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Thermocouple measurements from the main tower in CASES-99

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Abstract

As part of the Cooperative Atmosphere-Surface Exchange Study (CASES-99) thermocouple measurements were made at 34 levels to help understand turbulency intermittency and the role of mesoscale disturbances on exchanges of energy within the nocturnal boundary layer. This paper presents an overview of the thermocouple measurements and details of the data processing.

1. Introduction

The Cooperative Atmosphere-Surface Exchange Study (CASES-99) thermocouple data were collected during October, 1999 from the National Center for Atmospheric Research (NCAR) Atmospheric Technology Division (ATD) 60-m tower located east of Leon, Kansas (latitude 37° 38.88'N, longitude 96° 44.14'W). These data were part of a large-scale effort to understand the processes which control energy exchange between the land and the atmosphere within the nocturnal stable boundary layer. The thermocouple data are unique since they supply the CASES community with hi-resolution temperature information in the vertical and temporal domain. In addition to the thermocouple measurements there were 6 aspirated, slow-response temperature sensors maintained by ATD on the tower. The ATD temperatures are compared with the thermocouple temperatures, and some results are shown. Access to the thermocouple data is available on the WWW at: http://www.mmm.ucar.edu/science/abl/cases/

More information about the CASES-99 project can be found at:
www.colorado-research.com/cases/CASES-99.html

The purpose of this document is to provide details of the thermocouple experimental setup and summarize data processing techniques of these data.

2. Thermocouple Measurement Details

The thermocouple data were collected at 5 samples per second (5-Hz) using 3 Campbell CR23X data loggers and E-type (Chromel/Constantan) thermocouples located at 34 different levels on and near the main ATD tower (the two lowest levels were slightly
1 displaced from the main tower; see Figure 1). The thermocouple probes were made at Yale University under the supervision of Dr. Xuhui Lee. The Campbell CR23X data loggers were placed at low-, mid-, and high-level positions on the main tower which made it possible to reach any location on the tower with thermocouple wire of reasonable length.

The CR23X uses a thermistor to measure the thermocouple reference junction temperature within the CR23X connection box. The accuracy of the reference thermistor (±0.25°C, for a range of 0-40°C) is crucial to the absolute accuracy of the thermocouple measurement. To correct for discrepancies between the 3 data-loggers, and improve the relative accuracy of these data, a thermocouple from each data logger was placed at the 22.1 m level and it was assumed that data from these thermocouples should agree with each other.

As part of the data acquisition, the 12 channels of 5-Hz thermocouple data were written to a laptop hard drive in 468 Kb 1/2 hour-long data files (this program was written by Xinzhang Hu, a Yale graduate student). The file name includes all the information about the local time and day of data collection since no time stamp is stored within the data file. For example, the file "92920730.dat" is data from 1999, JD 292 (19 October), starting at 07:30 CST and ending at 08:00 CST. No information about whether the data are from the high-, middle-, or low-level data logger are included in the raw data files. The entire thermocouple raw data set is about 2 Gb. As part of the data processing, each 1/2 hr data file was loaded into MATLAB and then stored in files which correspond to 24 hrs of thermocouple data. The size of each "daily" file is about 76 Mb.

3. Thermocouple Data Processing

Thermocouple data processing was done on the 5-Hz data. After processing these data, lower resolution data at 1-Hz and 0.05-Hz (i.e., 1 sample per 20 seconds) were created by "picking off" points from the 5-Hz data. The 1-Hz and 0.05-Hz data are available on the WWW in netCDF format. (NetCDF was one of the acceptable data formats decided upon by the CASES-99 PIs; information about the netCDF data format is available at www.unidata.ucar.edu.) The 0.05-Hz data cover the entire month in one 18.6 Mb file and the 1-Hz data are in 28 24-hour files of 13.3 Mb each. The 1-Hz data files are from 12:00 CST (17:00 UTC) to 12:00 CST of the following day. Time stamps with the NetCDF data are in UTC time (5 hours ahead of the local time (CST) at the time of the experiment). The 5-Hz temperature data are available upon request.

Thermocouple temperatures recorded with the middle-level CR23X data-logger (S/N 1692) were found to have several (correctable) problems. Most of the processing techniques described herein are based on data from the three thermocouples at 22.1 m. The processing steps are:

- Remove spikes present in data recorded with the mid-level CR23X data logger
- Account for time differences and mean differ-

ences between data from the three different data loggers

- Comparisons with ATD aspirated temperature data

In addition to these steps other quality control measures were implemented as well. For example, any temperature data greater than 35°C or less than -15°C were deemed to be unrealistic and treated as spikes. It should be noted that some of the spikes were due to time periods when the instruments were being set-up or other work was being done on them. These time periods were typically during the daylight hours, and the nighttime data are less likely to have data quality problems.

3.1. Spike Removal

Temperature data from the middle-level CR23X were found to be contaminated with spikes (Figure 2a). The spikes were apparently related to the data logger since they always occurred simultaneously on all 12 channels and were 1-sample in duration. Typically, about 2.3% of the mid-level data were spikes. In Figure 2, two of the time series shown are from the mid-level CR23X while the other two are from the low- and high-level CR23X data loggers. Efforts to identify and remedy the mid-level CR23X spike problem in the field were unsuccessful. (Initially we suspected a grounding problem and we also tried switching the middle and lower laptops.) In the end, it was suspected that the reference thermistor within the middle-level CR23X was the cause of the spikes. Further evidence that the mid-level reference thermistor was faulty can be seen in Figure 2a, where there is a large mean difference in temperature between the mid-level 22.1 m temperature and the 22.1 m temperature from the other 2 data loggers (this problem is discussed in Section 3.2). Once it was discovered that the spikes in the mid-level data were correctable in post-processing, it was decided to leave the middle-logger data "as-is" and correct these data after the project was over.

