Rocketsonde Repeatability and Stratospheric Variability

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ABSTRACT

In an attempt to separate instrument system "noise" from actual stratospheric variability, six pairs of meteorological rocketsondes (Datasonde instruments) were launched on 20 June 1969, with five pairs being released at 1-hr intervals; the two individual rockets comprising a pair were separated by time intervals of no more than 5 min. The average rms difference between paired soundings was 1.08C and ~3 m sec^{-1}. These rather low rms values contrasted sharply with rather large changes observed in both the temperature and wind fields. Further research is needed into the interpretation of this variability in terms of mesoscale and small-scale phenomena.

1. Introduction

For any meteorological measurement, the final confidence level that is imposed upon the data is a function of the accuracy of the measurement and how well it represents the parameter which we are attempting to survey. In this regard, there has been considerable discussion in the recent literature concerning the accuracy of temperatures measured by meteorological rocketsondes (e.g., Wagner, 1964; Thompson and Keily, 1967; Ballard, 1967), with the emphasis being placed on determining a technique for "correcting" the temperature measurements for such factors as dynamic heating, radiation effects, etc. (Ballard, 1967). However, users of the data are occasionally faced with certain inconsistencies in the measured temperatures that cannot be resolved by any of the correction schemes (e.g., Miller, 1969a,b). In these instances, the question has remained as to whether the cause of these discrepancies is natural atmospheric variability or an instability of the measuring system.

TABLE 1. Launch schedule of Datasonde experiment, 20 June 1969.

Time (GMT)	Condition	Radar
0130	Average	AN/FPQ-6
0135	Average	AN/FPS-16
1535	Average	SPANDAR
1540	Average	AN/FPQ-6
1635	Average	SPANDAR
1640	Average	AN/FPQ-6
1735	Below average	SPANDAR
1740	Below average	AN/FPQ-6
1835	Below average	SPANDAR
1840	Below average	AN/FPQ-6
1935	Average	SPANDAR
1940	Average	AN/FPQ-6

Radar type	Range precision (yards)	Angular precision (mils)
AN/FPS-16	5	0.1
AN/FPQ-6	5	0.05
SPANDAR	10	1.0

In an attempt to answer this question, an experiment was devised whose purpose was to compare the wind and temperature repeatability characteristics of the Datasonde instrument system and at the same time relate this repeatability to the observed changes over an extended period.

As shown in Table 1, the experiment schedule included five pairs of rocketsonde launches during the afternoon with 5-min separation within the pairs, and 1-hr separation between pairs. The one nighttime pair (0130, 0135—all times GMT) was included as a possible comparison for radiation effects on the instrument. The launch date of 20 June was selected since "synoptic" variability should be at a minimum during the summer period. Also shown in Table 1 are the radars employed in this study and their manufacturers' quoted precisions.

2. Description of experiment

The current rocketsonde sensor package, the Datasonde, uses a thin-film mylar loop mount to support a 10-mil aluminized bead thermistor. However, Thompson (1968) has shown that the actual shapes and exterior coatings of the 10-mil bead thermistors employed in meteorological rocketsondes tend to vary considerably. Therefore, it was decided at the outset that a thorough assessment would be made of the quality of each instrument destined for the experiment. Hopefully, any discrepancies due to instrument manufacture would then be recognizable.

The authors examined an entire lot of 10-mil beads at the manufacturer's plant and selected 12 that were then mounted on the Datasonde instrument.

Inasmuch as we were uncertain what effect the bead variability would have on a measurement, it was decided that 8 of the 12 beads should be of at least average quality with respect to shape, coating, etc., and 4 below average. While the beads did, indeed, show the expected variations in shape, etc., one was of particular interest in that it had a small crack in the outer coating near the lead entry point. The relative condition of each instrument is depicted in Table 1 where the comparison basis is the total instrument quality based on the state of the bead, the number of solder joints used in mounting, etc.

Fig. 1 indicates the position of each instrument relative to Wallops Island when the descending parachute was at a height of 45 km. The maximum horizontal separation within pairs was ~5 km, with an average separation of ~3 km.

