by Mark Blonquist & Bruce Bugbee

ACTIVE OR PASSIVE

The challenge of accurately measuring air temperature

Active aspiration improves accuracy, but requires power; passive natural-aspiration minimizes power use, but reduces accuracy

Air temperature is the most widely measured environmental variable. It influences what we wear and our choice of activities, affects properties of materials, and impacts nearly all biological, chemical and physical processes.

Air temperature is measured by home thermometers the world over, reported and forecast on the news, and required in nearly all environmental measurement programs, especially scientific research. The first thermometers were developed in the 1600s, but accurate measurement of air temperature remains a challenging task today.

Platinum resistance thermometers and precision thermistors provide high accuracy, but the challenge is far greater than having an accurate sensor. The sensor must be shielded from solar radiant heating so that it is in thermal equilibrium with the air. While it isn't difficult to measure air temperature to within a couple of degrees Celsius, accuracy of 0.2°C is often required. As a result, research continues to quantify measurement errors and develop new instruments.

Air temperature measurement at automated weather stations

Temperature sensors in automated weather stations are typically shielded from solar radiation by either a passive (static) or active (fan-aspirated) housing. Passive radiation shields are louvered enclosures that rely on natural aspiration from the wind to dissipate absorbed solar energy and equilibrate the sensor to the air. Active radiation shields dissipate absorbed solar energy and maintain equilibrium with the air through fan aspiration.

Passive shields do not require power, making them simple and cheap, but they warm above air temperature in low wind (Figure 1) or high solar radiation. This warming is minimized with active shields, which are more accurate under high solar radiation loads or low wind, but power is required for the fan. Historically, the average

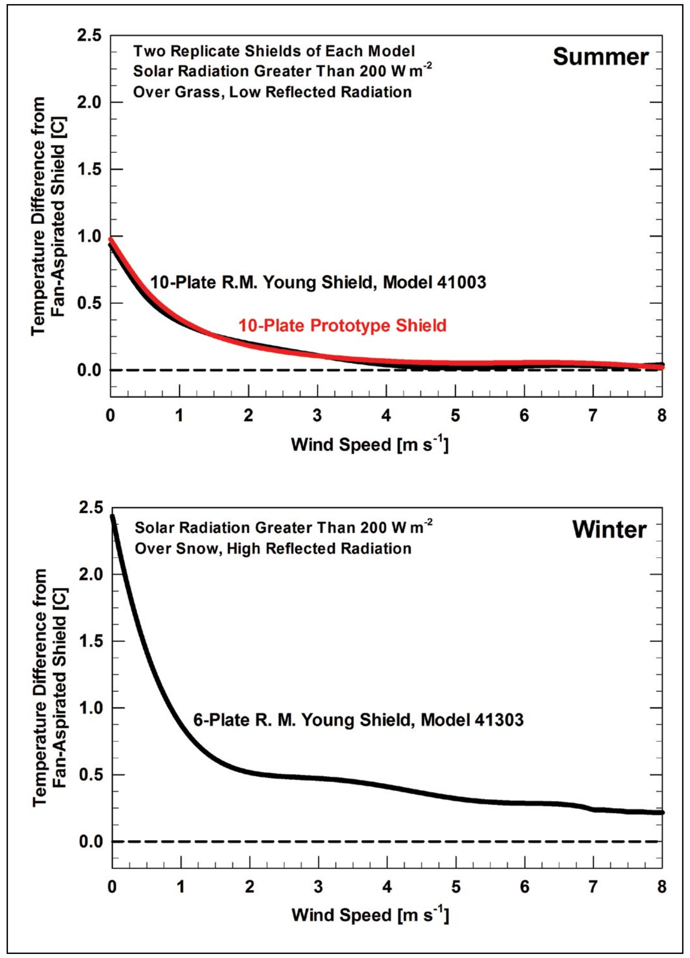

Figure 1: Temperature increase of two models of 10-plate passive shields as a function of windspeed in summer and of a six-plate passive shield in winter. Sensors in all the shields were the same model (Apogee Instruments model ST-110, 2mm diameter) and were calibrated and matched before deployment. Trends were derived from five-minute mean data collected over six-month periods in different locations. Over grass, both passive shields warmed above the reference active shield at windspeeds less than 4m/sec, and the warming increased sharply at windspeeds less than 2m/sec. Over snow, the warming was greater and the passive shield tended to remain warmer at all windspeeds. The temperature increase is generally larger when temperature is measured with a more thermally massive humidity probe

