Radiosonde Temperature-Baseline Inaccuracy

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ABSTRACT

An analysis of tropical radiosonde temperature measurements made during the Line Island Experiment suggests that conventional radiosonde preflight procedures are inadequate in a remote tropical environment. Temperatures computed from conventional and modified baseline techniques are compared at five pressure surfaces, 1000, 800, 600, 400 and 200 mb. Temperatures obtained from the two baseline techniques showed an average deviation at 1000 mb of 0.96C for 62 soundings. These comparisons indicate that a careful examination of radiosonde calibration techniques is needed before large investments are made in future global experiments.

1. Introduction

In preparation for the Line Island Experiment, a data gathering effort in the tropics sponsored by the National Center for Atmospheric Research (NCAR) in the spring of 1967, we investigated ways of improving the accuracy of the upper air temperature measurements without making major modifications to conventional upper air equipment. A careful examination of the entire upper air system indicated that a most critical phase of an upper air sounding is the baseline check. The baseline check is a one-point calibration, matching a blocking oscillator modulator to a thermistor and hygristor. While Hodge and Harmantas (1965) have mentioned several potential sources of temperature error in baseline procedures, we will discuss one point in detail which is particularily important in the tropics. The conventional radiosonde modulator suffers a decrease in resolution at both very high and very low temperatures. If one makes the baseline at either temperature extreme in the region of relatively low temperature-frequency response, he sacrifices the accuracy of the entire sounding. This is because each point in a temperature profile is evaluated using the baseline check point as a reference.

We propose that an expanded-scale baseline modulator be used to establish the temperature baseline for a radiosonde when the baseline must be conducted at high temperatures. The expanded scale precision baseline modulator is inexpensive and its use requires little additional effort on the part of the technician. There are other ways to accomplish a more accurate baseline check but they would require more modification to conventional upper air equipment.

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2. Statement of the problem

In routine radiosonde ascents a procedure called the baseline calibration is followed prior to flight in order to provide an absolute calibration of a particular temperature-sensing thermistor used in conjuction with the particular blocking oscillator modulator unit in the radiosonde. This calibration procedure, spelled out in detail in the operations manuals (U. S. Weather Bureau, 1957) and followed meticulously by typical observers, is called the baseline check. Using high temperatures for baselining a radiosonde forces one to make the baseline in a relatively insensitive part of the temperature-frequency scale. The upper curve on Fig. 1 illustrates a typical frequency-temperature response of a conventional Weather Bureau modulator and air temperature thermistor. Since the slope of the curve is less at high temperatures, it is more difficult to resolve temperature accurately as a function of frequency.

Normally, the baseline check is made at or above room temperature since conventional baseline check boxes do not include cooling devices. This places a severe constraint on tropical upper air data because high temperatures force one to perform the baseline on a relatively flat part of the upper curve in Fig. 1. As an example, let us take the extreme temperature range 40–50C which exhibits a mean slope of 0.3 ordinate value $(°C)^{-1}$. A careful observer can consistently read frequency to within 0.2 ordinate value which, for this extreme temperature range, corresponds to 0.67C. For the 30–40C range, the uncertainty is 0.55C.

Our primary goal was to minimize the uncertainty in the temperature baseline check. A self-imposed constraint was that we utilize the standard upper air system and equipment with a minimum of modification.

