# Upper Atmosphere Pressure Measurements with Thermal Conductivity Gages

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## ABSTRACT

Recent studies of meteorological rocket data have shown a significant diurnal variation of temperature, pressure and density in the stratopause region; however, some doubts have been expressed concerning possible effects on the bead thermistor sensing system which may contribute to the large diurnal changes previously observed. While all known effects have been accounted for and no evidence to the contrary has been offered, it seemed worthwhile to investigate this possibility with an independent system which would not be subject to the external effects encountered by the exposed bead thermistor as employed with standard rocketsondes. Consequently, two pressure soundings between approximately 30 and 60 km were obtained with thermal conductivity gages which were incorporated with standard rocketsondes. The thermal conductivity gages were found to be very efficient and reliable in the low subsonic regime encountered with parachute-suspended sounding systems, and good agreement was obtained between the computed and measured pressure and also between the computed and measured temperature.

## 1. Introduction

For some years, temperature has been measured in the upper stratosphere and lower mesosphere with bead thermistor rocketsondes in connection with the Meteorological Rocket Network (MRN) (Webb *et al.*, 1962), and corresponding pressures and densities have been computed (Thiele, 1961, 1963) from the temperature using the hydrostatic equation and equation of state based on an initial pressure obtained from a supporting balloon-borne radiosonde. Even assuming negligible error in the radiosonde pressure, there still remains the problem of time and space variability. While there are some assumptions in hydrostatically integrating upward for pressure, primarily the assumption of hydrostatic equilibrium, the only other significant source of possible error is the measured temperature. Intensive theoretical and experimental studies (Wagner, 1961, 1964; Ballard, 1961,[1] 1967), with considerable emphasis on the radiational environment, have not revealed any unaccounted-for effects on the rocketsonde sensing system up to an altitude of at least 60–65 km. Nevertheless, questions have been raised concerning the possible existence of unknown, and thus unaccounted-for, radiational effects on the rocketsonde instrumentation, particularly above 40 to 50 km, which may contribute to the measurement of large diurnal variations of temperature in the vicinity of the stratopause. Therefore, to further evaluate bead thermistor measurements and computed pressures and densities, a sensor was sought which could be incorporated with meteorological rocket payloads, and which would not be subject to the influences of radiation and aerodynamic heating.

Earlier, Thiele and Beyers (1967) attempted to measure pressure at two altitudes during a normal rocketsonde sounding utilizing on-board precalibrated pressure switches. With the switching function providing the event times at which the pressures were reached, one could determine the corresponding radar altitudes and hydrostatically compute the mean temperature between these points for comparison to the measured temperature; or, the pressure at these points could be compared with the pressures computed from the temperature measurement. Unfortunately, difficulties were encountered relative to the switching circuit, but the one good pressure measurement which was achieved, however, did demonstrate the feasibility of a thermal conductivity gage for accurately measuring pressure in a low subsonic regime. It was subsequently determined that with some modifications to the system, pressure could be provided on a more or less continuous basis during the rocketsonde sounding.

## 2. Instrumentation

Many improvements have been incorporated into the earlier generation rocketsonde instruments. The more significant modifications are the use of solid state modulation circuits and thin-film thermistor mounts. The solid state circuit reduces the internal heating of the bead thermistor to a negligible value amounting

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[1] Ballard, H. N., 1961: Response times of and effects of radiation on the VECO bead thermistor. Preprint 167-LA-61, Instrument Society of America—American Meteorological Society, 11–15 September 1961, Los Angeles, Calif., 28 pp. (available from author).

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to approximately 0.5C under the worst circumstances, but even this small effect is accounted for. At the altitudes of interest, the thin-film mounts eliminate heat conduction into the thermistor and, since these films have a superior surface area to mass ratio relative to the bead and, consequently, a faster response, the temperature gradient between the mount and bead is reversed, thus improving the overall sensor response. The bead thermistor is coated to reduce radiation effects; however, the inverted exposure of rocketsonde instruments minimizes incident sunlight. When the parachute oscillations do expose the bead periodically to solar radiation, this effect, approximately 1 to 2C, is detectable in the raw telemetry data and is eliminated during the data reduction process. Based on the measured fall speed, dynamic heating corrections are applied to the temperature measurements at the higher altitudes.