The wind determination scheme, which is also that employed in processing the regular Wallops Island data, is based on a constant altitude difference between measured points. In this method, the time of the sonde's position at 1 km above and 1 km below every whole kilometer level is subjectively interpolated from the radar plot board (one point every 10 sec) (e.g., Hyson, 1968; Miller, 1969b). Winds are then computed by dividing the positional difference by the time difference. Temperatures are determined from the temperature-time recorder trace with 1C departure from linearity employed as the criterion for a significant level. The heights associated with the temperature values are obtained from a computer output of the fine-scale wind fields (described below).

Unfortunately, shortly after the experiment was conducted, additional information (Hixon and Bollermann, 1970)[1] indicated that the Datasonde employed in this study seemed to show a warm bias at lower levels compared to the rawinsonde. Additional tests performed at Point Mugu indicated that the cause of these discrepancies seemed to lie in the placement of the bead thermistor against the mylar film in this particular design. Comparisons of instruments with the bead in contact with and away from the mylar film indicated that, indeed, the former design gave temperatures which were too warm at the lower levels by several degrees, but that the effect at higher altitudes was not discernible. While this problem raises the question of instrumental *accuracy*, the basic premise of the experiment was still valid. That is, a bias would not invalidate the results since our interest is in the difference between soundings. Until such time as the effect of bead placement is fully determined, the results of this study should not be considered as an indication of the absolute accuracy. A study directed at answering the accuracy question is in progress.

3. Results

Presented in Fig. 2 is a typical example of the paired temperature data (1735, 1740) as well as an anomalous pair (1835, 1840). Maximum differences in the typical data are on the order of 2–3C and exist over height ranges of ~2 km. The observations at 1835, 1840, on the other hand, indicate much larger differences especially at the higher levels. At 59 km the temperature difference between the observations was greater than 6.5C. As mentioned above, the thermistor mounted on the 1835 observation had a crack in the coating and was employed in this study especially to test for this effect. Comparison of the 1835, 1840 series with those before and after suggests that the 1835 observation was too warm. It should be mentioned that all beads inspected by the authors in preparation for the experiment had already passed the manufacturers inspection programs and would, in due course, have been mounted on a standard instrument. This is not pointed out to ascribe blame to the manufacturer as this was the only cracked bead found in a lot of about 100. Rather, it is meant to indicate to the users a possible source of a non-representative sounding.

As a simple check on the comparability within pairs, the rms differences between paired observations were calculated and the results shown in Table 2. As expected, the maximum differences occurred for the 1835, 1840 pairs with the remaining observations having values between 0.7 and 1.4C, including the one other below-average pair at 1735, 1740. If we exclude the 1835, 1840 pair, the average rms difference for the five pairs is 1.08C. It should be emphasized that this represents the total

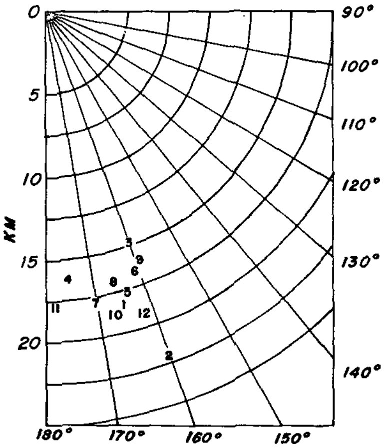

FIG. 1. Launch times and locations of rocket soundings at 45 km altitude with respect to Wallops Island. Soundings are identified by numbers beginning with 1 at 0130 GMT and ending with 12 at 1940 GMT. See Table 1.

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[1] Hixon, B. R., and B. Bollermann, 1970: Rocketsonde temperature errors. Paper presented at Fourth National Conference on Aerospace Meteorology, Las Vegas, Nev.

