The SSEC Radiosonde Launch of 19:45 UTC, 20 December 1996

A report on data handling, launch procedures and preliminary data analysis from a demonstration radiosonde flight

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Contents

1.0 Introduction

On December 20 at 19:45 UTC, personnel from the Space Science and Engineering Center (SSEC) released a radiosonde from the roof of the SSEC building on the University of Wisconsin–Madison campus. The primary objective of this launch, led by Dan DeSlover, was to allow a group of SSEC scientists interested in sonde data to learn more about the pre-launch preparation process, observe the launch itself, and investigate the data processing undertaken in the production of a typical sonde data file. Those observers present were David Tobin, Mervyn Lynch, Bob Knuteson, Barbara Whitney, and Brian Osborne.

This document describes the launch and gives some background to the technical aspects involved. Data analysis on the flight is presented in Section 4.0. The document is not intended to be a complete scientific investigation on the radiosonde launch process, but rather a useful reference for those who observed the flight, as well as an introduction for others with minimal sonde experience who wish to learn more about radiosonde data. A graphical approach to comparison between different kinds of data output is presented in Section 5.0.

2.0 The Sonde Flight

2.1 Preparing the Sonde

The model of sonde used for the flight was the Vaisala RS 80-15 L — a popular model used by a wide variety of atmospheric research groups. Dan DeSlover demonstrated the steps required to prepare the sonde. These include activating the battery, extending the antennae, removing the sensor's protective caps, and running the accompanying sonde calibration coefficient tape (unique to each sonde) through the Vaisala processor described in Section 2.2.1.

The sonde would later be attached to a 200-g balloon filled with helium to a pressure of approximately 450 psi. The amount of helium normally used varies from between 400 and 500 psi — pressures towards the 500 psi end of the range can be used to achieve a faster ascent, which is desirable when a sonde launch is used in conjunction with uplooking AERI and LIDAR instruments co-located at the launch site. A faster ascent allows the sonde to achieve altitude directly above the launch site and increases the likelihood that the sonde, AERI, and LIDAR will measure identical atmospheric conditions. Under-inflation may result in the sonde being blown down wind before much height is reached. If the spatial variability of the atmosphere is significant, this will complicate comparisons between instruments.

2.2 Receiving and Distribution of the Sonde Transmission

The radiosonde begins transmitting data, at a nominal frequency of 403 Mhz, when the battery is connected. Two different antennae are used to receive the signal: a fixed omni-directional antenna for close-range use or for use in very still conditions where the sonde goes directly up; and a directional Yagi antenna, orientated from inside the building by remote servo control, used in most cases once the signal from the omni-directional antenna becomes weak.

It is important to note that the sonde transmits two distinct datasets: the sonde-measured temperature, relative humidity and pressure (i.e., thermodynamic) information; and navigation information provided by the U.S.-wide Loran-C network of navigation transmitters (see Section 2.2.2). The thermodynamic and navigation data are handled separately by the Vaisala sonde data processor and Loran receiver respectively. These instruments are described in Sections 2.2.1 and 2.2.2. A description of the CLASS (Cross-chain

Loran Atmospheric Sounding System) software and hardware package, which plays a key role in the radiosonde operation, is deferred until Section 2.2.3.

2.2.1 The Vaisala Receiving Unit

The thermodynamic data extracted from the sonde transmission is passed to a Vaisala PP 15 sounding processor unit. The primary function of this instrument is to convert voltage and capacitance information from the sonde's sensors to pressure, temperature, and humidity using coefficients from the sonde calibration tape. A secondary function is to provide low-level data processing. For example, the time interval between the output edited pressure, temperature and humidity levels ("Computing density") can be changed between 2 (the default), 5, and 10 seconds. Users can also control when interpolation between missing data should occur and when 999's should be posted in the output, depending on their particular data integrity requirements. Though depending on the settings used, if a 10-s period of data loss occurs, the software will typically interpolate between known data points. No sign of this interpolation is evident in the final output file. There are a number of other options in the Vaisala software which can alter the output format somewhat. In addition, the Vaisala manual alludes to various "processing, editing and smoothing programs" which are not explained in detail.

It must be stressed, however, that *both* the Vaisala unit and the CLASS software, to which the sonde data is passed next, contain data processing procedures which have the potential to degrade the purity of the original, sonde-transmitted data. As the Vaisala unit does not permanently record incoming data, attention must be made to the settings before the flight to ensure that, if necessary, high-resolution data can be retrieved in the future. This is of particular relevance to those hoping to obtain high-resolution data from files created by other investigators; depending on the settings used, this may not be possible.

2.2.2 The Loran Navigation System

The Loran navigation network, administered by the U.S. Coast Guard, is a radio-navigation system in which chains of transmitters and calculations of time differences between their received signals are used to provide position information for ship, aircraft, and radiosonde operators. Navigation information collected by the sonde is re-transmitted to an Advanced Navigation, Inc. (ANI) 7000 Loran receiver unit at SSEC. The Coast Guard quotes an absolute navigation accuracy of 0.25 nautical miles, and a relative accuracy of 18 – 90 meters. The navigation information is used primarily to calculate windspeeds, but has the useful secondary function of allowing the operator to track the position of the sonde once aloft, and aim the Yagi antenna accordingly. In this way maximum signal strength can be maintained throughout the flight.

Part of the pre-launch preparation involves monitoring the Loran transmission acquisition through the CLASS PC display. Often, prior to launch, a whip antenna affixed to the building is used; the radiosonde's receiver is used once the sonde is airborne.

Those interested in sonde data from the Combined Sensor Program (CSP) cruise in the Tropical Western Pacific should be aware that for this cruise Vaisala RS 80-15 N sondes were used. These are identical to the RS 80-15 L model except that they contain electronics required to use the Omega radio navigation system (developed by the U.S. Navy), rather than the Loran system. The Omega network provides coverage to the south Pacific and other remote areas not serviced by the Loran system through eight globally-positioned transmitters. The Omega system provides less accurate location information, with 2-4 NM predictable accuracy.

2.2.3 The CLASS Software and Hardware Package

Developed by UCAR, the University Corporation for Atmospheric Research, the CLASS (Cross-chain Loran Atmospheric Sounding System) hardware and software package's key role is to facilitate and expedite radiosonde operation. Written in BASIC, the CLASS software is run easily on a DOS-equipped 386 PC. The software merges thermodynamic data from the Vaisala processor and navigation information from the ANI receiver, and executes interpolation routines (as required) to produce the final data output file. It also calculates additional columns of data, such as sonde altitude and data quality information. In addition, the CLASS system holds responsibility for archiving the flight information on disk and, by prompting the operator at each stage of the procedure, managing Loran signal acquisition, surface data entry and so on, effectively coordinates the launch.

A primary motivation for this demonstration sonde launch was to enable comparison between the final archive contents on the CLASS PC and the raw data obtained by the Vaisala unit. Initial investigations reveal that, under the operating procedure used for this launch, they are far from identical.

2.3 Entering Surface Station Data

By convention, surface meteorological parameters are not taken from the sonde sensors, but from independent ground-based instruments. A user-entered value for surface parameters can be entered up to five minutes before the sonde is launched (further delay will cause the CLASS software to prompt the user to re-enter the information).

2.3.1 Ramifications of the 5-minute Delay for Launches from Moving Platforms

The permitted 5-minute delay, if taken full advantage of, could cause problems with sonde launches from a moving platform such as a ship. At a nominal cruising speed of 13 knots, a ship will travel slightly over one nautical mile in a this period. Conditions at the position and time of the actual launch could therefore differ substantially from that entered by the operator and recorded in the first line of the sonde data file. Naturally this problem can be avoided by ensuring surface data is entered as close to the time of the actual launch as practical. In addition, it is worth noting that surface-instrument measured parameters (pressure, temperature, humidity, and current wind direction and velocity) are entered *manually* into the CLASS processing software from either a computer display (supposing a surface instrument tower with data acquisition systems is available) or alternative instruments. Opportunity for errors arise in this procedure, as occasional incorrect data in the CSP sonde archive demonstrate.

2.4 Acclimatizing the Sonde and the Issue of Solar Heating

Once the sonde transmission was successfully received, the sonde was hung outside for several minutes to let it acclimatize to the outdoors. This was especially important for this launch because of the substantial difference between the temperature of the preparation room (which was well heated) and ambient (−10°C).

During the time when the sonde is left outdoors to acclimatize, there is the opportunity for solar heating of the sensors to occur. This has received some interest of late. UCAR's Surface and Sounding Systems Facility (SSSF) responds to the issue in their web page (see Section 7.0) as follows:

"Experience has shown that if the sonde sensor arm is not protected or properly ventilated prior to launch, it can be adversely affected by solar heating. This can result in a temperature reading that is too high. This might produce a false near-surface super-adiabatic lapse rate. Due to the small thermal mass of the temperature sensor and its supportive structure this effect is not long lived. The thermal time constant of the sensor structure is on the order of 2.5 seconds and thus the problem goes away within the first ten seconds after launch (adequate sensor ventilation)."

Also affected are the humidity and dewpoint measurements. The humidicap sensor and the part of the arm on which it is mounted is rather larger than the temperature sensor, so solar heating has a potentially larger effect. As the web page notes:

'Heating of the sonde temperature/humidity sensor arm prior to launch (during sunny daytime launches) can produce an error in the low level humidity measurement (and hence dew point).The humidity sensor gives a reading of the humidity relative to the temperature of the sensor surface itself. In a situation where the sensor surface is warmer than the surroundings, the humidity reading will be lower than ambient (vapor pressure remains unchanged, "sensed" saturation vapor pressure value goes up). Due to the thermal time constant of the sensor arm (convective cooling) of about 10 seconds, the initial heating of the sensor arm affects the humidity data for roughly the first 40 seconds of the flight. (In a shaded, well ventilated situation, in which the sensor surface is in thermal equilibrium with its surroundings, an accurate ambient humidity measurement at the surface can be obtained.)"

