Nighttime Offset and Capping Experiment Results of the Isothermal Pyranometer at the 2001 Diffuse Shortwave IOP

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Introduction

There is, as yet, no standard or reference for the measurement of the diffuse component of solar radiation. The 2001 Diffuse Shortwave intensive operational period (IOP) held at the Southern Great Plains (SGP) site compared data from a number of currently available and prototype instruments mounted on trackers with shading balls. The IOP paid particular attention to the tendency of most pyranometers to register a negative output during clear nights and for that offset to carry over to the diffuse measurement during clear days. This effect, due to energy exchange between the sensing surface and the inner dome, is a primary source of error in shaded measurements. A number of methods have been tried to reduce or correct for the effect. The Isothermal Pyranometer incorporates a unique approach to measuring broadband solar radiation that virtually eliminates offsets due to the influence of the inner dome. This was shown during the IOP by the consistent lack of any nighttime offset and the return of the output to zero during capping experiments.

Principle of Operation

Black surface pyranometers measure the temperature rise due to solar radiation of a black surface above some thermal reference. The temperature of the black surface typically differs from that of the inner dome, sometimes markedly (Bush, Valero, and Simpson 2000). In contrast, the Isothermal Pyranometer maintains an isothermal environment around the black receiver running from the receiver to the inner surface of the inner dome. Errors due to temperature gradients and associated non-solar energy flows to and from the receiver are thereby eliminated. Irradiance is measured by the effort required to *prevent* a rise in temperature of a black surface that receives solar radiation above that of a reference thermal mass. The temperature of the thermal mass, in turn, is regulated to match that of the inner dome. The detector assembly consists of an annular receiver surface, dual-purpose thermoelectric coolers, a thermal base, an infrared detector, and the case, which acts as a heat sink to ambient. Miniature resistors on the back of the sensor disk allow direct measurement of linearity by electrical substitution and are used to characterize the instrument. The configuration of these elements is shown in Figure 1.

Two closed loop control systems work together to maintain the isothermal condition. Both consist of sensors that measure a temperature difference that serves as the error signal, a control law, output amplifiers, and thermoelectric coolers (TECs) to pump heat and thereby reduce the error signal. Temperatures are measured relative to the thermal base, an aluminum disk sandwiched between coolers,

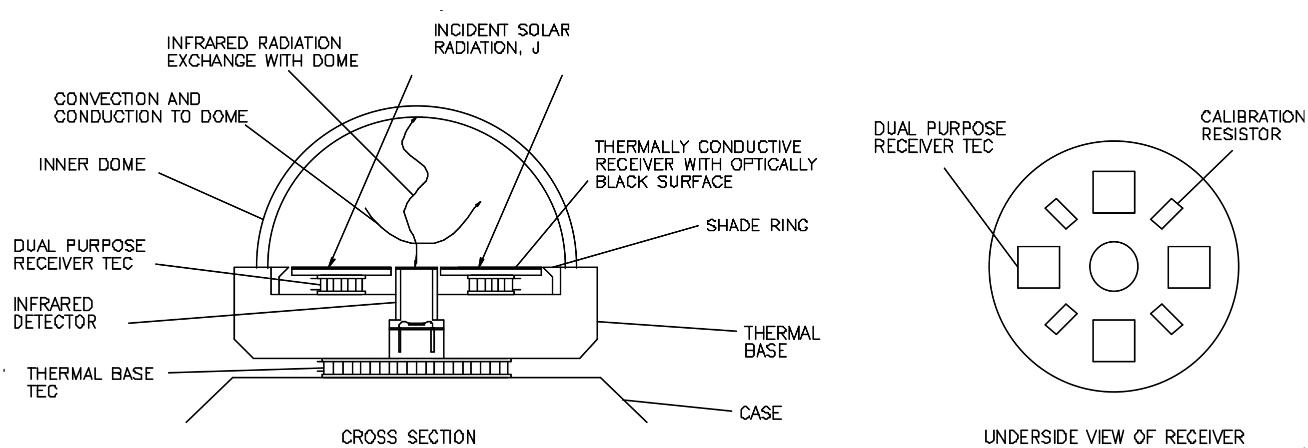

Figure 1. Schematic cross section of sensor and view of underside of the receiver annulus.

which are, in turn, between the receiver and the case. A control loop sampled at 80 Hz keeps the black receiver at the temperature of thermal base. Temperature rise of the receiver is measured with the sensing sections of four small dual-purpose thermoelectric devices. The devices also contain cooling elements that are used to pump heat from the receiver. The controller adjusts current to the pumping elements to null the error signal from the sensing elements. A control loop, sampled at 10 Hz, maintains the thermal base at the same temperature as the inner thermal base, views the inner dome. The electrical output of the infrared (IR) detector is proportional to the difference in temperature between the detector and the dome and serves as the error signal to the controller that modulates current to a large TEC between the case and the thermal base. The controller drives the IR error signal, and therefore the temperature gradient, to zero.