As alluded to in the introduction, thermal conductivity gages (Guthrie, 1958) were chosen for the secondary sensor because of their efficiency at low pressures and at relatively low velocities as are obtained with parachute-suspended rocketsondes. A gage of this type, which utilizes the change of the thermoconductivity of a gas to measure its pressure, was engineered and manufactured for our particular application of accurately measuring atmospheric pressure between approximately 30 and 60 km altitude by MetroPhysics, Inc., Santa Barbara, Calif.

The pressure gage contains three basic components: a temperature controlled thermistor pressure sensor, a regulated constant voltage source, and a high-gain dc amplifier. The constant voltage source supplies a constant power to the thermistor sensor to maintain a constant temperature at low pressures. As the pressure begins to increase, the thermal conductivity of the gas between the thermistor and its housing begins to increase. Then, as the power that heats the thermistor begins to be dissipated to the housing, the temperature of the thermistor begins to decrease. This decrease in temperature results in a change of the thermistor resistance and the change is sensed by the high-gain dc amplifier, which immediately attempts to maintain a constant resistance by increasing the power supplied to the thermistor. Therefore, the power needed to maintain the thermistor at a constant temperature is a function of pressure. Since the output is basically a voltage measurement, a voltage reference of the blocking oscillator type modulator is also included.

The thermistor housing must be held at a constant temperature, and this is accomplished with a solid state thermostat. Even so, small changes occur under severe exposures and the internal housing temperature is measured for compensation.

These particular sensors were designed to measure pressure from approximately 0.1 to 10 mb. The response of these gages is about 0.5 sec at 60 km, and about one or two tenths of a second at 50 km; however, this lag is accounted for utilizing the measured fall speed. The high precision calibrating equipment used indicates that these gages should sense ambient pressure to within ±1%. Fig. 1 is a typical calibration curve.

To avoid the complexity of a multichannel telemetry system, the existing single channel was commutated even though the sensors characteristically function continuously. Fig. 2 is a functional diagram of the payload and Fig. 3 describes the sequence of data transmission.

## 3. Discussion of data

Two pressure sensing payloads, as described above, with 4.6-m diameter silk parachutes were flown on board Arcas meteorological rockets at 0205 and 1805 MST on 7 October 1966. Both were successful regarding

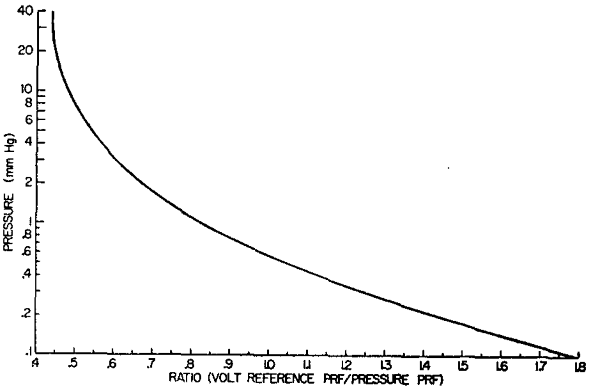

FIG. 1. Typical calibration curve for thermal conductivity gage. The instrument is calibrated in terms of the ratio of the transmitted voltage reference and pressure data pulse repetition frequencies (PRF).

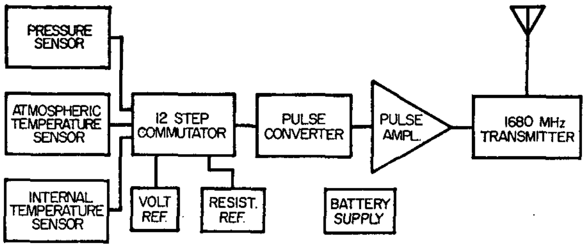

FIG. 2. Functional block diagram of the pressure-temperature rocketsonde.

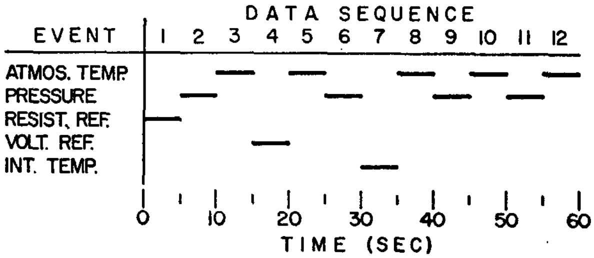

FIG. 3. Measurement cycle of the transmitted data. The commutator cycles once per minute.