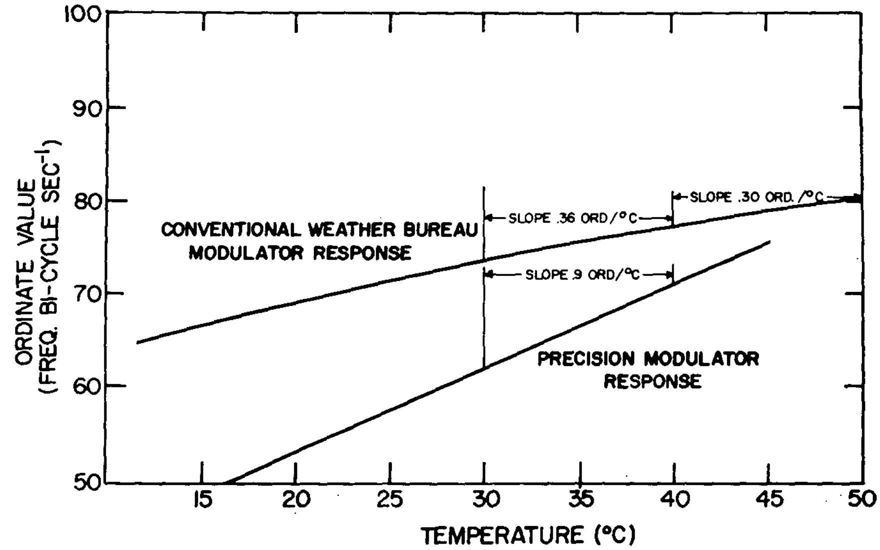

FIG. 1. Comparison of conventional and precision Weather Bureau modulator temperature-ordinate response.

3. Proposed solution of the problem

In order to assure high baseline calibration accuracy, a carefully calibrated, high sensitivity, temperature-baseline modulator was used to baseline many of the Line Island Experiment radiosonde ascents. In essence this was simply a means to use a calibrated thermistor as a sensitive thermometer and a means to insert the thermistor to be used in the actual flight into a sensitive measuring circuit. All measurements were recorded on the strip chart as well. This baseline modulator was not used to make the sounding but only to baseline the conventional sonde.

Fig. 2 is a partial schematic diagram of a baseline modulator designed to increase the slope of the frequency-temperature curve for the temperature range 10–50C. It is basically a conventional Weather Bureau radiosonde modulator and military modulator with the resistors R_0, R_0' and capacitors C_1, C_1' changed to give a steeper frequency-resistance curve. The two baseline modulators are to be used with their respective type of radiosonde. We have also added the precision scaling resistors R_1, R_2, R_3 which served to calibrate the resistance-frequency scale from which the baseline data were taken. While the modified circuit does draw approximately 0.4 mA as compared to 0.2 mA in the conven-

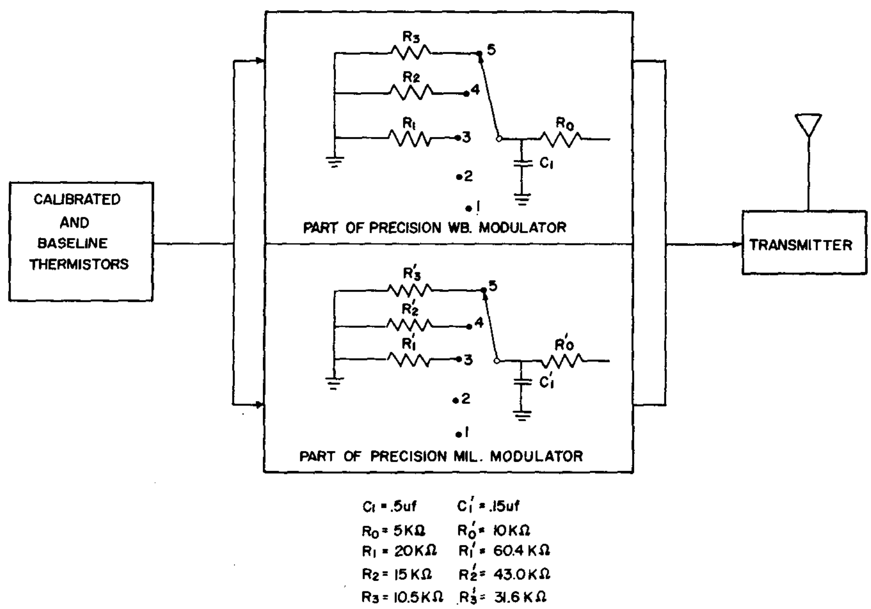

FIG. 2. Schematic diagram of the precision baseline modulator.

