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Technical Note

Low-Cost Radiation Shielding for Use in Mapping the Thermal Environments of Rangeland Animals

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Abstract

Variations in its thermal environment can influence how an animal utilizes a rangeland landscape. Mapping the spatial and temporal air temperature patterns throughout a landscape may be helpful in predicting range animal distribution and habitat use. Many sampling points are required to effectively map air temperature levels throughout extensive and topographically diverse rangelands. Self-contained air temperature data loggers are commercially available, but these require shielding from solar radiation to provide accurate measurements. Commercial shields are expensive and fragile. A low-cost, robust, and effective alternative to commercial shields is needed for air temperature mapping applications. Two types of shields, vented cylinder and inverted-U shaped, were constructed from PVC pipe. Temperature loggers protected in either of these shielding types provided more accurate air temperature measurements than unshielded loggers. Temperature measurements from loggers protected by inverted-U shields were within ±2.5°C of a reference instrument in 94.7% of 2 496 observations. About 86.2% of observations acquired by loggers within vented-cylinder shields were within ±2.5°C of the reference. Conversely, only 66.1% of the measurements from unshielded loggers were within ±2.5°C of the reference. Both shielding types were designed to be attached to a swiveling mounting system, thus avoiding damage by animals and eliminating the need for protective exclosure fencing. Materials costs for constructing either shield type, including the mounting system, were $8.00 or less. In contrast, commercially available radiation shields with mounting hardware cost $75.00 or more. Compared to the use of commercial shielding, construction and deployment of these PVC-pipe shields would reduce the cost, time, and labor required to collect accurate air temperature data at many points across an extensive landscape.

Resumen

Las variaciones en el ambiente térmico pueden influenciar como el animal utilza el pastizal. Mapear los patrones temporales y espaciales de la temperatura del aire a través del paisaje puede ser útil para predecir la distribución animal y el uso del hábitat. Se requieren muchos puntos de muestreo para mapear efectivamente los niveles de la temperatura del aire a lo largo de paisajes extensos y topográficamne diversos. Registradores de datos de la temperatura del aire están comercialmente disponibles, pero estos requiren protección de la radiación solar para proveer mediciones certeras. Los protectores comerciales son muy caros y frágiles. Se necesita una alternatia de protección de bajo costo, fuerte y efectiva para las aplicaciones de mapeo de temperaturas del aire. Se construyeron dos tipos de protectores con tubo de PVC, un cilindro ventilado y uno con forma de U invertida. Los medidores de temperatura protegidos con cualquiera de estos tipos de protección proveyeron mediciones de temperatura más certeras que los medidores sin proteger. Las lecturas de temperatura de los medidores con protectores en U invertida estuvieron dentro de ±2.5°C del instrumento de referencia en el 94.7% de 2 496 observaciones. Aproximadamente 86.2% de las observaciones adquiridas por los medidores dentro de los protectores de tubo ventilado estuvieron dentro de ±2.5°C de la temperatura de referencia y de los medidores sin protección solo el 66.1% de las mediciones estuvieron en este rango. Ambos tipos de protección fueron diseñados para ser fijados en un sistema flexible que evita el daño por animales y elimina la necesidad de una cerca de exclusión para protección. Los costos de los materiales para ambos tipos de protectores, incluyendo el sistema de montaje fue de 8.00 dólares o menos. En contraste, los protectores de radiación comercialmente disponibles cuestan 75.00 dólares o más. Comparado con los protectores comerciales, la construccción y desarrollo de estos protectores de tubo de PVC pudieran reducir los costos, tiempo y trabajo requerido para colectar datos certeros de temperaturas del aire en muchos puntos a través de un paisaje extenso.