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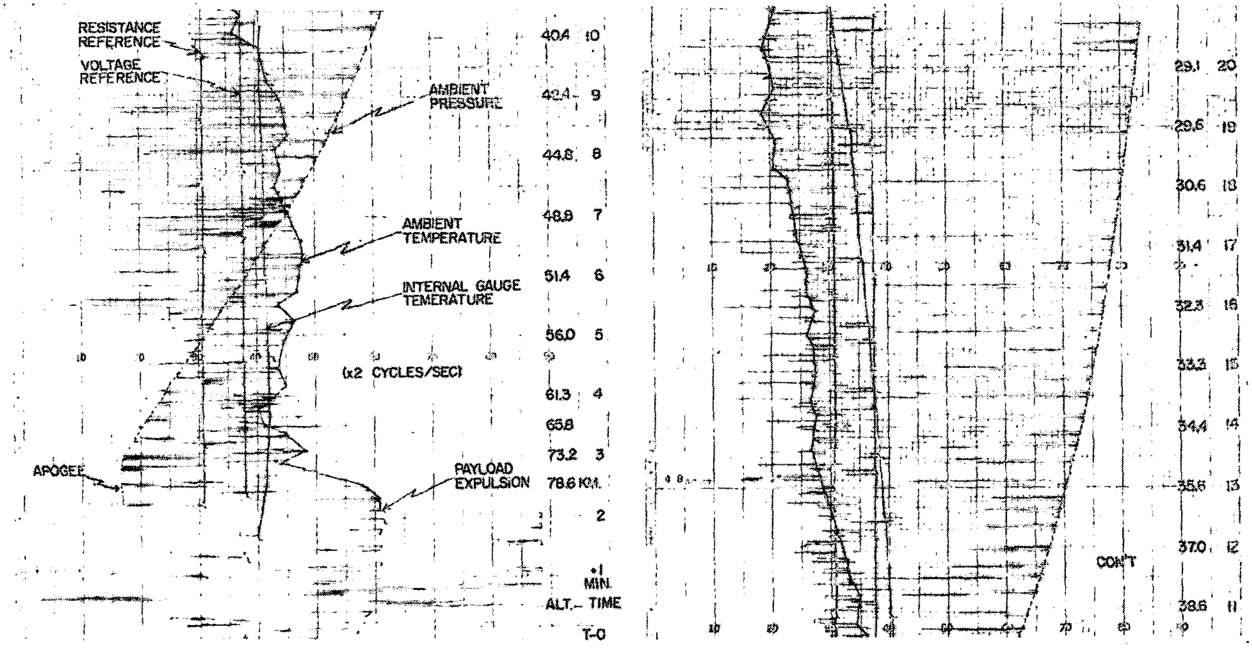

FIG. 4. AN/TMQ-5 frequency-time recording of pressure-temperature rocketsonde sounding. The ordinate values are half the pulse repetition frequency. The altitudes were obtained by a time correlation with AN/FPS-16 radar data.

the pressure measurements; however, the temperature sensing element failed on the 1805 sounding. These data, as is the case with normal rocketsondes (Clark and McCoy, 1965), are telemetered in the form of pulses with the intelligence being contained in the pulse repetition frequency (PRF). The data were recorded on magnetic tape to insure maximum detail, but for backup and preliminary analysis, the standard AN/TMQ-5 frequency-time recorder was also used (Fig. 4). The curves connecting the data of each channel were supplied for purposes of identification and continuity. For clarity, the five channels of data are identified directly in the figure. The steadiness of the resistance reference and the voltage reference indicates that such in-flight calibration references are not an absolute necessity; however, the reassurance gained outweighs the loss of a small amount of data during their periodic function. The temperature trace is typical of rocketsonde bead temperature measurements. As would be expected, because of its indirect exposure, the internal gage housing temperature changes vary gradually. A slight increase is noted as a result of environmental heating during the upward portion of the rocket flight, and subsequently a gradual decrease as the instrument was exposed to colder temperatures. Useful pressure data begin at the time of payload expulsion, which in this case occurred prior to peak altitude. Here the pressure profile can be seen to decrease and then increase again as apogee was traversed. Near the lower altitudes, it is seen that the pressure gage was beginning to approach its limit as the higher pressures were reached. Thermal conductivity gages are characteristically limited to pressure measurements below 10–15 mb. The upper limit of accurate resolution may also be noted in the calibration curve (Fig. 1).