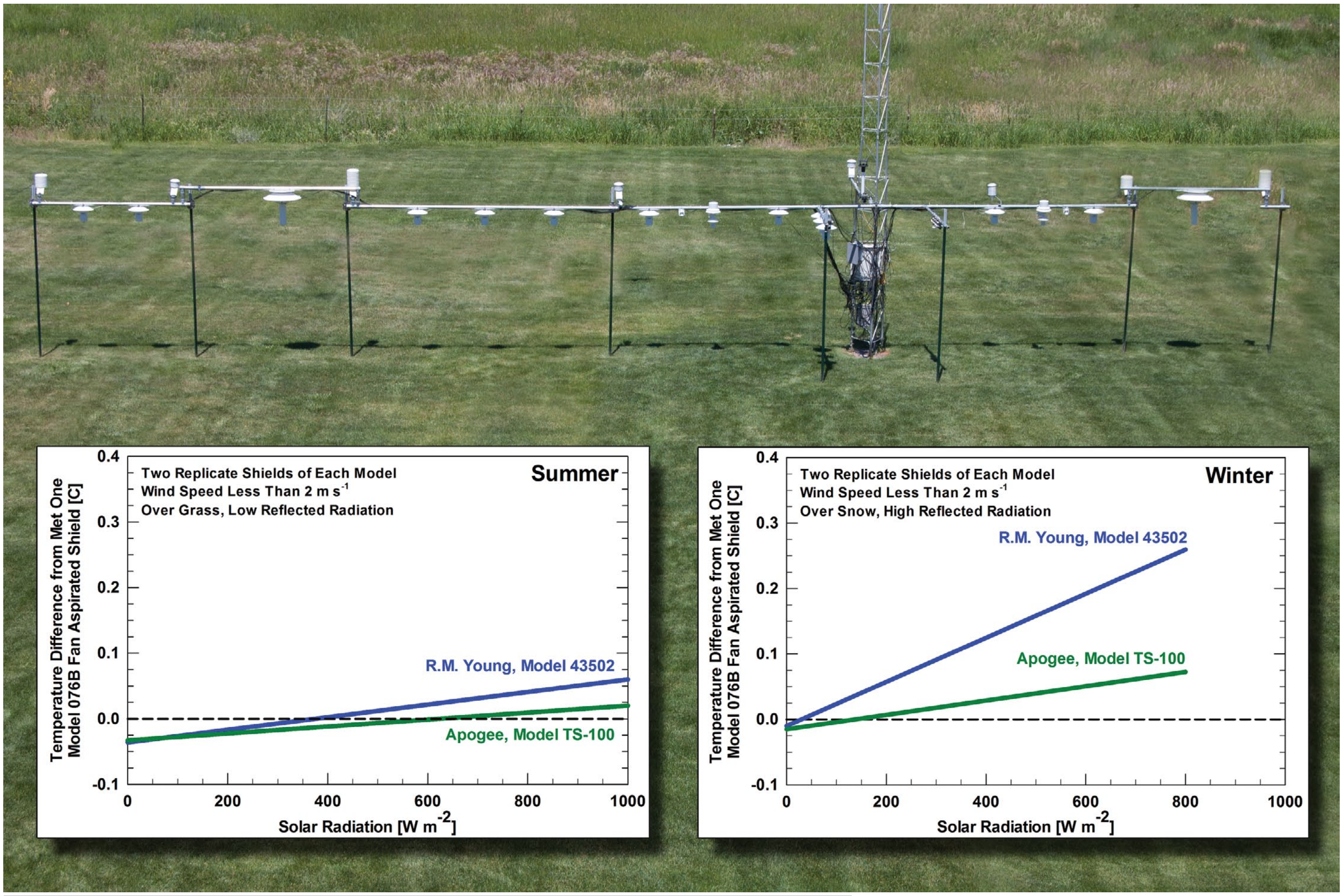

Figure 2: Temperature differences among three active radiation shields as a function of incoming solar radiation. Sensors in all the shields were the same model (Apogee Instruments model ST-110) and were calibrated and matched before deployment. Trends were derived from five-minute mean data collected over a one-year period. All three shields were within 0.05°C during summer, but deviation was greater and increased with increasing solar radiation during winter

daily power requirement has been 3-6W (250-500mA). For solar-powered weather stations this can be 95% of the power used by the entire station. Fan aspiration has typically required a large solar panel and large battery, which has led to the use of less accurate passive shields on many solar-powered stations.

Low-power active-shield design

Achieving the accuracy of an active shield without high power consumption required a novel approach. In 2013, Apogee Instruments, based in Logan, Utah, introduced a unique low-power fan-aspirated radiation shield (model TS-100, see opening image, right-hand side).

This shield incorporates an optimally curved inlet radius to help maintain laminar flow and draw air into the shield during high cross winds, and a rocket nozzle contour to constrict air flow inside the shield and increase its velocity as it flows past the sensor. A small, 2mm diameter, precision thermistor (Apogee Instruments model ST-110) is used to enhance equilibration with air. The shield includes a sensor port in the side to accommodate standard humidity probes (optional), which are mounted above (downwind of) the temperature sensor. Pulsewidth modulation can be used to reduce fan speed and save power at night or when the windspeed is greater than 3m/sec. Average daily power consumption is less than 1W (60mA), which is 10-20% of other active shields.

