DEPARTMENT OF COMMERCE
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Technical Memorandum ERL ARL-113

STRATOSPHERIC THERMOMETRY: AN OVERVIEW AND BIBLIOGRAPHY

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Robert H. Cordella, Jr.

National Oceanic and Atmospheric Administration
Air Resources Laboratories
6010 Executive Blvd.
Rockville, MD 20852

1. INTRODUCTION

Stratospheric thermometry is a diverse topic and this short note attempts to impart a flavor of uncertainties arising from atmospheric dynamics, the vehicle/atmosphere interface, and the thermometer itself. The sources cited here should be referenced directly for details; mean and RMS values are usually given, extremes are rarely mentioned but occasionally appear in graphs in source documents.

2. THE STRATOSPHERE

The U.S. Standard Atmosphere 1976 [1] is probably the best known of several current models [9] which define the atmosphere as strata of known, slowly varying parameters. While the model is termed standard, it is not typical in the sense of here and now around an in situ experiment; it is typical in the sense of average. The model itself is evolving and has been redefined about every six years since the 1954 version [2]. Through the changes the basic model remains: from the perfect gas law and the hydrostatic equation, pressure is defined in terms of geopotential height and temperature, which is itself a function of height.

The stratosphere has a low temperature lapse rate and is defined as a region in which temperature changes little [3]. However, a close reading of [1] shows the variance in data from which the model constants are gleened. Figure 25 in [1] summarizes the systematic variations over time and location as ±30°C at 10 km and ±45°C at 40 km.

The natural variability of stratospheric temperature profiles is such that measurements at one point are not usually representative of another point [4]. Belmont [5] emphasizes this with the warning not to accept any temperature reading as typical of a large region; he presents much tabulated data.

When working with probes sent along similar paths within several hours of each other, diurnal and finer variations become important. Dickenson et al. [6] discuss the 24-hour component of temperature variations poleward of ±30° latitude. A 5°C diurnal amplitude at 50 km is cited. Similarly, Kantor and Cole [7] report roughly sinusoidal variations of 4, 5, and 3°C at 50, 40, and 30 km, respectively, over 24 hours. A true sinusoid of 5°C amplitude and 24-hour period has been used by Ballard [8] in comparing accuracies of measurements near 48 km. Likewise, Ney [11] reports a 5 to 10°C diurnal temperature variation.

3. THE VEHICLE'S ENVELOPE

Here, the envelope is defined as that disturbance of the local atmosphere caused by the vehicle (i.e., balloon or rocket) so that a temperature sensor reports not the atmospheric temperature but that of the air between the unperturbed atmosphere and the vehicle itself. Similarly, balloon or rocket indicates the vehicle itself, rigging, gondola, etc.

That the vehicle affects local temperatures has been noted for quite some time. In 1948, Brasefield [10] reported moving an early radiosonde thermistor out of a protective duct and improving the temperature accuracy by 20°C at 30 km. Although the duct shielded it from direct radiation, it also enclosed it in a false temperature space. Later, Ney [11] published a still referenced and valid study on temperature measurements where he recommends sensors be at least 3 feet from the gondola and 15 feet (2.5 balloon diameters) from the balloon. He also states that the balloon could be up to 15°C colder than ambient if it recently passed the tropopause. His graphics on temperature induced downwash at night and upwash by day about a stable balloon system have been often repeated in the literature.

Wagner [13] also did original work in the heat exchange of a balloon system by using scale models in liquids of appropriate Grashoff numbers. His recommendation of 2 to 3 balloon diameter separation echoes that of Ney.

In the search for better balloon materials and techniques of altitude prediction, Lucas [14, 15] and Carlson [18] report excellent computer models of the gas/balloon/atmosphere/radiation interface and substantiate them with empirical data. Ballard [8, 16] notes measurements of atmospheric temperature to ±1°C by removing the sensor 2 to 3 balloon diameters from the balloon. Davis et al. [17] nicely review much of the work mentioned here with new citations plus diagrams and data.

Generalizing about the vehicle induced perturbations is difficult. Depending upon material, the balloon's altitude history, solar radiation, time of day, etc. it could be 20°C cooler to 40°C warmer than ambient. All authors agree on maximizing the separation of balloon and sensors.

4. THE SENSOR

4.1 General Comments

All of the temperature measurements mentioned here have been with thermistors because of their large, roughly exponential, change in resistence versus temperature. Before proceeding to discuss radiosondes and rocketsondes, a few words on the basic device are appropriate. Ney et al. [11] and Wagner [12, 13] discuss the theory of air temperature measurement between 1 and 1000 mb from the classical approach to heat transfer. Various calculations concerning ventilated and unventilated sensors are substantiated by laboratory tests and flight data. Both authors note that balloon boundary induced errors may equal or exceed systematic errors. Ballard et al. [8, 16] report similar results including the corrections necessary to compensate for solar radiation at very low pressures.

