NOTES AND CORRESPONDENCE

Evaluation of an Inexpensive Temperature Datalogger for Meteorological Applications

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18 May 1999 and 5 August 1999

ABSTRACT

Recent advances in electronics miniaturization have allowed the commercial development of sensor/datalogger combinations that are sufficiently inexpensive and appear to be sufficiently accurate to deploy in measurement arrays to resolve local atmospheric structure over periods of weeks to months. As part of an extended wintertime field experiment in the Columbia Basin of south-central Washington, laboratory and field tests were performed on one such set of battery-powered temperature dataloggers (HOBO H8 Pro from Onset Computer, Bourne, Massachusetts). Five loggers were selected for laboratory calibration. These were accurate to within 0.26°C over the range from $-5°$ to $+50°$C with a resolution of 0.04°C or better. Sensor time constants were 122 ± 6 s. Sampling intervals can be varied over a wide range, with onboard data storage of more than 21 000 data points. Field experiences with a set of 15 dataloggers are also described. The loggers appear to be suitable for a variety of meteorological applications.

1. Introduction

Surface-based air temperature measurements are an essential component of many meteorological field programs. Temperature measurements are usually taken with dataloggers that sample a temperature sensor at fixed time intervals and either store the data on location for later analysis or transmit the data to a central repository via radio or telephone links. Improvements in electronics have recently resulted in the production of lower-cost, miniaturized temperature dataloggers. Because larger numbers of dataloggers are now affordable, this development may lead to opportunities to improve the spatial sampling of air temperatures in meteorological applications.

Micro- and mesoscale climate studies may benefit greatly from this technology. Examples of applications include the mapping of temperature for frost investigations in orchards or vineyards; the determination of complex terrain influences on air temperature; and the measurement of microclimatic temperature variations in caves, vegetation canopies, or other special environments. Some of the new dataloggers are small enough to be attached to small mammals, birds, or other fauna to determine the microclimates to which they are exposed in their living spaces. The development of temperature dataloggers has been accelerated somewhat in recent years by government regulations regarding the handling and transport of food products. Of special concern is the monitoring of the temperature–time history of refrigerated shipments of foods, flowers, and other temperature sensitive goods. This paper documents the characteristics of one such datalogger, the HOBO H8 Pro, developed by Onset Computer of Bourne, Massachusetts (Fig. 1), that has been weatherproofed for outdoor use and is thus suitable for extended meteorological investigations.

2. The temperature datalogger

The HOBO H8 Pro circuitry is housed in a plastic case that is sealed from moisture by two rubber O-rings; one is at the base of the plastic case, and the other is on a threaded plug that is removed from the face of the case by the user to upload instructions to the logger and to download data. The version of the logger that we tested had an internal temperature sensor located inside the plastic case and an external thermistor in a 0.5 cm by 3.0 cm epoxy-potted cylinder at the end of a 2-m electrical lead. The manufacturer's specifications for the logger are provided in Table 1.

The datalogger is started (launched) by removing the threaded plug and connecting an interface cable between a data port within the logger case and the serial port of a computer. A computer program provided by the manufacturer is then run, and the user selects datalogger launch instructions including the logging interval, the

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FIG. 1. Photograph of HOBO Pro Temp/Ext Temp datalogger and radiation shield mounted on a fence post. The round white plastic datalogger is mounted on the underside of the radiation shield mounting bracket; a 2-m electrical cable runs from the logger to a thermistor that is placed inside the radiation shield. A threaded plug at the end of a cylindrical projection from the face of the datalogger is removed to gain access to the logger for uploading instructions and downloading data.

time at which data collection should begin, the channels to be logged, and the resolution desired (8 or 12 bits). The datalogger uses the computer's clock to automatically set its initial time. The logger carries a unique serial number in its software. To facilitate identification of the logging location, the user may enter an additional logger name. The logger is then disconnected from the computer and installed at the field location. Data can be downloaded at any time from the logger using a computer and the same software and cable. A small handheld data-downloading and storage device (HOBO Shuttle) that facilitates the field collection of data from multiple dataloggers is also available from the manufacturer. The shuttle is connected to the datalogger via an interface cable through the data port, and a single button is pushed to download the data, reset the logger clock, check the logger's battery, and relaunch the logger. The 468 kbytes of data storage in the shuttle is sufficient for storing data from seven full dataloggers.