2.5 Launching the Sonde

Barbara Whitney released the sonde once everything was set. Barbara has been investigating sonde files from a slightly different sonde processing system, in which the actual launch time is determined by the software. While this is not the case for our system, we decided to take particular note of when the sonde was actually released. For this launch, a period of 118 seconds occurred between the time the launch command was given by the CLASS software (henceforth recorded as time = 0) and the actual release of the balloon. The balloon and sonde dipped slightly a moment after release, then were away, heading to the northeast.

2.6 Sonde Descent

Those of the observation group who stayed long enough had the opportunity to observe data arriving at the Vaisala unit after the balloon had popped and the sonde was descending. Later referral to the 10-s data file revealed that for our ascent, the balloon reached a height of 21.867 km (39.4 mb) at time 5310 s (1 hr 28 min 30 sec).While data from the falling sonde is not normally recorded, for this flight we allowed the CLASS software to continue recording data for as long as possible by setting the Vaisala processor to "research mode". This is also supposed to cause "edited PTU data filtering [to be omitted]", according to the manual. (PTU data is the pressure, temperature, and humidity data). As will be shown in Section 4.3, however, some filtering does seem to occur somewhere along the processing line.

2.7 Sonde Termination

After approximately 1 hour and 40 minutes, (6010 s) the sonde failed: all thermodynamic parameters in the printout which records incoming data had become '999's, ("missing data") and the data recording was halted.

3.0 The Sonde Flight Data

The CLASS software stores the sonde flight data in a binary file. Users can then create various ASCII output files. These are described in Section 3.2, after a brief description on the filename convention used (Section 3.1).

3.1 Filename Convention

The file name convention for CLASS output files is to incorporate the file format, month, day and time in the 8-digit kernel using the format ?MDDHHMM. The first character denotes the file format: interpolated, raw, or 10-second. The month is given in hexadecimal (i.e., 1-9 for January through September, A-C for October through December). A three-digit suffix is used to denote the location of the launch (e.g., PSU – Penn State University, MAD – Madison).

3.2 ASCII Data Files

We selected 10-second, interpolated, and raw data options from the CLASS menu. Brief descriptions of each file follow. The first twenty lines of each file (40, in the case of the raw data file), appear in Appendix A.

3.2.1. 10-second data

This file, XC201945.MAD, is described in the CLASS user's manual as "...[including] 10-s wind data, the smoothed thermodynamic data, position data, and the computed data quality flags...".

3.2.2. Interpolated data

This file, IC201945.MAD, interpolates the 10-s average file to user-defined pressure intervals (for our case 5-mb). This file format is identical to that used by Chris Fairall for the Combined Sensor Program cruise.

3.3.3. Raw Thermodynamic data

This file, MC201945.MAD, restricts the listed variables to the basic thermodynamic data recorded by the sonde's meteorological sensors: pressure, temperature, relative humidity, dewpoint, plus an error indication. Originally thought to contain all data transmitted by the sonde, it appears that this is not the case. Finding where the data is lost (i.e., in the Vaisala unit or the CLASS software) is a high priority. Dan DeSlover suggests that data throughput problems may be a factor. The fact that the "raw" data appears in the file at no regular intervals in terms of time, pressure, or other parameters (see Section 4.3), suggests that this is the case.

4.0 Data Analysis

The following refers only to findings from the single ascent on December 20 and no generalization to a typical sonde ascent is implied.

4.1 Data Description

As given by the CLASS Operator's manual, the fields of data output from the CLASS system are

1. Time (s)
2. Pressure (mb)
3. Temperature (C)
4. Dewpoint (C)
5. Relative Humidity (%)
6. U Winds (m/s)
7. V Winds (m/s)
8. Wind Speed (m/s)
9. Direction (deg)
10. Vertical Velocity (m/s)
11. Longitude (deg)
12. Latitude (deg)

13. Range Downwind (km)
14. Azimuthal Angle (deg)
15. Altitude (m)
16. Qualification for P
17. Qualification for T
18. Qualification for H
19. Qualification for U Winds
20. Qualification for V Winds
21. Qualification for UV Winds

4.2 Data Integrity

As a result of the sonde radio frequency transmission's susceptibility to electrical noise and interference, data losses occasionally occur. In the 10-second data file, containing 532 lines, for example, missing thermodynamic data occurs about 1% of the time, as shown by '999' entries. Data losses in the raw thermodynamic data file are reflected simply in an omission of an expected data package, as identified by the 'time' column.

The table below gives complete performance parameters for the ascent portion of the flight from launch to 5310 s. As might be expected, performance deteriorated considerably during descent (20 temperature errors had occurred by 6010s).

Parameter	Number of errors	% Errors	Parameter	Number of errors	% Errors
Press	3	0.56	Lat	0	0.00
Temp	3	0.56	Rng	0	0.00
Dewpt	241	45.30	Az	0	0.00
RH	6	1.13	Alt	3	0.56
Uwind	13	2.44	Qp	3	0.56
Vwind	13	2.44	Qt	3	0.56
Wspd	13	2.44	Qh	220	41.35
Dir	13	2.44	Qu	13	2.44
dZ	0	0.00	Qv	13	2.44
Lon	0	0.00	Quv	13	2.44

Table 1: Parameter, Number of Errors, and % Errors due to telemetry problems for the ascent portion of the sonde flight, as recorded in the 10-second data file (532 data points).

The high incidence of 999's for the dewpoint temperature data simply reflects the fact that the relative humidity was reported as zero for a significant portion of the flight. Note the impressive performance for the navigation information, a good demonstration of the robust nature of the Loran system. In fact, the Coast Guard boasts an availability of 99.7%.

4.3 Data Frequency

In order to compare the frequency at which data packages arrive from sonde and at which data is recorded in the "raw data" file produced by the CLASS system, Brian Osborne observed and noted manually the consecutive pressure levels at which incoming data was being displayed on the Vaisala processor LCD screen. New data arrived at the rate of approximately one every one-and-a-half seconds. These noted pressure levels were then compared with consecutive pressure levels for data contained in the "raw data" file.

Those consecutive pressure levels between arbitrary pressures of 245.7 mb and 242.0 mb read off the Vaisala unit were:

245.7, 245.5, 245.3, 245.0, 244.7, 244.6, 244.3, 244.1, 243.9, 243.6, 243.4, 243.2, 243.0, 242.7,.242.4, 242.2, and 242.0 mb.

For the same pressure ranges, only data for the following pressure levels was written to the CLASS archived "raw data" file:

245.7, 243.6, 243.2, 242.0 mb.

A closer inspection reveals that this is a rather typical section of the flight. The sampling rate is given by the Vaisala PP 15 processor manual as "according to sonde cycle, within 0.5 to 2.5 s". The actual average time interval between readings as archived in the "raw" CLASS output file was 5.85 seconds, with a standard deviation of 3.7. (These figures are until the sonde burst — data retrieval was slightly more sporadic after this). It is shown by Figure 1 that there is no strong correlation between time intervals between consecutive data points and the altitude or, correspondingly, time into the flight. Figure 2 shows the spread of values for the time interval, sorted from shortest to longest.

Time intervals between successive "Raw" data as a function of flight time

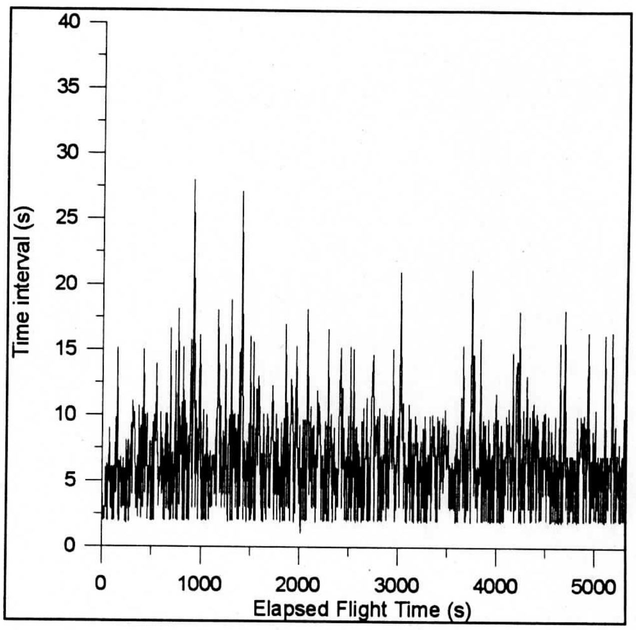

Figure 1: A line plot of time intervals between successive data in the "Raw Data" output and the time into the flight.

The problem of missing data holds some serious ramifications for the likelihood of being able to obtain high spatial resolution profiles in the boundary layer from CLASS-produced binary data files. The CLASS guide in fact states the minimum altitude for a measurement as 50 m (i.e., the height reached 10 seconds after launch). However, the Vaisala manual implies that use of the "full sensor resolution available from the radiosonde" can be obtained through the software. The header information contained in the CLASS output indicates the Vaisala PP-15 was set to 20-second smoothing, yet the research mode option should override this. Further investigation of the Vaisala equipment is necessary.

4.4 Ascent Rate

Barbara Whitney and Hank Revercomb have been investigating theoretical and experimental ascent rates of radiosonde balloons. For a 450 psi 200-g balloon, our average ascent rate was 4.1 m/s for the flight with a standard deviation of 1.05 m/s (these statistics are for the 10-s data averages). UCAR use cubic feet of helium, rather than pressure units: "Varying weight balloons are used with the radiosondes. A 200 gram balloon filled with roughly 40 cubic feet of helium will take a Vaisala sonde to 50 or 60 mb before the balloon bursts. The ascent rate obtained with this amount of helium and a Vaisala sonde is on the order of 4.5 m/s."