The Arcas nose cones were fitted in the normal manner for rocketsondes and were not vented for the purpose of possibly evaluating pressure changes during the up-leg portion of the rocket flight. However, it was interesting to note that the pressure inside the nose cone dropped to a value which appeared to be somewhere between 40 and 70 mb, and continued with that internal pressure until expulsion.

## 4. Results

The absolute values of the pressure measurements are contained in Figs. 5 and 6. These values agree closely with an earlier seasonal analysis of derived pressures for autumn at White Sands Missile Range (Thiele, 1963). Included for reference purposes is the 1962 U. S. Standard Atmosphere for pressure and the upper portion of the supporting balloon-borne hypsometer radiosonde. The agreement of these early October data with the reference atmosphere is reasonable since, being an annual standard, it is more nearly representative of autumn or spring conditions. The agreement with the radiosonde pressure data was also found to be consistent.

For a closer inspection of the differences obtained, the pressure data are described (Fig. 7) in terms of per cent variation with respect to the Standard. This also, of course, shows the per cent difference between the two soundings. During the autumn and at this latitude of approximately 32N, temperatures are normally warmer than the Standard between 35 and

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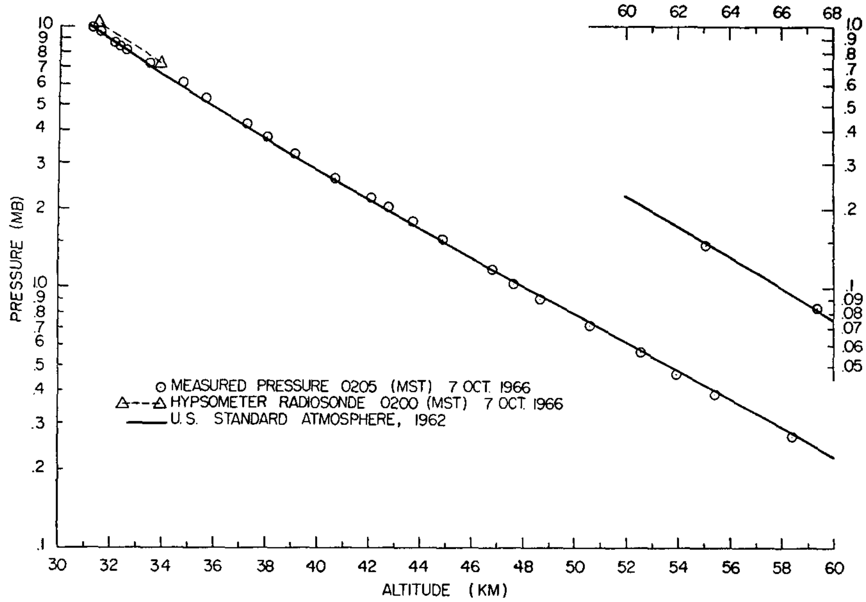

Fig. 5. Pressure sounding at 0205 MST 7 October 1966.

45 km resulting in higher pressures in this region. The lower pressures in the stratopause region appear to be associated with the times of day. Thiele (1966) has found that diurnal maximum and minimum pressures occur in the vicinity of noon to 1400 and midnight to 0200, respectively.

In Fig. 8 the hydrostatically computed pressure is compared with the measured pressure for the 0205 MST sounding. As noted earlier, only this sounding obtained both temperature and pressure. While not large, there is a consistent difference in the vicinity of the stratopause extending from approximately 45 to 60 km where the computed pressures are higher. If one assumes absolute hydrostatic equilibrium, which may not be completely true in the turbulent stratopause, then this difference would imply a somewhat colder temperature than that measured by the bead between approximately 45 and 52.5 km and warmer above 52.5 km where the slope reverses. This is evident in Fig. 9 where the measured and hydrostatically computed temperatures are compared. This does not necessarily imply, however, that the bead measured temperature