3. Testing of the temperature datalogger

We performed four tests of the datalogger and shuttle. First, the time constant of the sensor/datalogger was determined in still air. Second, temperature accuracy was determined by comparison with a platinum thermometer in a stirred water bath. Third, an overnight field test was performed to compare the temperatures recorded by multiple loggers in an outdoor setting. Finally, the time accuracy of the shuttle was determined in laboratory tests. The results of the tests are provided below.

TABLE 1. Manufacturer's specifications for HOBO Pro Temp/Ext Temp datalogger.

Characteristic	Specification
Number of channels	Two (internal and external temperatures)
Operating range (logger)	−30° to +50°C
Time accuracy	±1 min per week at 20°C
Measurement capacity	21 763 measurements (one channel at 12-bit and one at 8-bit resolution)
Memory	Nonvolatile eeprom
Data offload time	<1 min
Size	102 mm high, 81 mm wide, 55 mm deep
Weight	145 g
Battery	1/2 AA lithuim, user-replaceable
Battery life (continuous use)	3 yr
Storage temperature	−30° to +75°C
External temperature sensor	Thermistor on 1.8-m lead
Response time	<5 min in still air
Resolution	Variable over temperature range, <0.1°C over the range 0° to 40°C
Accuracy	Variable over temperature range, better than 0.4°C over the range from −10° to 50°C
Cost	$169 (Apr 1999)

a. Time constant

The time constants of the external and internal temperature sensors were determined by exposing a set of five loggers to a step change in temperature while sampling at 2-s intervals. The loggers were brought to equilibrium in a freezer compartment at a temperature near −18°C. They were then removed and the five sensors, exposed in a loose bundle, were allowed to equilibrate to room temperature (20°C) in a location without direct ventilation. Time constants [i.e., the time required for the datalogger/sensors to respond to $1 - (1/e)$ or 63.2% of the temperature difference between the two temperature states] were determined from a linear regression of the time rate of change of temperature against temperature. From the five loggers, the external sensor time constant was 122 ± 6 s (mean ± standard deviation); the internal sensor time constant was 557 ± 83 s.

b. Temperature accuracy, stirred bath

The temperature accuracy of the five loggers used in the time-constant determinations was measured in a CHP Model 2006 circulating bath using ethylene glycol as the working fluid. This calibration apparatus maintains the desired temperature using an automatic control loop. The

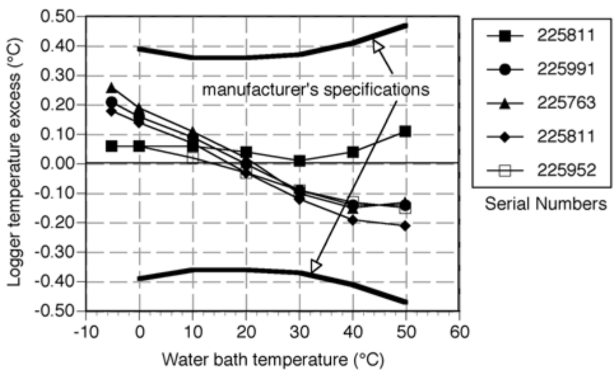

FIG. 2. HOBO datalogger temperature excess relative to the recirculating bath. The heavy lines represent the manufacturer's accuracy specifications.

bath temperature was monitored with a separate National Institute of Standards and Technology traceable Kaye RTD monitor that uses a calibrated platinum resistance element as the sensing device. The loggers were maintained at room temperature during these tests, with the five thermistors and about 0.15 m of electrical cable immersed within a thin vinyl sheath in the ethylene glycol. The thermistors surrounded and were in thermal contact with the platinum resistance element. The temperature of the bath was varied in steps over the nominal range between −5° and 50°C. At each temperature step the automatic control loop caused the bath temperature to cycle over a narrow range of temperatures (from 0.05° to 0.18°C) about the nominal temperature. The datalogger temperatures, as averaged from 2-s readings taken over the time period when the bath temperatures were stable, were compared to the mean bath temperature during the same period. The results are shown in Fig. 2. All five dataloggers were within 0.26°C of the temperature standard over the entire temperature range.