2

The removal of data spikes consists of two parts: (1) identifying which data are spikes, and (2) a method to estimate a reasonable value which replaces the unreasonable data. A filtering technique was used to identify which data were spikes. When reasonable data were available spikes were corrected by using the median of the 14 samples near the spike. [this section needs more explanation].

3.2. Mean Corrections

Mean temperature differences between the three thermocouples at 22.1 m height are primarily due to disagreements between the internal temperature reference sensors (a thermistor) within the three CR23X data loggers. The differences were much more dramatic for data from the mid-level logger which was 2-3°C lower than data from the low- and high-level data loggers (Figure 2a). To correct for these differences, the low-level CR23X was used as the reference and data from the 2 other CR23Xs were adjusted to create a consistent data set (Figure 2b).

A mean correction value was calculated from the three 22.1 m thermocouples for each 1/2 hour of data, and Figure 3 shows the corrections througout the entire experiment. The temperature difference between data from the 3 different data loggers is influenced by incoming solar radiation, as shown in Figure 4.

Figure 3

Figure 4

3.3. Time Lags

Similar to the mean-difference problem, temperatures from the 3 thermocouples at 22.1 m revealed clock differences between the 3 CR23X data loggers. To determine the value of the time differences, 22.1 m data from the mid-level and high-level CR23Xs were shifted relative to the low-level CR23X. For each 3-hour time period, the variance of the difference between these data was calculated (see Figure 5) as the data were shifted one sample at a time. The minimum variance corresponds to the "optimal" time difference between data loggers. It should be noted that the larger variance in the "mid vs low" data of Figure 5 is due to the spikes in the mid-level data (discussed in Section 3.1).

Figure 5

After checking time-difference values for several different days (as shown in Figure 5) it was clear that the time difference between data loggers changed as the experiment progressed. A complete summary of the time shifts relative to the low-level CR23-X is given in Figure 6, where a positive value indicates that temperatures from the mid- or high-level data logger are lagging the low-level data logger data. From this information a MATLAB function was created which returns the optimum shift value for any given day and time, which were used as part of the data processing. The large jump on the afternoon of JD 296 in Figure 6 may be due to a power reset which occurred near that time. From the ATD Logbook (entry #166 by Steve Semmer):

Figure 6

ADAMS, Site tower, Sat 23-Oct-1999 17:04:27

> CDT All the ADAMS were reset at 16:09 local. At this time, I do not know why. They came back up without the need for human input.

As a final check that the corrections were being applied correctly to the data 2.5 minute time series of the 22.1 m data were plotted for eight different times throughout a given day. An example of such a plot
7 is given in Figure 7. The top panel in each 2-panel pair shows the temperature data before despiking and shift corrections, while the lower panel shows the same data after applying corrections.

3.4. ATD Comparisons

As mentioned previously, ATD maintained aspirated, slow-response temperature sensors on the main tower at 5, 15, 25, 35, 45, and 55 m. The ATD data were compared with the thermocouple data to get an estimate of the thermocouple data accuracy. There is a small offset between these two data sets which switches sign comparing the nighttime and daytime data. During the night the aspirated ATD sensors are slightly warmer by 0.1-0.2°C.

There was one ATD sensor whose temperature agreed well with the nighttime thermocouple temperature, but that sensor was an old sensor which was replaced part way through the experiment. [need to add more here]. From the ATD Logbook (entry #147 by Steve Semmer):

> TRH, Site tower, Wed 20-Oct-1999 11:37:37 CDT, 15m TRH replaced The 15m TRH humidity level has been low compared to the other sensors on the tower, ~2%. The sensor was replaced with one of the spares. This occurred at ~11:20 local time. Will monitor its performance.
>
> 1500 CDT, Oct 20 This appears to have increased both the T and RH values slightly and they now both fit into the 55m tower profile better. Steve found that the previous 50Y was an older type and the PRT had been replaced with a smaller, faster-response transducer (during CASES97?) – twh

4. Discussion and Conclusions

Techniques used to process the CASES thermocouple data were presented. These processed temperature data will provide the CASES community with an excellent source of high vertical resolution temperature information near the ATD tower.

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References

Anderson, S. P., and M. F. Baumgartner, Radiative heating errors in naturally ventilated air temperature measurements made from buoys, *J. Atmos. Oceanic Technol.*, *15*, 157-173, 1998.