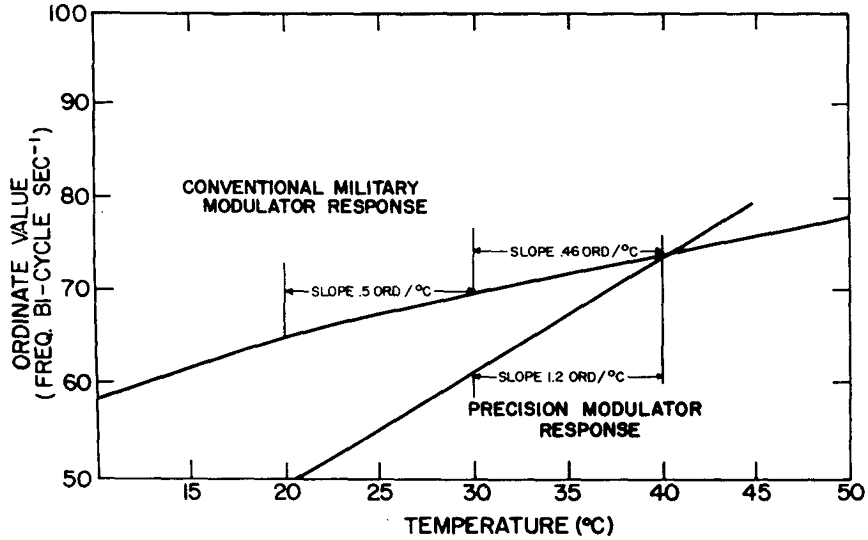

Fig. 3. Comparison of conventional and precision military modulator temperature-ordinate response.

tional sonde, tests revealed no detectable self-heating of the thermistor.

The lower line on Fig. 1 shows the temperature-ordinate relationship for the precision baseline modulator. The increase in sensitivity over the conventional sonde is obvious from a comparison of the slopes of the ordinate-temperature curves. For the temperature interval 30–40C the precision modulator gives a 2.5 times larger ordinate change for a given temperature increment than the conventional modulator, and 3.0 times greater ordinate change for the 40–50C interval. For the military sonde, Fig. 3, the precision modulator yields 2.6 times the ordinate change that the conventional sonde gives for the 30–40C interval.

The modified baseline procedure used during the Line Island Experiment on many of the upper air soundings consisted of measuring a fixed known resistance with both the baseline modulator and the radiosonde modulator, and measuring the resistance of the radiosonde thermistor and of a calibrated thermistor held in close proximity to the radiosonde thermistor, with the baseline modulator. A calibrated Weather Bureau type thermistor was used with the Weather Bureau baseline modulator and a calibrated military type thermistor with the military version. All data from this baseline check were recorded directly on the strip chart recorder used to record the radiosonde data, providing a permanent record of the baseline temperature from the calibrated thermistor trace. One may refer back to this trace and check the baseline temperature, *ex post facto*.

Clearly, the accuracy of this baseline system is dependent upon the precision of the original calibration of the calibration thermistor. This calibration may be performed under carefully controlled laboratory conditions and may be made quite accurate. It is certainly superior to the calibration which one makes in the conventional baseline where a thermometer is visually read under the pressure of a launch schedule and one has less control over the physical conditions.

The new baseline information must be converted into a form compatible with the radiosonde temperature-frequency slide rule. Over the temperature range 15–45C, the baseline-modulator frequency and the rod thermistor measured temperature are linearly related and the temperature may be computed directly. The expanded-scale frequency corresponding to the radiosonde thermistor may be converted into resistance from a frequency-resistance calibration of the precision modulator.

One may next apply (1) to compute the corresponding ordinate value for the conventional modulator, i.e.,

$$f = R_3 f_0 / (R_{\mathrm{thrm}} - f_0 K R_{\mathrm{thrm}} + R_3 f_0 K), \qquad (1)$$

where K is the reciprocal of the low reference frequency and R_{thrm} the resistance of the baseline thermistor as deduced from the precision modulator. A frequency-resistance calibration for each conventional sonde was established by placing a precision resistor, R_3 in Fig. 2, in place of R_{thrm} in the grid circuit of the sonde and recording the corresponding frequency f_0. Substituting for R_3, R_{thrm}, and f_0 into (1), one may solve for f, the conventional frequency corresponding to the temperature T. Then f and T make up the temperature baseline point. While the above conversion may appear formidable, it may be simplified by using a specially constructed slide rule.