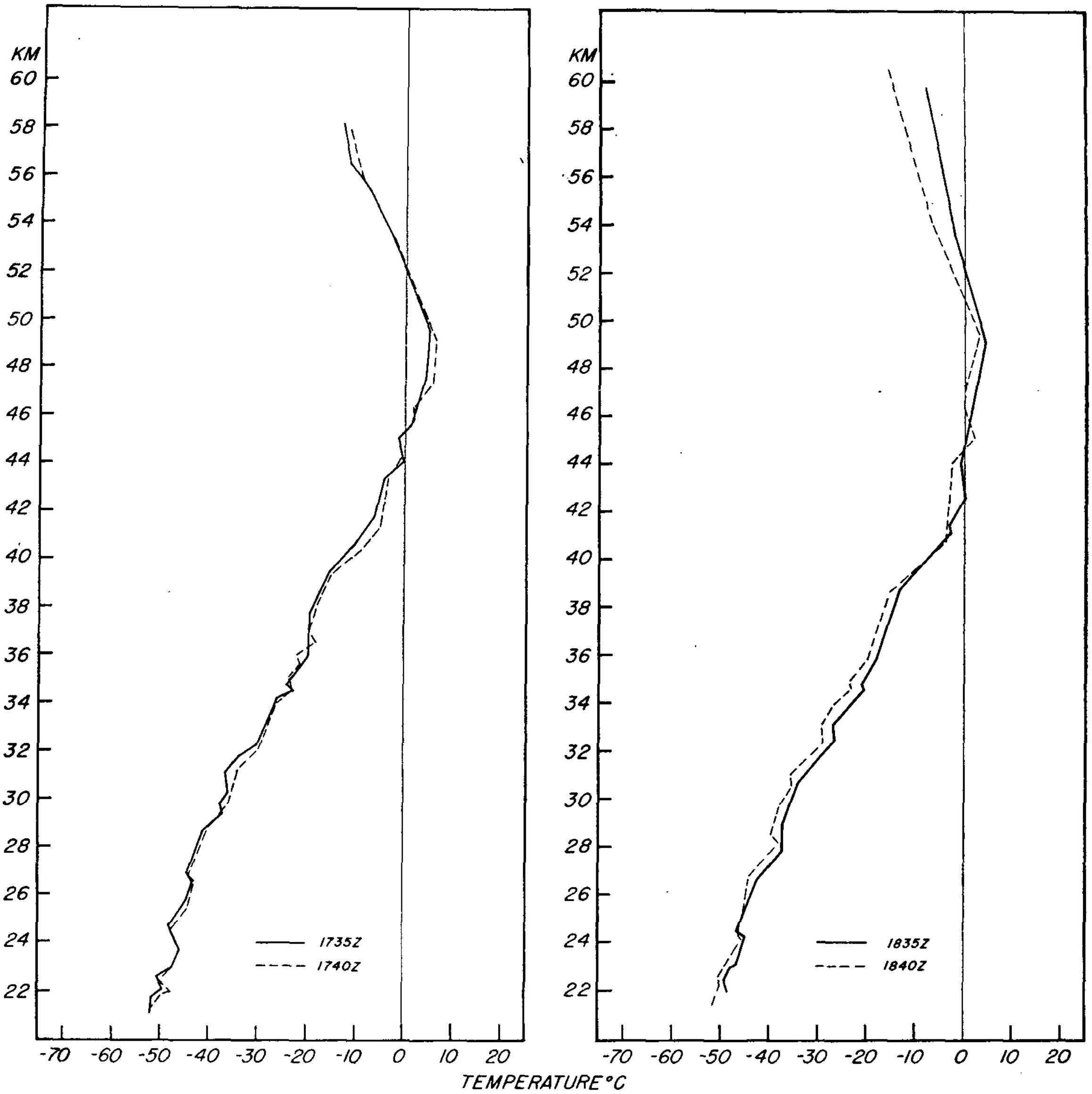

FIG. 2. Comparison of temperature profiles at 1735, 1740 GMT (left) and 1835, 1840 GMT (right).

system rms and includes such effects as the two GMD tracking systems (e.g., Hodge and Harmantas, 1965), as well as any time and space differences. Of course this rms value does not reflect the accuracy of the system, just the repeatability; as mentioned above, the former aspect still requires intensive study.

TABLE 2. Root mean square temperature differences (°C) between paired observations.

Paired observations GMT	rms differences	Number of data points
0130, 0135	0.9	36
1535, 1540	1.4	35
1635, 1640	0.7	35
1735, 1740	1.1	35
1835, 1840	2.8	35
1935, 1940	1.3	34
Average*	1.08	

* 1835, 1840 not included.

With regard to the measured winds, Table 3 presents the rms differences between the paired observations of the zonal and meridional wind components. It should be remembered that the wind determinations are separate from the temperature measurements and the height of the topmost point in either case depends on a somewhat subjective decision by the observer as to when the instrument is fully sensing the atmosphere; as a result there is a difference in the number of observed points per sounding between Tables 2 and 3. Because of this inherent subjectivity, rms differences were also calculated for the top 5 km of reported data with the results being shown in parentheses.

