

Video Article

# Construction of a Compact Low-Cost Radiation Shield for Air-Temperature Sensors in Ecological Field Studies

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URL: <https://www.jove.com/video/58273>

DOI: [doi:10.3791/58273](https://doi.org/10.3791/58273)

Keywords: Environmental Sciences, Issue 141, Air temperature, climate change, data logger, thermochron, radiation shield, field studies

Date Published: 11/6/2018

Citation: Terando, A.J., Prado, S.G., Youngsteadt, E. Construction of a Compact Low-Cost Radiation Shield for Air-Temperature Sensors in Ecological Field Studies. *J. Vis. Exp.* (141), e58273, doi:10.3791/58273 (2018).

## Abstract

Low cost temperature sensors are increasingly used by ecologists to assess climatic variation and change on ecologically relevant scales. Although cost-effective, if not deployed with proper solar radiation shielding, the observations recorded from these sensors will be biased and inaccurate. Manufactured radiation shields are effective at minimizing this bias, but are expensive compared to the cost of these sensors. Here, we provide a detailed methodology for constructing a compact version of a previously described custom fabricated radiation shield, which is more accurate than other published shielding methods that attempt to minimize shield size or construction costs. The method requires very little material: corrugated plastic sheets, aluminum foil duct tape, and cable ties. One 15 cm and two 10 cm squares of corrugated plastic are used for each shield. After cutting, scoring, taping and stapling of the sheets, the 10 cm squares form the bottom two layers of the solar radiation shield, while the 15 cm square forms the top layer. The three sheets are held together with cable ties. This compact solar radiation shield can be suspended, or placed against any flat surface. Care must be taken to ensure that the shield is completely parallel to the ground to prevent direct solar radiation from reaching the sensor, possibly causing increased warm biases in sun-exposed sites in the morning and afternoon relative to the original, larger design. Even so, differences in recorded temperatures between the smaller, compact shield design and the original design were small (mean daytime bias = 0.06 °C). Construction costs are less than half of the original shield design, and the new design results in a less conspicuous instrument that may be advantageous in many field ecology settings.

## Video Link

The video component of this article can be found at <https://www.jove.com/video/58273/>

## Introduction

In light of anthropogenic global warming, there has been a growing interest in recording air temperature in a variety of settings to understand and predict ecological responses to climate change<sup>1,2,3</sup>. With the advent of small, low-cost environmental data recorders (also referred to as data loggers, thermochrons, or hygrometers), it is now possible to deploy high-density networks of sensors to measure hyper localized temperature variation, increasing ecologists' ability to more directly observe the ambient environmental conditions experienced by organisms and ecosystems under study. Compared to existing, well-calibrated and rigorously tested—but sparsely distributed—permanent weather stations, such networks present opportunities to assess climatic variation on ecologically relevant scales but may reduce accuracy or comparability among studies if inconsistently or inappropriately deployed.

Near-surface air temperature sensors typically require some type of solar radiation shielding to prevent direct heating of the sensor element, which would result in erroneously warm measurements. Common ways to limit sensor bias include: 1) using existing environmental features such as trees for shading<sup>4</sup>, 2) bias correction and sensor calibration<sup>5</sup> that derived corrections based on the thermal properties of sensors, and 3) the use of manufactured or custom fabricated shields<sup>6,7</sup>. Many researchers choose to use custom fabricated shields because of the low-cost and easy deployment, and necessity in situations where environmental conditions do not provide natural shading. However, a review of the ecological literature indicated that the design of custom fabricated shields varies widely among studies, and individual designs are rarely tested for accuracy. Untested shields can be susceptible to poor choice of materials and design that cause additional heating of the air molecules immediately surrounding the sensor, direct absorption of solar radiation by the sensor itself, or both—leading to average biases of up to 3 °C<sup>7</sup>. On the other hand, simple and cost-effective designs<sup>6,7</sup> are quite effective at shielding sensors (biases of 1 °C or less) and are comparable to commercially manufactured radiation shields.