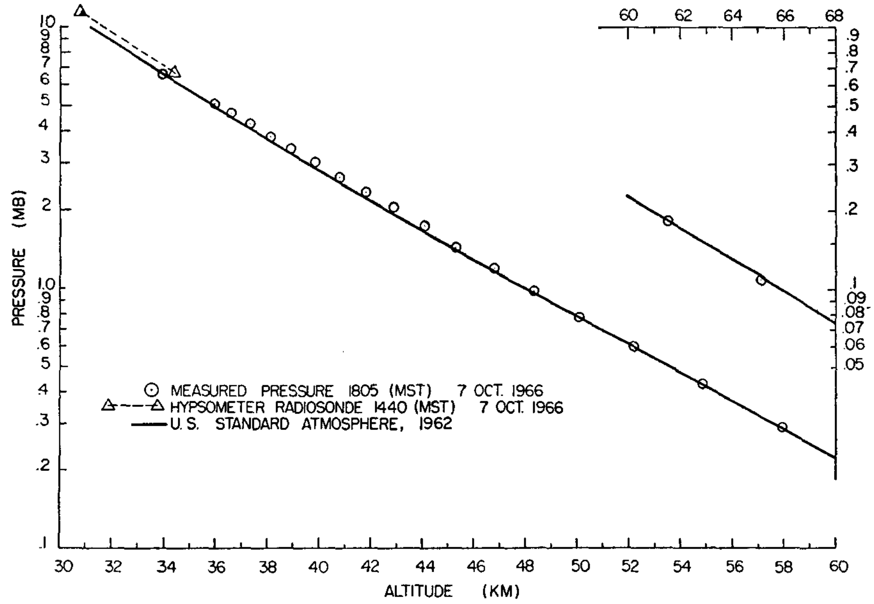

Fig. 6. Pressure sounding at 1805 MST 7 October 1966.

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is in error by the amount shown. There will, of course, be some departure, however small, from the absolute temperature as a result of instrumentation and data reduction limitations relative to both sensors.

It should be noted that the computed temperature values as shown represent a mean through the layer of computation and are plotted at the mean altitude of the layer. This will result in some loss of detail and cause considerable individual differences at some levels. The extreme sensitivity of minor slope changes to hydrostatically computed temperatures makes it difficult to reduce the layer thicknesses very much more and still obtain a reasonable profile. While the mean would not likely be affected, a much more erratic profile would result. If one compares the mean temperature of each profile through the layer of 45–60 km, a difference of 0.8C is found (bead measured temperature colder by that amount). Over the total layer of approximately 30 to 60 km, the difference is only 0.4C (again, in the same direction). While the overall agreement between the two methods is reasonably good, more such comparisons will be required to detect any systematic differences.

Only the computed temperature profile for the 1805 MST sounding is shown in Fig. 10 since thermistor measured temperatures were not obtained during that flight. The temperature was found to be warmer in the stratopause region, and this is consistent with earlier findings by Beyers and Miers (1965) and Beyers *et al.* (1966) relative to diurnal temperature variations, particularly in the region of 45–55 km. On comparing the mean temperature of the 1805 MST sounding through the 45–55 km layer with the computed mean temperature of the 0205 MST sounding, a difference of 5C is found, or 4C in the case of the measured temperature. If one assumes a near sinusoidal diurnal temperature variation with maximum and minimum values near 1400 and 0200 local time, respectively, as most data have shown (Beyers and Miers, 1965; Beyers *et al.*, 1966), a rate of either 4C or 5C per 4 hr is obtained, resulting in a diurnal range of 12 or 15C. This also agrees closely with the results of Beyers and his associates.

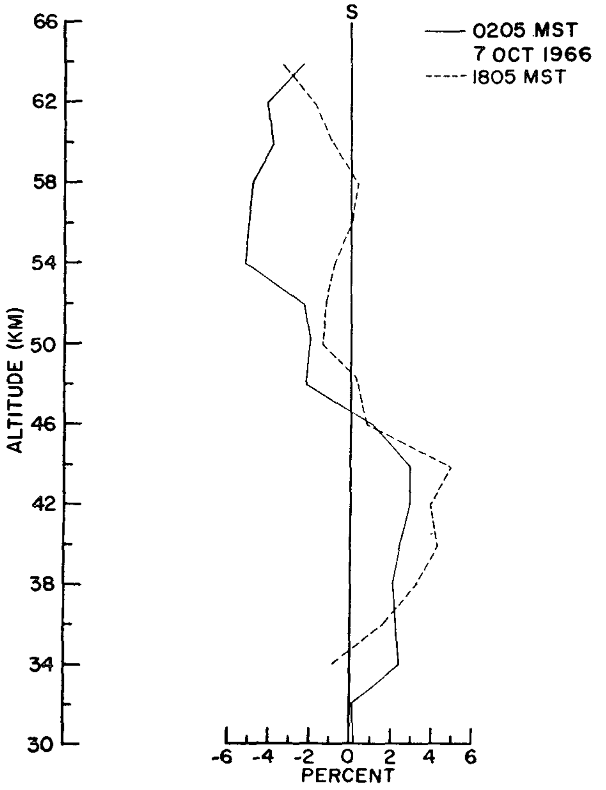

Fig. 7. Per cent variation of the two measured pressures with respect to the 1962 U. S. Standard Atmosphere (S).