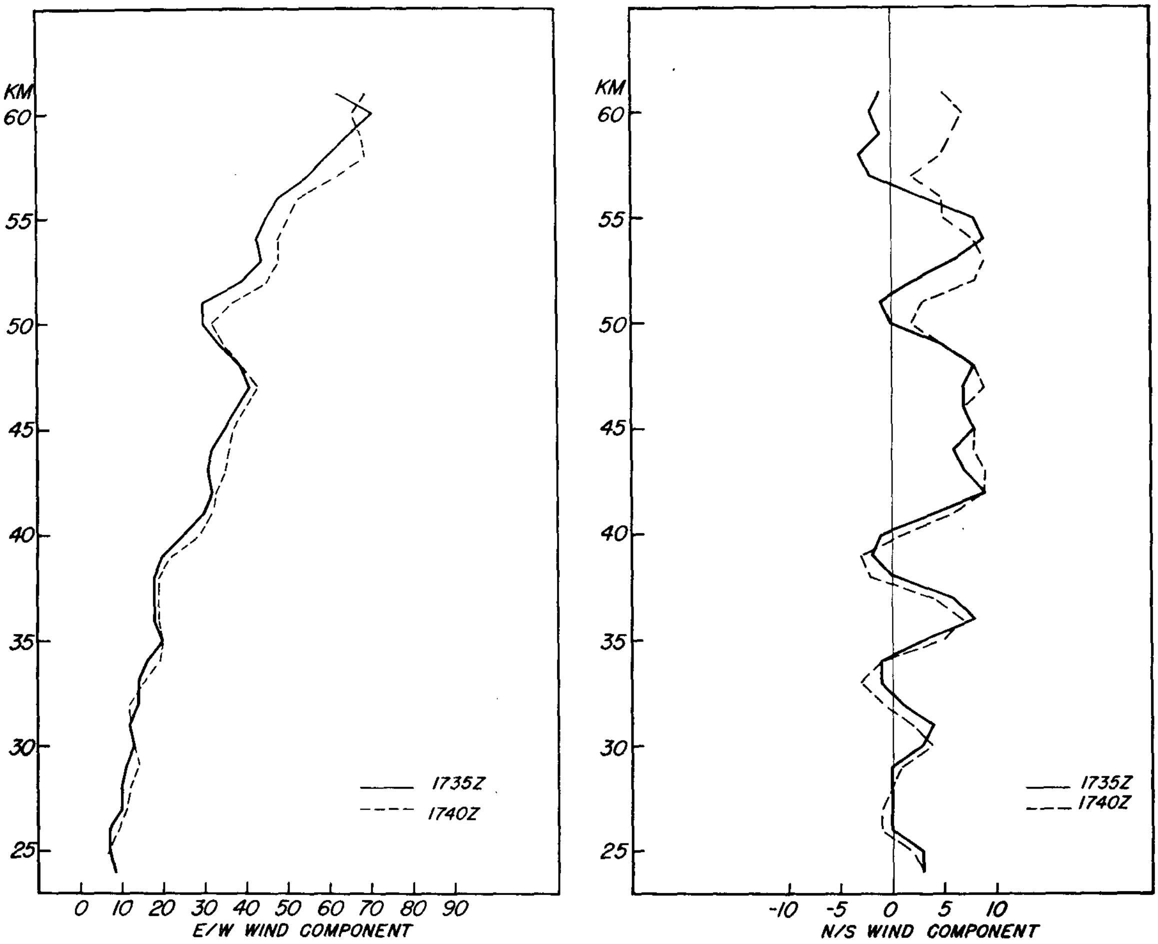

Fig. 3. Comparison of wind profiles (m sec^{-1}) at 1735, 1740 GMT. Zonal winds presented on left, meridional winds on right.

As would be expected, the smallest rms differences occurred within the evening pair when the two most precise radar systems (Table 1) were available. During the day, the rms differences include the different precisions of the AN/FPQ-6 and SPANDAR radars. Nevertheless, the differences are less than 5 m sec^{-1} which is the often quoted accuracy of rocketsonde winds (e.g., Hyson, 1968). Of particular interest, however, is the fact that the rms differences of the top 5 km tend to be about twice as great as those for the total sounding. This indicates that the problem of choosing and evaluating the topmost representative winds by the present method can be quite serious in reducing the data and that the overall rms differences can be reduced by neglecting the higher altitudes. The fall rates of the instrument were studied in an attempt to account for the above differences, but were found to be within a few meters per second of each other.