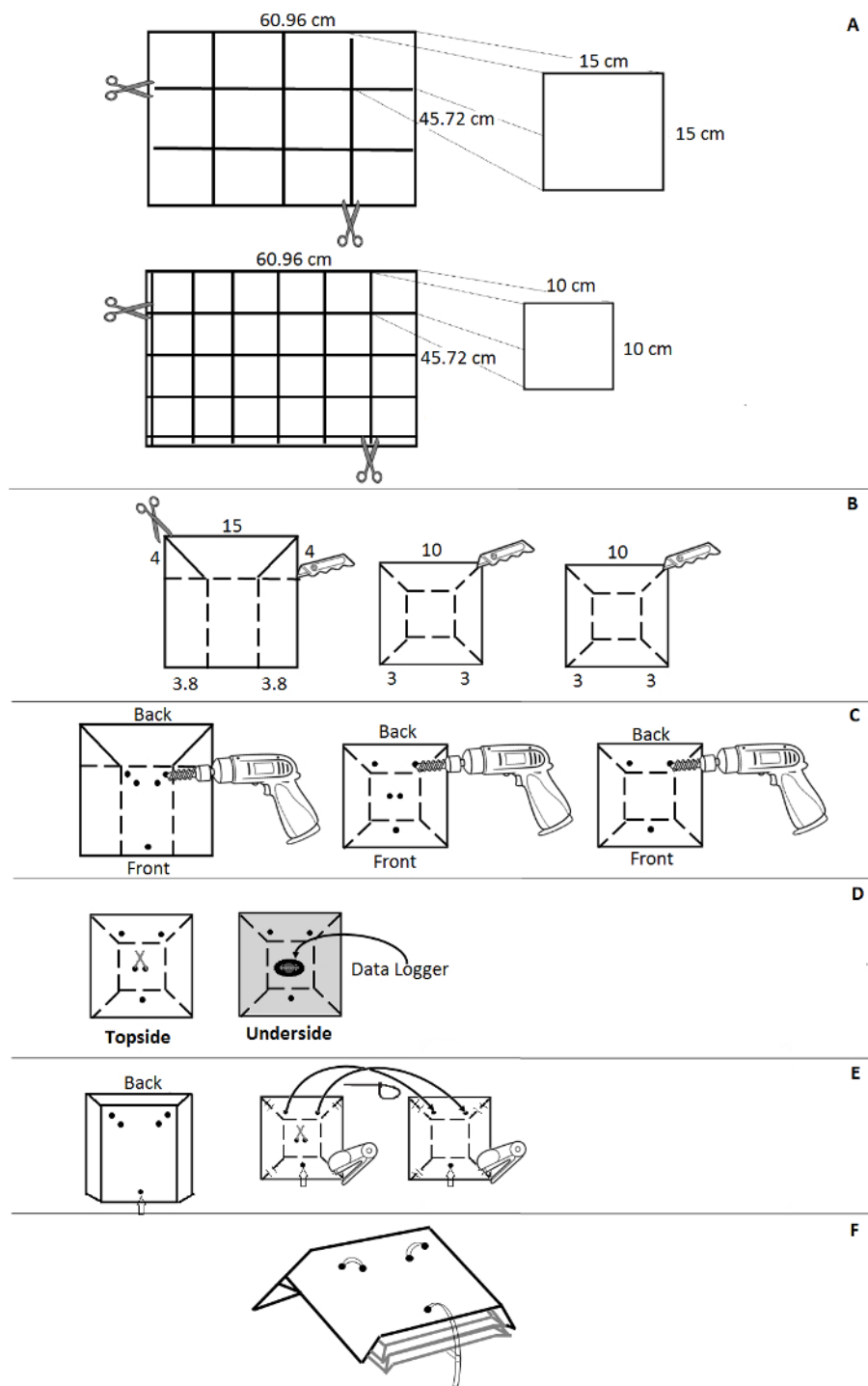
Here, we provide a detailed methodology for constructing a previously evaluated custom fabricated radiation shield<sup>7</sup> for use with inexpensive thermochron temperature sensors. The shield design is a modification of one previously described and tested in an open Ponderosa Pine forest setting<sup>8</sup>. In recent tests of several custom-fabricated shield designs, this montane-tested shield resulted in the lowest biases when paired with small thermochrons<sup>7</sup>, but we found it cumbersome and too conspicuous to deploy in the field. The design protocol proposed here reduces the dimensions of the radiation shield by 50%. Such a reduction in size has several benefits: 1) it is less conspicuous and therefore less susceptible

