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Short communication

Design and evaluation of an inexpensive radiation shield for monitoring surface air temperatures

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ABSTRACT

Inexpensive temperature sensors are widely used in agricultural and forestry research. This paper describes a low-cost (∼3 USD) radiation shield (radshield) designed for monitoring surface air temperatures in harsh outdoor environments. We compared the performance of the radshield paired with low-cost temperature sensors at three sites in western Montana to several types of commercially available instruments. Comparisons included observations made under a tree canopy and in full sun with both passive and mechanically aspirated radiation shields. Beneath a forest canopy, temperature sensors housed within the radshield showed bias of less than 0.5 °C for hourly temperatures when compared with the same sensors housed in an unaspirated Gill-style shield. Sensors and shields mounted on poles in full sun were slightly warmer under low-wind conditions, but overall were cooler than data from an adjacent Remote Automated Weather Station (RAWS). When compared with observations from a high-quality temperature sensor housed in a mechanically aspirated solar radiation shield used in the Automated Surface Observing Systems (ASOS), observations from inexpensive temperature sensors housed within radshields were biased with mean absolute error of 0.99 °C, but performed as well as those housed within a more expensive, commercially available Gill-style radiation shield. Our initial evaluation suggests that the radshield, instrumented with a low-cost sensor is suitable for monitoring surface air temperatures across a range of outdoor environments.

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1. Introduction

Inexpensive temperature sensors are widely used in agricultural and forestry research and management studies. Several inexpensive (20–35 USD) temperature sensors are now commercially available. For example, Maxim's Thermochron® iButtons® are being widely used for outdoor environmental applications including surface air temperature monitoring (Beever et al., 2010; Holden et al., 2011; Holden and Jolly, 2011; Hubbart et al., 2007; Lundquist and Cayan, 2007; Ashcroft and Gollan 2012; Fridley, 2009). However, comparably low-cost radiation shields are needed to make the use of inexpensive sensors cost effective. This paper describes and evaluates an inexpensive, lightweight radiation shield for use in outdoor environments, and reports on its performance in conjunction with ThermoWork's Logtag® data logger.

Accurately recording air temperatures in harsh outdoor environments poses several challenges. Temperature sensors and their surroundings warm when exposed to direct and diffuse solar radiation. In addition, solar radiation reflecting off of snow beneath sensors in the spring can significantly influence temperature measurements if the sensor is not protected from below (Lin et al., 2001; Huwald et al., 2009). Gill radiation shields are commonly used to shield temperature and relative humidity sensors (Gill, 1979). The Gill shield design allows passive natural ventilation, while heat that accumulates in the upper plates dissipates via conduction and radiation. While it is well documented that unaspirated shields may have deviations of up to 10 °C (e.g. Genthon et al., 2011; Maunder et al., 2008), the difficulty of powering fans that perform reliably in harsh, remote locations and without biasing the measurements is not easily achieved without added complexity. For these reasons, unaspirated radiation shields are widely used for a variety of applications. However, commercially available Gill-style shields are relatively expensive in comparison to the cost of modern miniature data loggers (20–50 USD). Shields from Onset Computer Corp.® (the maker of Hobo® products) cost 80 USD while a similar shield from Decagon Devices Inc.® costs around 60 USD. This expense (several times the cost of the temperature sensor) becomes significant when hundreds or thousands of sensors are deployed.

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Fig. 1. Inexpensive solar radiation shield (radshield) mounted on a PVC pole adjacent to the Ninemile RAWS station, Montana.

Several radiation shield designs have been proposed as alternatives to more expensive commercial Gill-style radiation shields (e.g. Clark et al., 2006; Tarara and Hoheisel, 2007). However, these designs all report significant temperature errors relative to standard Gill-style radiation shields. Several previous studies using Thermochron iButtons have used two nested, inverted funnels placed over the sensor (Hubbart et al., 2005; Holden et al., 2011; Holden and Jolly, 2011; Hubbart et al., 2007; Lundquist and Cayan, 2007). However, this design does not shield the sensor from snow albedo effects unless sufficient vegetation is present beneath the sensor. Lundquist and Huggett (2008) propose that vegetation in tree canopies can be used to shield the sensors from direct and reflected radiation. However, in relatively dry areas of the western United States, (e.g. low elevation, south-facing slopes in the northern Rocky Mountains and the southwestern US) where vegetation productivity is relatively low and forest canopies are open, this often is not possible. Additionally, the height at which observations are made will vary using this method. Alternative, inexpensive radiation shielding devices that perform consistently across a range of environments are still needed.