As an indication of a typical set of paired wind profiles, the observations for 1735, 1740 are presented in Fig. 3. Maximum differences in the component winds appears to be ~10 m sec^{-1}, although, as indicated above, the differences tend to be larger at the topmost levels.

Utilizing the paired rms differences as an estimate of the instrument repeatability, we are now able to examine the variations of temperature and wind as a function of time during the day.

Fig. 4 presents an analysis of the temperature structure as a function of time and height with the 1835

Table 3. Root mean square wind differences (m sec^{-1}) between paired observations.*

Paired observations (GMT)	rms values Zonal winds	 Meridional winds	Number of data points
0130, 0135	1.7 (2.5)	1.4 (2.3)	38
1535, 1540	4.4 (10.2)	2.6 (5.57)	36
1635, 1640	3.1 (6.2)	2.4 (4.2)	42
1735, 1740	3.5 (6.5)	3.1 (7.0)	40
1835, 1840	4.6 (10.2)	4.7 (11.0)	41
1935, 1940	2.8 (5.4)	2.3 (3.3)	40
Average	3.35 (6.8)	2.8 (5.6)	

* Values in parentheses are for the top 5 km of the sounding.

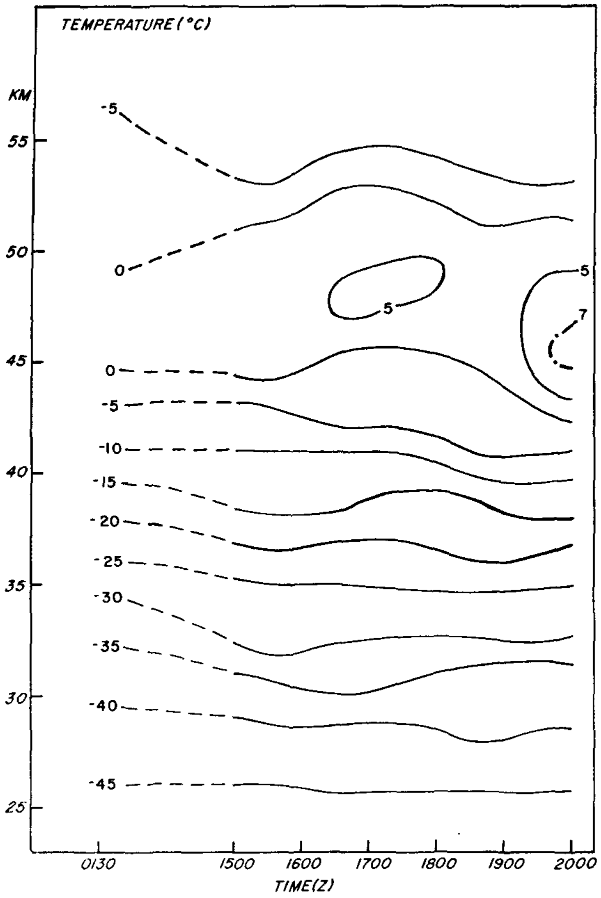

FIG. 4. Analysis of temperature structure as a function of time and height. Region between 0130, 0135 and 1535, 1540 GMT observations is dashed to depict uncertain analysis.

observation excluded. The region between the 0130, 0135 pair and the remaining soundings is connected by a dashed line simply for the sake of continuity and to give an idea of the total change during this period.

The greatest temperature change over a deep layer seems to occur at ~45 km where the temperature varies from −1.4, −1.3C at 1735, 1740 to 6.8, 7.5C at 1935, 1940. This maximum in variability occurs at a level just below the observed stratopause. Of course, the possibility that these maxima may be related to the instrument design (solar radiation, for example) cannot be completely ruled out. It is difficult, however, to understand what instrumental factor would result in such large changes over a limited height range (Hixon and Bollermann, *loc. cit*). While we are unable to delineate the absolute maximum associated with the 1935, 1940 data, it is worthy of note that the estimated diurnal amplitude at 45 km during this period is only ~1.4C (Lindzen, 1967), so that the source of this observed temperature variability must be sought elsewhere. Also of particular interest is the minimum variation at the lower levels as this is the region of overlap between rocketsondes and support rawinsondes.