to tampering, 2) it can be more feasibly used in a wider variety of ecological settings where space is limited (e.g., on smaller urban street trees), 3) it is more accurate than other published shielding methods that attempt to minimize shield size or construction costs<sup>7</sup>, and 4) it is less expensive than the original, larger design due to the reduced quantity of construction materials required. After describing the construction methods, we explore the effect of the size reduction on sensor accuracy relative to the original shield design using results from a field trial conducted under high downward solar radiation conditions.

## Protocol

### 1. Construction of the Radiation Shield

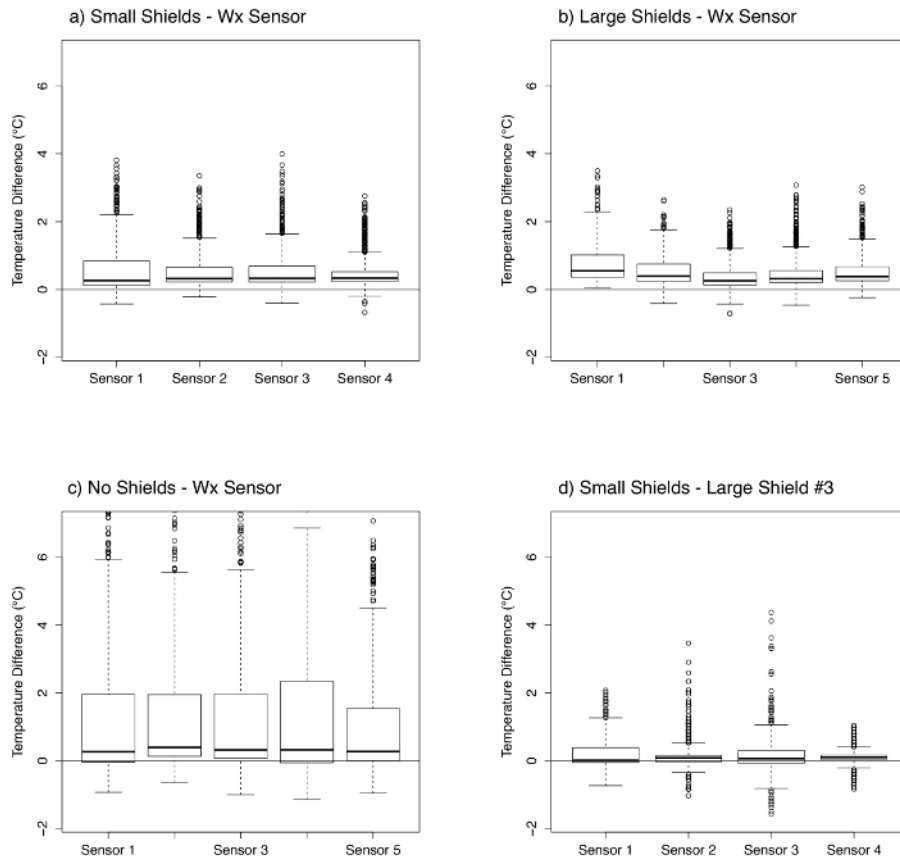
1. Using a utility knife, cut the corrugated plastic sheets into squares (**Figure 1A**). One 15 cm square and two 10 cm squares will be needed for each shield.
2. Cuts for the top layer of the small radiation shield (**Figure 1B**; left image):
  1. On the 15 cm square, measure 4 cm from one edge and draw a line with a pencil. Use a straightedge as a guide to score along the line. (Herein, "scoring" means using a knife to make a cut that goes through only one layer of corrugated plastic sheet, rather than the entire sheet.) Henceforth this edge of the square will be referred to as the "top" (**Figure 1B**; left image).
  2. Measure 3.8 cm from the edges that are perpendicular to the 4 cm line. Use a straightedge as a guide to score from the bottom up to the 4 cm line (**Figure 1B**; left image).
  3. Draw a line from both corners above the 4 cm line to the junction of the 4 cm and 3.8 cm lines. Cut along this line (**Figure 1B**; left image).
3. Cuts for the middle and bottom layers of the small radiation shield (**Figure 1B**; middle and right images):
  1. Using a straightedge, draw a 6 cm square in the middle of each 10 cm square (**Figure 1B**; middle and right images).
  2. Score all around the 6 cm square, and from each corner of the 6 cm square to the outer corners of the 10 cm square (**Figure 1B**; middle and right images).
4. Use aluminum foil tape to completely cover the scored side of the 15 cm square and one of the 10 cm squares, and the un-scored side of the other 10 cm square.