c. *Temperature intercomparison, outdoor*

A group of 15 dataloggers were placed outdoors on the night of 11–12 November 1998 with the thermistors exposed in a loose bundle to ambient air that was stirred by a fan. Data were recorded at 5-min intervals throughout the night when temperatures varied between 1° and 9°C. All logged temperatures agreed within a range of about 0.4°C (Fig. 3).

d. *Timing accuracy*

The time accuracy of the shuttles was tested at two operating temperatures, room temperature (~20°C) and refrigerator temperature (~2°C). Accuracies were tested by setting the shuttles to an accurate time standard and then checking them against the same standard several days later. At room temperature, a set of three shuttles ran slow, losing 0.29 to 0.33 min per week. At ~2°C, the same three shuttles ran fast, gaining 0.12 to 0.21 min per week. The shuttle time accuracies met the manufacturer's stated specifications.

4. Field experience

Field experience was gained from a network of 15 temperature dataloggers operated on the sides of two

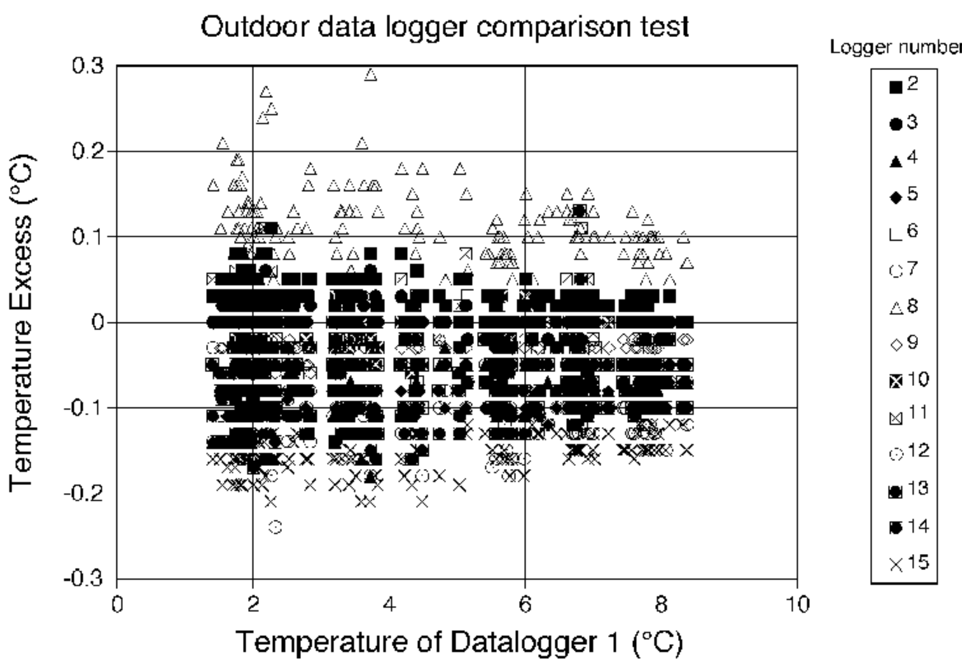

FIG. 3. HOBO dataloggers 2–15 temperature excess relative to HOBO datalogger 1. Dataloggers were exposed overnight to ambient air stirred by a fan in Richland, WA, on 11–12 November 1998.

mountains in the Columbia Basin near Richland, Washington. Eleven of the loggers were placed on a line that ran up the north face of Rattlesnake Mountain (43.394°N latitude, 119.595°W longitude, 1111 m MSL) and continued up the east ridge of the mountain to the summit. This line of loggers, placed over an elevation range from 133 to 1111 m MSL, was operated from 16 December 1998 to 30 March 1999. The experiments were designed to determine if ''vertical'' profiles of temperature obtained from networks of surface-based dataloggers on mountainsides could be used to indicate the presence of temperature inversions and persistent cold air pools in the Columbia Basin. The datalogger temperature profile was to be compared with 10-min average virtual temperature profiles made each half hour with a nearby Radio Acoustic Sounding System. The results of the intercomparison will be published in a separate paper; here we concentrate on temperature datalogger performance.

