P9.5

THERMOCOUPLE TEMPERATURE MEASUREMENTS FROM THE CASES-99 MAIN TOWER

Sean P. Burns* and Jielun Sun†

National Center for Atmospheric Research‡, Boulder, Colorado

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 (Colorado Research Associates 1999). The thermocouple data are unique since they supply the CASES community with high-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. These air temperature measurements are compared in this study.

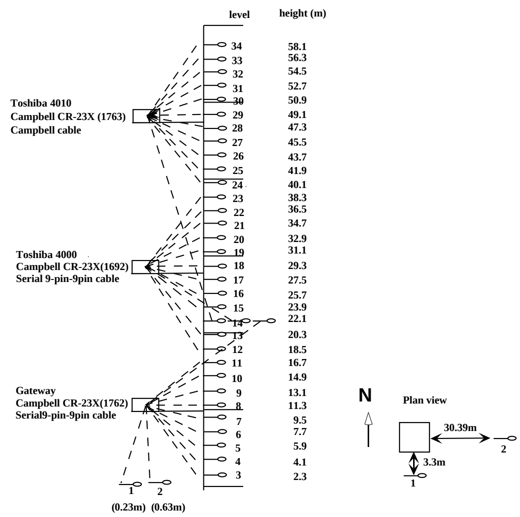

Figure 1: Thermocouple configuration on the ATD 60-m main tower.

2. MEASUREMENTS

The thermocouple data were collected at 5 samples per second (5 Hz) using 3 Campbell CR23X data loggers, 3 laptop computers, and E-type (Chromel/Constantan, 0.0254 mm diameter) thermocouples located at 34 different levels on and near the main ATD tower (the two lowest levels were slightly displaced from the main tower; see Fig 1). The thermocouple probes were made at Yale University under the supervision of Dr. Xuhui Lee. The Campbell CR23X data loggers (and laptops) were each placed at low (6 m), middle (28 m), and high (47 m) positions on the main tower which made it possible to reach any location on the tower with thermocouple cable 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 internal data-logger thermistors, and improve the relative accuracy of the $T_{\rm tc}$ measurements from different data-loggers, three thermocouples (one connected to each data logger) were placed near each other (less than 2 cm separation) at the 22.1 m level (Fig 1). It was assumed that data from these three thermocouples should be in agreement. An example time series of the raw thermocouple data is given in Fig. 2a. (The same data after applying corrections described in section 3, are shown in Fig. 2b.) Data recorded by each of the 3 data-loggers will be designated as $T_{\rm tc}^{\rm high}$, $T_{\rm tc}^{\rm mid}$, and $T_{\rm tc}^{\rm low}$, respectively.

The aspirated temperature sensors are Vaisala 50Y Humitter sensors (platinum-resistance devices) which are mechanically aspirated and enclosed in a dual-concentric-cylinder shield. Each sensor was individually calibrated by NCAR ATD, and has an estimated field accuracy of about ±0.1°C. The 6 sensors on the main tower were located at nominal heights of 5, 15, 25, 35, 45, and 55 m.

*Corresponding author address: S. P. Burns, P.O. Box 3000, National Center for Atmospheric Research, Boulder, CO 80307-3000; e-mail: sean@ucar.edu.

†Also affiliated with PAOS, University of Colorado

‡NCAR is sponsored by the National Science Foundation

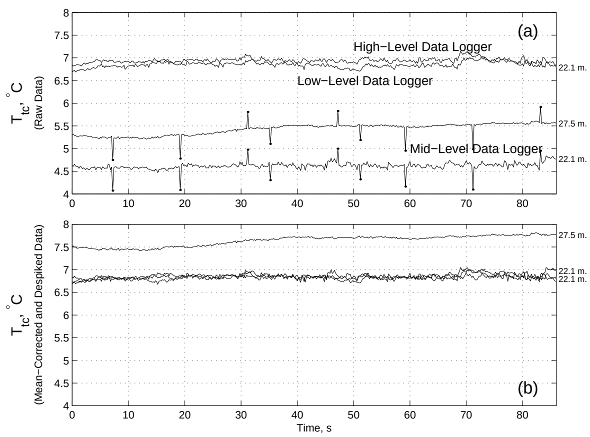

Figure 2: An 86-s time series of thermocouple temperature (a) without and (b) with mean correction and despiking. Three sensors are at 22.1 m (low, mid, and high data loggers) and one is at 27.1 m (mid-level data logger) from 17 October (JD 290), 23:58:33 - 24:00:00 CDT. The height of each sensor is 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.)