5. Using a 1/4" drill bit, drill holes as shown in **Figure 1C**, in each of the shield layers.
6. Attach a temperature sensor to the underside of the 10 cm square, which is taped on the scored side and has the two holes drilled into the middle, by running the cable tie through the eyelet of the sensor housing (or its mounting device) and through the holes in the 10 cm square (**Figure 1D**).
7. Folding the sheets.
  1. Fold the 15 cm sheet along the scored lines. Pressure may be needed in case the tape makes the sides tight and difficult to fold.
  2. Tuck the small triangular flaps on the inside of the larger back flap. When this is done correctly, only taped sides are visible from above. The cut edge of the back flap should be flush with the folded sides.
  3. Use another layer of aluminum tape to secure the folded sides to the back flap. The back flaps could also be stapled together, with a heavy-duty stapler, for added strength.
  4. Take the 10 cm sheets and pinch the sides together along the diagonal scored line. Using a heavy-duty stapler, staple the pinched sides together (**Figure 1E**). The end product will have a square-bowl shape.
8. Tying the sheets together with 20 cm cable ties.
  1. Beginning with the 10 cm sheet taped on the un-scored side, with three holes, place the taped side down. Thread a cable tie through the left back hole of both 10 cm sheets. Leave 2 cm vertical spacing between the two sheets to ensure air flow around the temperature sensor. Repeat this step for the back right hole (**Figure 1E**; middle and right images).
  2. Take the 15 cm sheet and pass a cable tie through the two side-by-side holes, in the back left (**Figure 1E**; left image). Attach this tie to the 10 cm sheets, also leaving 2 cm of space between the 15 cm sheet and the top of the upper 10 cm sheet. Repeat this step for the two side-by-side holes in the back right (**Figure 1E**; left image).
  3. Finally, pass one cable tie through all three holes in the front of the sheets (shown by the arrow; **Figure 1E**). Tighten the cable tie, ensuring the space is even between all three sheets (**Figure 1F**).
9. Drill additional holes into the back end of the final assembled product to facilitate mounting, where needed. Wherever the shield is mounted, ensure that the three sheets lay parallel to the ground.