The current to the cooler under the receiver is a measure of the energy pumped to null the incoming solar radiation. If the TEC is used only within a small fraction of its heat-pumping capacity, the current is very nearly proportional to the radiant energy; linearity is within 0.5% without any corrections. Cooler current also depends on the temperature of the coolers and the rate of change of temperature of the receiver. The efficiency of a TEC increases with increased temperature; other properties, such as the thermal conductivity of materials, also vary with temperature. As with all pyranometers, a correction must be made for temperature. In addition, a change in temperature of the thermal base, brought about by a change in the ambient conditions, means that energy must be supplied to or taken from the receiver to maintain the isothermal condition. A digital controller uses the temperature of the thermal reference (needed anyway for temperature correction) to calculate the required correction.

Results at the 2001 Diffuse Shortwave IOP

The 2001 Shortwave IOP took place at the SGP site of the Atmospheric Radiation Monitoring (ARM) Program in September and October. Fourteen pyranometers were mounted on trackers with shading spheres. Voltages were measured with Campbell Scientific CR23x and CR10x recorders and archived. Although digital data was also recorded directly from the Isothermal Pyranometer, all results presented here are from analog data recorded on the Campbell recorders. Of these instruments, eight were unaltered, commercially available models (Eppley PSP, Eppley model 8-48, K&Z cm11, K&Z cm21, K&Z cm22, EKO MS801, Schenk Star, CIMEL B&W), two were commercial models with modifications (Eppley PSP modified by Martial Haeffelin, and a K&Z cm22 modified by Rolf Philipona), and four were prototypes (YES Isothermal Pyranometer, Carter Scott Designs EQ08-A, a new Eppley B&W, Scripps Total Solar Broadband Radiometer).

Nighttime Offset

Nighttime offset is any non-zero signal from a pyranometer during the night. In this case, night is defined as when the elevation of the sun is more that 10 degrees below the horizon. The nighttime outputs of the Isothermal Pyranometer and the three of the five pyranometers that Michalsky et al. (2002) found had the closest agreement (848, pspmh, cm11, cm22, cm22rp) are shown in Figure 2. Also shown for comparison, are the PSP and eq08. The pspmh data shown has been corrected based on the dome and case temperatures, as well as the square root of the output if the output is positive (Haeffelin et al. 2001). The output of the Isothermal Pyranometer is centered at zero and varies less than about $\pm$ 0.5 Wm^{-2}. The instruments of the first group have offsets ranging from slightly positive to about -2 Wm^{-2}. The modified instruments (pspmh and cm22rp) show the least offset of this group, while the others show -1 to -2 Wm^{-2} offsets. The output of the eq08 is centered on zero, but shows considerable scatter. The output of the PSP is offset by -4 to nearly -12 Wm^{-2}. The PSP with dome temperature