Performance testing

Two replicate TS-100 shields were compared with replicates of two widely used active shields. Continuous measurements for one year in Logan showed that differences among shields were less than 0.3°C (Figure 2). Differences increased with increasing solar radiation, particularly during winter months when there was snow (high reflectivity) on the ground.

The Met One model 076B shield was used as a reference because sensors in this shield tended to read slightly cooler than those in the others. These data demonstrate the ability of the TS-100 to yield accurate measurements with much lower power.

Comparison of a passive and an active shield

Measurements at a remote mountain site in northern Utah demonstrate the challenge of obtaining accurate winter air temperatures with a passive shield (Figure 3). Data from one week near the time of peak snowpack shows that a six-plate passive shield matched an active shield (Apogee Instruments model TS-100) within 0.2°C at night, and within 0.5°C when conditions were overcast and windy (day of year 89, in the calendar year), but differences on sunny

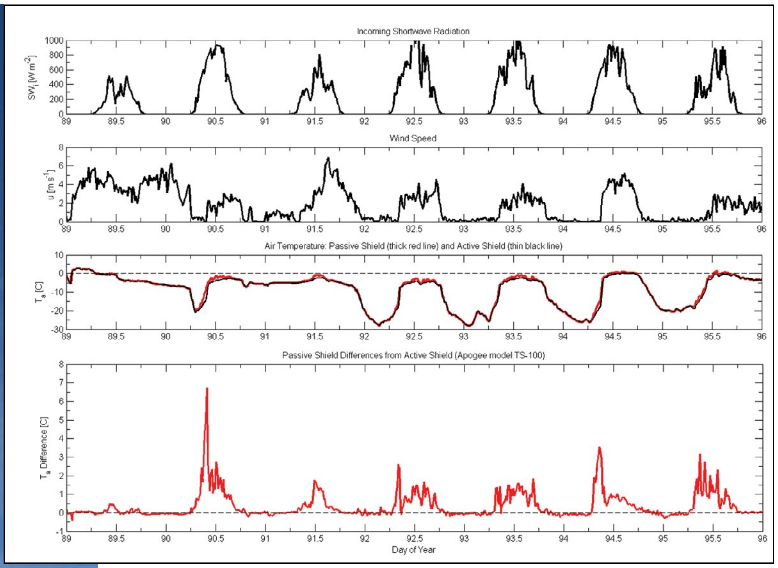

Figure 3: Comparison of passive and active radiation shields at the Peter Sinks site (2,488m) in the Bear River Mountains east of Logan, Utah. One-week time series (day of year 89 through 95; March 30 through April 5, 2014) of incoming shortwave radiation (SWi, top graph), windspeed (u, second graph), air temperature (Ta, third graph; the black line is temperature from the model TS-100 shield and the red line is the temperature from the six-plate passive shield), and temperature difference between shields (Ta Difference, bottom graph). Sensors in both shields were the same model (Apogee Instruments model ST-110) and were calibrated and matched before deployment. Figures are fifteen-minute means of measurements made every 10 seconds. Warming of the passive shield was greater than 1°C on most days

Figure 4: A GAMUT network weather station next to the Logan River in Logan, Utah

days with moderate wind were often 2-3°C (day of year 91-95) and as high as 7°C with low wind (day of year 90).

These figures indicate the magnitude of possible errors with passive shields when there is reflected radiation from snow.

Impact of temperature on snowfall

Mountain snowpack is an essential source of water in regions of the world where much of the annual precipitation accumulates as snow in winter. Small changes in air temperature can have a major impact on water availability because temperature determines whether precipitation falls as rain or snow.

Temperature also impacts the timing and amount of spring runoff. Accurate air temperature measurements are vital in studying and managing water resources. To better understand how climate change influences snowfall, snowpack and water resources, multiple weather stations have been deployed in a network called GAMUT (Gradients Along Mountain to Urban Transitions, Figure 4).

The GAMUT network is a collaboration of Brigham Young University, the University of Utah and Utah State University. This network monitors snowfall, snowpack, spring runoff and water quality over three watersheds in northern Utah, where a rapidly growing population is increasing demand for water that is predominantly supplied by winter snowfall and snowpack.

Commenting on air temperature measurements for the project, Jobie Carlisle, lead research technician, says, “We needed higher accuracy than that provided by static shields, but power was a concern due to the remote location of many of the stations and the expense of large solar panels and batteries. The Apogee shield was a good fit for the project because it combines high accuracy and low power use.”

Air temperature measurements are an essential component of weather monitoring and climate research worldwide, and continue to be challenging given the trade-off between accuracy and power consumption with passive and active shields. The TS-100 provides a unique solution by yielding high accuracy with low power consumption. ∎

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