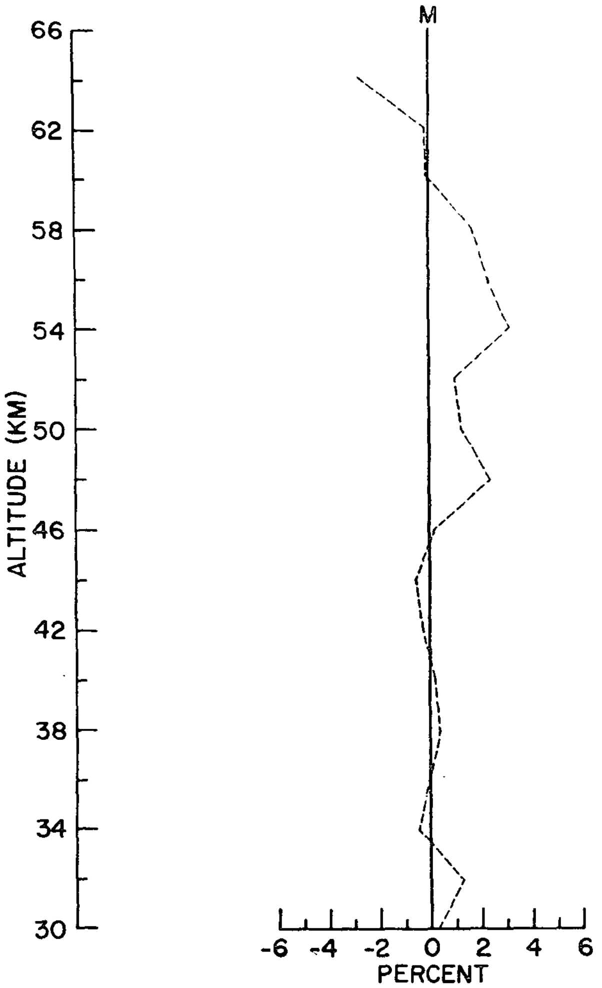

Fig. 8. Per cent variation of the computed pressure with reference to the measured (M) pressure for the 0205 MST sounding.

The per cent variation of the measured density with respect to the 1962 Standard (Fig. 11) is similar to and consistent with the pressure results. Here, the term "measured" density refers to a direct calculation of

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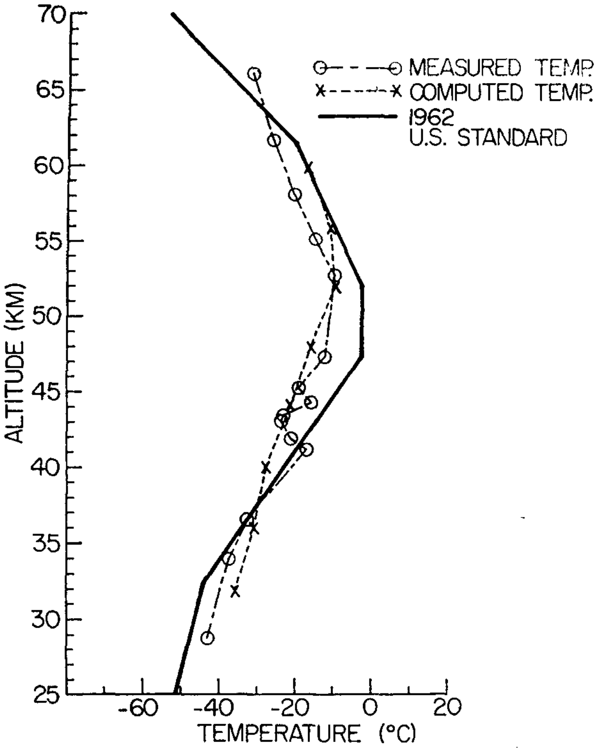

FIG. 9. Measured and computed temperature profiles for the 0205 MST sounding.

