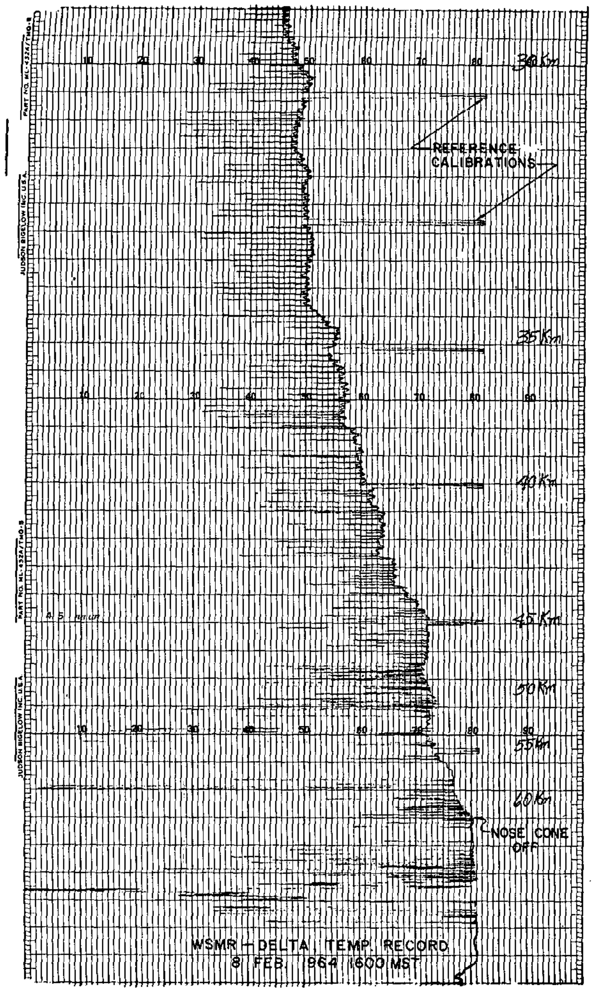

FIG. 6. Section of recorder record from Deltasonde instrument taken during daylight hours.

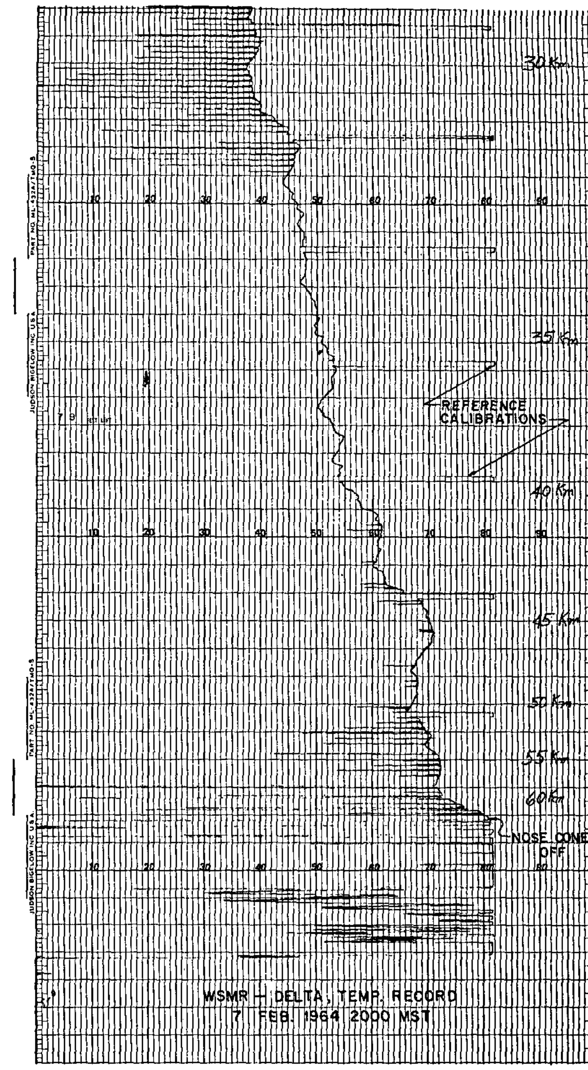

FIG. 7. Section of recorder record from Deltasonde instrument taken during nighttime hours.

equal amplitudes, are evidenced. Minimum diurnal temperatures occur near 0400 to 0600 MST and maximum diurnal temperatures are found around 1400 MST. The February data, together with the soundings of 21 and 22 November, indicate a diurnal temperature range of at least 15–20C between 55 and 60 km decreasing to near 5C at 30 km. This diurnal temperature range is several times larger than the change which has been predicted through consideration of ozone radiative equilibrium, thus the explanation must be sought elsewhere. Possibly dynamic considerations can provide an explanation, or perhaps there are other constituents whose importance has been underestimated in the radiation balance calculations. Certainly, though, the diurnal changes measured in these two cases cannot necessarily be considered representative of the entire annual cycle on the basis of such a limited time sample. Additional sampling is required.

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