Key Words: air temperature, environmental factors, grid, habitat mapping, sampling, solar, spatial, thermal

INTRODUCTION

Air temperature is a critical environmental factor influencing habitat use by range animals (Ehrenreich and Bjugstad 1966; Parsons et al. 2003). Mapping air temperature variability at the habitat-unit scale may be useful for predicting range animal distribution and habitat use (Beaver and Olson 1997). A large number of sampling points, however, is needed to adequately

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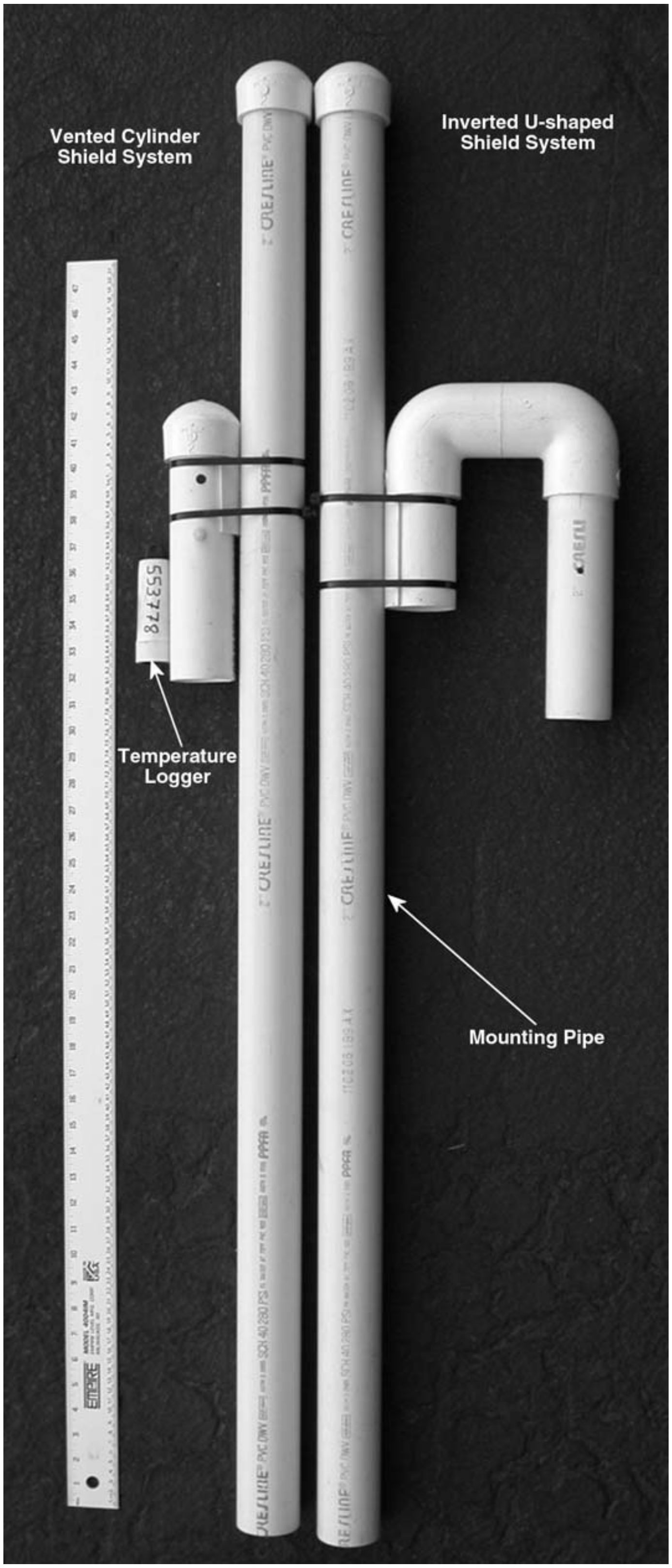

Figure 1. Air temperature monitoring system components including (from left to right) steel rule (1.2 m tall, shown for scale reference only), temperature logger (serial number 553778), vented-cylinder shield attached to mounting pipe with heavy-duty cable ties, and inverted-U-shaped shield attached to mounting pipe.

map air temperature in extensive landscapes with complex topography (Lookingbill and Urban 2003). Temperature sensors and data loggers, packaged as self-contained units, are commercially available at reasonable cost (about $100–$120). Without shielding from solar radiation, however, these temperature logging systems are subject to solar heating, thus resulting in erroneous readings. Radiation shields for these temperature loggers are commercially available but commonly cost nearly as much as the loggers themselves. These commercial shields are also very fragile and prone to damage by animals unless installed within a fenced exclosure. The combined cost of the temperature loggers, commercial shielding, and exclosure fencing, consequently, may be prohibitive for mapping extensive areas. The objective of this study was to develop a simple, low-cost radiation shield and mounting system that would allow collection of accurate air temperature data while avoiding physical damage from range animals.

