4.1 RADIOSONDE TEMPERATURE, HUMIDITY, AND PRESSURE RESPONSE AT LOW TEMPERATURES

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Three types of radiosondes were tested at South Pole Station to characterize their response to the large changes in ambient conditions that they undergo when being moved from inside a building to the cold environment outside. The response to such large changes has not been well characterized, but needs to be understood to make reliable upper-air measurements from cold stations. The sondes tested were Vaisala RS80, and two sondes from Atmospheric Instrumentation Research, Incorporated (AIR): AIR-4A and AIR-5A. Since the AIR sondes are not widely used, only the RS80 data will be presented here.

These tests were performed by initializing a sonde inside a building, then taking it outside and leaving it on the snow surface until it reported stable values of temperature, humidity, and pressure. In most cases the buildings were heated, with indoor temperatures between -5° and +25°C. In some winter tests an unheated building, with indoor temperature between -43° and -56°C was used. During the tests, outside temperatures ranged from -24° to -71°C, and were 11 to 94 K lower than the indoor temperature.

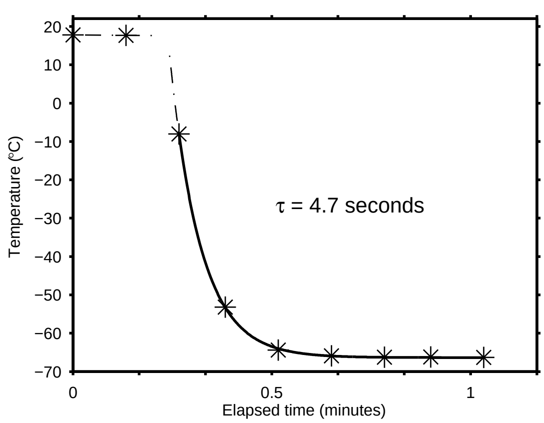

Figure 1. *RS80 temperature response when moved from a +18°C building when the outdoor temperature was -66°C. The asterisks are the reported data; the solid curve is an exponential fit; the dash-dot line approximates what would have been seen at higher resolution.*

The reported temperature responded with a simple exponential decay towards the outside temperature. Figure 1 shows the response of an RS80 temperature sensor after the sonde was moved outside from a +18°C building when the outdoor air temperature was -66°C. In this case, the e-folding time constant was about 4.7 seconds. Thirty-three tests were done with the RS80, in which this time constant ranged from 2.6 to 10.9 seconds, with a median of 5.4 seconds. These results are similar to the results of Mahesh et al. (1997).

The relative humidity response was not as easily characterized. A typical response is shown in Figure 2, where we can see that the reported humidity initially decreased, before increasing with an exponential decay to the outside value. Perhaps this initial decrease is caused by thermal lag of the hygrometer, so that it is sensing the low ambient vapor pressure, but is still warmer than the ambient air. In Figure 2 about 70 seconds pass before the exponential decay begins, and that decay has a time constant of 320 seconds. Table 1 summarizes the responses that were observed in different conditions, and shows that the response was much faster in summer than in winter.

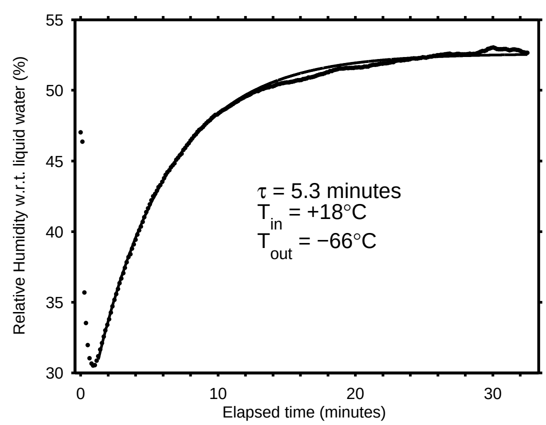

Figure 2. *RS80 humidity response for the same case as Figure 1. The dots are the reported data, and the solid curve is an exponential fit to the data.*

Table 1. *Times associated with the RS80 relative humidity response. The time t_1 is the amount of time that passed before the exponential decay, with time constant τ, began.*

	Summer	Winter	Unheated Winter
Number of tests	5	24	2
Inside T [°C]	+8 to +24	+2 to +24	-43
Outside T [°C]	-24 to -25	-45 to -71	-60
t_1 [seconds] Range (Median)	5-30 (30)	5-120 (33)	60-90 (75)
τ [seconds] Range (Median)	13-20 (15)	30-420 (146)	50-120 (85)

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Surprisingly, the reported pressure also showed a significant response in these tests. Figure 3 shows that after being moved outside, the reported pressure increased by over 8 millibars in about 300 seconds, before recovering to the actual pressure with a time constant of about 330 seconds. Table 2 summarizes the times associated with the pressure response at different temperatures. We have limited data from the summer because we did not notice this response until the winter months, and departed South Pole in spring. From the data we do have, it appears that, over the observed temperature range, the times associated with the response are not affected by the temperature or magnitude of the temperature change, but that the magnitude of the maximum pressure error increases with increasing thermal shock.