In order to expedite the baseline procedure in the field, we constructed a slide rule, shown in Fig. 4, for the Weather Bureau baseline modulator which directly converts the new baseline information into conventional baseline parameters. It is utilized by first setting one calibration point on scales A and B which correspond to

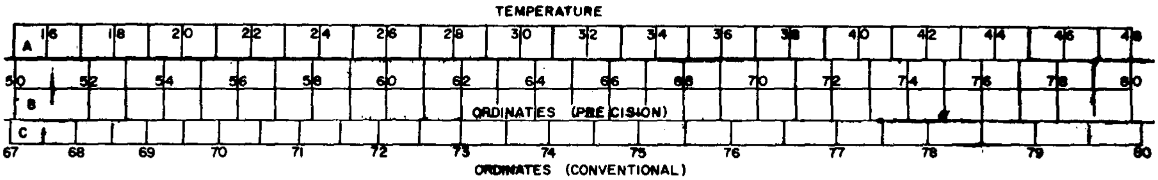

FIG. 4. Precision baseline slide rule for conversion of precision baseline data into conventional baseline parameters.

temperature and baseline modulator ordinate, respectively. Scales A and B are set once for a particular combination of a calibrated thermistor and baseline modulator and left unchanged until either the thermistor or baseline modulator is replaced. Scale C, which moves relative to scale B, enables one to convert from the precision baseline ordinate to a conventional ordinate value. The arrow at 75 on scale B must be aligned with the ordinate observed from the conventional sonde when the precision resistor R_3 is placed in the blocking oscillator grid circuit. This must be done for each sonde baselined.

The total procedure of making the precision baseline and converting to conventional baseline parameters adds approximately 4 min to the preflight preparation normally made for a radiosonde ascent.

4. Results

The Line Island Experiment offered an opportunity to test the new baseline technique in a tropical field experiment. The high temperatures and humidities provided the extreme environmental conditions to make conventional baselining techniques inadequate. Conventional baseline procedures call for a carbon hygristor element to be calibrated at values between 20 and 40% relative humidity, hardly typical of a tropical environment. In the Line Island Experiment chemical desicants were not adequate to reduce the relative humidity to the desired level so the calibration box was heated in order to lower the relative humidity to the prescribed value. While this procedure met the requirements for the relative humidity baseline, it had a serious detrimental effect on the temperature baseline, forcing the use of the flat part of the temperature-ordinate scale for the baseline calibration. The mean conventional baseline temperatures at the Palmyra and Christmas Island stations were 39.9C and 42.2C, respectively.

Thirty-nine Christmas Island soundings and 23 Palmyra soundings were evaluated using both the modified and conventional baseline techniques. The only variable between the modified and conventional evaluations was the temperature baseline; both evaluations were made from the same ordinate input data.

The precision and the conventional baseline techniques have been compared in two ways. The temperatures obtained from the two different baseline techniques at various levels were subtracted and Table 1 presents the average deviations for the Palmyra and Christmas Island soundings. The average deviation for the 1000-mb surface was 0.59C and 0.35C at 200 mb for the Palmyra soundings and 1.17C at 1000 mb and 0.75C at 200 mb for Christmas Island.

The average deviation and the arithmetic average deviation for the Christmas Island data are relatively close; however, for Palmyra the two differ markedly.

TABLE 1. Comparison of temperature data (°C) evaluated using precision and conventional baseline checks.