MATERIALS AND METHODS

Study Site

The study site for this radiation shield evaluation was located within an antelope bitterbrush (*Purshia tridentata* [Pursh] DC.)-mountain big sagebrush (*Artemisia tridentata* Nutt. spp. *vaseyanna* [Rydb.] Beetle) stand at 1 584-m elevation within the Reynolds Creek Experimental Watershed in southwestern Idaho (lat 43°6′24.91″N, long 116°46′22.75″W). Terrain surrounding the site was a relatively flat bench elevated approximately 40 m above the Reynolds Creek floodplain to the east. Steep hillslopes existed east of Reynolds Creek and west of the study site. The site is subject to strong, diurnal up- and down-canyon airflow events.

Shielding Design and Construction

Radiation shielding was designed to contain temperature loggers with dimensions of 4.45 × 12.7 cm or less (1.75 × 5.0 inches; Hobo Pendant Temperature Data Logger™ or Hobo Water Temperature Pro™, Onset Corporation, Bourne, MA). Two types of radiation shields were constructed from 5.1-cm (2-inch)-diameter schedule 40 PVC pipe and fittings (larger-diameter PVC pipe could be used, however, to construct shields for oversized temperature loggers). The first shield type was a simple, vented cylinder made from a 23.5-cm length of pipe and a glue-on cap (Fig. 1). Two vent holes (0.95-cm diameter) were made by drilling completely through the pipe at a point 5.1 cm below the top of the pipe. A second set of holes (0.64-cm diameter), drilled 10.2 cm below the top of the pipe, was used for suspending the temperature logger inside the pipe. The logger mounting hardware consisted of a 7.6-cm length of threaded, nylon rod (0.64-cm diameter), nylon nuts, and spacers (1.9-cm long) cut from plastic tubing (0.64-cm inside diameter). Nylon and plastic hardware were used because they are more thermally stable and less likely to conduct solar heating to the temperature loggers than metal hardware. The rod was passed through 1 mounting hole, through a spacer, then through the anchor hole on the temperature logger, through another spacer, and then finally through the hole on the opposite side of the pipe. Nuts were tightened on both ends of the rod to secure the mount to the pipe. The spacers on either side of the temperature logger were used to keep the logger hanging centered within the pipe. Gluing a standard PVC end cap on the top end of the pipe completed construction of this shield.

The second type was an inverted-U-shaped shield, constructed using 2 PVC elbows and 3 short lengths of PVC pipe (Fig. 1). Pipe forming 1 leg (23.5 cm long) of this U-shaped shield was cut 10.2 cm longer than the other leg. The third length of pipe (7.6 cm long) was used to connect the 2 PVC elbows. All pipe joints were primed and glued using standard PVC assembly products. The temperature logger was hung inside the longer leg of the shield using the same suspension system and dimensions as described previously for the vented-cylinder shield. It was assumed this shielding style would self-vent because the height differential between the openings of the 2 legs would create a draft, drawing air up through the longer leg and out the shorter leg.

Both types of shields were designed to be mounted to a 137-cm length of PVC pipe using large, plastic cable ties (Fig. 1). The shorter, 13.3-cm-long leg served as the mounting leg for the U-shaped shield style. A short, lengthwise section cut from PVC pipe was fastened to the mounting pipe with short machine screws. This section of PVC pipe served as a stabilizing shim between the shield and the mounting pipe. The mounting pipe was capped, allowing the mounted shield to be slipped down over a steel fence post or T-post. Once installed, the mounted shield pivoted freely on the top of the fence post. This mounting system was intended to prevent cattle and other large animals from damaging the shielding by rubbing or scratching on it. It was assumed that when an animal attempted to rub, the shield would pivot away and/or slide up and down on the post rather than giving the animal purchase to rub or scratch. During four 30-day-long field deployments of 52 temperature loggers in large, range cattle pastures (200 ha), only 1 shield suffered damage. In that case, a cow managed to bend the steel post over by pushing and thus pressing the base of the mounting pipe against the ground, preventing the shield from pivoting. Rubbing then broke the cable ties securing the shield, an inverted-U-shaped type, and it was found lying on the ground near the mounting post. The temperature logger was not damaged during the incident and continued to record data. This problem might be avoided by using a more rigid mounting post, such as a 3.8-cm-diameter steel pipe rather than a T-post. This alternative design, however, would likely increase the cost of the system.