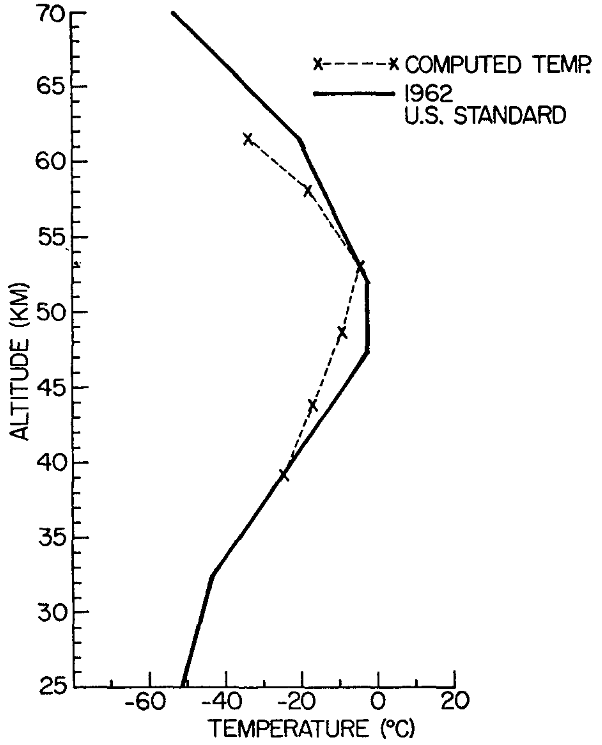

FIG. 10. Computed temperature for the 1805 MST sounding. (A measured temperature was not obtained with this sounding.)

density utilizing the measured pressure and measured temperature. Since no temperature measurement was obtained with the 1805 MST sounding, a segment of density was derived from the pressure measurement. Again, the difference between soundings appears to be related to the time of day.

## 5. Conclusions

The reliability and overall performance of the pressure sensors were very encouraging. It was unfortunate that daytime data were not obtained, thus precluding an evaluation of solar effects on the bead thermistor sensing system; however, it is believed that further experiments with this type instrumentation with more emphasis on daytime soundings, could resolve any remaining doubts associated with bead temperature measurements and corresponding computed pressures and densities up to at least 65 km. It also appears possible to resolve the details relative to the true shape, phase, and amplitude of the diurnal pressure wave in the stratopause region. Furthermore, it would appear that this system, utilizing the measured pressure and temperature, is capable of providing far more accurate density data in the 30–65 km altitude region than have ever been obtained previously. This does not, however,

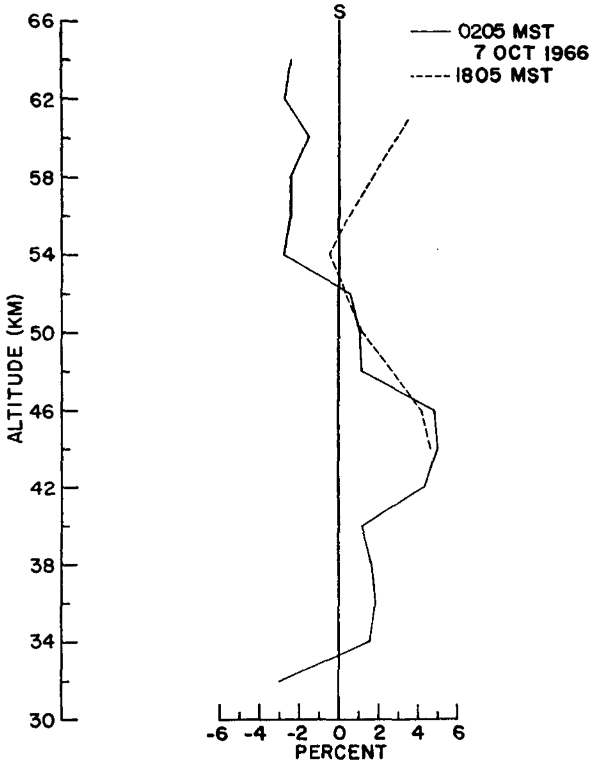

FIG. 11. Per cent variation of density with respect to the 1962 U. S. Standard Atmosphere (S).

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imply that the standard rocketsonde is in any way inadequate for routine synoptic observations, but only that where special requirements for detailed pressure or density data exist, the use of the somewhat more costly pressure-temperature sonde appears practical.

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