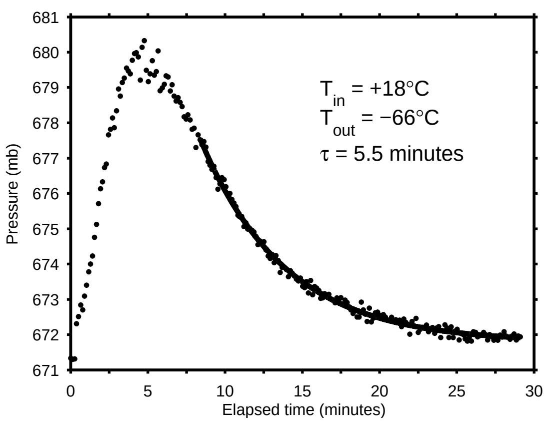

Figure 3. *Pressure reported by an RS80 when taken outside for the same case as Figures 1 and 2. The dots show the reported data, and the solid curve is an exponential fit to the latter data.*

Table 2. *Times associated with the RS80 pressure response curves. The time interval t_1 is the amount of time that passed before the maximum error, δP, was reached. The recovery had an e-folding time of τ.*

	Summer	Winter	Unheated Winter
Number of tests	1	24	2
Inside T [°C]	+24	+2 to +24	-43
Outside T [°C]	-25	-45 to -71	-60
t_1 [seconds] Range (Median)	450-450 (450)	175-450 (300)	275-400 (338)
δP [millibars] Range (Median)	3.3-3.3 (3.3)	3.5-10.0 (6.0)	0.4-1.6 (1.0)
τ [seconds] Range (Median)	Not enough data after peak to characterize	230/600 (380)	Data not exponential. About 1500 s to fully recover.

These erroneous pressures will cause an error in the reported temperature profile; an example is shown in Figure 4. To create this plot a polynomial was fit to the pressure error (similar to that shown in Figure 3) from a test on a day when the surface temperature was -61°C. This polynomial was then used to adjust the routine radiosonde profile. The error in reported pressure would not reach zero until the sonde reached 250 millibars. While the magnitude of the resulting temperature error is less than 1 K in most of the sounding, it does approach 2 K near the surface, where the magnitude of the lapse rate is very large. The maximum pressure error (not shown) occurs at about 550 millibars.

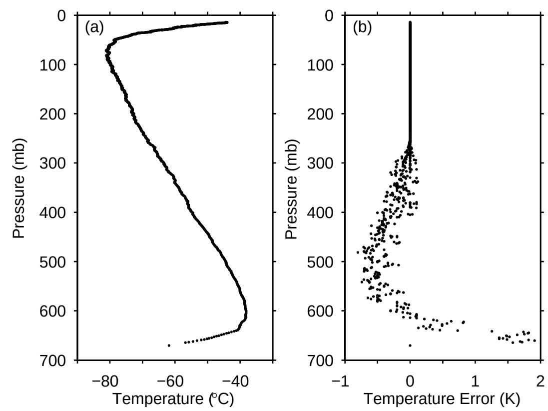

Figure 4. *The temperature profile (a) from the sounding of 00 UTC 16 October 2001, made using an RS80, and the estimated error (b) in the temperature profile that results from the pressure error.*

Finally, tests were carried out to see if the RS80 sondes could accurately report smaller changes in temperature, humidity, and pressure once they had equilibrated to ambient conditions. To do this, a sonde was tied to one end of a line that ran from the surface, through a pulley at the top of a 22-meter tower, back to the surface, and then raised to about 20 meters, allowed to equilibrate to the conditions at that height, then returned to the surface. Because of the persistent surface-based inversion at South Pole, the temperature was 3-5 K higher, and the relative humidity was 3-5% higher at 20 meters than at the surface. Ascent and descent rates ranged from 0.4 to 1.0 m s^{-1}.