Shielding Evaluation Procedures

To evaluate shield effectiveness, a Hobo Water Temperature Pro™ temperature logger (certified accuracy = 0.2°C), was installed in each of 4 inverted-U-shaped shields and in each of 4 vented-cylinder shields. These shielded loggers were compared to 4 unshielded loggers, each of which was secured on the outside of a 137-cm-long PVC mounting pipe. Each unshielded logger was freely suspended from a 7.6-cm length of threaded nylon rod (0.64-cm diameter) that extended horizontally from a PVC pipe shim. Nylon nuts and 2 plastic spacers (1.9 cm long) were used to secure and stabilize the logger on the nylon rod. The shim, rod, and logger were secured to the mounting pipe using cable ties as described previously. The mounting pipes for all 12 temperature loggers were slipped over tall T-posts that were installed 1 m apart along an east–west transect line within 10 m of a meteorological monitoring station. The location of each logger, along this transect, was determined by random draw.

The meteorological station at the study site was equipped with a Vaisala HMP45D platinum resistance thermometer (PRT; Vaisala, Inc., Boulder, CO; complies with EMC standard EN61326-1:1997) housed within a nonaspirated RM Young gill shield. Gill-shielded PRT systems are commonly used in automated meteorological stations, thus providing a useful standard for this shield evaluation experiment. Logistical constraints prevented use of 2 or more colocated PRT systems; consequently, this experiment did not have a strict control. The PRT system used in this experiment, however, had been recently calibrated and was error checked by rigorously comparing its output to PRT systems at 3 nearby stations (i.e., <5 km distant and within 250-m elevation) throughout the duration of the experiment. This PRT system was assumed, therefore, to provide a very reliable standard for comparison of radiation shield functionality.

The PRT sensor within this system was located at a height 2 m above the ground. The height of each temperature logger installation was adjusted to place the sensor end of each logger at the same level as the PRT sensor. Temperature data from the temperature loggers and PRT reference system were collected instantaneously at 15-minute intervals for 26 days (19 March–13 April 2004) thus yielding 2 496 observations for each sensor. Replication of each of the shielding treatments (unshielded, vented-cylinder shield, and inverted-U shield) yielded a total of 32 448 individual temperature measurements from this experiment.

Statistical Analysis

Scatter plots revealed that measurements from the temperature loggers tended to exceed that of the PRT during the daylight hours and were lower than the PRT during the night. To deal with this measurement bias, the air temperature data were divided into 2 sets, 1 containing only daytime (0800–1945 MST) temperature measurements and the other only nighttime (2000–0745 MST) temperatures. Solar radiation data collected at the meteorological station were used to confirm which air temperature measurements had been made during daylight or night. Descriptive statistics were then generated for each of the 2 data sets (Table 1).

For each observation time, the mean of temperature from each shielding type was calculated on the basis of the 4 measurements (i.e., 1 measure from each temperature logger) made per shield type. The differences between the mean temperature from each shield type and the reference temperature from the PRT for each observation time were reported. An empirical cumulative distribution function (CDF) was calculated for both the negative and the positive measurement differences resulting from each shielding treatment (Fig. 2).