Temperature sensors must be shielded from solar and terrestrial radiation to provide acceptable air temperature data. Thus, for our field experiments, the external thermistors were placed inside six-plate radiation shields, and the dataloggers were secured to the mounting brackets at the foot of the radiation shield to make a self-contained datalogger/shield assembly. The assemblies were secured to steel fence posts so that the thermistors were exposed approximately 1 m above the ground. Data were logged at 5-min intervals. The radiation shields used in our experiments were designed by Gill (1983) and manufactured by the R. M. Young Company of Traverse City, Michigan (Model 41301-5). The design uses 12-cm-diameter plates made of UV-stabilized white thermoplastic. The plates are stacked to cover the sensor completely, shading it from direct and reflected solar radiation, upward and downward longwave radiation, and precipitation. The design comes in several standard configurations including 6-, 9-, and 12-plate shields. The number of plates is chosen based on the size of the temperature sensor assembly that must fit in the shield. The root-mean-square (rms) temperature excess in this unaspirated shield, as reported by the manufacturer for solar radiation of 1080 W m^{-2}, is 0.4°C in 3 m s^{-1} winds, 0.7°C in 2 m s^{-1} winds, and 1.5°C in 1 m s^{-1} winds. These and similar shields have been extensively tested (e.g., Fuchs and Tanner 1965; Gill 1983; Payne 1987; Crescenti et al. 1989; Andersson and Mattisson 1991; Anderson and Baumgartner 1998). Andersson and Mattisson (1991) performed a nearly 1-yr-long comparison of 1-min-average temperatures obtained with high-quality platinum resistance thermometers exposed in a 12-plate R. M. Young radiation shield and in an adjacent continuously aspirated Teledyne radiation screen. Temperatures differences were greatest during calm conditions under clear skies. The maximum 1-min-average error in the entire period of record was 3.36°C. Temperature differences never exceeded 1°C for longer than 1 h; and June, December, and annual rms errors were between 0.1° and 0.2°C. Anderson and Baumgartner's (1998) field tests with a nine-plate radiation shield found a maximum instantaneous radiative overheating of 3.4°C and mean daytime errors of 0.27°C. Because of shield geometry, the maximum heating errors occurred for sun elevations of approximately 45°.

The dataloggers performed well during the experiment, providing an uninterrupted temperature record for each station, except for a 2-week data loss at one logger whose sensor cable was severed by an inquisitive elk or deer. Figure 4 presents data from sites located at various elevations on the side of Rattlesnake Mountain. In Fig. 4a time series of 5-min-temperature data are presented for a subset of six sites for the period from 19 to 23 December 1998. Pseudoprofiles obtained from the Rattlesnake Mountain dataloggers by averaging the 5-min data over 1-h intervals are shown for two periods in Figs. 4b,c. Figure 4b is an example of a near-neutral profile during a high wind night when mean winds on the summit of Rattlesnake Mountain varied between 19 and 31 m s^{-1}. Figure 4c is an example of a set of 3-hourly temperature profiles on a clear night with weak ambient winds. Shown are hour-averaged soundings at 2100, 0000, 0300, and 0600 LST. These profiles use all 11 of the Rattlesnake Mountain dataloggers (as does Fig. 4b) to illustrate the development of a nocturnal temperature inversion.

5. Conclusions

Inexpensive temperature dataloggers are now becoming available for applications in meteorology. We have investigated the characteristics of one such datalogger and have reported our operating experience. The loggers are suitable for meteorological measurements in situations in which the data do not require real-time delivery to a central location (as with radio or telephone links) or an onboard display of data (although data from this particular logger can be displayed in real time if a portable computer is connected to the logger). Because the loggers are inexpensive, large numbers of dataloggers might be purchased to facilitate detailed studies of the spatial structure of temperature fields. They are small, yet provide acceptable accuracy and sufficient storage for many meteorological and climatological investigations. In our field investigations, the datalogger temperature sensors were shielded from solar and terrestrial radiation in unaspirated radiation shields. Other investigators have reported on the magnitude of temperature errors in such shields, which can reach several degrees Celsius under intense insolation when wind speeds are low. The dataloggers record instantaneous temperatures at the selected sampling times but have no built-in capability for obtaining average temperatures from multiple samples (e.g., hour averages from 5-min samples). Such averages can, however, be performed on archived data after data collection if the sampling rate is high enough. The relatively long time constant (122 s) of the presently available external thermistor provides an averaging of its own. Sampling at rates shorter than this