With respect to the observed wind changes, time cross sections of zonal and meridional wind components are shown in Figs. 5 and 6. Because of the different precisions of the radars, however, the isolines are drawn only for the data obtained by the AN/FPQ-6 and AN/FPS-16 radars. As was the case for the observed temperatures, relatively little variation occurs at the lower levels; this is consistent with the generally observed agreement between rocketsonde and rawinsonde winds in the overlap region.

At higher altitudes the interpretation is somewhat more confused for wind than for temperature because the theoretical diurnal tide (Lindzen, 1967) has an amplitude of 5–10 m sec^{-1} above ~45 km, and this would seem to account in a general sense for some of the observed changes. Thus, the difference between the nighttime minimum easterlies at 45–50 km and the maximum during the afternoon, and the contrast between evening northerly winds and afternoon southerlies, may, in part, be due to the diurnal tide. On the other hand, it seems clear that the rather abrupt wind changes around the 1640 GMT maximum southerly winds at 55 km require further explanation. It should be noted, though, that the time scale of this phenomenon is considerably smaller than the planetary-type waves recently found by Muench (1968).

The concept of relatively small-scale perturbations superposed upon the basic trend has been recognized for some time (e.g., Webb, 1965; Weinstein *et al.*, 1966; Miller *et al.*, 1968). Unfortunately, a complete delineation of these features requires extensive data coverage, which up to now has been unavailable. Thus, very little is known about the horizontal-vertical time scales of motions other than those associated with the simple wave theories (e.g., Hines, 1960).

The temporal spacing of the afternoon launches offered an excellent opportunity to study the time changes of the perturbation fields. Accordingly, fine-resolution winds were calculated on the computer using 10 point sec^{-1} data available from the radar. For this study only the data from the AN/FPQ-6 and AN/FPS-16 radars were considered. Winds were calculated by filtering the raw positional data with a symmetric smoother consisting of 21 points at 0.2-sec intervals and plotted at that scale.

An inspection of the wind plots revealed that adequate information for our purposes could be gained by considering points at 250 m increments of height. The linear trend was removed from the data and the residual for 1540, 1640 and 1740 are presented in Fig. 7 as typical examples.

This figure clearly shows that there is considerable persistence in the zonal winds with a characteristic vertical wavelength of ~5–10 km, while very little persistence is revealed in the meridional winds. Even if the 1640 meridional observation is discounted as perhaps being influenced by some mesoscale phenom-

Table 4. Correlation coefficient of wind perturbations at zero lag.

Paired observations (GMT)	Zonal winds	Meridional winds
0130, 0135	0.89	0.87
1540, 1640	0.72	−0.37
1640, 1740	0.83	0.21
1740, 1840	0.69	0.04
1840, 1940	0.86	−0.14

enon, there still remains less persistence between the 1540, 1740 meridional winds than between the zonal winds. To quantify these observations, correlation coefficients for the zonal and meridional components were calculated for the data at 1-hr intervals. The results are indicated in Table 4.

The nighttime observations were first correlated as a test case with coefficients of 0.89 and 0.87 being obtained for the two components. The afternoon data, on the other hand, show significant correlations for all five pair in the zonal winds, but nearly zero correlation in the meridional winds. Additional computations were made at up to 20 lags (each lag 250 m), but the same basic pattern resulted.

