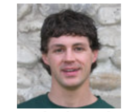
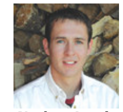
Design and Calibration of a New Infra-red Radiometer

Bruce Bugbee[1], Mark Blonquist[2], and Nathan Lewis[2]
[1]Crop Physiology Laboratory, Utah State University
[2]Apogee Instruments, Inc., Logan, UT


Bruce Bugbee


Mark Blonquist


Nathan Lewis

Introduction

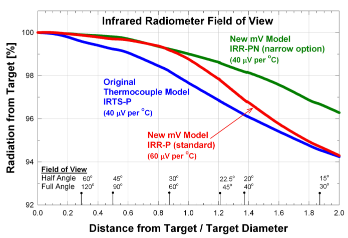
Accurate measurement of leaf to air temperature gradients are crucial for determining incipient water stress and measuring stomatal conductance. This gradient is often less than 1°C, which means that leaf temperature must be known to within about ± 0.1°C. This is a challenging task. Here we describe design and calibration procedures to achieve this accuracy with an infra-red radiometer.

Correction for sensor body temperature

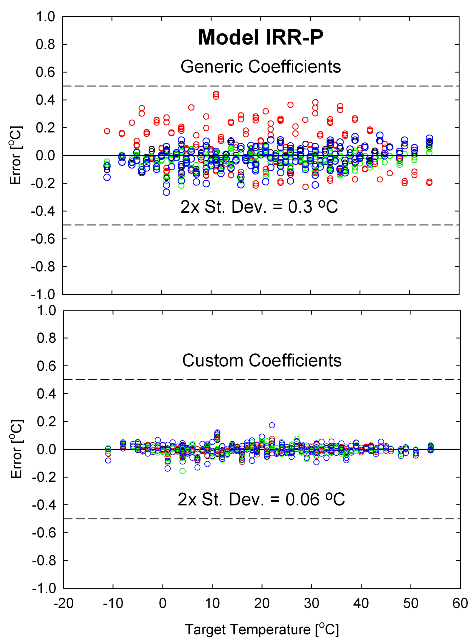
The output of infrared sensors is determined by the difference between the target temperature and the temperature of the infra-red detector (the reference temperature). Consequently, an error in the measurement of the detector reference temperature results in an error in the measurement. The device used to measure the detector temperature is usually not in perfect equilibrium with the detector so reference temperature errors are particularly large when the sensor body temperature fluctuates. This error is minimized by adding thermal mass around the detector to prevent rapid temperature changes and to keep all parts of the sensor at the same temperature. Published calibration procedures often describe detailed procedures to determine the temperature and emissivity of the black body calibration target but neglect the effect of sensor body temperature.

Original thermocouple output sensor with 6.5-14 µm window | **New mV output sensor with 8-14 µm window**

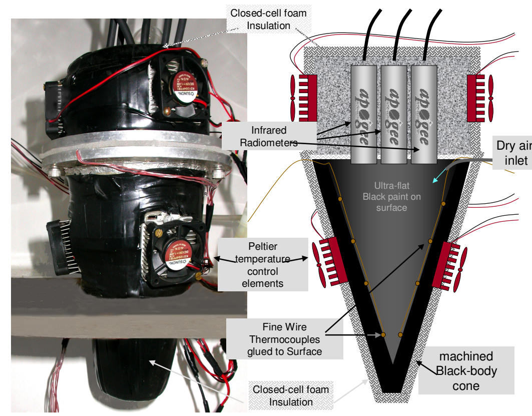
Field of view



The energy received by the infra-red detector depends on the sensor field of view (FOV). A wide FOV integrates a larger target area than a narrow FOV. The radiation incident on a typical radiation sensor is determined by the cosine of the angle viewed, which means that the incoming signal is primarily from the region directly in front of the sensor, but there is significant peripheral vision. Significant peripheral vision occurs in many applications because the sensor is not sufficiently close to the object. The error in temperature measurement caused by peripheral vision depends on the relative amount of radiation emitted by the target and surroundings. This error can be significant when the sky is in the sensor field of view



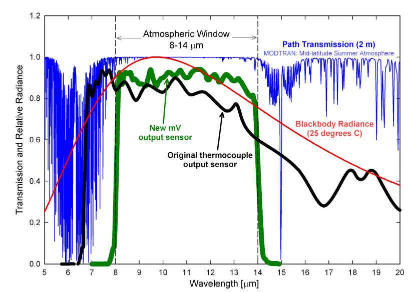
Calibration chamber



Accurate calibration requires independent control of both sensor body and target temperatures because the correction for sensor body temperature is not constant at all temperatures. We developed a calibration device to independently control both temperatures. The black body (BB) cone is 9 x 3.8 cm diameter, which increases the effective emissivity of the BB by the ratio of the surface area of the cone to the surface area of the opening (Kalma et al., 1988). The sensor body and target housings are thermally separated. The temperature uniformity of the sensor block and BB are within 0.02 °C. The BB temperature is measured with eight fine wire type-E thermocouples glued to the surface. Desiccated air is continuously pumped through the BB cavity to prevent condensation. Set point temperatures are maintained by six Peltier heaters. Thermocouple temperatures were measured with an isothermal multiplexer (CSI, model AM25T). Temperatures are controlled using a PID algorithm implemented in a datalogger (CSI, model CR10T).

Atmospheric transmission

Water vapor absorbs radiation at wavelengths below 8 µm and above 14 µm. The error caused by this absorption is significant when the distance from the target exceeds about 10 m, but it may also be significant at distances of 1-2 m. For this reason we developed a new sensor with a germanium window matching the atmospheric window, 8-14 µm, which minimizes the effect of water vapor absorption bands.



Correction for emissivity

Longwave radiation coming from a surface is the sum of emitted and reflected radiation. The capacity to reflect longwave radiation is 1 – ε (where ε = emissivity). A perfect black body (ε = 1) does not reflect longwave radiation, but plant leaves have an ε of about 0.96, so approximately 0.04 (4%) of the energy from plant leaves is reflected radiation that originates from the surroundings. This introduces an error in the measurement that is determined by the ε of the target and the temperature and ε of the surroundings. If the surroundings are at the same temperature as the target, the ε error is zero, even for objects with a low ε (e.g. aluminum foil). The apparent temperature of a plant canopy in the field is affected by the canopy ε, sky temperature, and cloud cover. When the ε of the surroundings is similar to the leaves the error can be approximated by the equation:

$$\text{Emissivity error} = (1 - \varepsilon) * (T_{leaf} - T_{surroundings}).$$

Literature cited

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Kalma J. D., and H. Alksnis. 1988. Calibration of Small Infra-Red Surface Temperature Transducers. *Ag. and Forest Meteorology*, 43:83-98.