Histogram Plot of time intervals between successive "Raw" data

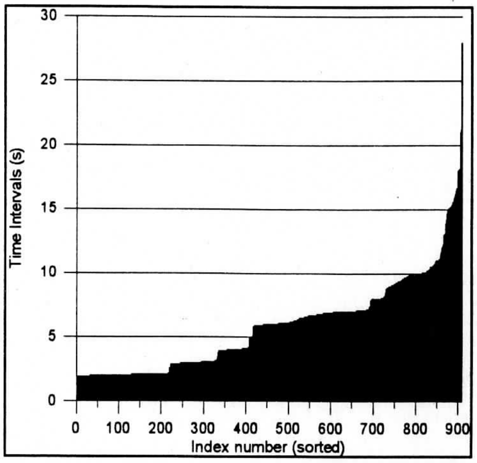

Figure 2: A histogram plot showing the spread of values of the time interval between consecutive data packages recorded in the "Raw Data" file from the CLASS software.

Initial plots of the ascent rate on the CLASS display indicated the ascent rate was quite constant. Figure 3 indicates this is approximately the case.

Radiosonde Ascent Rate

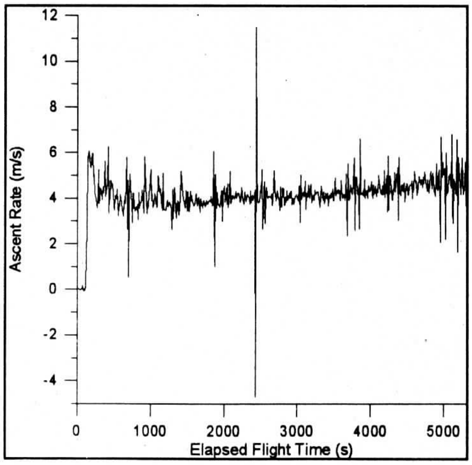

Figure 3: The relationship between the sonde ascent rate, calculated by the CLASS software using dZ/dt, for 10-second averages, and the elapsed flight time. The spike between 2000 and 3000 seconds does not appear to be significant.

5.0 Comparison of Raw, Interpolated and 10-s Data

One of the major objectives of this launch was to compare the raw, interpolated, and 10-s data files. In this section we graphically compare differences between the three files, ignoring the fact that the raw files seem to have somewhat lower resolution than expected. Emphasis is placed on the low-altitude information obtained by the sonde and its application to boundary-layer research. Please be aware that Vaisala gives accuracy specifications (appearing in Appendix B of this document) for each of the meteorological sensors. These should be reviewed in conjunction with the graphs to gain a feel for the size of the error bars which ideally would accompany each data point.

5.1 Temperature vs Time Graphs

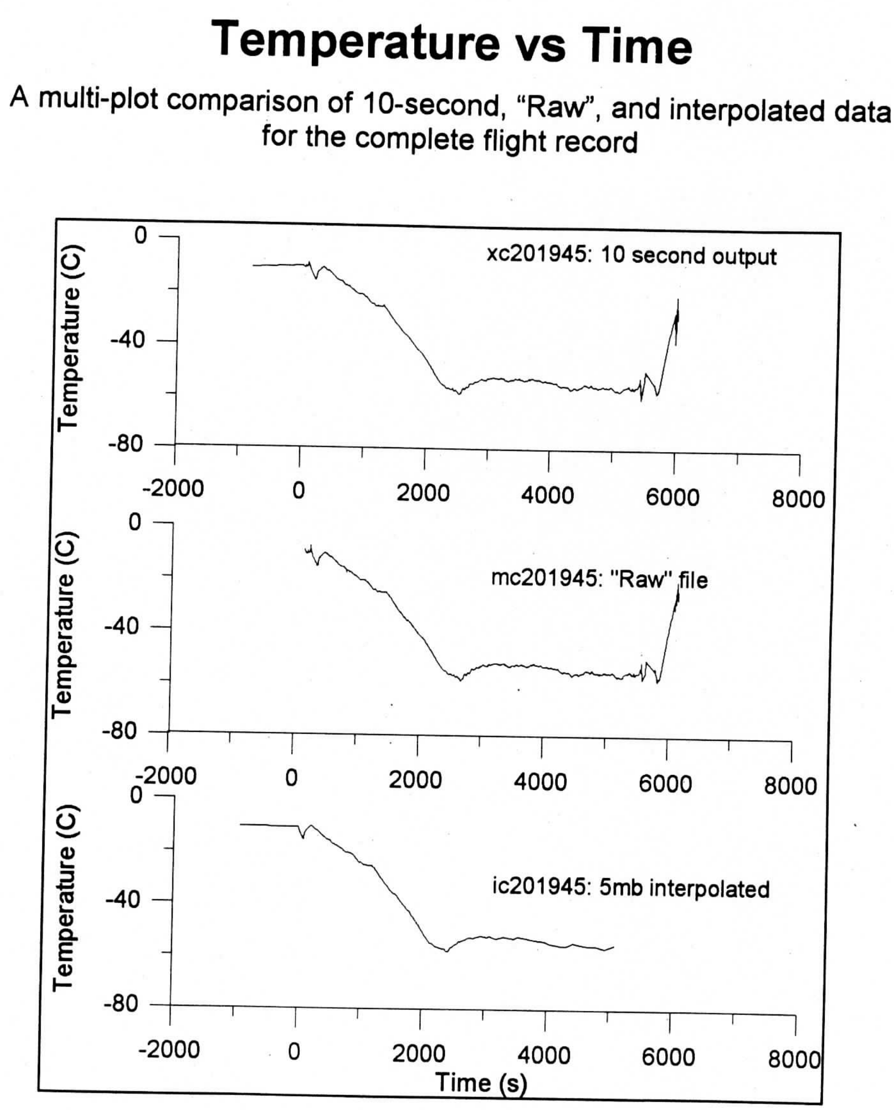

Figure 4: An overview comparison of the temperature record from the sonde as contained in the three output files created by the CLASS software. Note the 5mb interpolated file (bottom) does not contain data from the sonde descent.

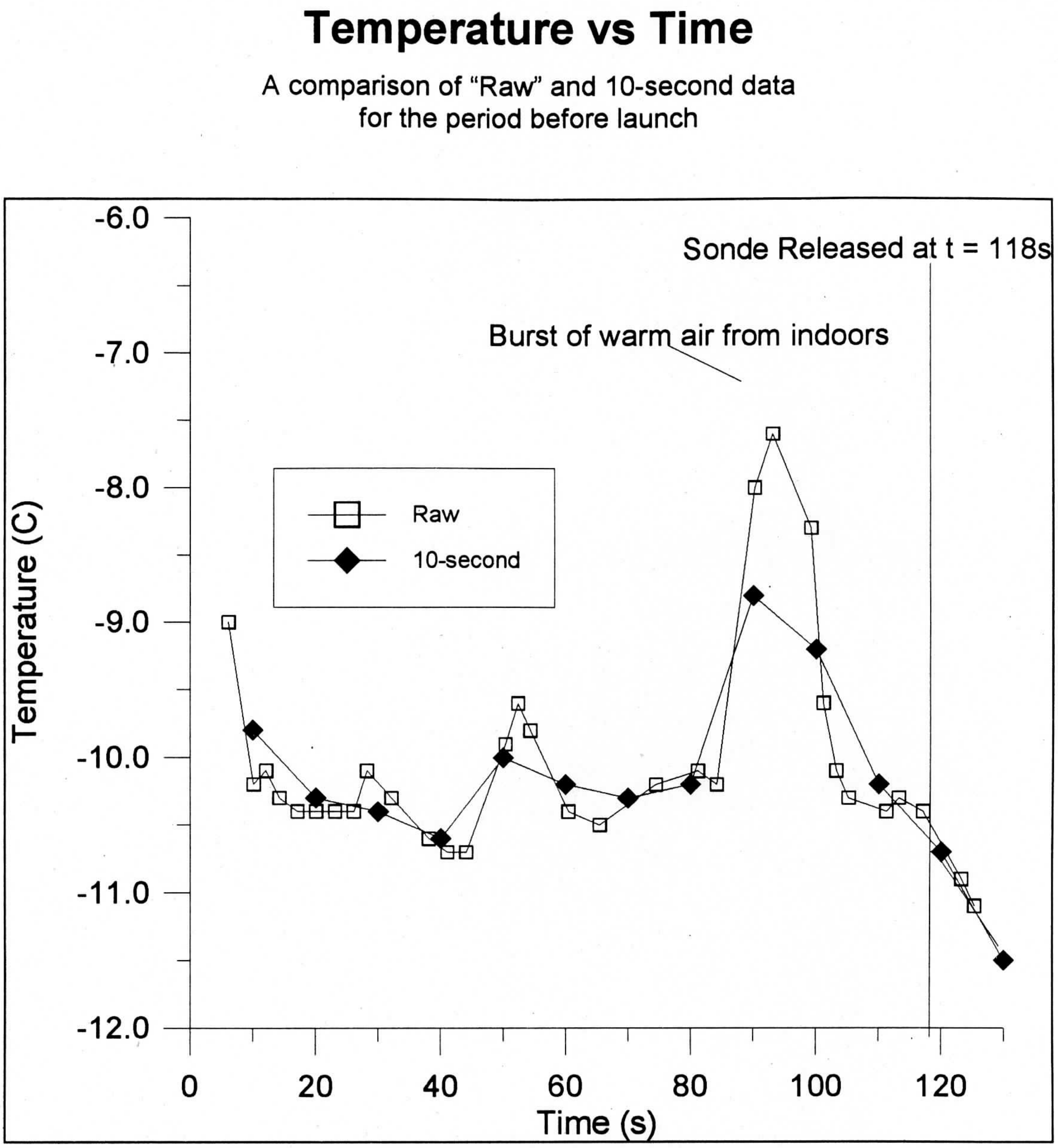

Figure 5: An overlay plot showing the sonde temperature record before launch, as portrayed by the "raw" and 10-second data files. Note the sharp increase in temperature at t = 90 seconds; this is a result of observers opening and closing the sliding door to the building in order to watch the launch from outdoors. This is a good demonstration of the sonde temperature sensor's rapid response.

