Automation of Grass and Soil Temperature Measurements at King's Park Meteorological Station of Hong Kong Observatory

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Abstract

Measurements of soil and grass minimum temperatures have been carried out at the King's Park Meteorological Station of the Hong Kong Observatory for more than half a century. In the early days, soil temperatures at 1 ft and 4 ft depths were measured manually along with the overnight grass minimum temperature. By late 1970s, manual measurements were made at 5 cm, 10 cm, 20 cm, 50 cm, 100 cm, 150 cm and 300 cm depths alongside the grass minimum temperature.

Around the end of 2005, platinum resistance thermometers were installed at the station to automatically take measurements of the soil and grass temperatures there. During the automation process, technical problems such as equipment set up, encoder errors, manual disparities were encountered. These problems were eliminated step by step and manual observations were eventually replaced by automatic readings in 2010.

This paper discusses the equipment set up, a comparison between manual and automatic observations, the problems encountered as well as the solutions employed. The paper also highlights some of the experiences gained during the course of the automation process.

Introduction

For more than half a century, soil temperature and grass minimum temperature measurements have been carried out at the King's Park Meteorological Station of the Hong Kong Observatory. During the early years of operation, soil temperatures at 1 ft and 4 ft depths were measured manually along with the overnight grass minimum temperature. By the late 1970s, soil temperature measurements were revised and expanded to measure at depths 5cm, 10cm, 20cm, 50cm, 100cm, 150cm and 300cm (Figure 1).

Automation of the soil and grass temperature measurements began around the end of 2005, when seven platinum resistance thermometers were installed next to the conventional soil thermometers at each depth, and an additional exposed platinum resistance thermometers was fixed next to the grass minimum thermometer position to measure the grass temperature. During the implementation, the automatic grass and soil temperature measurement system underwent several modifications to improve its performance and overcome problems observed during the initial testing phase. The initial designs were found to be highly prone to errors induced from external factors such as high ambient air temperature and direct sunlight.

Similar to other new systems, a period of parallel operation, usually a period of 12 consecutive months or more, was conducted between the automatic and the conventional systems.

This quantified the measurement differences between the two systems and also assessed the suitability of the automatic system for the task at hand.

Conventional Measurement System

In the conventional manual soil temperature measurement system, two types of thermometers were used for soil temperature measurements depending upon the depth. For the shallower depths (5 cm, 10 cm and 20 cm) right angled pattern mercury-in-glass thermometers were used. Angled pattern thermometers are basically thermometers that have a right angle bend in its stem. The length between the bulb and the bend determines the depth at which the thermometer is designed to measure. They were directly inserted into the earth with the bulb at the desired depth and the remaining part of the thermometer lied flat on the ground (Figure 2). In-situ temperature measurements could be performed without disturbing the thermometer itself. For the deeper depths (50 cm, 100 cm, 150 cm and 300 cm) sheathed pattern mercury-in-glass thermometers, fitted inside a transparent glass sheath, sat at the bottom of an open ended stainless steel tube that had been driven down to the required depth with the core excavated. To take measurements, it was necessary to withdraw the thermometer from the bottom of the tube (Figure 3). The bulb of the thermometer was encased in a paraffin wax to slow the response of the thermometer such that the measurements would not vary considerably while the thermometer was withdrawn from the tube during measurement readings. Soil temperatures were taken twice daily at 7 a.m. and 7 p.m. local time.

Overnight grass minimum temperature was measured using a sheathed pattern grass minimum thermometer placed onto a cradle such that the thermometer sit at an angle of around 2 degrees with the bulb just above the blades of the grass (Figure 4). The thermometer would be reset and sited after sundown and the overnight minimum temperature read at 8 a.m. the following morning.

Automatic Measurement System

In the automated soil temperature measurement system, PT100 platinum resistance thermometers (PRT) were used to measure the temperature of the soil. PRTs are widely used in automated systems to measure temperature in place of traditional mercury in glass or spirit type thermometers. The PRT is a member of resistance temperature detectors (RTD) where the electrical resistance of the material changes with temperature. They offer excellent accuracy over a wide temperature range, typically from –200 to +85°C. In most cases, the resistance increases with temperature and the PT100 PRTs are characterized by having 100Ω resistance at 0°C and has a linear response throughout the range 0°C to 100°C.