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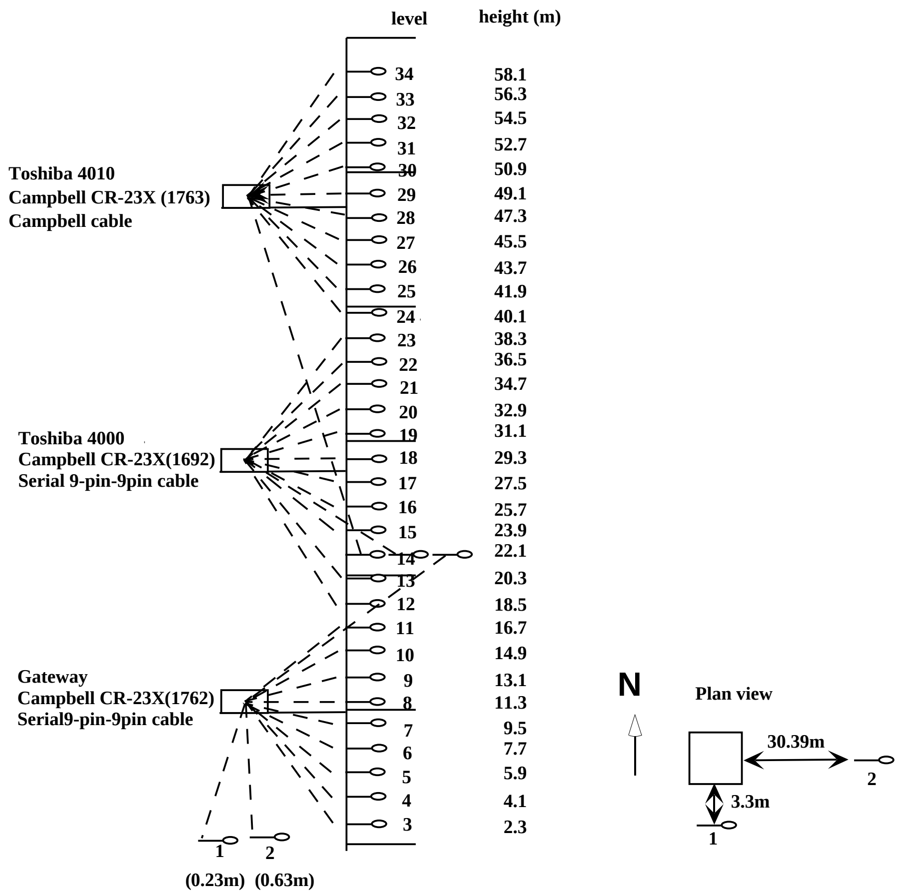

Figure 1. Thermocouple configuration on the ATD 60-m Tower.