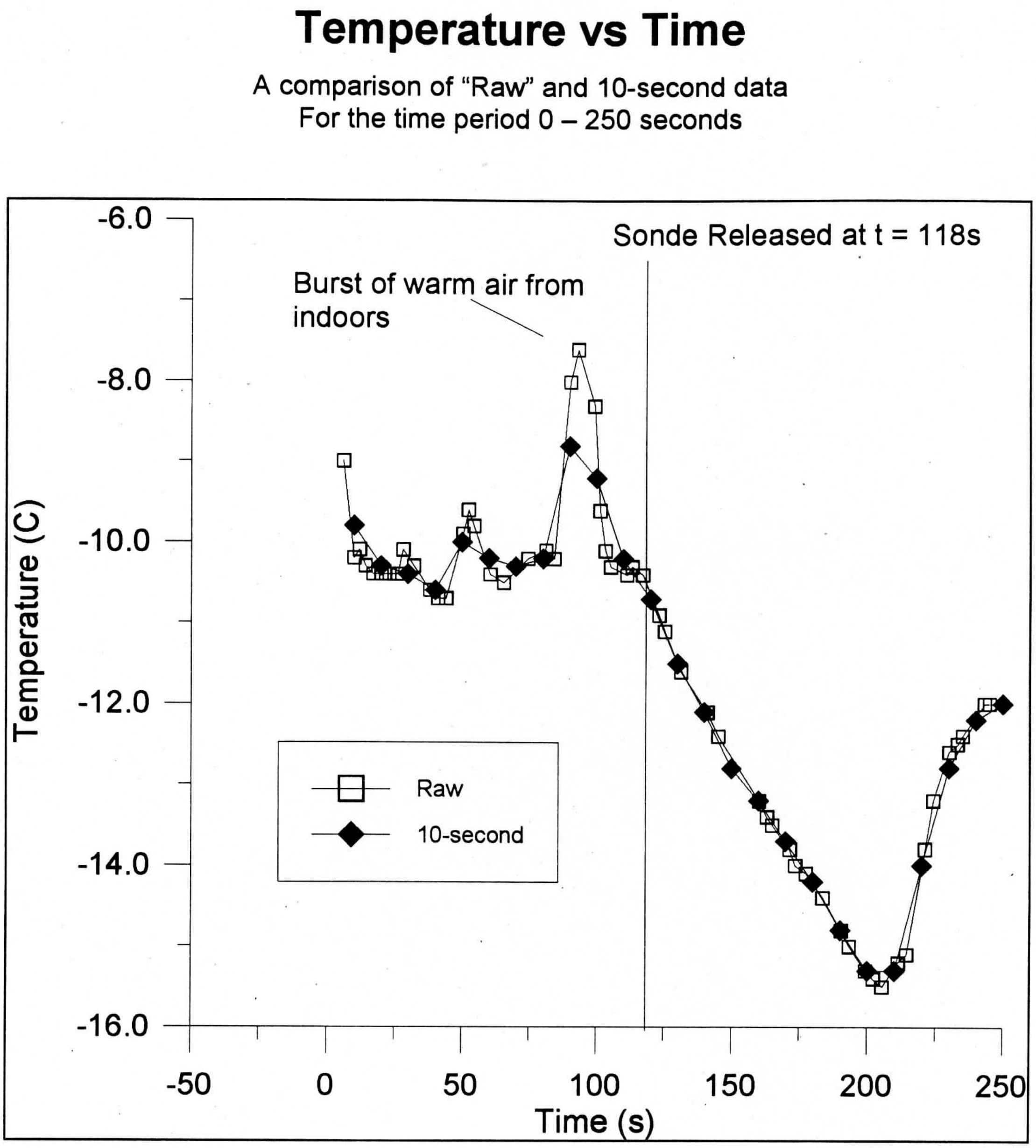

Figure 6: A comparison of "raw" and 10-second data for the pre-launch period as well as the first 132 seconds of the flight. Recall that, on average, the raw data has about twice the temporal resolution than the 10-second data. Note however, the irregular timing of the raw data points (this is especially evident in the straight section of the graph between 118 and 200 seconds).

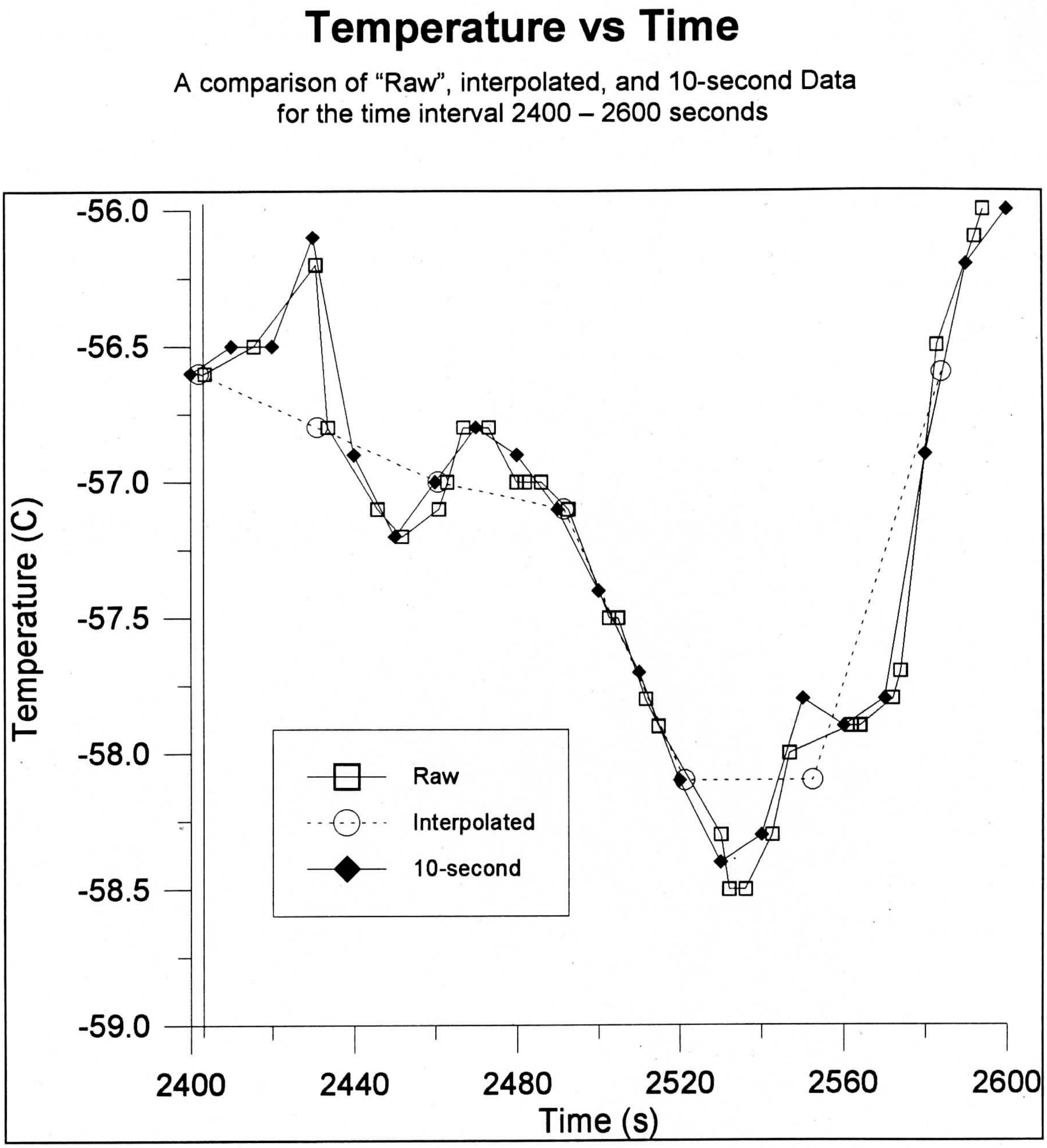

Figure 7: A demonstration of the differences between "raw", 10-second, and interpolated data for a period of significant temperature change, encountered between 2400 and 2600 seconds. Note that the interpolated data, as expected, does not show the structure revealed by the raw and 10-second data.