The PRTs for the shallow depths were simply buried horizontally at the desired depth of soil next to the conventional angle pattern thermometers. The tips of the PRTs were in thermal contact with a brass head (Figure 2) to ensure good thermal conduction between the soil and the PRTs. For the deeper depths, PRTs were installed in a similar fashion to the conventional thermometers by placing them inside open ended PVC tubes that had been driven down to the required depth (Figure 3). Although the conventional system used stainless steel tubes, PVC tubes were used for the automatic system to reduce the thermal conduction from the surface. The PRTs themselves were housed in sealed glass sheaths in the same manner as the sheathed pattern thermometers. But unlike the conventional system, the tip of the PRTs where the sensing element was located were not encased with paraffin wax but were in thermal contact with a brass head, in similar fashion to the PRTs used for the shallow depths, and were exposed at the bottom end of the glass sheath (Figure 5). The sheathed PRTs were placed on the bottom of PVC tubes with the brass head in contact with the soil at the bottom of the tube.

For the grass temperature, a temperature probe was fashioned with the PRT installed inside a sealed glass tube (Figure 4). In the original prototype, the sensing element of the PRT was in thermal contact with a brass plug that sat inside the glass sheath. However, with the grass temperature probe being in an exposed location, the brass plug heated up quite rapidly during the day and at times had caused the tube to crack especially during fine sunny weather. The final design had the PRT simply fixed inside a sealed glass sheath with a capsule of desiccant to dry the air within to prevent condensation and improve the thermal conductivity of the air inside the glass sheath.

Data Logging System

A schematic diagram of the first prototype design, shown in Figure 6, revolved around a resistance to current converters (RCC) to determine the resistance of the PT100. The RCC connected to a current to voltage converter (CVC) that in turn fed an analogue to digital converter (ADC) to digitize the analogue signal before converting the reading to a temperature. However, the site condition at the King's Park Meteorological Station was found to be not suitable for this design since it required long cables to connect the RCC at the measurement site to the CVC at the station office. Data captured in 2005 and 2006 showed that the prototype was prone to instrumental fluctuations and errors caused by external factors such as noises and direct sunlight, the latter of which caused significant diurnal variations in the temperatures especially during hot and sunny weather. The effects were quite marked for the deeper depths where temperature changes at these depths should be slow, say rarely over 0.1°C within a day.

The final prototype replaced the RCC/CVC concept and had the PRTs connected directly to a Campbell Scientific CR1000 logger in a bridge configuration. Figure 7 shows the schematics of the final design. This design compensates for the longer leads between the logger and the sensor by using the three wire bridge configuration where the third wire senses the wire resistance.

The CR1000 data logger is programmed to provide 1-minute mean soil and grass temperatures sampled every 10 seconds. In addition, the soil temperatures at 7 a.m. and 7 p.m. are recorded automatically to coincide with the old manual practice using the conventional thermometers. Similarly, the overnight grass minimum temperature represents the minimum 1-minute mean grass temperature measured each day between 8 p.m. and 8 a.m. the following morning.

Discussion and Results

Direct comparison was made between the conventional and automatic measurements using data obtained during the 24-month period between 1 September 2007 and 31 August 2009. For the soil temperatures, the daily manual observations of the soil temperatures taken at 7 a.m. and 7 p.m were compared with the 1-minute mean temperature obtained by the automatic system. For the overnight grass minimum temperature, the grass minimum thermometer reading was compared with the lowest 1-minute mean temperature measured by the grass temperature probe between 8 p.m. and 8 a.m. the following morning.

The differences between the measurements taken by the two systems were calculated with respect to the manual system for each data pair (Figure 8). The results show that, with the exception of the 50 cm depth soil thermometer, the overall systematic differences for each soil depth and grass minimum temperature were within ±0.2ºC. Deeper depth thermometers showed better agreement with almost negligible differences (±0.1ºC). For the grass minimum temperature and the shallow soil thermometers (5 cm to 20 cm), the standard deviations of the data were up to twice those observed for the deeper depth thermometers. This is understandable as the comparison assumed that all measurements were taken at the correct time and that the temperatures did not vary considerably during the time of measurements. In practice, the actual time of manual observations would sometimes inevitably differ from the scheduled time while near surface temperatures would be more variable. At deeper depths where temperatures were not expected to vary a lot, the variance in the difference would obviously be much smaller.