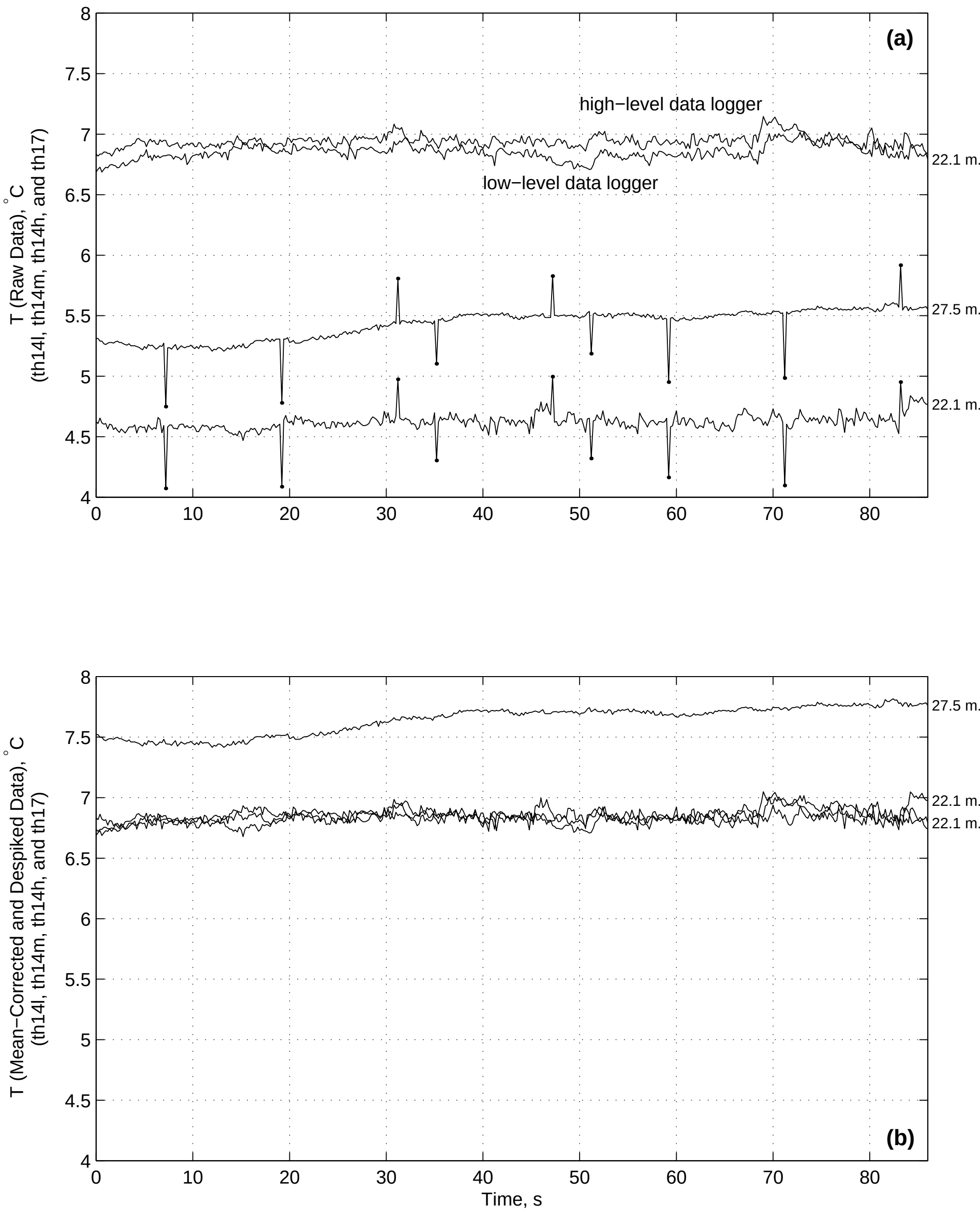

Figure 2. An 86-s time series of thermocouple temperature (a) without and (b) with mean correction and despiking. Three sensors are at 22.1 m (low, mid, and high data loggers) and one is at 27.1 m (mid-level data logger) from 17 October (JD 290), 23:58:33 - 24:00:00 CST. The height of each sensor is shown on the right-hand side. (Note that these are nighttime stable boundary layer data which is why the temperature at 27.5 m is warmer than at 22.1 m.)

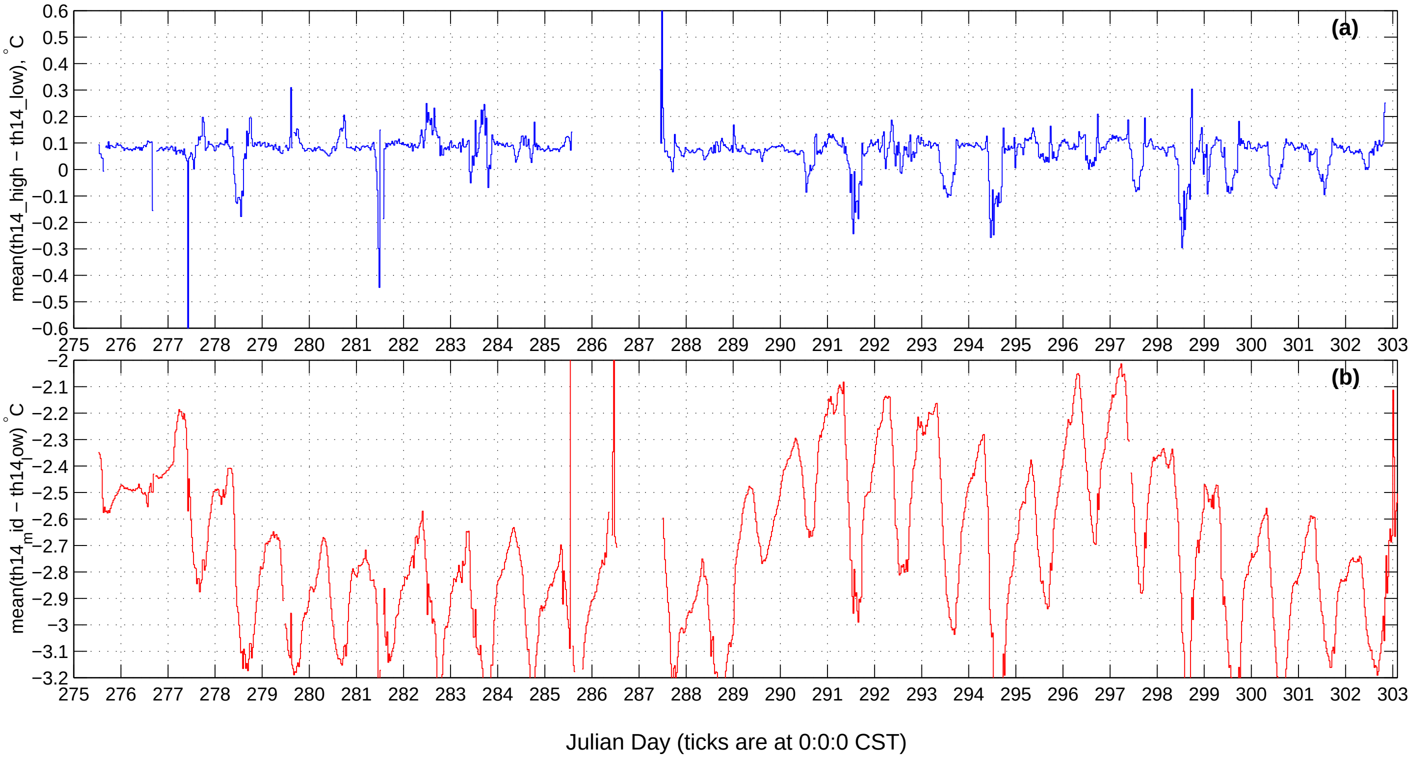

Figure 3. The mean correction to the (a) high-level and (b) mid-level logger thermocouple data (at 22.1 m) which makes the data agree with the 22.1 m temperature from the low-level logger. Mean corrections are calculated for each 1/2 hr of data.