3. DATA PROCESSING

Thermocouple temperatures recorded with the middle-level CR23X data-logger (SN 1692) were found to have several (correctable) problems. Most of the processing techniques described herein are based on data from three thermocouples at 22.1 m (Fig. 1). The processing steps are: (1) remove spikes from the time series, and (2) account for data-logger time-stamp differences and mean differences among data from the three different data-loggers. The spikes only appeared in the temperature data from the mid-level data logger.

The data spikes occurred simultaneously on all 12 channels in T_{tc} data from the mid-level data-logger (Fig. 2a). They were always 1-sample in duration. 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). After confirming that the spikes were removable in post-processing, no further action was taken to fix the problem in the field. During post-processing, a low-pass filter technique was used to identify the $T_{\mathrm{tc}}^{\mathrm{mid}}$ spikes, which were subsequently eliminated by replacing the spike with the median of the 14 values around it (Fig. 2b).

Figure 3a is a composite of the temperature differences between the three T_{tc} measurements at 22.1m made by each of the three data loggers throughout of the entire observational period. The average $T_{\mathrm{tc}}^{\mathrm{mid}}$ is about 2-3°C lower than the temperature from the other two data loggers. In addition, differences involving $T_{\mathrm{tc}}^{\mathrm{mid}}$ have a large standard deviation (0.25°C) because the difference slowly changed throughout the experiment. As shown in Fig. 3a, temperature differences between $T_{\mathrm{tc}}^{\mathrm{mid}}$ and $T_{\mathrm{tc}}^{\mathrm{high}}$ at 22.1 m ranged from -0.15°C (daytime) to +0.15°C (nighttime), which is within the ±0.25°C absolute accuracy of the reference thermistor within the data loggers.

Comparisons between aspirated temperature data T_{atd} at 55 m and T_{tc} data near the same level were used to decide whether $T_{\mathrm{tc}}^{\mathrm{low}}$ or $T_{\mathrm{tc}}^{\mathrm{high}}$ were the more accurate measurements (Fig. 3b). The thermocouples immediately above and below the aspirated sensor are both included in the comparison and reveal that, in general, the nighttime vertical temperature gradient near the 55 m level was very small. In Fig. 3b, one pair of curves is the $T_{\mathrm{tc}}^{\mathrm{high}}$ data without any correction (dashed) and the other pair (solid) has $T_{\mathrm{tc}}^{\mathrm{high}}$ corrected assuming that $T_{\mathrm{tc}}^{\mathrm{low}}$ data are the most accurate. The conclusion is that the $T_{\mathrm{tc}}^{\mathrm{high}}$ data used "as-is" are in better agreement with T_{atd} and it would be better to use the 22.1 m thermocouple which is connected to the high-level data-logger as the mean "reference" sensor for data processing. The mean corrections used in the thermocouple data processing were calculated for each 0.5 hours of T_{tc} data. The differences shown in Fig. 3b are similar in magnitude

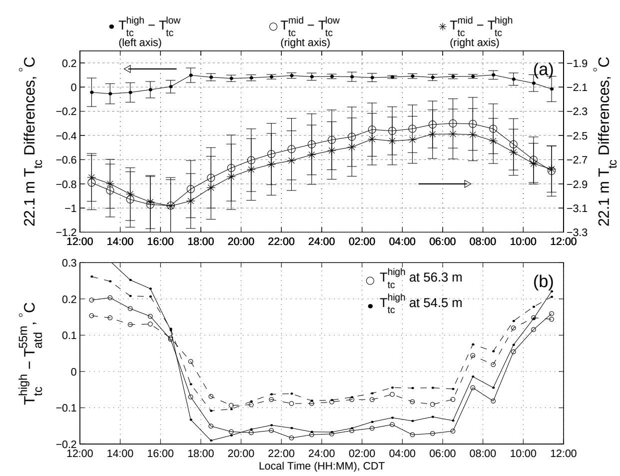

Figure 3: Hourly bin-averaged measurements for the entire 20 day deployment time period of the differences between (a) the 3 thermocouples at 22.1 m and (b) the thermocouples at 56.3 m and 54.5 m and the 55 m ATD aspirated temperature data for low-level data logger adjusted data (solid) and data taken as-is from the high-level data logger (dashed). The error bars in Fig. 3a indicate plus-or-minus one standard deviation of the data in that bin.