	Christmas Island ($K=39$)		Palmyra ($K=23$)		Total ($K=62$)	
Pressure (mb)	Average deviation	Arithmetic average deviation	Average deviation	Arithmetic average deviation	Average deviation	Arithmetic average deviation
1000	1.18	1.02	0.58	−0.05	0.96	0.63
800	1.06	0.85	0.54	−0.06	0.87	0.51
600	0.95	0.79	0.51	−0.06	0.79	0.48
400	0.84	0.72	0.44	−0.04	0.69	0.44
200	0.75	0.57	0.35	−0.03	0.60	0.35

$$\text{Average deviation} = \frac{\sum_{n=1}^{K} |T_p - T_c|_n}{K-1}$$

$$\text{Arithmetic average deviation} = \frac{\sum_{n=1}^{K} (T_p - T_c)_n}{K-1}$$

T_p is the temperature deduced from the precision baseline
T_c is the temperature deduced from the conventional baseline
K is the number of observations

The small arithmetic average deviation for Palmyra indicates that the deviation tends to be random. The lower resolution of the conventional sonde would tend to induce a random error on the temperature data since the observed baseline ordinate is as likely to be too high as too low. That this is not the case of the Christmas Island data indicates the presence of a systematic error.

A possible explanation for the systematic error is that a temperature gradient existed between the thermistor and the thermometer during the conventional baseline. Although the baseline check box is designed to minimize gradients, the large gradients between room temperature and the baseline box, as much as 15C, could be expected to exaggerate the effects of any imperfection in the gradient suppression design of the box. It is interesting to note that the mean conventional baseline temperature at Palmyra was 39.9C with a standard deviation of 0.7C while at Christmas Island the mean baseline temperature was 42.2C and the standard deviation was 3.1C.

Following this line of reasoning, one may interpret the deviation noted at Palmyra as due to the temperature-frequency insensitivity of the conventional sonde at high temperatures. However, at Christmas Island it would appear that both temperature-frequency insensitivity and the temperature gradient problems were present. Of course, some human error was involved in the instrument baseline and data analysis even though the above discussion neglects this point.

In spite of the above comparison, one may still question which answer is more correct, the temperature obtained from the conventional baseline or the one obtained from the precision baseline. We need a test which shows which method gives better, or more realistic, results.

Christmas Island data is representative of the equatorial dry zone, an area which generally experiences very steady weather conditions with remarkably little hour-to-hour or day-to-day variation. For this reason we hypothesized that the baseline procedure which produced the smoother time-sequence of air temperature on a given pressure surface was the better procedure.

The results of these comparisons are shown in Figs. 5 and 6 and Table 2. Clearly, the modified baseline procedure produces a smoother time sequence. In addition, it results in approximately 1C larger mean temperature values for all pressure surfaces than does the conventional baseline. This type of analysis was not carried out for the Palmyra data because Palmyra was in the Intertropical Convergence Zone, a region where one does not expect horizontal and temporal uniformity of temperature.

5. Conclusions

An analysis of Figs. 1 and 3 alone indicates that the resolution of the conventional radiosonde modulator is of questionable adequacy at high temperatures. The relatively simple baseline modulator makes it possible to obtain significantly more accurate temperature data in the tropics with minimal additional cost.

The baseline modulator and techniques were developed hastily in order to assure the accuracy of the Line Island upper air data. We do not pretend that these procedures are the ultimate; however, they have shown the need for a review of baseline procedures for