The high variability observed with the grass minimum temperature differences is more difficult to pinpoint. One likely reason is the different temperature response of the grass minimum thermometer and the PRT as the two are fully exposed to the environment overnight. Another factor that would cause a degree of variation is that the grass minimum thermometer is placed onto its cradle shortly after sundown, while the automated system uses the minimum temperature within the 12 hour period between 8 p.m. and 8 a.m. the next morning.

An additional complication lies with the calibration error of the minimum thermometers themselves. Over the 24-month period of parallel operation, the grass minimum thermometer was replaced several times due to bubbles forming inside the core, which is a common problem with spirit thermometers, rendering them unreliable or physical damage to the thermometers themselves. Although each minimum thermometer has a calibration error of ±0.2ºC, bench testing of two calibrated minimum thermometers under controlled conditions in a water bath gave a persistent difference of 0.42ºC between the two thermometers. Therefore, the degree of bias of each replacement grass minimum thermometer, either positive or negative with respect to the PRT, would certainly have contributed to the overall variability. Further bench test comparisons of spirit minimum thermometers with a mercury-in-glass thermometer with a calibration error of ±0.1°C showed that the spirit minimum thermometers had an increasing bias with respect to the mercury-in-glass with increasing temperature. The biases were found to range from <0.1ºC at around 5ºC to up to 0.5ºC at around 25ºC. On the other hand, the PRTs were found to have a more constant bias with respect to the mercury-in-glass thermometer. With the ambient grass minimum temperatures at the site varying from 5ºC in winter to 27ºC in summer over the 24-month period, the varying bias of the spirit grass minimum thermometers would certainly have affected the overall differences observed with the PRTs.

Throughout the 24-month period, disparities between the manual and the automatic measurements due to human error have also been observed. These disparities are most evident at the deepest 300cm soil depth where temperatures are expected to vary by no more than ±0.1°C per day at most but differences of up to +1.3°C between the two systems have been observed (Figure 9). These disparities can be clearly illustrated by the timeline of the morning and evening measurements of the 300 cm depth soil temperature between 1 September 2008 and 31 August 2009 where the trace of the manual readings are in contrast to the relatively smooth trace of the automatic measurements (Figure 10). Although these obvious errors can be correctly managed with the deeper depth soil temperature measurements, they are more difficult to identify with the grass and shallower soil depth measurements and would therefore contribute to the overall variability of these measurements.

Summary

The Hong Kong Observatory has implemented an automatic soil and grass temperatures system at its King's Park Meteorological Station since 2005. The final design of the system utilized PRT and data logger in a bridge configuration, replacing an earlier RCC/CVC concept which was prone to adverse effects of long cabling and site environment.

A 24-month parallel run of the system with the manual observations was carried out between September 2007 and August 2009. A few significant differences in the readings were sometimes observed between the automatic system and manual observations, in particular the overnight grass minimum temperature as well as the soil temperatures at shallower depths (5 cm, 10 cm and 20 cm). Most of them were found to be caused by human irregularities and fast ambient changes near the ground surface. Notwithstanding this, the comparison results showed that the automatic system in general performed consistently and reliably, as well as eliminated human errors. The automated grass and soil temperature measurement system was fully operational on 1 January 2010.

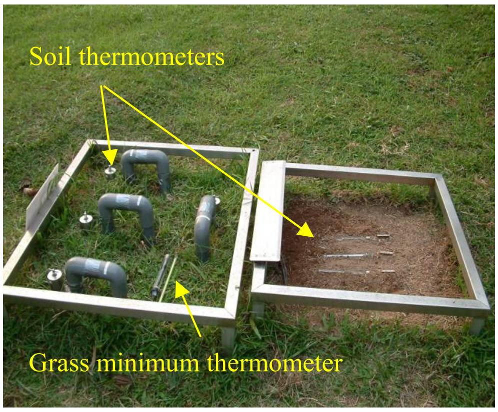

Figure 1. The soil and grass thermometers at King's Park Meteorological Station.