**Figure 1: Step-by-step instructions to construct a small radiation shield.** (A) 15 cm and 10 cm squares are cut out of the large sheet of corrugated plastic. (B) The 15 cm sheets are then cut and scored, and the 10 cm sheets are scored to allow bending of the shield to the correct shape. (C) Holes are drilled on each sheet. (D) The sensor is tied to one of the 10 cm sheets. (E) The shield is assembled using several cable ties. (F) The final shield is ready for installation. [Please click here to view a larger version of this figure.](#)

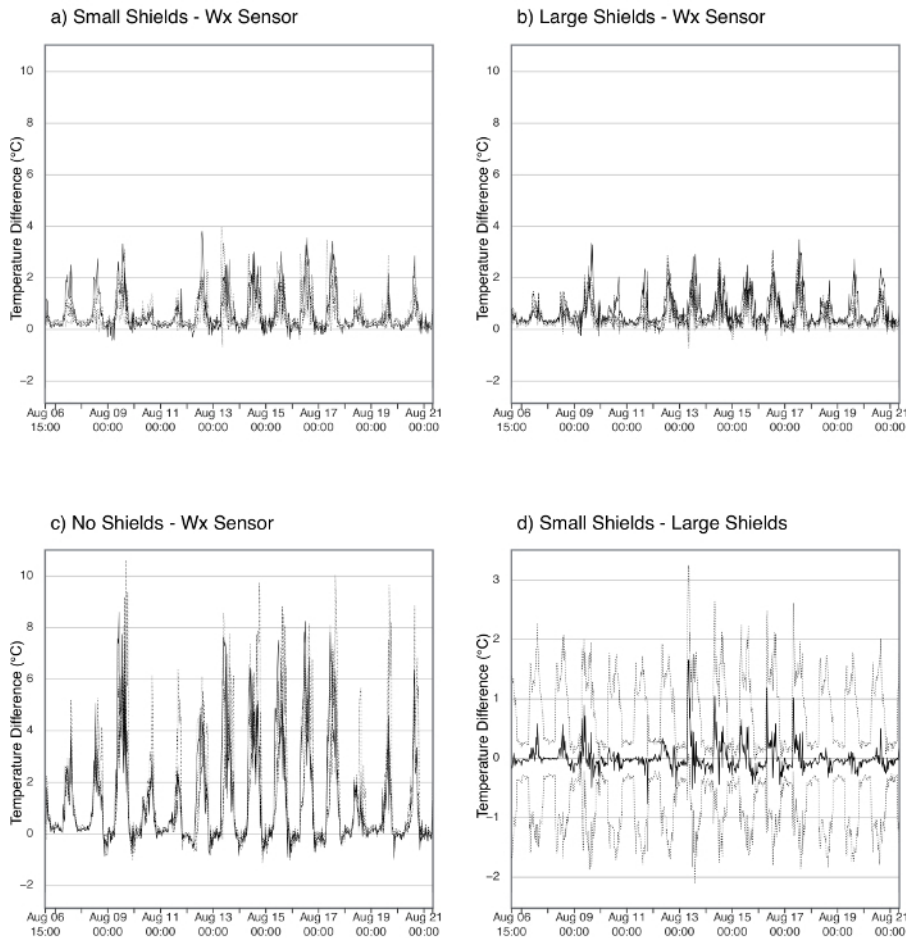
## Representative Results

Representative results using thermochrons outfitted with the new, smaller shield design, the original larger shield design, and the thermochrons with no radiation shield are shown in **Figure 2** and **Figure 3**. These data were recorded at a fully exposed rural location near Raleigh, NC (35.728°N, 78.680°W), and were affixed to a well-calibrated permanent weather station outfitted with a VAISALA platinum resistance air temperature sensor (HMP45C) mounted inside a wind-aspirated multiplate radiation shield<sup>7</sup>. In **Figure 2a**, boxplots are shown of the differences in recorded temperatures between four sensors using the small radiation shield, and the permanent weather station. Positive biases are found across all four tested sensors (mean bias = 0.56 °C), but are similar to those found using the original, larger shield design (**Figure 2b**; mean = 0.56 °C), and are much less than the biases of the unshielded sensors (**Figure 2c**; mean = 1.23 °C). The small shields result in the sensors recording some outlier warm temperatures relative to the original shield design (**Figure 2d**), although the overall differences are small (mean bias = 0.16 °C).



**Figure 2: Example boxplot results from a field experiment comparing temperature differences using different radiation shield treatments.** Distribution of temperature differences between the thermochrons with (A) the small radiation shield design (B) the original large radiation shield, and (C) no shields and the calibrated, permanent weather station recorded in August 2015 at a sunny, exposed location in Raleigh, NC. (D) shows the distribution of recorded temperature differences between the four thermochrons outfitted with the small radiation shield and the large shield-outfitted thermochron that had the smallest bias (*i.e.*, Sensor 3 in B). Differences above 7 °C are excluded from the plot in C (values extend up to 10.6 °C). [Please click here to view a larger version of this figure.](#)