Solar radiation (langleys) measurements recorded at the weather station were included in a mixed-model regression analysis to determine the relationship between radiation levels and measurement differences in recorded temperature for each shielding type (SAS Institute, Inc. 2003). The database containing only daytime (0800–1945 hours) temperature measurements was used in this analysis. Successive temperature

Table 1. Variation in air temperature values acquired by sets of similarly shielded temperature loggers over a 26-day period from 19 March 2004 to 13 April 2004. Shielded loggers were protected from direct solar radiation by either a vented-cylinder ($n = 4$) or an inverted-U-shaped shield ($n = 4$). Unshielded loggers ($n = 4$) were not protected from solar radiation.

Shielding	Maximum deviation among similarly shielded sensors (°C)	Mean deviation among similarly shielded sensors (°C)	Standard deviation from shielding-type mean (°C)
Day only			
Unshielded	13.60	3.99	3.24
Vented cylinder	4.96	1.36	1.20
Inverted U	3.94	0.82	0.71
Night only			
Unshielded	3.14	0.50	0.29
Vented cylinder	0.90	0.16	0.09
Inverted U	1.06	0.39	0.15

Table 2. Regression parameters for predictive models describing the relationships between incoming solar radiation and air temperature measurement differences[1] for unshielded temperature loggers and loggers protected with vented-cylinder or inverted-U-shaped radiation shields.

Parameter	Coefficient estimate	Standard error	Degrees of freedom	Probability
Unshielded				
Intercept	−0.6059	0.2769	25	0.0383
Solar	0.2700	0.02708	284	<0.0001
Solar$^{1.5}$	−0.02017	0.003066	284	<0.0001
Vented cylinder				
Intercept	−0.7798	0.1304	25	<0.0001
Solar	0.1408	0.01302	284	<0.0001
Solar$^{1.5}$	−0.01097	0.001473	284	<0.0001
Inverted U				
Intercept	−0.7365	0.1154	25	<0.0001
Solar	0.1236	0.01101	284	<0.0001
Solar$^{1.5}$	−0.01022	0.001251	284	<0.0001

[1] A platinum resistance thermometer (PRT), housed in an RM Young gill shield, was used as the reference standard for determining air temperature measurement differences.

observations collected throughout each day ($n = 48$ observations•logger•d) were assumed to be serially correlated. An ARIMA (1, 1) model that estimated 2 covariance parameters—autoregression (rho) and integrated moving average (gamma)—was found to adequately describe the serial correlation structure. This correlation structure was then accounted for when estimating the standard error for each parameter of the final regression model (Table 2).

RESULTS AND DISCUSSION

Intratreatment Variability

Variability in day- and nighttime temperature measurements among the 4 temperature loggers used for each shielding type is shown in Table 1. Air temperature measurements from unshielded temperature loggers appeared to exhibit more variability than measurements from loggers in either of the 2 shield types. These unshielded loggers likely experienced a more variable environment than the shielded loggers. Unshielded loggers likely had more exposure to convective heating/cooling caused by air movement and to variable solar heating during partly cloudy days. Both of these conditions would contribute to erroneous measurements. The greater measurement variability from the unshielded loggers, however, may also have resulted from actual responses to very short-term air temperature changes. Loggers contained in the more stable environment of either shielding type may not have experienced these short-term temperature change events at all. Use of radiation shielding may thus involve a compromise between increased air temperature measurement accuracy at the expense of reduced sensitivity to short-term changes.

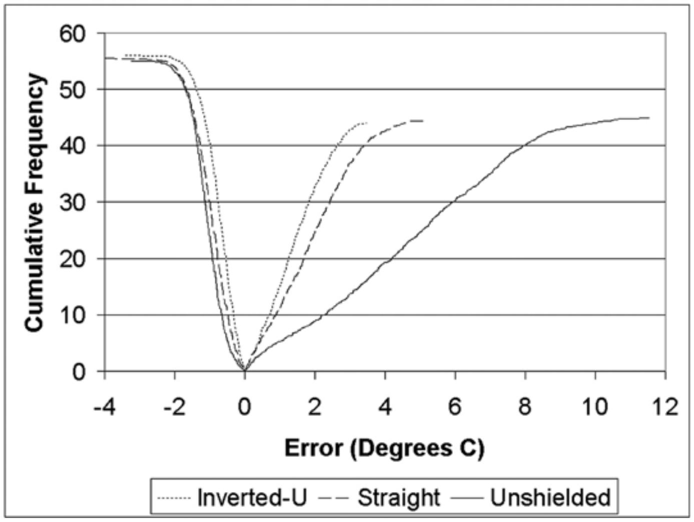

Figure 2. Cumulative distribution function (CDF) plot of measurement differences in data collected by temperature loggers contained in either vented-cylinder or inverted-U-shaped radiation shields or by unshielded loggers relative to measurement standard values obtained with a platinum resistance thermometer (PRT) housed in a RM Young gill shield.