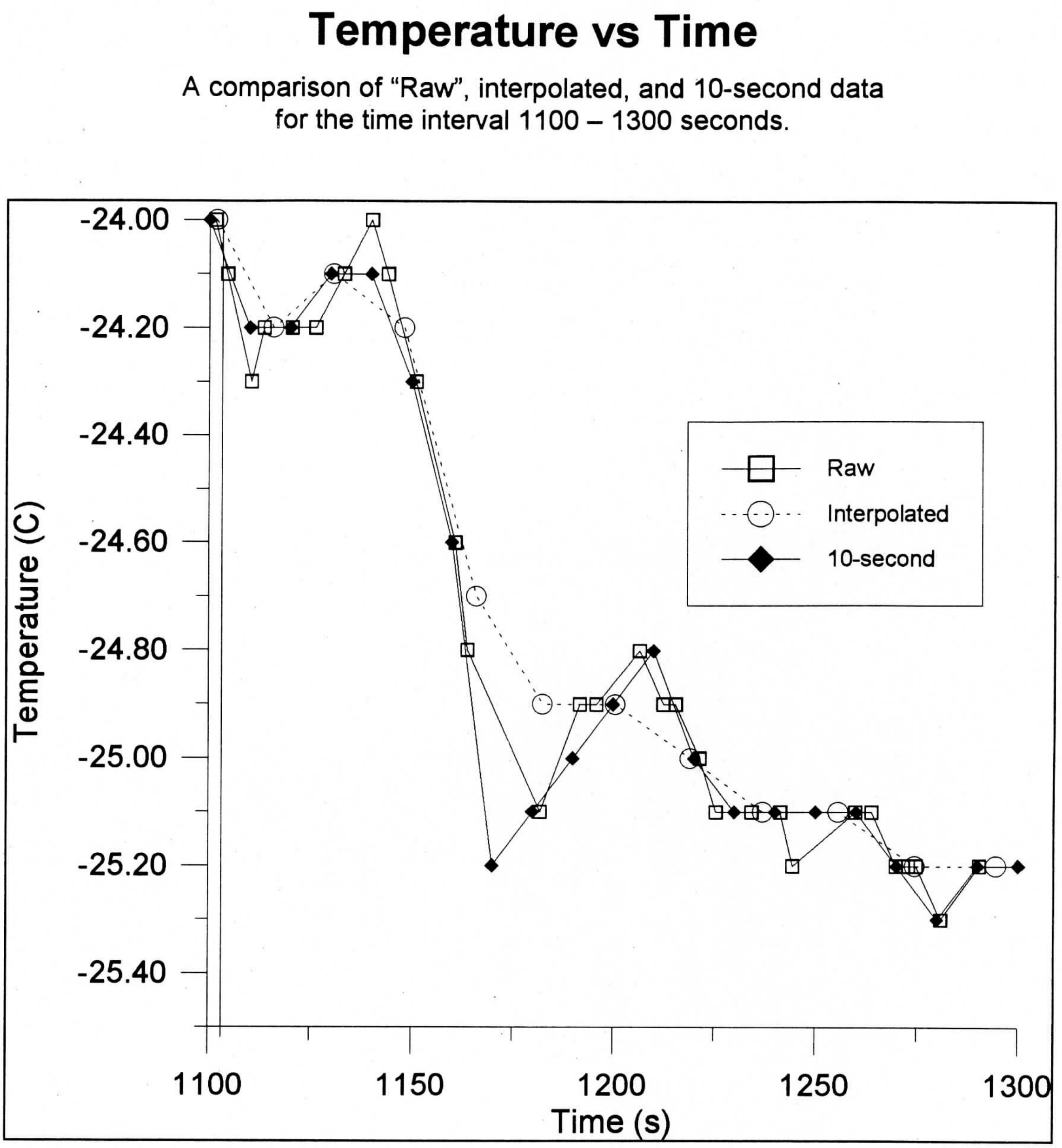

Figure 8: A comparison of another section of rapid temperature change between 1100 and 1300 seconds. Again, structure revealed in the "raw" data is not shown in the interpolated data. What needs to be determined, however, is whether this structure is significant.

5.2 Temperature Profile Graphs

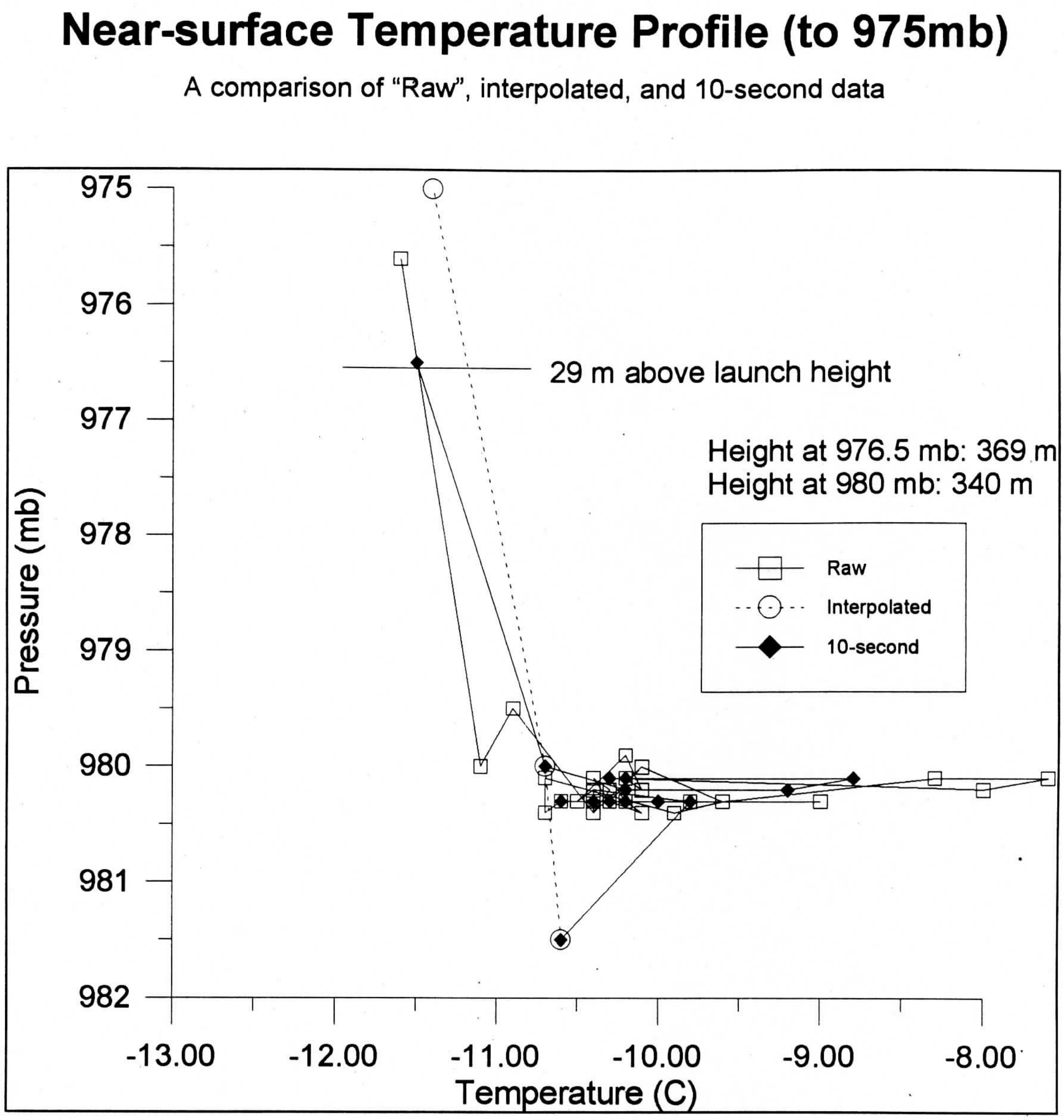

Figure 9: The low-altitude (~30m) temperature profile, as revealed through "raw", 10-second, and interpolated data files. As can be seen, in this case there is not a great deal of improvement gained in going to the raw or 10-second data in order to get a better resolution of the temperature structure. The outlier at (-10.6°C, 981.5) mb is the user-entered surface data at approximately 13 and a half minutes before the launch command was given. This is not recorded in the raw sonde data file. The scatter in results for the surface pressure (980mb) is artificially high as a result of the warm air mass from indoors passing over the sensor. Note also the scatter in the 10-second pressure data before the launch is only 0.3 mb, suggesting the stated accuracy of 0.5 mb is a conservative estimate.

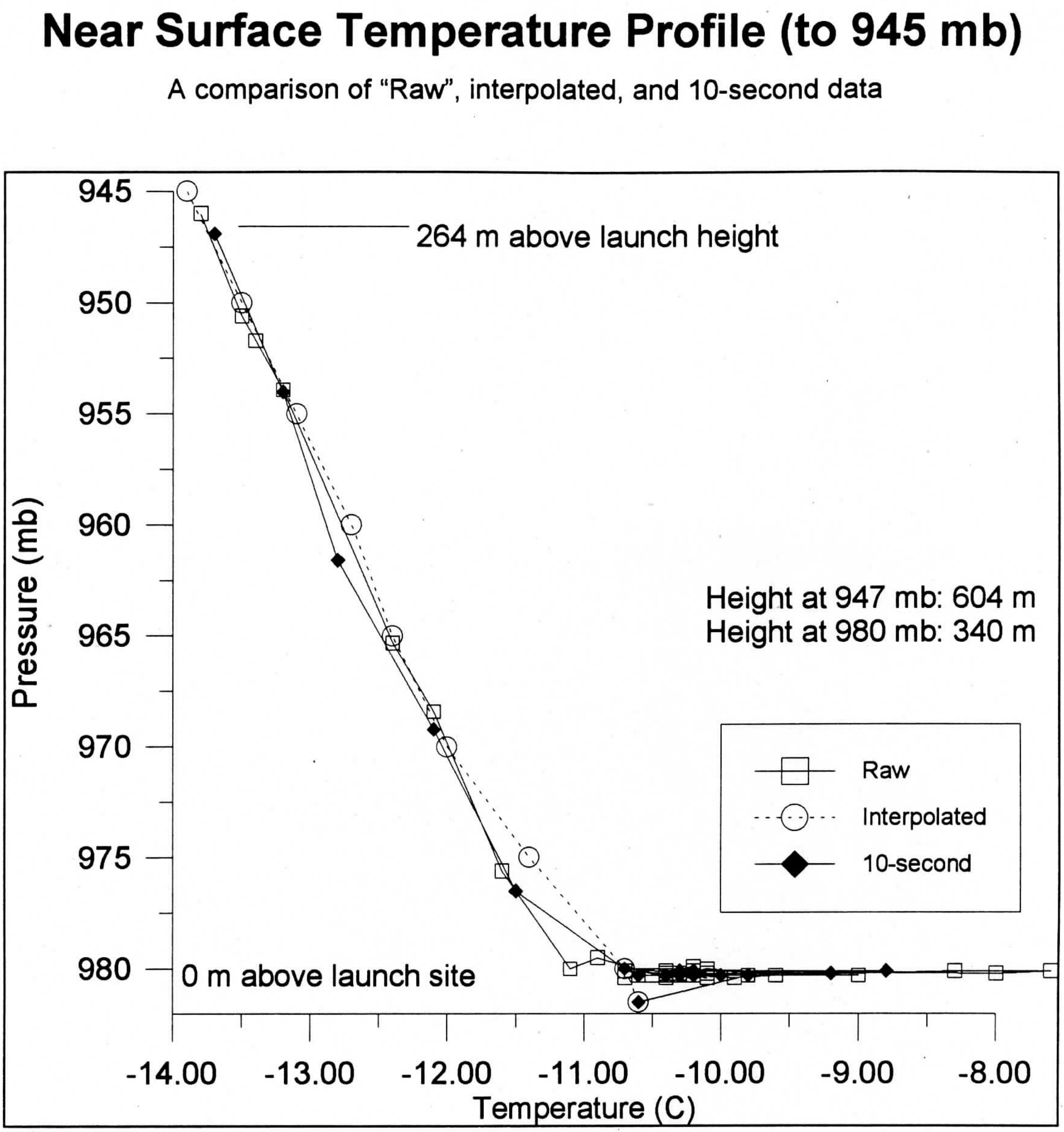

Figure 10: A demonstration of the very similar temperature profile information returned by all three data files once a larger scale is considered. Note that, while the raw data file does include more points, there is not sufficient structure to necessarily warrant them, especially for this portion of the launch. Of interest is the outlier in the 10-s data at 961.6 mb. No raw data point exists between pressures of 965.3 and 953.9 mb; it appears as though the CLASS software has simply extrapolated the pressure and temperature from the two data points at 965.3 and 968.4 mb.