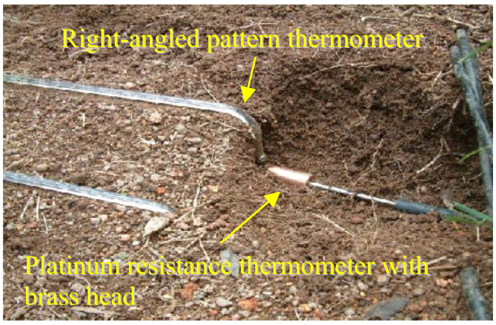

Figure 2. Angled pattern earth thermometer (Cassella) installed next to a platinum resistance thermometer for shallow depth soil temperature measurement.

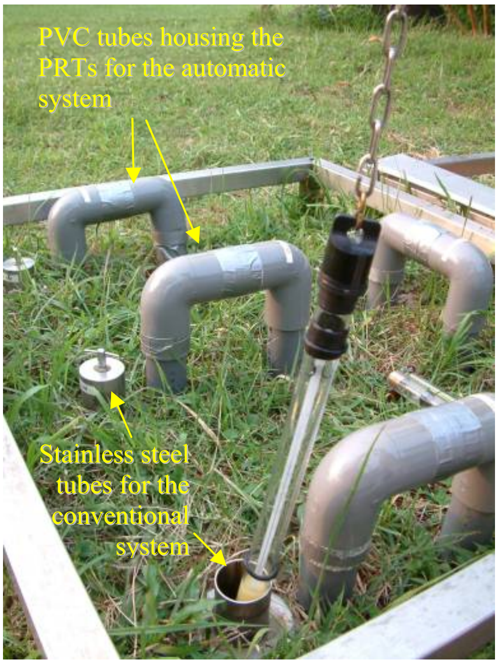

Figure 3. 50 cm depth sheath pattern earth thermometer (Cassella) extracted from its stainless steel tube for measurement. The grey PVC tubes next to the conventional thermometers houses the individual PRT thermometers of the automated system for each depth.

Figure 4. Sheathed PRT for the grass temperature alongside the conventional grass minimum thermometer. The brass plug inside the glass sheath was removed in final the operational system.

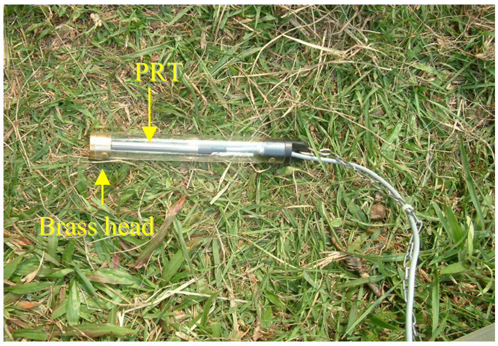

Figure 5. Sheath pattern PRT for deeper depth soil temperature measurement. The PRT inside is in thermal contact with a brass head for better thermal conduction between the soil and the PRT.

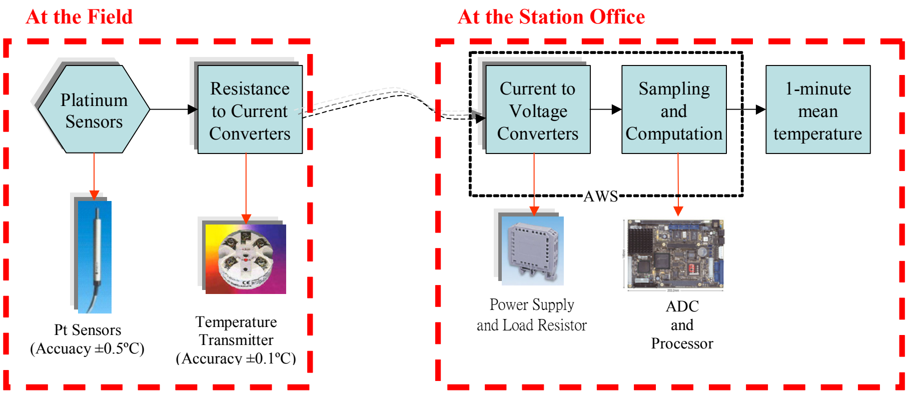

Figure 6. Data logging system of the initial prototype automatic system. The design revolved around the resistance to current converter and the current to voltage converter. Unfortunately the design suffered form external influences such as noise and direct sunlight,. causing the system to overestimate the PRT temperature.