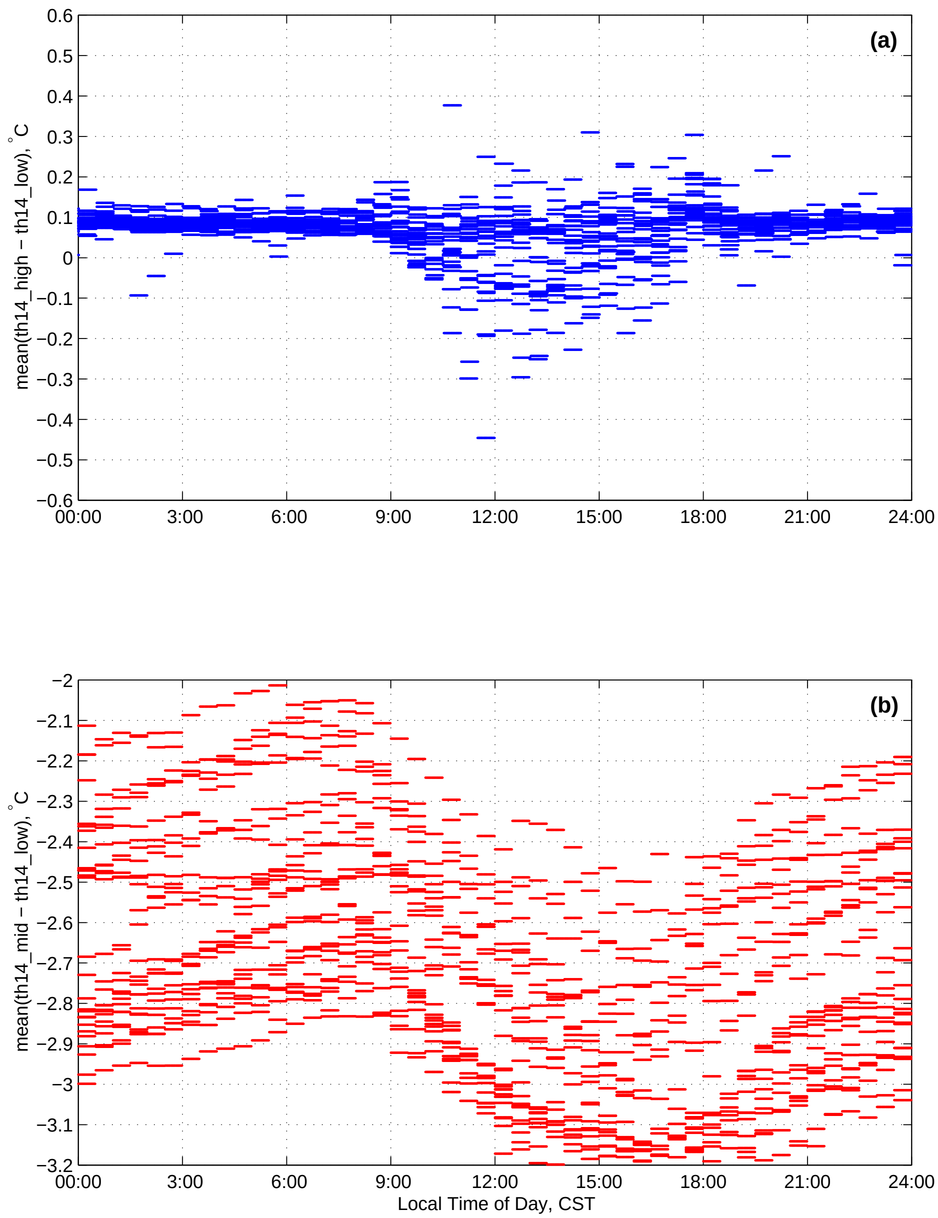

Figure 4. Same data as in Figure 5, but plotted versus the local time of day (CST).