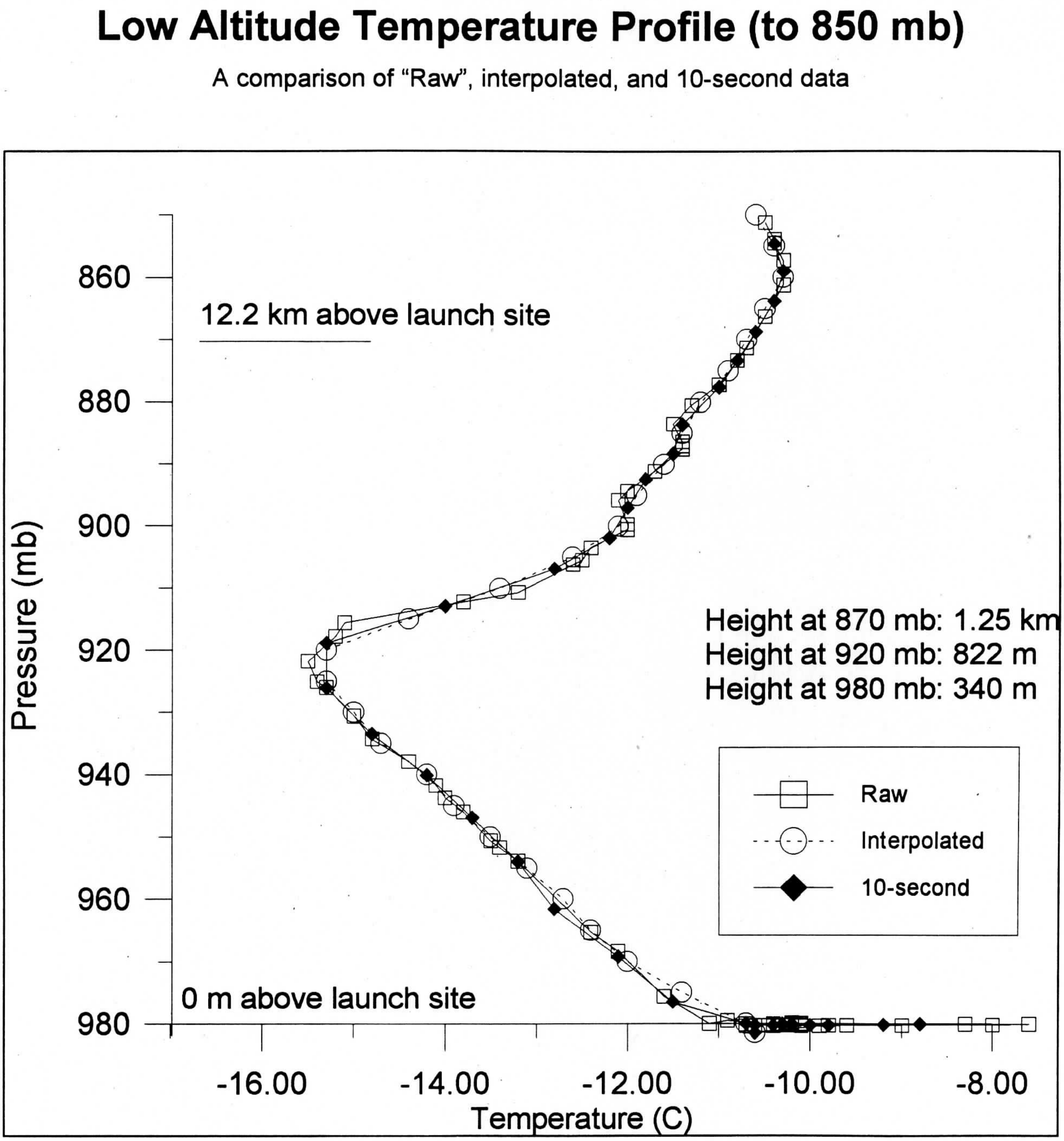

Figure 11: The temperature profile from the three output data files to 850 mb. No significant differences between the files can be seen except for the very lowest portion of the atmosphere.

5.3 Calculation of the Sonde Altitude

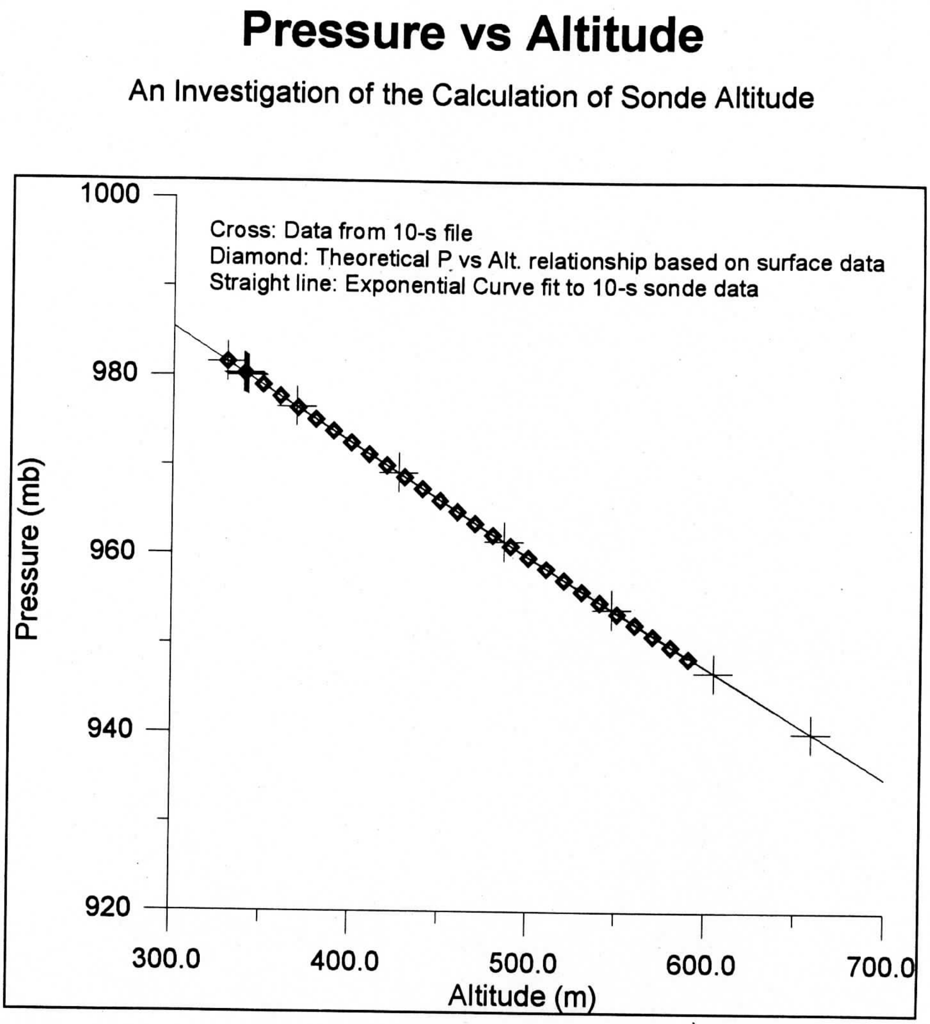

Figure 12: Pressure and altitude information from a number of sources. An investigation was made into the altitude data column which appears in the 10-s and interpolated files. Altitude information does *not* come from the Loran navigation system (this gives 2-dimensional fixes only), but by way of the standard pressure-altitude relationship and the sonde's pressure sensor. Exactly which values are used to initiate the relationship needed to be confirmed. Shown on the graph are data points from the 10-s data file, an exponential curve fit produced by the graphing software, and a theoretical relationship based on surface data. The perfect match between the sonde data (crosses) and the theoretically expected relationship (diamonds),

$$Pressure = 981.5\ (mb) \times \exp\ (-0.00013143 \times (Altitude(m) - 330m)).$$

shows that CLASS software takes the manually entered pressure and altitude values and determines a pressure and altitude relationship from this single data point. This is confirmed by the curve fit equation, which gives the pressure-altitude relationship as produced in the 10-s data file as

$$Pressure = 1025.0534\ (mb) \times \exp\ (-0.00013143 * Altitude(m)$$

which is simply a rearrangement of the first equation. As pressure decreases by approximately 1.3 mb every 10 m at launch altitude, it is clear that care must be taken when entering station data to ensure accurate heights can be determined from the resultant data files, especially in the boundary layer.