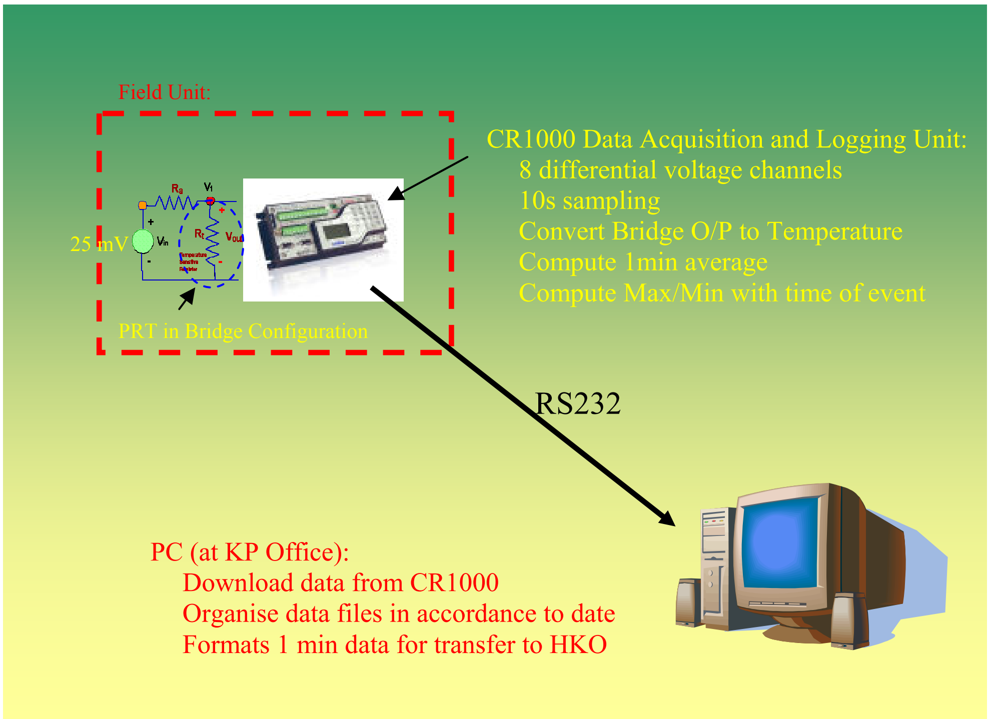

Figure 7. The final data logging system uses a bridge configuration fed into a Campbell Scientific CR1000 data logger to determine and record the PRT temperature. The configuration is more immune to noises and external influences.