The consensus is that measurement accuracies of ±1°C are achieveable and ±.5°C are possible if one is very careful. Whether one measures what he thinks is being measured depends on the thermistor's placement.

4.2 Radiosondes

Radiosondes of one form or another have been in use for over thirty years. A recent manufacturer's brochure [30] indicates that over 3 million units had been used by 1975. Since the object of this overview is not historical, only recent reports on radiosondes that adhere to the National Weather Service specification [31] are considered. Contemporary radiosondes [31] are specified at 0.4°C RMS accuracy.

Hodges and Harmantas [19] compared military and US Weather Bureau radiosondes by launching balloons with two radiosondes separated by 25 ft. (7.6m). They report that "the small systematic difference in temperature between the two groups is almost lost in the scatter and in the individual differences between pairs". The absolute of the difference is about 1°C. They discuss data in various ways, over pressure ranges, etc. and summarize that the root mean square difference for all observations is 0.51°C.

Lenhard [21] was more interested in assessing the accuracy of AN/GMD-1 radiosondes and concluded that while temperature errors for a single sounding may be about 0.7°C, the RMS "temperature errors should be considered 0.3°C or at most, 0.4°C." This coincides nicely with the manufacturer's specifications.

Report [22] on radiosonde data quality using techniques similar to [19] notes that the standard deviation of temperature measurements is +0.67°C when based on time from release +0.61°C based on pressure, and +0.84°C when processed for (interpolated) 300m intervals.

Luers [23] further substantiates these error estimates and attributes them to (1) a typical calibration error of 0.3°C plus (2) a random error of 0.2 to 0.5°C. However, citing a 1968 paper by Ballard and Rubino, he adds a radiation error of 0.4 to 1.8°C from 5 to 30 km respectively.

4.3 Rocketsondes

The same problems facing radiosondes apply to rocketsondes, but they are made worse by the decreasing air density with altitude. Most measurements are corrected through various schemes to compensate for errors discussed by Wagner and by Ney. Schmidlin [24] compares paired U.S. rocketsondes from 30 to 70 km and finds that the temperature difference increases with altitude and time between the paired flights. The RMS differences are 3.4°C at 30 km 5.0°C at 70 km. However, data analysis suggests that the repeatability of any rocketsonde is 1 to 2°C. Similar numbers are presented in Schmidlin [25]. He also found the temperature differences at altitudes of 25 to 55 km to be 1.0-1.5°C for 5 min. separations, 1.5-2.0°C for 10 min., and about 3.4°C for 20 to 60 mins. Miller [26] further substantiates these findings with a 1.08°C RMS difference between soundings of no more than 5 minute separation, but admits that an altitude increased to 59 km, 6.5°C differences were found.

Finger et al. [27] and Schmidlin [28] compare rocket measurements of various countries.

4.4 Radiosonde/Rocketsonde Comparison

Morrissey [20] reviews the significant energy transfer processes with regard to repeatability and accuracy for rockets and balloons. Configurations extant in standard 1680 MHz radiosondes and Loki/Super Loki rockets are analyzed. He presents detailed results, as a function of wavelength of ambient radiation altitude, that support previously noted numbers. However, he cautions about any general statements of comparability. "Any definitive statement on the accuracy of the measured data is not possible. It should be noted that these physical effects are correlated in many ways so that any attempt to combine them into an accuracy statement should be considered a loose approximation and recognized as non-vigorous."

Finger [29], faced with the problem of hemispheric analysis, reports on radiosondes, rocketsondes, and their comparisons. Although he notes in the radiosonde section that local "empirically derived" corrections may have to be added to the raw data, he states that the "mean radiosonde-rocketsonde temperature differences at 25 km approximated 2-3°C during winter months"; with radiosondes indicating warmer temperatures. Note that this is a mean figure from one year's data; it should be applied with the knowledge that errors in individual readings may differ substantially.

5. CONCLUSION

Selecting a meaningful summary from the information held in the articles listed in References is a formidable task. In general, radiosondes are accurate to ±1°C and rocketsondes to about ±2°C. These accuracies can be improved by about a factor of two but it is very difficult. When care is taken to remove the sensor from the vehicles envelope, refined instruments and measurement techniques show that the stratosphere exhibits local short-term temperature variations.

6. ACKNOWLEDGEMENTS

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