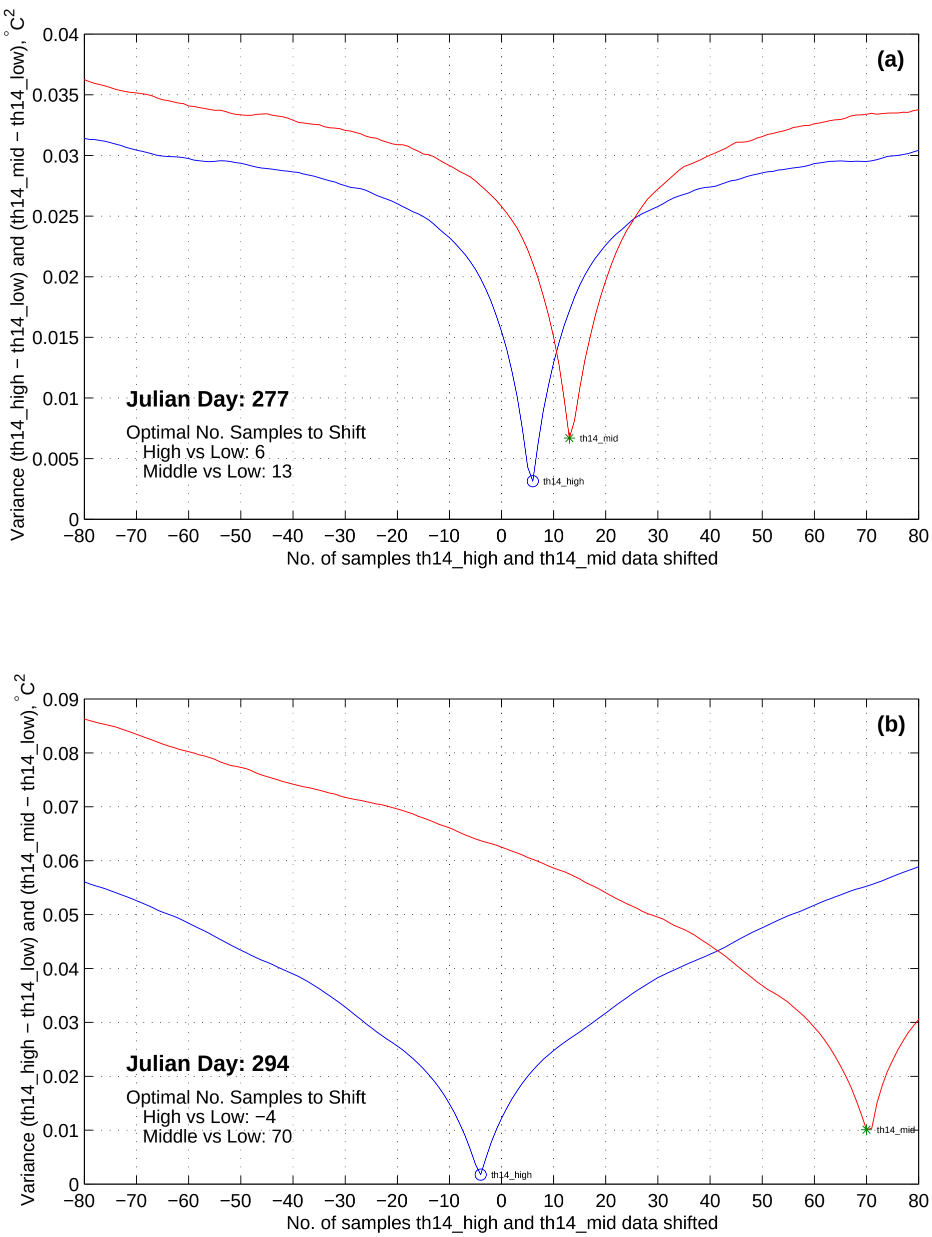

Figure 5. The method used to estimate time differences between the low-level Campbell data loggers and the high- and mid-level data loggers. To calculate these statistics 3 hours of data are used from the 3 thermocouples at 22.1 m for Julian Day (a) 277 and (b) 294.

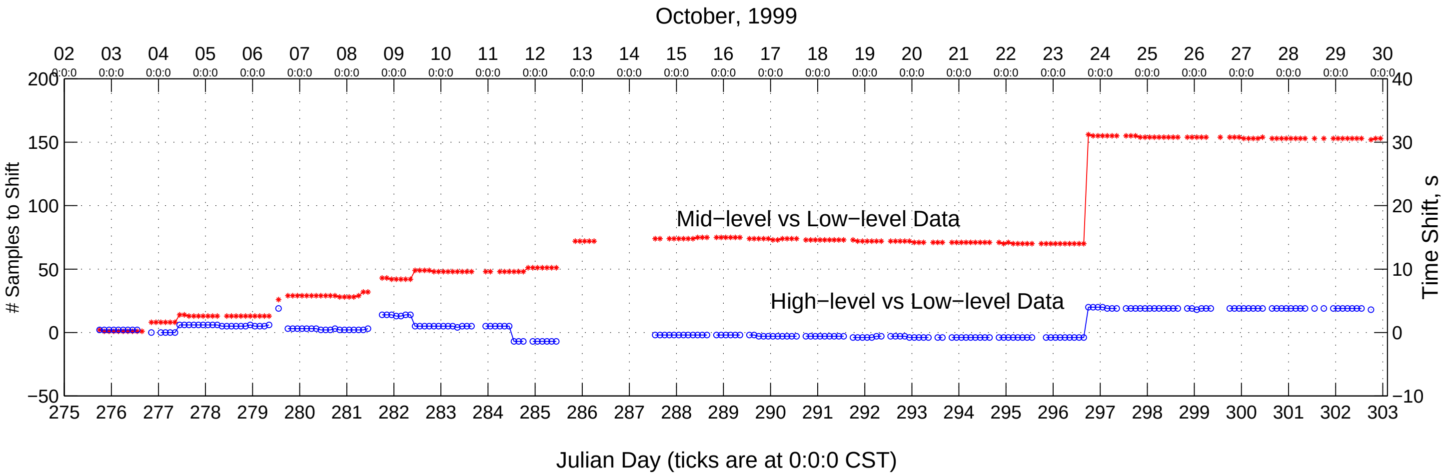

Figure 6. Time differences between the 22.1 m temperature data from the low-level data logger and mid- and high-level data loggers throughout the entire experiment. Values are calculated based on 3-hour time periods.