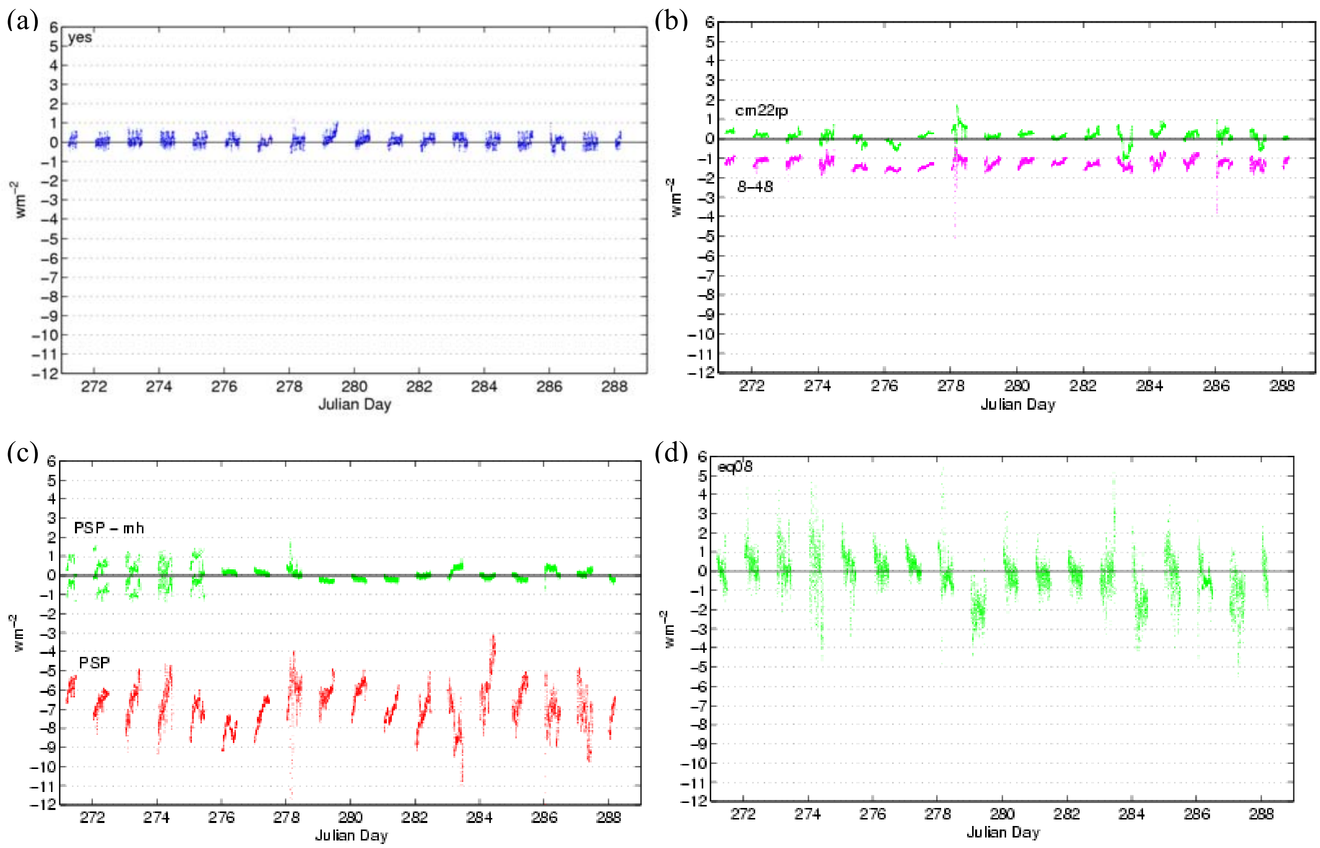

Figure 2. Nighttime offsets during the IOP of five pyranometers.

correction and the YES Isothermal Pyranometer both have a mean nighttime offset of less than 0.1 Wm^{-2} over the period, while the standard PSP has the greatest mean nighttime offset, -6.8 Wm^{-2}. The mean signal from the PIR thermopile was -88.6 Wm^{-2}, indicating good radiative cooling on average.

Capping Test

The capping test took place on September 29, 2001, and consisted of placing opaque caps over the domes of all the (shaded) pyranometers for a period of two to three minutes during the afternoon of a clear day. This was repeated four times at ten-minute intervals. The tests show both the time response and the approximate offset of the instruments. The latter assessment assumes that the response of the instrument is much faster than the time it takes for the glass domes and case to reach a new thermal equilibrium under the cap. The amount of offset seen in the capping test largely follows the offsets seen at night. Figure 3 shows outputs of all instruments during the fourth capping. The trends seen in the other capping tests are similar. Note that the capping was only roughly synchronized between instruments. The pspmh curve includes correction for dome temperature. As can be seen in the nighttime data, the YES and cm22rp go to within 1 Wm^{-2} of zero, while the 848, cm22, and schenk stay within 2 Wm^{-2} of zero. Other instruments show greater offsets. Normalized responses of the cm22rp, yes, and 848 when the cap was removed are compared in Figure 4. The Isothermal Pyranometer has a 1/*e* time constant of 3 seconds compared to just over 1 second (cm22) and more than 5.5 seconds (848).