In **Figure 3**, the diurnal nature of the biases is apparent in the time series. As in **Figure 2**, temperature differences are shown between the thermochrons outfitted with the small and large radiation shields and the calibrated permanent weather station (**Figures 3a, 3b**). Warm biases are strongest during periods of peak solar radiation, but in both cases are much less than the biases of the unshielded sensors (**Figure 3c**). The mean temperature difference between all combinations of sensors outfitted with the small radiation shield compared to the original design (solid black line, **Figure 3d**) is 0.002 °C and 0.06 °C for daytime hours (0700-2000 h LST). Interestingly, the largest differences with respect to the hourly estimated standard deviation (dashed lines, **Figure 3d**), are at 1400 and 0800 LST. The large differences in the afternoon during the heat of the day are to be expected considering the smaller size of the radiation shield. However, the source of the additional large differences in the morning soon after sunrise is not clear and could be due to sub-optimal shield-sensor angles (*i.e.*, the thermochrons were not parallel to the ground) which would expose the thermochrons to additional heating.



**Figure 3: Example time series results from a field experiment comparing temperature differences using different radiation shield treatments.** Time series of temperature differences between the thermochrons with (A) the small radiation shield design, (B) the original large radiation shield, and (C) no shields and the calibrated, permanent weather station recorded in August 2015 at a sunny, exposed location in Raleigh, NC. The mean (solid black line) and two standard deviations (estimated for each hour; dashed lines) of the temperature differences between all combinations of shielded thermochrons ( $n = 4$  small shields,  $n = 5$  large shields) are shown in (D). Note scale change in the ordinate axis in D compared to A through C. [Please click here to view a larger version of this figure.](#)

## Discussion

The accuracy and repeatability of air temperature measurements depend on the use of an appropriate solar shield that protects the sensor from direct and reflected solar radiation. Here we describe the construction of such a shield that is more compact in size, less expensive, or faster to construct than similar, previously described devices<sup>6</sup>, without sacrificing accuracy. 94% of the recorded temperatures for the thermochrons outfitted with the smaller shield were within 1.0 °C of the best performing thermochron outfitted with the original large, radiation shield, and 71% of the observations were within 0.25 °C.

The design of this shield, like that of its larger precursor, is a variation on the widely used, passively aspirated Gill shield. Ideal properties of a passive shield include shading the sensor from solar radiation from all angles; allowing air to flow freely through the shield; and absorbing minimal radiation into the shield material<sup>8</sup>. Design is often a compromise between shading and airflow. Designs that maximize passive airflow prevent complete shading and risk direct heating of the sensor; those with complete shielding hinder airflow and risk heating within-shield air relative to the air at large.

As a passively ventilated shield, the small radiation shield is inaccurate at low wind speeds (less than 1-2  $\text{ms}^{-1}$ ), when lack of ventilation promotes radiative heating of the air within the shield relative to the air at large<sup>7</sup>. This is a universal source of bias in passively ventilated shields, including costly manufactured ones. This bias is overcome in mechanically aspirated shields, but their electric requirements are generally prohibitive in replicated field studies. Biases in passive shields can be addressed through model-based corrections<sup>5,9,10</sup>. Such corrections, however, require simultaneous measurement of wind speed and shortwave radiation, which may also be impractical in the kinds of studies that rely on custom-fabricated shields. A final option is simply to accurately report shielding methods and acknowledge bias so that any reader attempting to compare temperatures reported across different studies can make informed interpretations.

Compared to a manufactured Gill shield, the small radiation shield described here has a daytime bias of 0.81 °C compared to a bias of 0.75 °C for thermochrons outfitted with the original shield design<sup>7</sup>. In direct comparison, its performance was nearly indistinguishable from that of the previously described large radiation shield, but represents significant savings in materials. We built the small radiation shields for \$1.36 US (2015

dollars) each in materials, including corrugated plastic, aluminum tape, and cable ties. In contrast, the original large radiation shield, because of the larger quantities of plastic and aluminum, would cost \$3 US (the authors' 2013 estimate) to \$4.75 US (our estimate)<sup>6</sup>. Cost estimates do not include the logger itself, its manufacturer-specified mounting bracket, or any structure upon which the shield might be mounted in the field.