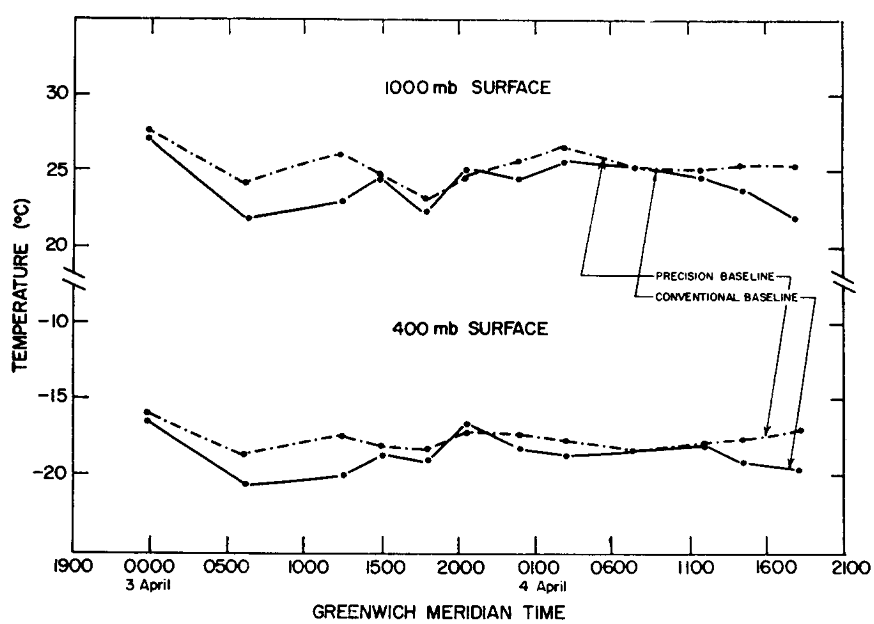

Fig. 5. Comparison of temperature evaluation from precision and conventional baselines for Christmas Island serial ascents, 3–4 April 1967.

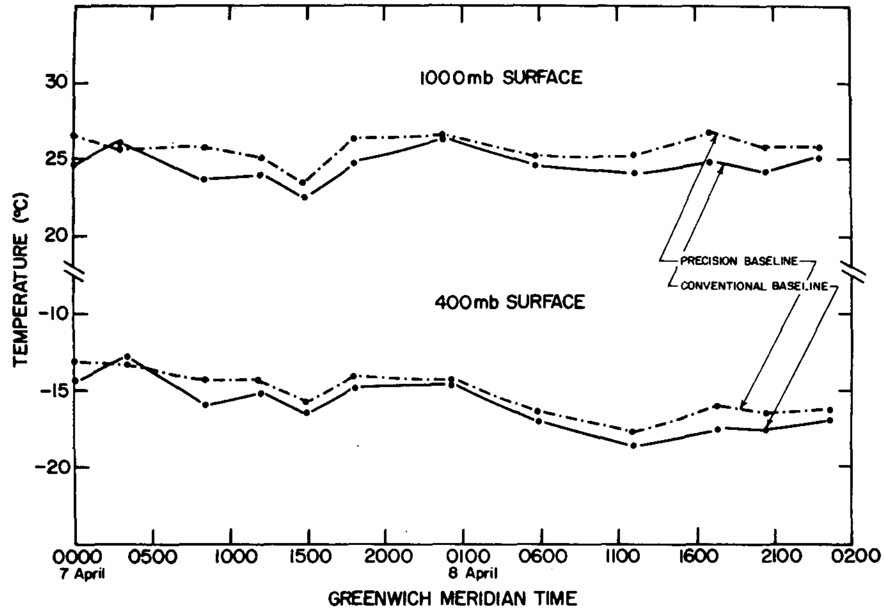

FIG. 6. Comparison of temperature evaluation from precision and conventional baselines for Christmas Island serial ascents, 7–8 April 1967.

TABLE 2. Comparison of Christmas Island serial ascent temperature data (°C) evaluated using precision and conventional baseline checks.

Pressure (mb)	3–4 April 1967 Mean temperature Precision	Conventional	Standard deviation Precision	Conventional	7–8 April 1967 Mean temperature Precision	Conventional	Standard deviation Precision	Conventional
1000	25.4	24.2	0.99	1.76	25.7	24.6	0.91	1.03
800	15.6	14.6	0.97	1.46	17.3	16.3	1.86	2.04
600	1.6	1.0	1.35	1.51	3.5	2.5	0.98	0.82
400	−17.7	−18.6	0.65	1.36	−15.1	−15.8	1.47	1.95
200	−53.3	−53.9	1.09	1.33	−53.9	−54.6	0.90	0.90

conventional radiosondes in tropical environments or whenever high baseline temperatures are encountered. It is beyond the scope of the interest of the authors to further pursue this question; however, it is of extreme importance that the calibration problems brought out in this study be considered seriously before large investments in future global experiments are made.

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