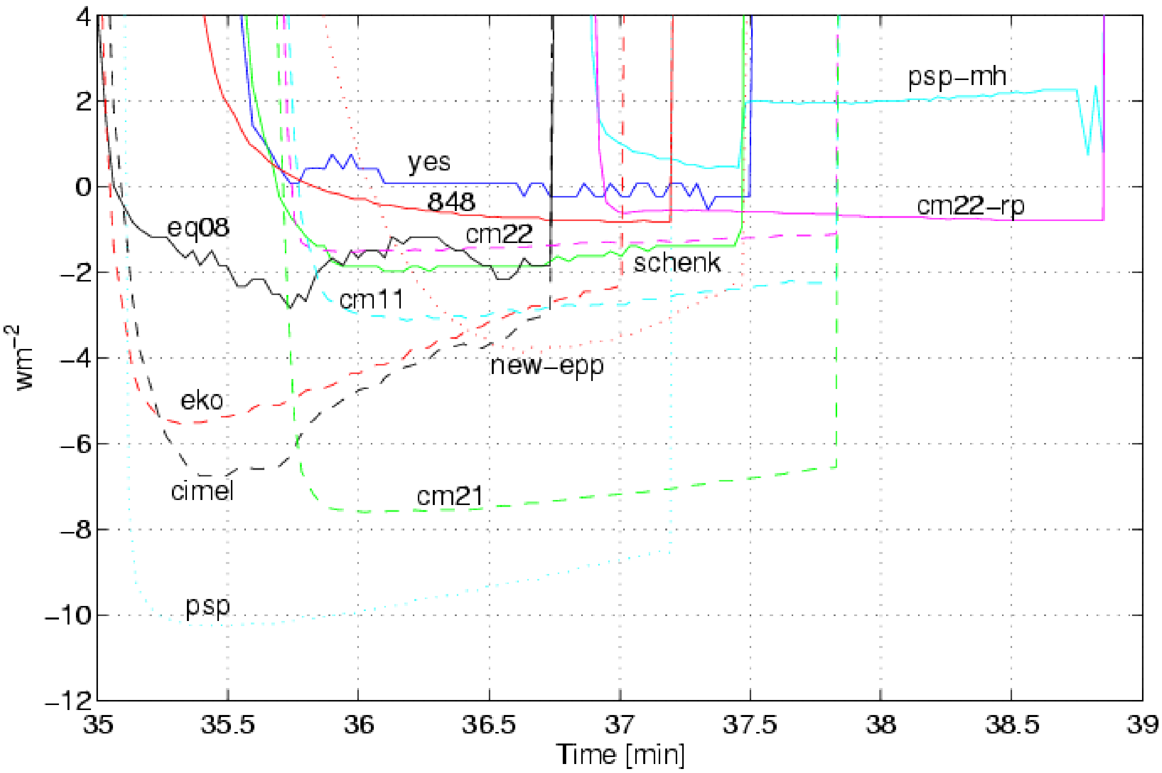

Figure 3. Output of all instruments, while capped.

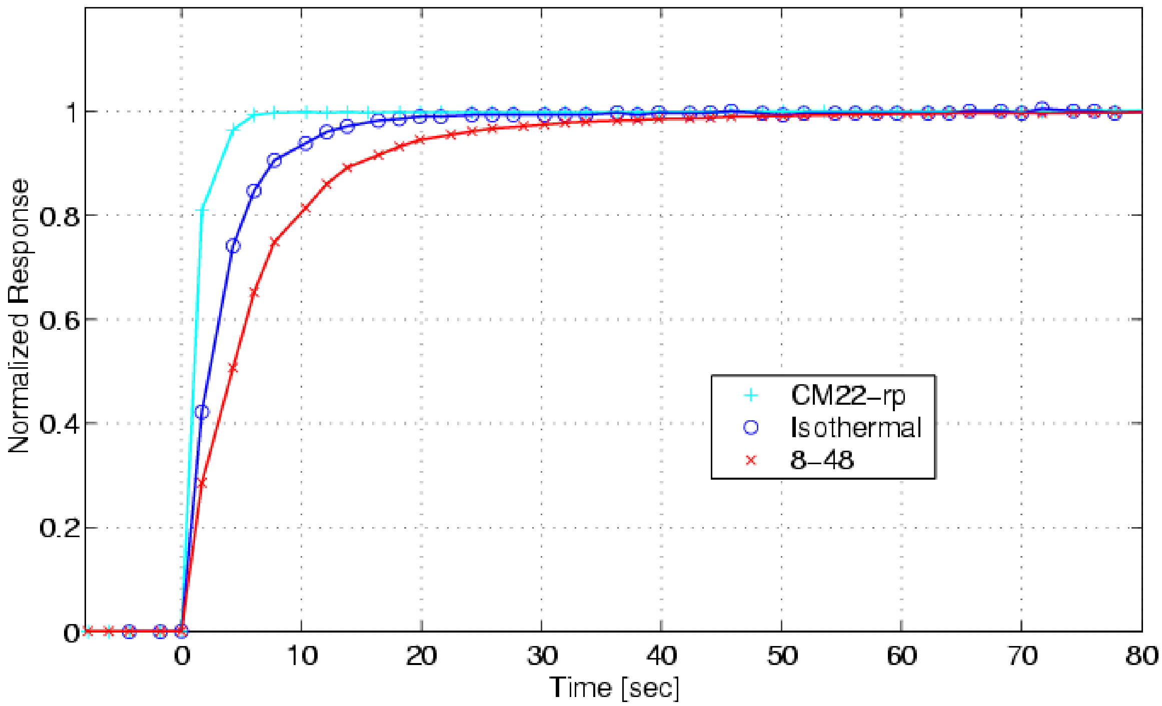

Figure 4. Normalized step responses of the yes, cm22rp, and 848 instruments.

Conclusions

Data from 2001 Diffuse Shortwave IOP demonstrate that the Isothermal Pyranometer does not show an offset at night and or while capped during the day, a major source of error in the measurement of diffuse solar radiation. This performance is due to the isothermal environment around the receiver that eliminates extraneous heat flows.

Acknowledgments

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