Accuracy Improvement

Temperature loggers in both shielding types provided more accurate air temperature readings than unshielded loggers. Use of an empirical CDF plot (Fig. 2) provides a detailed view of the proportional measurement differences observed for each shielding type. The inverted-U-shielded temperature loggers exhibited measurement differences between −2°C and 0°C in 55.3% of the 2 496 observations and differences between 0°C and +2°C in 32.8% of the observations. Consequently, the measurement difference for the inverted-U shield type was within ±2°C of the PRT for 88.1% of the observations and within ±2.5°C for 94.7% of the observations. Measurements from loggers in the vented-cylinder shielding were within ±2.5°C of the reference in 86.2% of observations. Conversely, only 66.1% of the air temperature measurements collected by the unshielded loggers were within ±2.5°C of the PRT measurements. Erell et al. (2003) found similar results when contrasting air temperature measurement differences between PVC pipe shields (vertically and horizontally oriented and double walled), gill-type shields, and the Stevenson shield (reference standard). Although they did not evaluate an inverted-U-shaped shield, horizontally oriented pipe shields were found to give lower measurement differences, relative to the standard, than vertical pipes.

Modeling Solar Effects

Regression functions of the form shown here were fit to the daytime temperature data for each shielding type using the 26 days modeled as random replicates:

$$\text{Difference} = \text{a} + \text{b} \cdot \text{solar} + \text{c} \cdot \text{solar}^{1.5} \qquad [1]$$

The regression coefficients, standard errors, and *P* values derived for each shielding type are shown in Table 2. Scatter plots including the regression mean and predicted upper and lower 95% confidence limits for unshielded air temperature loggers and loggers contained in the inverted-U and vented cylinder are shown in Figure 3. This information suggests that increasing solar radiation enlarges the positive measurement difference in shielded temperature loggers relative to the PRT until air circulation is sufficient to cool the sensor and that this measurement difference stabilizes at about 2.0°C (Fig. 3). Allowing adequate air circulation seems to be critical to the performance of a radiation shield; wind may also adversely influence air temperature measurement accuracy in some shielding types (Van der Meulen 1998).

Cost

Materials costs for constructing an inverted U-shaped shield were about \$3.00 and \$1.00 for a vented-cylinder shield at the time of publication. Addition of mounting components, including a steel fence post, lengths and section of PVC pipe, and machine screws, brought the total system costs to \$8.00 for the U-shaped shield and \$7.00 for the vented cylinder. Approximately ½ to 1 hour of labor was required to construct a single shield with mounting system. Construction time was reduced to 15–20 minutes per unit where 50 or more units were mass-produced by a single person in a well-equipped shop using some simple jigs. In contrast, a commercial radiation shield with mounting hardware and post would cost about \$75 and require 10–15 minutes to assemble.

Radiation shielding constructed of short lengths of PVC pipe was much less prone to damage by livestock or wildlife than