5.4 Temperature and Relative Humidity Graph

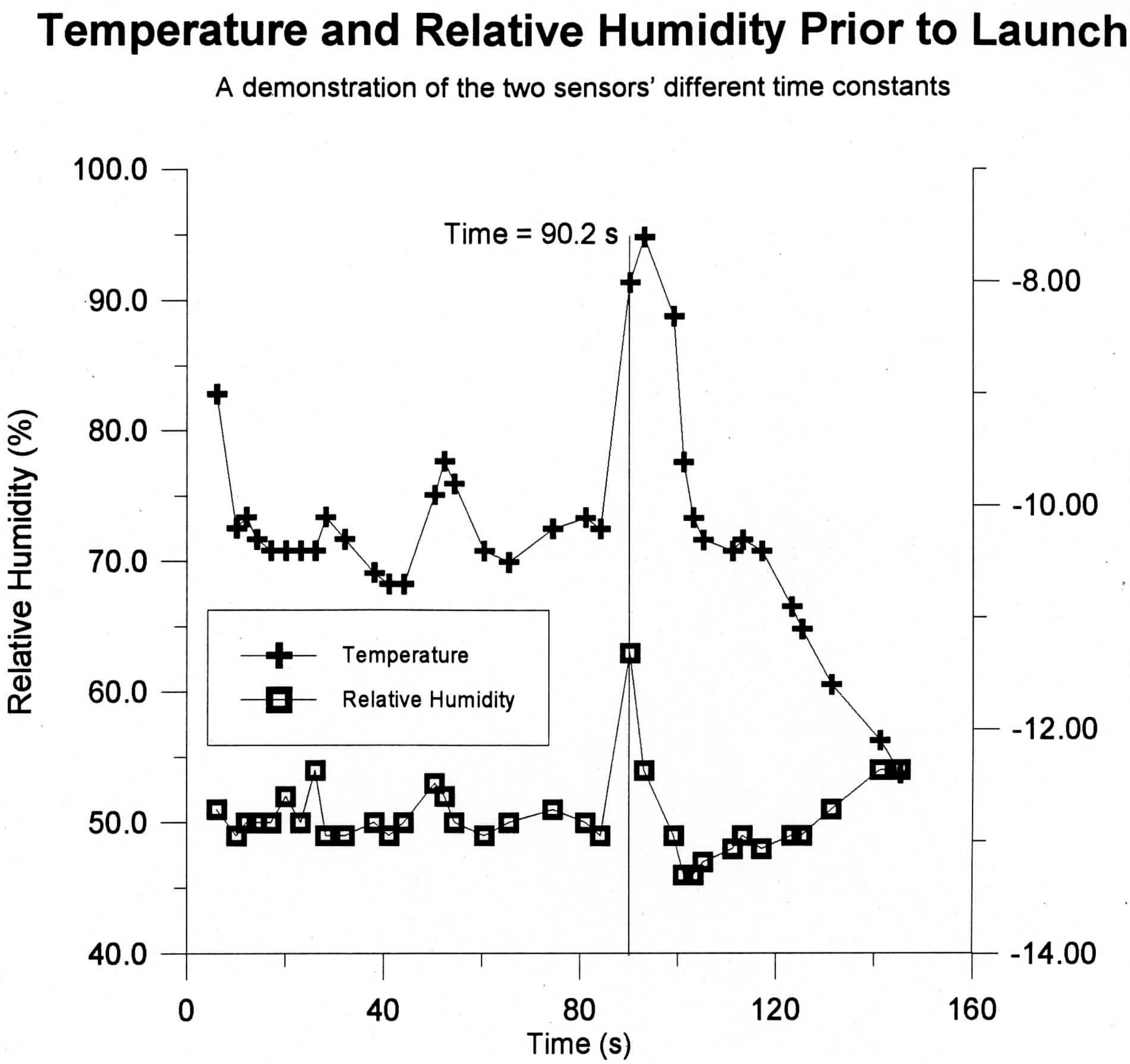

Figure 13: A comparison plot of the temperature and relative humidity as a function of time for the first 160 seconds of the raw data file record. Of interest is the difference in response time demonstrated by the two sensors to the brief burst of warm air from indoors at approximately 90.2 seconds. The relative humidity sensor reacts about twice as quickly to the brief burst of warm air from indoors as the temperature sensor. Consultation of the radiosonde specifications (Appendix B) reveals that this is as predicted by the time constants. (Recall that the *thermal* time constants of the sensors are the other way around, as discussed in Section 2.4).

6.0 Conclusion

Although radiosondes have well publicized disadvantages, such as limited frequency of flights, a normally far from vertical ascent (our flight traveled 74 km downwind), and sparse data coverage over the oceans, radiosondes still play a vital role in atmospheric research. Because of their widespread use, students and scientists alike will almost certainly come across radiosonde data at some stage of their career. It is helpful, therefore, to be aware of issues such as solar heating of the sensors, uncertainties in data processing, sensor lag, and to simply understand more about radiosonde operation in general. This document, while focusing more on ramifications for lower-altitude research, has hopefully provided useful information in this regard.

This report has investigated data processing in some detail. While the CLASS software and hardware facilitates radiosonde launches for operational use, a large amount of processing is undertaken which is not explained fully. Further research, by viewing the code if necessary, may be required to completely understand the processing involved. Similarly, the Vaisala unit must be investigated further to identify where raw data is being lost.

For those concentrating on the full range of sonde data, from the surface to high altitude, the differences between raw, interpolated, and 10-s data are minimal. For those dealing with the boundary layer, such as the author, questions remain about the usefulness of sonde data. Problems listed above take on more significance at smaller scales and complicate accurate retrieval of boundary layer properties.

There is clearly still much to learn. Understanding more about the capabilities and limitations of the radiosonde can only help in furthering our understanding of the atmosphere in which it travels.

7.0 Further Reading

For those wishing further information on the CLASS system and sonde operation in general, the University Corporation for Atmospheric Research (UCAR) SSSF home page provides a useful starting point:

http://www.atd.ucar.edu/sssf/facilities/sssf_facility_descrip/CLASS.specs.html

This page includes the sonde sensor specifications which appear as Appendix B of this document.

Further information on the Loran system is available through the U.S. Coast Guard, at

http://www.navcen.uscg.mil/loran/loranff.htm

and in more detail as the on-line Loran Users Handbook, available at

http://www.navcen.uscg.mil/loran/lgeninfo/h-book/h-book.htm

The Vaisala PP-15 and CLASS users' manuals, which provided background information for this document, are also useful documents for those wishing to learn more about radiosonde operation.

8.0 Acknowledgments

I would like to acknowledge the helpful assistance of Dan DeSlover in preparing this document.

I would also like to thank Bob Knuteson for suggesting, and helping to arrange, the demonstration sonde launch.

Appendix A: Data File Examples

MC201945.MAD Listing

Time	Press	Temp	Dewpt	RH	Err	Time	Press	Temp	Dewpt	RH	Err
6.1	980.3	-9	-17.3	51	0	38.1	980.3	-10.6	-19	50	0
10.1	980.3	-10.2	-18.9	49	0	41.1	980.4	-10.7	-19.4	49	0
12.1	980.4	-10.1	-18.6	50	0	44.1	980.1	-10.7	-19.1	50	0
14.2	980.3	-10.3	-18.7	50	0	50.4	980.4	-9.9	-17.7	53	0
17.1	980.2	-10.4	-18.8	50	0	52.4	980.3	-9.6	-17.6	52	0
20.1	980.2	-10.4	-18.4	52	0	54.4	980.3	-9.8	-18.3	50	0
23.1	980.3	-10.4	-18.8	50	0	60.5	980.2	-10.4	-19.1	49	0
26.1	980.4	-10.4	-17.9	54	0	65.5	980.3	-10.5	-18.9	50	0
28.2	980	-10.1	-18.8	49	0	74.5	979.9	-10.2	-18.4	51	0
32.1	980.3	-10.3	-19	49	0	81.2	980.2	-10.1	-18.6	50	0

Table A1: "Raw" data file sample, first 20 lines

Time	Press	Temp	Dewpt	RH	Err	Time	Press	Temp	Dewpt	RH	Err
117.1	980.4	-10.4	-19.3	48	0	177.5	941.7	-14.1	-20	61	0
123.2	979.5	-10.9	-19.5	49	0	183.6	937.9	-14.4	-19.9	63	0
125.3	980	-11.1	-19.7	49	0	190.4	934.3	-14.8	-20.1	64	0
131.3	975.6	-11.6	-19.7	51	0	193.4	930.6	-15	-20.1	65	0
141.1	968.4	-12.1	-19.5	54	0	199.4	926	-15.3	-20	67	0
145.2	965.3	-12.4	-19.8	54	0	202.3	925.1	-15.4	-20.1	67	0
160.3	953.9	-13.2	-19.7	58	0	205.5	921.8	-15.5	-20.1	68	0
163.2	951.7	-13.4	-19.7	59	0	211.4	917.8	-15.2	-19.8	68	0
165.1	950.6	-13.5	-19.8	59	0	214.5	915.6	-15.1	-19.9	67	0
171.6	946	-13.8	-19.9	60	0	221.2	912.2	-13.8	-18.6	67	0
173.6	943.7	-14	-19.9	61	0	224.3	910.7	-13.2	-18.6	64	0

Table A2: "Raw" data file sample for the first 20 lines after launch.