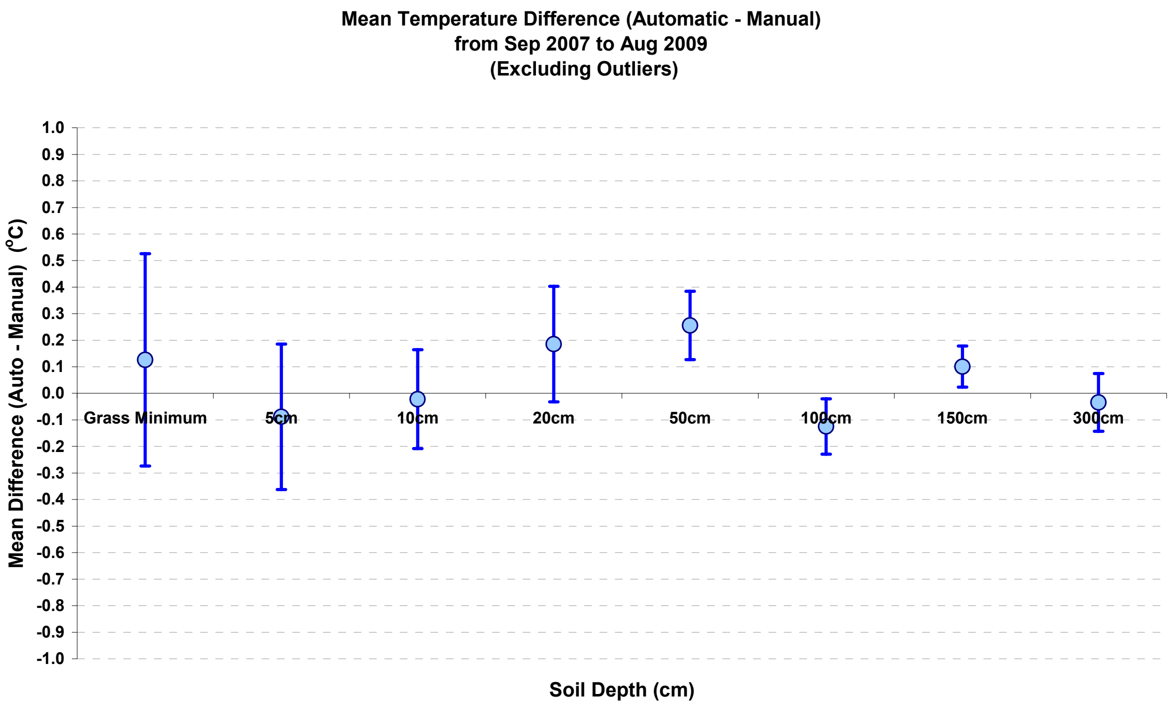

Figure 8. Mean temperature differences between the automatic and manual measurements of grass minimum and soil temperatures between 1 September 2007 and 31 August 2009 (Excluding outliers). Vertical bar denotes ±1 standard deviation.