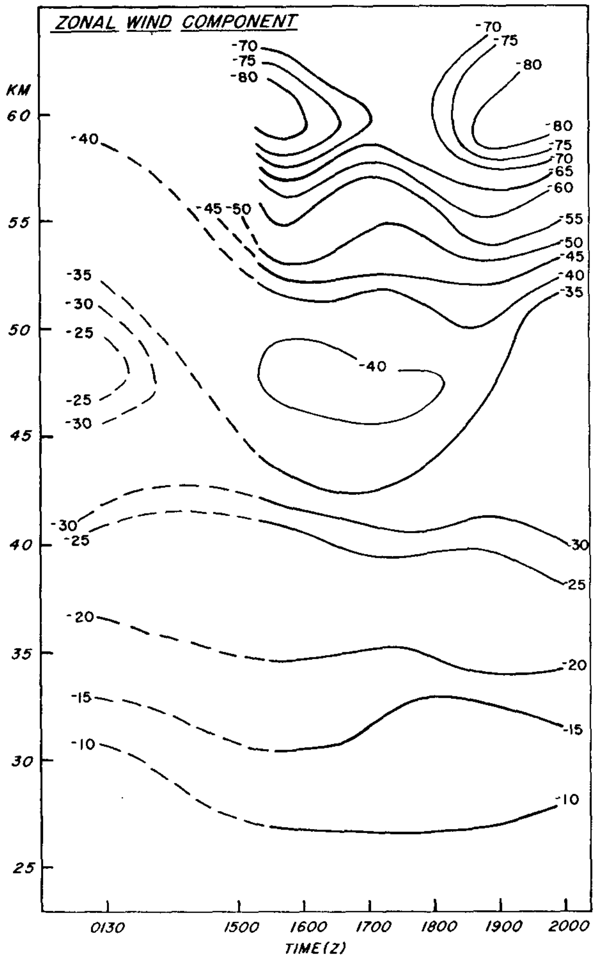

Fig. 5. Same as Fig. 4 except for the zonal wind component Contour units: meters per second.

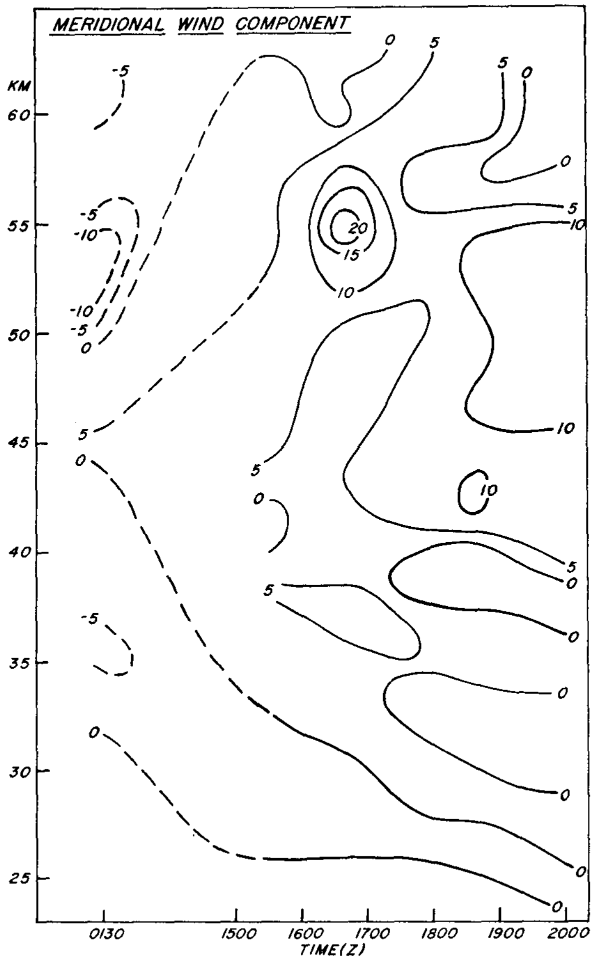

Fig. 6. Same as Fig. 4 except for the meridional wind component. Contour units: meters per second.

Unfortunately, because we know so little about the subplanetary structure at these heights, the interpretation of these data is somewhat clouded. For example, it is not at all clear whether the zonal maximum at ~50 km should be considered to be in approximate geostrophic balance or even what horizontal scale to associate with it. This has obvious importance not only in the wind and height determinations, but also in the temperature fields as the thermal wind equation would demand a reversal of the temperature gradient at ~50 km. This question would seem to demand additional attention in the future.

Unfortunately, near-sinusoidal temperature oscillations with amplitudes of several degrees evident in the temperature recordings (Hixon and Bollermann, *loc. cit.*) precluded an analysis of the small-scale temperature structure. Interestingly, these oscillations were not present in any of the nighttime data, suggesting that