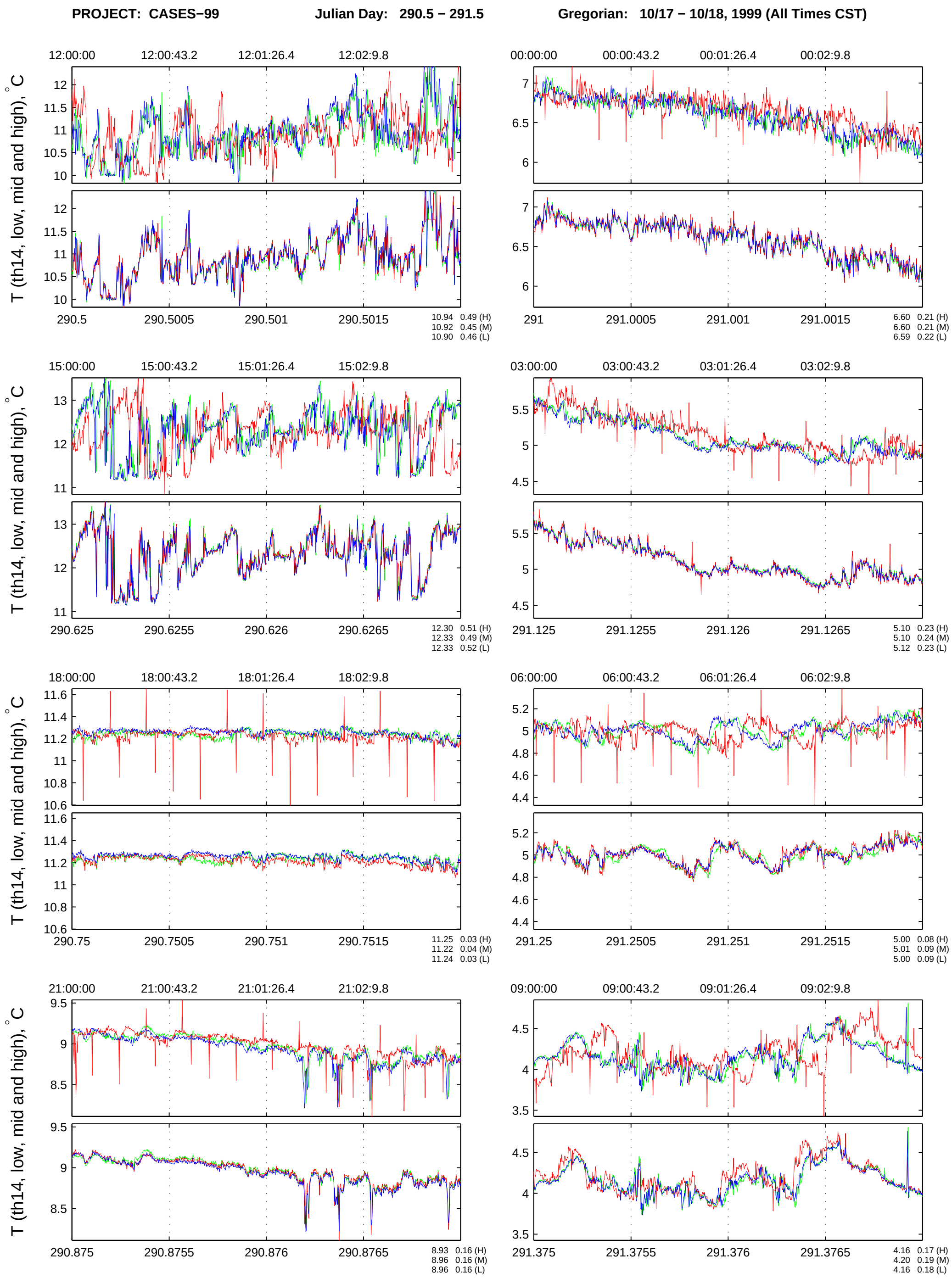

Figure 7. Temperature time series of the three thermocouples at 22.1 m from each of the three data loggers (high, mid, and low). Each time series pair is 2 minutes and 30 seconds long, and shows the data without despiking and lag-correction (top) and with these corrections applied (bottom). The mean correction has been applied to all data shown.