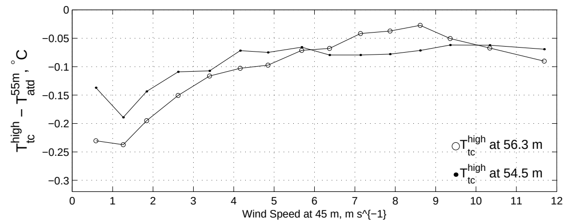

Figure 4: The difference between the thermocouple and aspirated temperature measurements versus wind speed. Only data between 18:00 and 6:00 CDT are considered.

to those observed in a previous study that compared temperatures from thermocouples (of various diameters) with those from aspirated temperature sensors (Campbell 1969).

To examine the effect of wind speed variations on the difference between $T_{\rm tc}$ and $T_{\rm atd}$ measurements only the nighttime data are considered (Fig. 4). Based on the overall data composite, an increase in wind speed from 1 to 5 m s^{-1} reduces the difference between $T_{\rm tc}$ and $T_{\rm atd}$ from 0.2 to 0.1°C. This result is also consistent with the findings of Campbell (1969).

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-stamp differences, $T_{\rm tc}^{\rm mid}$ and $T_{\rm tc}^{\rm high}$ data at 22.1 m (over a 3 hour period) were shifted one sample at a time relative to $T_{\rm tc}^{\rm low}$ at 22.1 m. For each shift the variance of the difference between $T_{\rm tc}^{\rm mid}$ and $T_{\rm tc}^{\rm high}$ relative to $T_{\rm tc}^{\rm low}$ was calculated, and the minimum variance corresponds to the time-stamp difference between data loggers. After checking time-difference values for several different days it was clear that the time difference between data loggers changed as the experiment progressed. The time shifts relative to the low-level CR23X for the entire experiment is given in Fig. 5, where a positive value indicates that temperatures from the mid- or high-level data logger are lagging the low-level data logger data. The large jump seen on October 23rd was near the time when main tower power was reset (23 October 16:09 CDT) and must have affected the CR23X data loggers. From the information shown in Fig. 5, relative time-stamp differences between the data loggers were removed in post-processing. Since the ATD tower data were time-stamped with GPS time, the 1-Hz aspirated temperature data (when made available) can be used in a similar time-stamp comparison between $T_{\rm tc}$ and $T_{\rm atd}$ and the absolute value of the thermocouple data logger time-stamp can be related to the nearest GPS second. Some consideration will be needed since the thermocouple and aspirated temperature sensor have different response times.

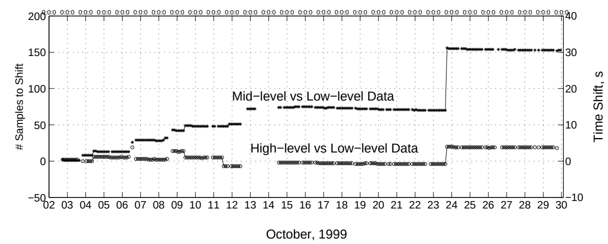

Figure 5: Time-stamp differences based on the 22.1 m thermocouple temperature data. Differences are relative to the low-level data logger for the entire experiment. Values are calculated based on 3-hour time periods (see text for details).