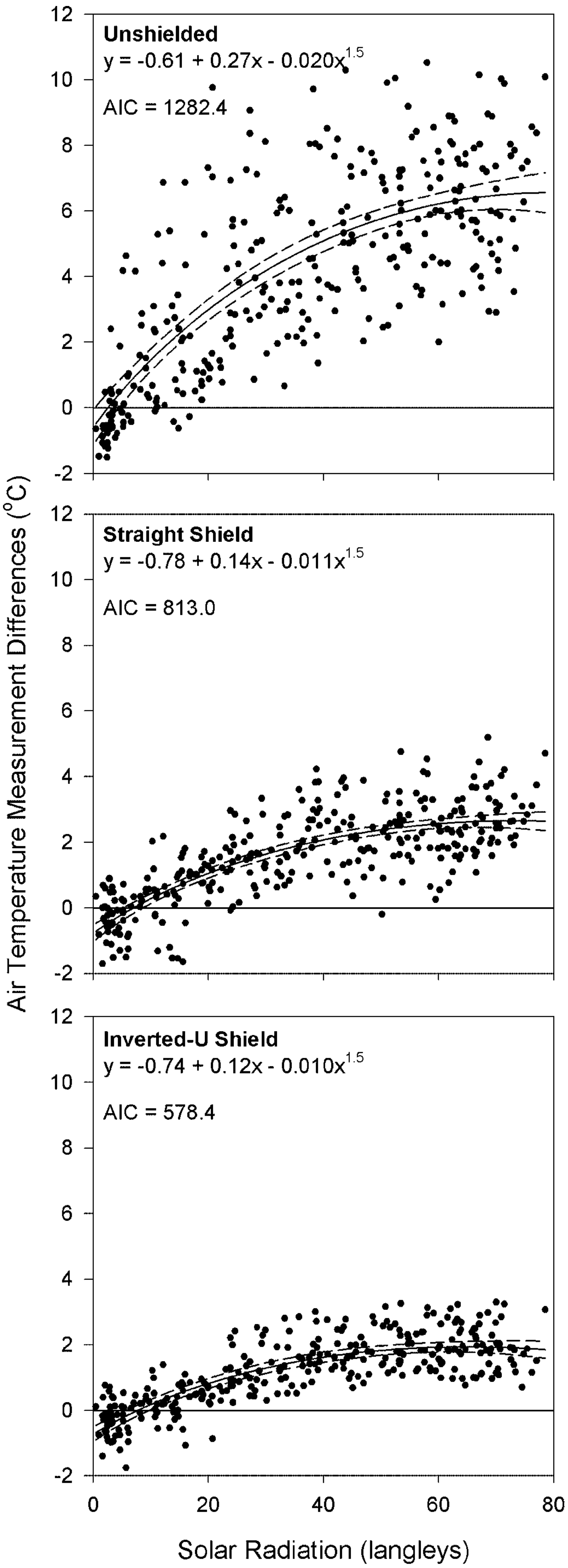

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Figure 3. Scatter plots of measurement difference values for air temperature measurements acquired by unshielded temperature loggers and by loggers contained in vented-cylinder and inverted-U-shaped radiation shields. Also shown are regression mean (solid line) and upper and lower 95% confidence limits (dashed lines) for each shielding type, which were derived using the following mixed model regression equation: $\text{Difference} = \text{a} + \text{b} \cdot \text{solar} + \text{c} \cdot \text{solar}^{1.5}$. The Akiake information criterion (AIC) value is a goodness-of-fit statistic for the ARIMA (1, 1) model used in this regresssion.

commercial shielding. Commercial gill-style shields are constructed with thin plastic fins, which would be more susceptible to damage than the PVC pipe shields even if both were installed on a swiveling mounting system. Consequently, installations using commercial shielding would require a protective exclosure fence to avoid damage, while the PVC pipe shields would not require additional protection. The pipe shields and mounting systems were completely assembled in the shop, including installation of the temperature data logger. Consequently, deployment of these systems involved only driving a steel T-post into the ground and slipping the mounting pipe over the post (Fig. 1). Deployment of a commercial radiation shield, including construction of a fenced exclosure to protect it, would take an hour or more.

MANAGEMENT IMPLICATIONS

For applications that can tolerate $\leq 2.5^\circ C$ of measurement difference, either the inverted-U-shaped or vented-cylinder shield types would likely provide adequate radiation shielding for air temperature measurement during the daylight hours. Although solar radiation is not an influencing factor at night, these low-cost shields also appeared to provide some accuracy improvement over unshielded loggers for nighttime air temperature measurement. Construction and deployment of the PVC pipe shields should reduce the cost, time, and labor required to collect accurate air temperature data at many points across an extensive landscape compared to the use of commercially available radiation shielding.

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