XC201945.MAD Listing

Time	Press	Temp	Dewpt	RH	Uwind	Vwind	Wspd	Dir	dZ	Lon	Lat	Rng	Az	Alt	Qp	Qt	Qh	Qu	Qv	Quv
-812	981.5	-10.6	-19.5	49	4	0	4	270	0	-89.407	43.07	0	0	330	77	77	77	77	77	77
10	980.3	-9.8	-18.2	50.1	-0.6	-0.3	0.7	60.2	0.9	-89.407	43.069	0	95.5	339.3	0.1	0.3	0.8	0.1	0.2	0.2
20	980.3	-10.3	-18.6	50.6	-0.6	-0.4	0.7	59.9	0	-89.407	43.069	0	114.6	339.8	0.1	0.1	1.7	0.1	0.2	0.2
30	980.3	-10.4	-18.7	50.4	-0.6	-0.2	0.6	72	0	-89.407	43.069	0	146.3	339.8	0.2	0.2	2	0.1	0.2	0.2
40	980.3	-10.6	-19.1	49.6	-0.6	0	0.6	93.3	0	-89.407	43.069	0	183.8	339.7	0.1	0.1	0.6	0.1	0.2	0.2
50	980.3	-10	-18.2	51	999	999	999	999	0	-89.407	43.069	0	183.8	339.4	0.1	0.2	1.6	99	99	99
60	980.3	-10.2	-18.6	50.1	999	999	999	999	0	-89.407	43.069	0	183.8	339.6	0.1	0.2	1.2	99	99	99
70	980.1	-10.3	-18.7	50.4	999	999	999	999	0.2	-89.407	43.069	0	183.8	341.3	0.2	0.1	0.2	99	99	99
80	980.1	-10.2	-18.6	50	999	999	999	999	0	-89.407	43.069	0	183.8	341.3	0.1	0.1	0.3	99	99	99
90	980.1	-8.8	-16.6	53	999	999	999	999	-0.1	-89.407	43.069	0	183.8	340.7	0.1	0.8	6.8	99	99	99
100	980.2	-9.2	-17.9	49.5	999	999	999	999	0	-89.407	43.069	0	183.8	340.4	0.1	0.5	2.9	99	99	99
110	980.2	-10.2	-19.3	47.6	1.5	1.6	2.2	224	0	-89.407	43.069	0	99	340	0.2	0.2	0.7	0.9	0.7	1.1
120	980	-10.7	-19.4	48.7	-0.8	2.6	2.7	162.2	0.2	-89.407	43.07	0	20.2	341.9	0.3	0.1	0.5	0.8	0.6	1
130	976.5	-11.5	-19.7	50.6	-1	3.8	3.9	165.7	2.7	-89.407	43.07	0.1	358.2	369.1	1.2	0	0.4	0.3	0.4	0.5
140	969.2	-12.1	-19.7	53.2	-0.1	6.1	6.1	178.7	5.8	-89.407	43.07	0.1	356	426.8	0.1	0.1	0.7	0.3	0.3	0.5
150	961.6	-12.8	-20.1	54	1.2	6.7	6.8	190.2	6	-89.407	43.071	0.2	359.4	486.4	88	88	88	0.2	0.3	0.3
160	954	-13.2	-19.7	58.1	999	999	999	999	6.1	-89.407	43.071	0.2	359.4	547.1	0.2	0	0.3	99	99	99
170	946.9	-13.7	-19.9	59.9	999	999	999	999	5.7	-89.407	43.071	0.2	359.4	604.2	0.4	0	0.3	99	99	99
180	940.1	-14.2	-19.9	62	999	999	999	999	5.5	-89.407	43.071	0.2	359.4	658.8	0.5	0.1	0.5	99	99	99
190	933.5	-14.8	-20	64.3	999	999	999	999	5.3	-89.407	43.071	0.2	359.4	712.3	0.9	0	0.4	99	99	99
200	926.1	-15.3	-20.1	66.7	999	999	999	999	6	-89.407	43.071	0.2	359.4	771.9	0.8	0	0.3	99	99	99
210	918.9	-15.3	-19.9	67.5	5.7	5.4	7.9	226.7	6	-89.406	43.072	0.2	8.3	831.5	0.5	0.1	0.7	0.4	0.3	0.5
220	912.9	-14	-19	66	6	5.8	8.4	226	4.9	-89.406	43.072	0.3	18	880.9	0.3	0.2	1.2	0.3	0.2	0.4
230	906.9	-12.8	-18.8	60.9	999	999	999	999	5	-89.406	43.072	0.3	18	931.1	0.5	0.2	0.7	99	99	99
240	901.9	-12.2	-19	56.8	999	999	999	999	4.2	-89.406	43.072	0.3	18	973	0.5	0	0.3	99	99	99

Table A3: 10-second data file sample, first 20 lines

IC201945.MAD Listing

Time	Press	Temp	Dewpt	RH	Uwind	Vwind	Wspd	Dir	dZ	Lon	Lat	Rng	Az	Alt	Qp	Qt	Qh	Qu	Qv	Quv
-812	981.5	-10.6	-19.5	49	4	0	4	270	0	-89.407	43.07	0	0	330	77	77	77	77	77	77
119.1	980	-10.7	-19.4	48.7	-0.6	2.5	2.6	165.8	0.2	-89.407	43.07	0	26.9	341.8	0.3	0.2	0.7	0.8	0.6	1
129.2	975	-11.4	-19.7	50.4	-1	3.7	3.8	165.5	2.8	-89.407	43.07	0	360	381	0.2	0	0.4	0.4	0.4	0.6
138.5	970	-12	-19.7	52.8	-0.3	5.7	5.8	177.4	5.3	-89.407	43.07	0.1	356.3	420.3	0.1	0	0.7	0.3	0.4	0.5
145.5	965	-12.4	-19.7	54.5	0.6	6.4	6.5	185.4	5.9	-89.407	43.071	0.1	357.8	459.8	0.1	0	0.6	0.3	0.3	0.4
152.1	960	-12.7	-19.7	56.1	1.4	6.7	6.8	191.6	6	-89.407	43.071	0.2	359.7	499.4	0.2	0	0.5	88	88	88
158.7	955	-13.1	-19.7	57.7	1.9	6.5	6.8	196	6	-89.407	43.071	0.2	0.7	539.3	0.2	0	0.4	88	88	88
165.6	950	-13.5	-19.8	59.1	2.4	6.4	6.8	200.5	5.9	-89.407	43.071	0.2	1.7	579.2	0.3	0	0.3	88	88	88
172.8	945	-13.9	-19.9	60.5	2.9	6.2	6.9	205.2	5.6	-89.407	43.071	0.2	2.8	619.3	0.4	0	0.4	88	88	88
180.2	940	-14.2	-19.9	62.1	3.5	6	7	209.9	5.5	-89.407	43.071	0.2	3.8	659.6	0.5	0.1	0.5	88	88	88
187.7	935	-14.7	-20	63.8	4	5.9	7.1	214.5	5.4	-89.407	43.071	0.2	5	700	0.8	0	0.5	88	88	88
194.7	930	-15	-20.1	65.4	4.6	5.7	7.3	218.6	5.6	-89.407	43.071	0.2	6	740.5	0.8	0	0.4	88	88	88
201.6	925	-15.3	-20.1	66.8	5.1	5.6	7.5	222.4	6	-89.406	43.071	0.2	7	781.3	0.7	0.1	0.4	88	88	88
208.4	920	-15.3	-19.9	67.4	5.6	5.4	7.8	225.9	6	-89.406	43.072	0.2	8	822.2	0.5	0.1	0.7	88	88	88
216.5	915	-14.4	-19.3	66.5	5.9	5.7	8.2	226.2	5.3	-89.406	43.072	0.3	14.6	863.5	0.4	0.2	1	0.3	0.3	0.4
224.8	910	-13.4	-18.9	63.5	6.4	6.3	9	225.3	5	-89.406	43.072	0.3	19.1	905.1	0.4	0.2	1	0.3	0.2	0.4
233.8	905	-12.6	-18.9	59.3	7.1	7.3	10.1	224.3	4.7	-89.405	43.072	0.3	21.1	947	0.5	0.1	0.5	0.3	0.2	0.3
243.9	900	-12.1	-19.1	55.9	7.8	8.3	11.4	223.3	4.2	-89.405	43.073	0.4	23.3	989.4	0.4	0	0.3	0.2	0.2	0.3
254.4	895	-11.9	-19.5	53.5	8.2	9.2	12.3	221.5	4.1	-89.404	43.073	0.4	26.4	1032	0.1	0	0.5	0.2	0.3	0.3
265.8	890	-11.6	-19.8	50.8	8.1	9.3	12.3	221	3.7	-89.403	43.074	0.6	30	1074.8	0.2	0	0.5	0.1	0.3	0.3
277	885	-11.4	-19.9	49.3	8.3	9.3	12.4	221.6	3.9	-89.402	43.075	0.7	32.2	1118	0.6	0.1	0.4	0.1	0.3	0.3
286	880	-11.2	-20.3	47	7.5	7.5	10.6	225.2	4.8	-89.401	43.076	0.8	33.6	1161.5	0.7	0.1	0.9	0.2	0.2	0.3
296	875	-10.9	-21	43.1	7.2	6.2	9.5	229.3	4.4	-89.4	43.076	0.9	35.1	1205.2	0.5	0	0.7	0.2	0.1	0.3
307.3	870	-10.7	-22	38.8	7.6	5.9	9.6	232.2	3.9	-89.399	43.077	1	36.7	1249.2	0.1	0	0.3	0.2	0.2	0.3

Table A4: Interpolated data file sample, first 20 lines.

Appendix B: Radiosonde Specifications[†]

Manufacturer, type	Vaisala RS 80-15 L or N Navaid Sonde
Mass	300 grams (with wet battery)
Dimensions	6cm × 9cm × 15cm
Ascent Rate	5 m/s avg
Transmitter Frequency	403.5 MHz
Transmitter Power	300 mW
Pressure Sensor	Capacitive aneroid
Manufacturer	Vaisala
Sensor	Capacitive aneroid
Range	3 to 1060 mb
Accuracy	0.5 mb
Data System Resolution	0.1 mb
Sensor Resolution	0.1 mb
Temperature Sensor	Capacitive bead
Manufacturer	Vaisala
Sensor	Capacitive bead
Range	-90°C to 60°C
Accuracy	0.2°C
Data System Resolution	0.1°C
Sensor Resolution	0.1°C
Time Constant	2.5 seconds @ 6m/s flow and 1000 mb
Humidity Sensor	HUMICAP thin film capacitor
Manufacturer	Vaisala
Sensor	HUMICAP thin film capacitor
Range	0 to 100% Relative Humidity
Accuracy	2.0% Relative Humidity
Data System Resolution	0.1% Relative Humidity
Time Constant	1.0 second @ 6m/s flow, 1000mb, 20°C

[†] As listed in the UCAR SSSF Homepage