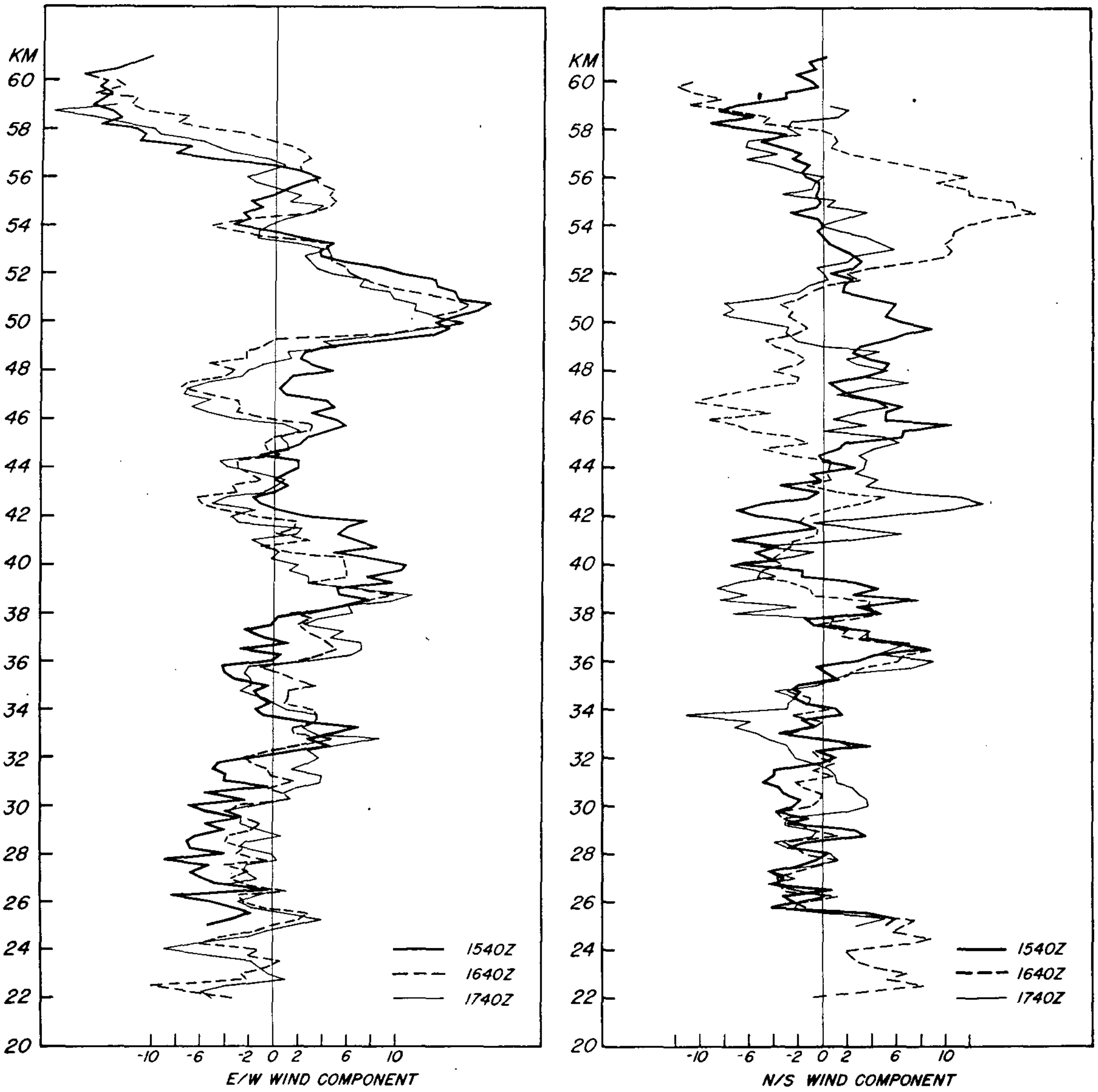

FIG. 7. Residuals (m sec^{-1}) from linear trend of the zonal (left) and meridional component (right) for 1540, 1640 and 1740 GMT observations.

they may due to radiation effects on the instrument. It should be stressed at this point, though, that these small-scale perturbations superposed upon the trend cannot account for the relative warming at about 45 km described above. A study directed at answering the question of the accuracy of the instrument including the radiation effect is in progress.

4. Final remarks

While the number of observations in this experiment was somewhat limited, we have shown the close repeatability of measurements by the Datasonde instrument taken under nearly identical observational circumstances; at the same time we have shown that extensive small-scale variability is possible in the atmosphere. This variability would certainly affect the data for any limited data sample and may explain some of the discrepancies that have been discussed to date, including those encountered in attempts at delineation of the diurnal tide. The interpretation of the observed variability in terms of mesoscale and small-scale features is very uncertain at this time and is worthy of increased investigation.

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