A representative sample of the results from these tests is shown in Figure 5, in which we see the data reported as a sonde was lowered from 20 meters to the surface. The pressure, shown in Figure 5a, seems to equilibrate to within the noise level by the time the sonde reaches the surface, indicating a rapid response to pressure changes. In Figure 5b we see that there was a temperature reported 7 seconds after the descent was complete that was still higher than later data, indicating that it took 8 to 15 seconds after the descent for the sonde to fully equilibrate to the surface temperature. Similar results in Figure 5c show that the humidity fully equilibrated after about 15 to 20 seconds.

While the results of the tests on the tower were not perfect, they indicate that, especially with the addition of a time-lag correction, the RS80 would be capable of producing much better profiles of temperature and humidity in cold conditions if they are given adequate time to equilibrate to outdoor conditions prior to launch. These results suggest that ideally sondes would be prepared at ambient conditions, regardless of temperature. Since that is not always practical, procedures should specify that after preparation in a building, the sondes be allowed to equilibrate outside for at least 30 minutes prior to launch, and not be taken back inside, even for a short period. While the data were collected at South Pole, they indicate that these kinds of errors may exist in radiosonde data from many continental, mid-latitude stations in the winter, and from Arctic and coastal-Antarctic stations during much of the year.

The full paper presenting this work has been submitted for publication (Hudson et al., 2003).

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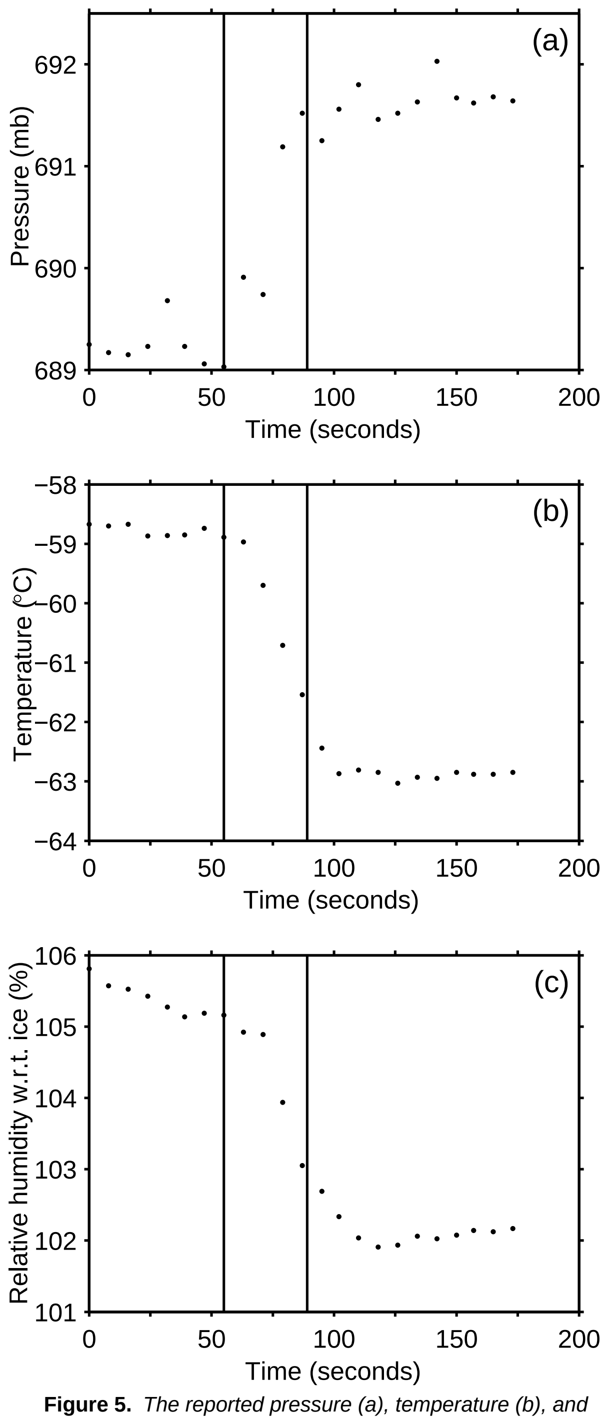

Figure 5. *The reported pressure (a), temperature (b), and relative humidity w.r.t. ice (c) as an RS80 was lowered from approximately 20 m above the surface to the surface. The dots indicate the data, at eight-second intervals, and the vertical solid lines show the times when the descent began and ended.*