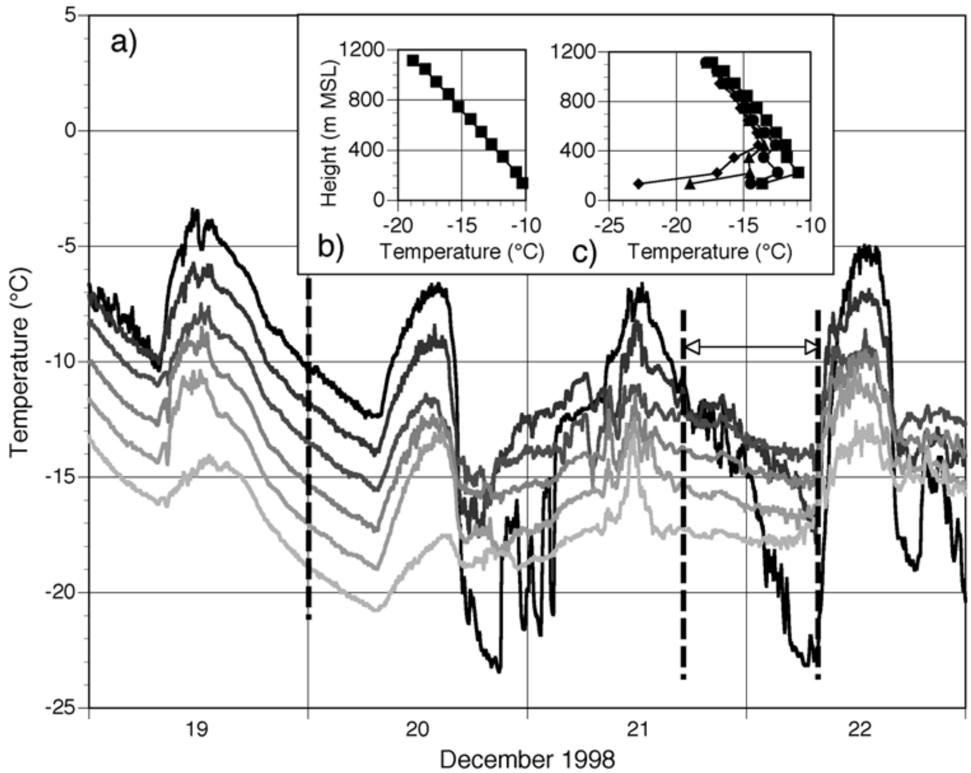

FIG. 4. Meteorological data from dataloggers at altitudes of 133, 343, 543, 743, 943, and 1111 m MSL on a line running up the side of Rattlesnake Mountain, WA. (a) Time series of 5-min temperature samples from 6 (of 11) loggers for the period 19–23 December 1998. (b) Temperature pseudoprofile for 0000 LST 20 December 1998. This profile was obtained from all 11 loggers using hour-averaged data centered on midnight. The vertical dashed line in (a) corresponds to the time of this profile. (c) Temperature pseudoprofiles at 3-h intervals from 2100 LST 21 December 1998 to 0600 LST 22 December 1998. The data in the profiles represent hour-average temperatures from all 11 dataloggers. The double arrow in (a) shows the time interval over which the pseudosoundings were obtained.

response time provides little additional information, even though allowable by the datalogger software.

Acknowledgments. Dr. Glen E. Liston at Colorado State University used a different version of the datalogger in Arctic applications. His work inspired the datalogger trials reported here. Mr. Owen Abbey performed the bath calibrations. Drs. Rich Barchet and Chris Doran provided useful comments on the manuscript. This research was supported by the U.S. Department of Energy, Office of Biological and Environmental Research, Environmental Sciences Division as part of their Atmospheric Studies in Complex Terrain program under Contract DE-AC06-76RLO 1830 at PNNL. The U.S. Department of Energy's PNNL is operated by Battelle Memorial Institute. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof, or Battelle Memorial Institute. The views or opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

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