Additional examples exist of custom-fabricated shields that have been well tested against manufactured shields<sup>11</sup>. In an 11-day test of a different handmade Gill shield<sup>11</sup>, two-thirds of all air temperature measurements in this shield were within 1.0 °C of those measured in a manufactured Gill shield. In our small radiation shield, accuracy of thermochrons was similar, with 83% of measurements within 1 °C of reference weather-station instruments at the sun-exposed site. The handmade Gill shield took its creators 45 minutes to construct, and would cost \$2 US (our estimate) to \$4 US (the authors' 2007 estimate) in materials. Again, the small radiation shield provides savings in materials and construction time.

Although we did not test for effects of variations in small radiation shield parameters, theory predicts that changes in materials, plate spacing, and fold angles would alter the ability of the shield to block radiation and allow airflow, and would yield results different from those reported here. Maximal shading of the sensor from both direct and reflected solar radiation requires the use of all three plates, folded as indicated, to block not only radiation from above, but also low-angle radiation from the sides and reflected radiation from beneath. Protection from reflected radiation is particularly important when sensors are deployed over snow, sand, pavement, and other non-vegetated surfaces<sup>7,12</sup>. Air flow within the shield is dictated by plate shape and spacing<sup>8</sup>; in the current design, any change to plate folding and spacing would influence air flow. Finally, use of a white material with aluminum-coated outer surfaces minimizes radiative heating of the shield itself; complete coverage of the top and bottom shield surfaces with reflective aluminum tape is essential to replicate this property. Shields need to be kept clean, or accumulation of dirt, bird droppings, and mold will alter their reflectance<sup>8</sup>. Finally, we also caution that, for comparability among multiple sensors in an array, they need to be deployed with the shield plates parallel to the ground and at a consistent elevation above ground-not always straightforward when the surface vegetation itself varies in height<sup>10</sup>.

Further improvements upon this shield design are undoubtedly possible. The use of clear coatings over an aluminum surface to improve thermal properties of radiation shields has long been known<sup>13</sup>. In tests with the large radiation shield however, other authors detected no benefit of additional coatings (mylar, white paint) over the aluminum tape alone<sup>6</sup>. The addition of rigid foam spacers between the plates, previously described in a custom-fabricated Gill shield<sup>11</sup>, is another potential modification that could standardize the design and prevent shifting of the plates in strong wind. A limitation of this shield is that its construction requires mounting on a horizontal bar or branch; it would be difficult, for example, to suspend this shield assembly from above while maintaining its correct orientation. Finally, for bulkier data loggers, the addition of another small interior plate with a cutout in the center could be desirable to create more space for the logger without altering plate spacing. Any of these changes would incur additional costs and construction time, and would require testing against the original standard or a calibrated weather station to assess performance.

We also stress that the current design was evaluated under a certain range of environmental conditions and any extrapolations of radiation shield performance outside of those conditions should be made with caution. In particular, this shield's design, in both this study and in the original paper where the larger version was introduced<sup>6</sup> were tested at high summer solar angles typically found at latitudes equatorward of ~45 degrees latitude. In areas with low seasonal solar angles, long daylengths, or both (such as experienced at high latitudes or in different seasons), different approaches to shield construction may be more appropriate.

With the advent of small, inexpensive temperature loggers, biologists have increasingly sought to assess air temperature at the fine spatial scales relevant to individual organisms and local ecological processes. Understanding microclimatic variation in air temperature can provide insights into local biological responses to recent and projected climate change. While additional thermal variables-such as soil, surface, or body temperature, each with its own accuracy considerations-may also be measured, air temperature is a common currency across studies of historical, current, and projected climates. Consistent use of radiation shields with well-documented properties will ensure that results of different studies can be meaningfully compared.

## Disclosures

The authors have nothing to disclose.

## Acknowledgements

We thank Emily Meineke for contributions to the original study design and experiment. We thank Ryan Boyles for facilitating access to the study sites and weather-station data. Jaime Collazo, Steven Frank, and Erica Henry provided the data loggers and radiation shields. Access to study site was approved by the North Carolina State Climate Office. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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