2. Methods

2.1. Radiation shield design

This inexpensive radiation shield (henceforth referred to as "radshield") was originally designed for measuring air temperatures in forested environments, but may be easily modified to work in a variety of settings (Fig. 1). Paramount to the design of any radiation shield is blocking incoming solar radiation (Fuchs and Tanner, 1965; Gill, 1979; Hubbard et al., 2001). This simple Gill-style shield is constructed by folding white corrugated plastic sheets into a series of plates secured with metal staples. The top of each of the plates are then covered with reflective aluminum foil duct tape, which minimizes absorption of incoming radiation. Because the temperature sensor is housed between three sheets of taped plastic (two above and one below), most incoming and reflected upwelling radiation is blocked. The outer, uppermost plate mounts to the bole of a tree (or to a simple pole or tripod) while smaller plates housing the sensor are suspended beneath it using uv-resistant cable ties. Those ties and air spaces within the walls of each sheet of corrugated plastic (4 mm in both directions) minimize conduction of heat through the shield. In addition, the approximately 3 cm of space between each plate enhance passive air flow within this non-aspirated shield.

In the case of the radshields discussed here, the walls of the radshield were constructed with Coroplast® twin-walled 4 mm white plastic sheets and the foil duct tape was Shurtape® AF-100 tape. The radshield can be constructed in approximately 10 min using materials widely available from home-repair supply stores that cost less than 3 USD per shield. A detailed schematic of the individual pieces and the fully assembled radshield is shown in Fig. 2. A short video detailing construction of the radshield can be found at http://www.youtube.com/watch?v=LkVmJRsw5vs.

2.2. Radiation shield comparison tests

We conducted four field tests of the radshield at sites in western Montana during summer and fall. Comparisons included observations made beneath a forest canopy and in full sun conditions, and using both passive and mechanically aspirated radiation shields. One potential source of concern regarding the materials used in the construction of the radshield is the use of aluminum foil tape. Aluminum is highly reflective, but has a very low emissivity in the infrared range of the electromagnetic spectrum (emissivity = 0.03) compared to other materials with comparable reflectivity. Thus, aluminum could effectively trap heat inside the shield without adequate ventilation. We tested for potential bias resulting from the use of an aluminum surface by coating the exterior surfaces of the radshield plates with higher emissivity materials, including acrylic white paint and aluminum backed mylar tape. The details of each test are described separately below. The data collected in each test, including number and type of sensor and duration of each test are shown in Table 1.

2.2.1. Test 1: radshield and passive radiation shield comparison beneath a forest canopy

Air temperature measurements were compared from ThermoWork's Logtag® TRIX-8 temperature sensors housed in radshields to measurements from the same sensors housed in commercially available 8-plate Gill shields (Model M-SRA, Onset Computer Corp.). Logtags are inexpensive sensors with a temperature range of −40 to 85 °C, and a stated accuracy of 0.5 °C. The test site was a thinned, open-canopy ponderosa pine forest. This site was chosen to represent the extremes of radiation environments that would be encountered during the summer within forests of the US northern Rocky Mountains. Three radshields instrumented with two Logtag temperature sensors each were mounted on three separate ponderosa pine trees at a height of 2 m. For comparison, a commercial 8-plate Gill radiation shield instrumented with 1 Logtag sensor was mounted to each tree. Temperatures were recorded at hourly intervals from 1 July to 31 August 2011.

2.2.2. Test 2: radshield and passive radiation shield comparison in full sun

Three radshields were mounted on Polyvinyl Chloride (PVC) poles and placed next to the Ninemile Remote Automated