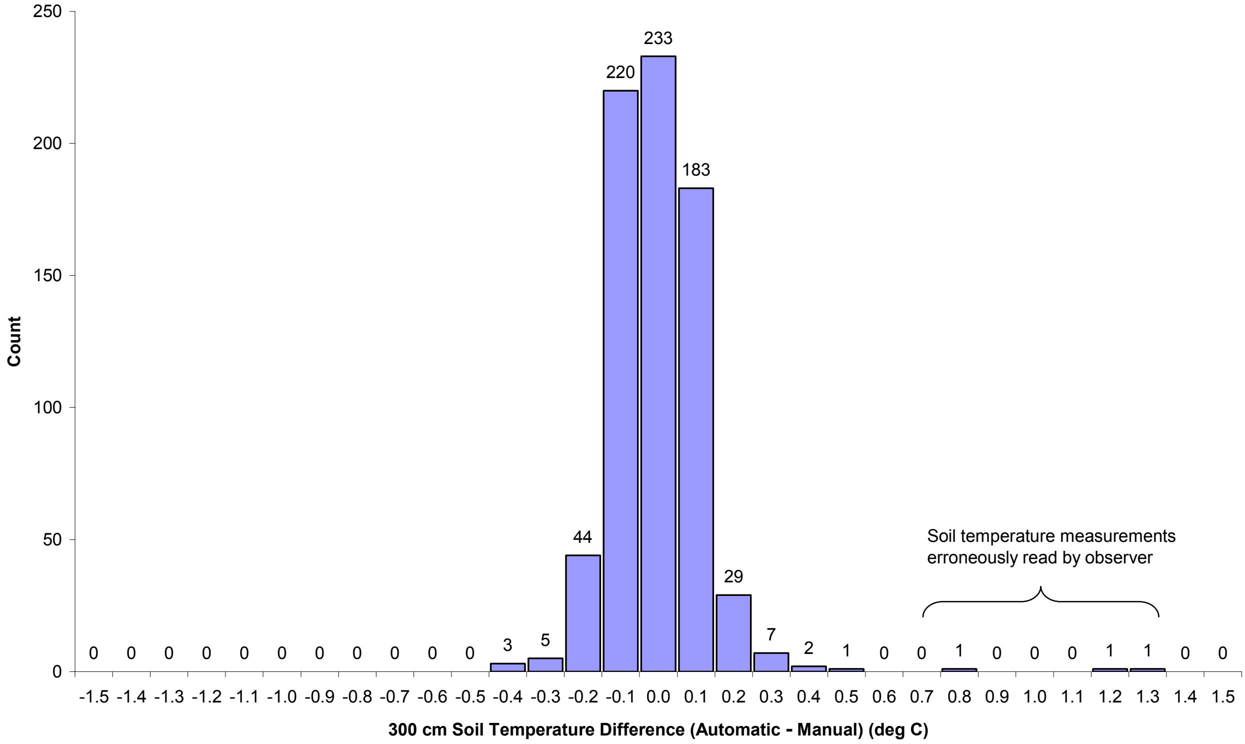

Figure 9. Frequency distribution histogram of the temperature difference between the automatic and manually taken 300 cm soil temperatures between 1 September 2008 and 31 August 2009. The histogram clearly shows occurrences of erroneous manual measurements.

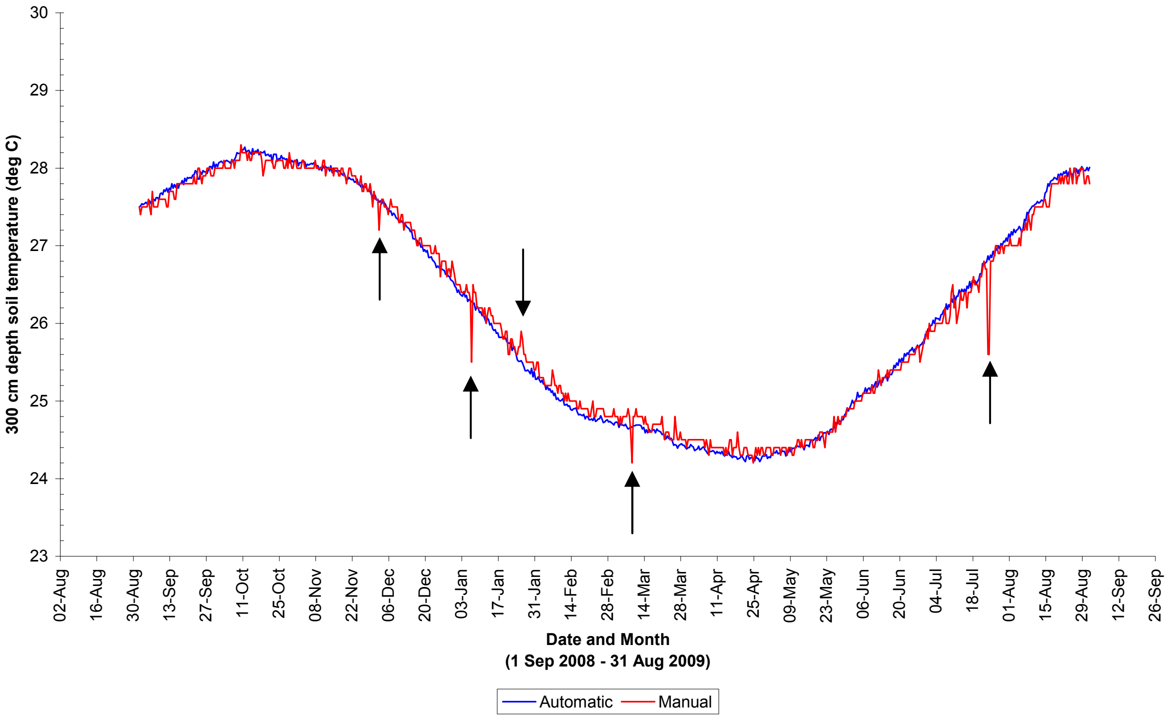

Figure 10. Time series of the daily 7 a.m. and 7 p.m. measurements of the 300 cm depth soil temperature over the period 1 September 2008 to 31 August 2009. The automatic measurements are shown in blue, the manual measurements in red. Obvious errors in the manual readings are arrowed.