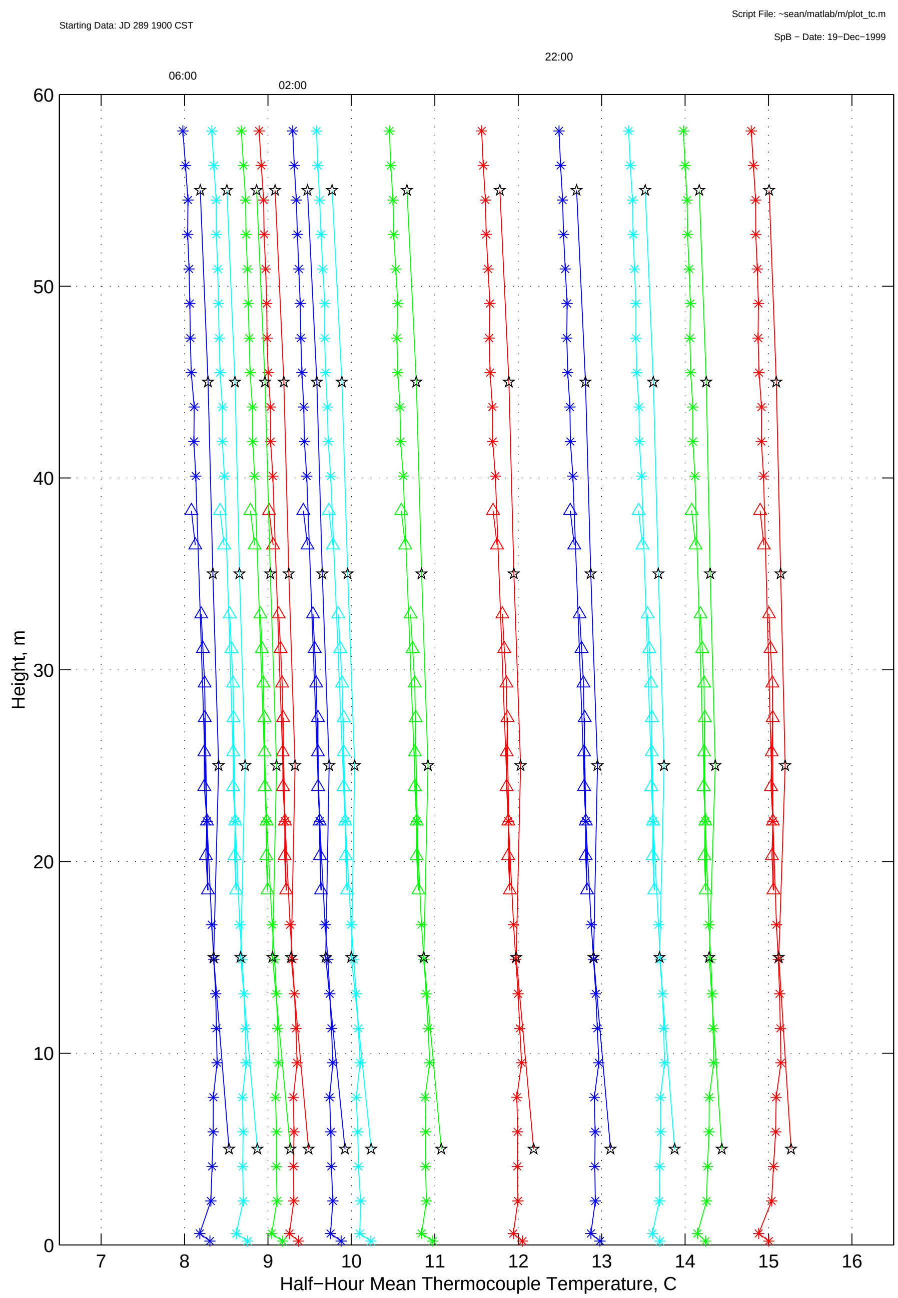

Figure 8. Temperature profile 1.

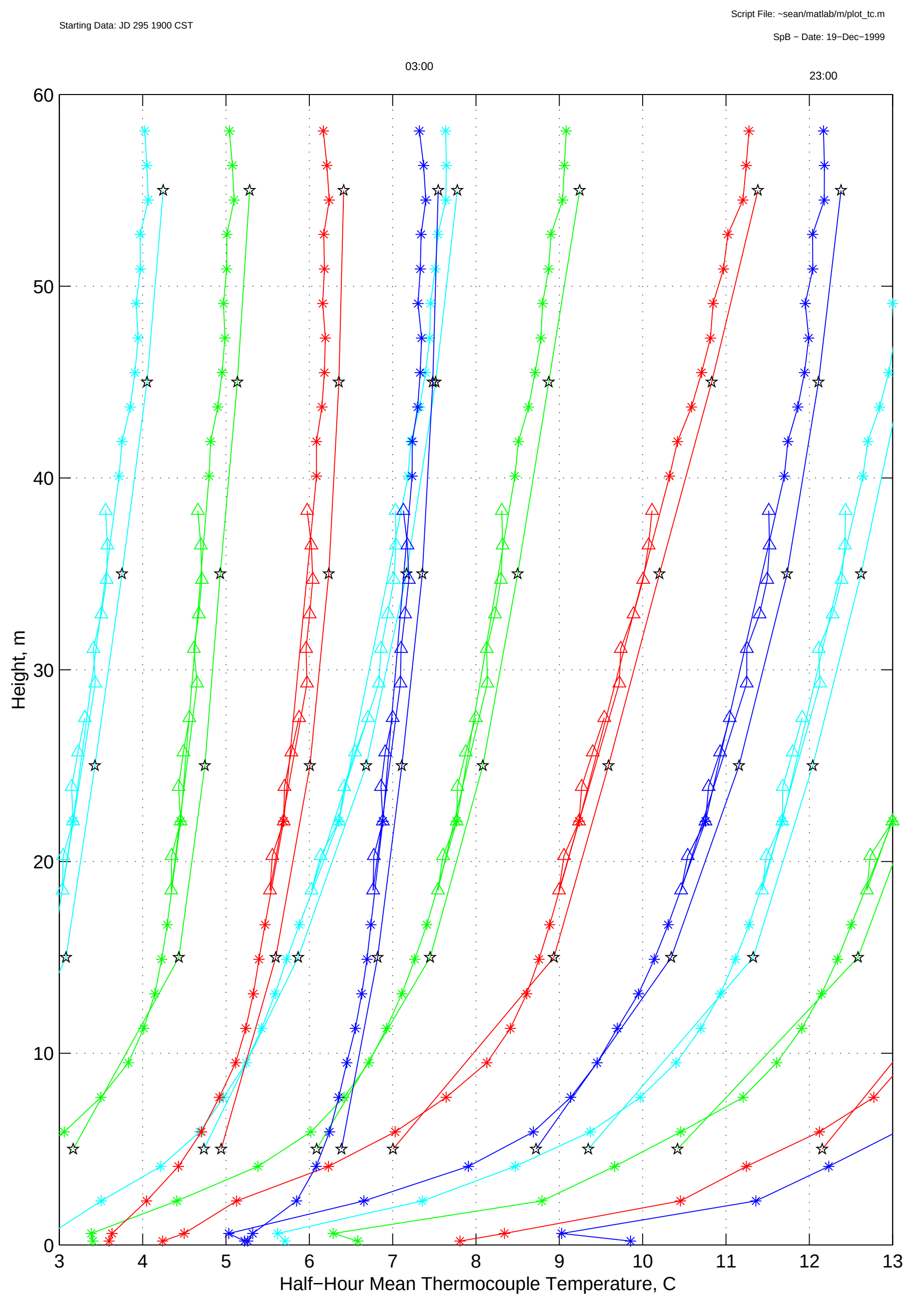

Figure 9. Temperature profile 2.