4. RESULTS

After applying all the corrections described in section 3 the resulting overall mean thermocouple measurements are shown in Figs. 6a and 6b. On average, the nighttime temperature at the top of the tower was about 7°C warmer than air temperature near the ground. As an example of the small-scale

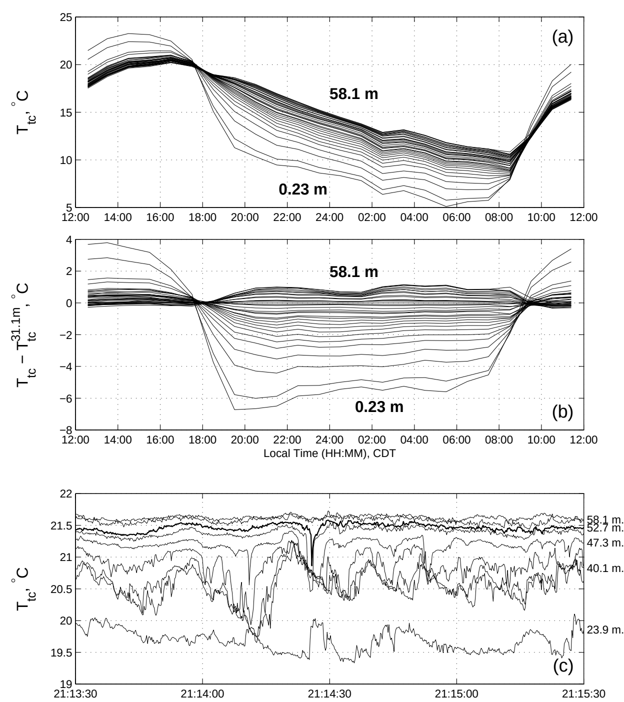

Figure 6: Hourly bin-averaged of (a) thermocouple measurements and (b) differences relative to the 31.1 m thermocouple data for the entire 20 day deployment time period. Time series of selected thermocouples from the night of 11 October 1999 are in Fig. 6c.

events captured by the dense vertical array of thermocouples Fig. 6c shows the thermocouple at 52.7 m (thick line) briefly detecting cold air (most likely transported up from below) while $T_{\rm tc}$ at 54.5 m is unaffected. For this brief period it is clear that the vertical mixing of air is all occurring below 54.5 m. More detailed scientific results using the thermocouple measurements can be found in Sun et al. (2000) and Oosterhuis et al. (2000).

5. CONCLUSIONS

Small diameter thermocouples were used to accurately measure 34 levels of temperature data between 0.23 and 58.1 m on the main tower during CASES-99. To process the thermocouple data time stamp differences between the 3 different data loggers were eliminated. The decision of which data logger to use as the reference for processing was based on comparisons with colocated temperature data from aspirated temperature sensors. These comparisons revealed nighttime thermocouple temperatures that were 0.1°C less than those from shielded, aspirated temperature sensors. Finally, an example time series of the processed $T_{\rm tc}$ data was given which shows how a closely-spaced vertical array of thermocouples sampled at a high rate is an effective tool for capturing small-scale temperature events within the atmospheric boundary layer. The thermocouple data from CASES-99 clearly demonstrated density currents, drainage flows, and interactions between mesoscale disturbances and bursts of turbulent events.

6. ACKNOWLEDGEMENTS

We thank Xuhui Lee and Xinzhang Hu from Yale University for constructing the thermocouples. This work was supported by Army Research Office Grant DAAD1999-1-0320 and National Science Foundation Grant ATM-9906637.

7. REFERENCES

Campbell, G. S., 1969: Measurement of air temperature fluctuations with thermocouples, *ECOM-5273*, Atmospheric Sciences Laboratory, White Sands Missile Range, New Mexico, 10 pp.

Colorado Research Associates (CoRA), cited 1999: Cooperative Atmospheric Surface Exchange Study 1999, operations plan, 1-31 October 1999. [Available on-line from http://www.colorado-research.com/cases/CASES-99.html.]

Oosterhuis, G., et al. 2000: Wavelet analysis of thermocouple measurements during CASES-99. Preprints. *14th Symposium on Boundary Layers and Turbulence*, Aspen, CO, Amer. Meteor. Soc., this volume.

Sun, J., et al. 2000: Turbulence intermittency in the stable boundary layer. Preprints. *14th Symposium on Boundary Layers and Turbulence*, Aspen, CO, Amer. Meteor. Soc., this volume.