P3.11 NIGHTTIME OFFSET AND CAPPING EXPERIMENT RESULTS OF THE ISOTHERMAL PYRANOMETER AT THE 2001 DIFFUSE SHORTWAVE IOP

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1. INTRODUCTION

There is, as yet, no standard or reference for the measurement of the diffuse component of solar radiation. The 2001 Diffuse Shortwave IOP held at the 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 a consistent lack of any nighttime offset and the return of the output to zero during capping experiments.

2. 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, including 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** and **Figure 2**.

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Two closed loop control systems work together to maintain an 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. 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 second control loop sampled at 10 Hz maintains the thermal base at the same temperature as the inner surface of the inner dome. An infrared detector located in the thermal base produces an electrical output proportional to the difference in temperature between the detector and the inner dome. This is 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 thermoelectric cooler is used only within a small fraction of its heat pumping capacity then the current is very nearly proportional to the radiant energy. Cooler current also depends on the temperature of the coolers and the rate of change of temperature of the receiver. A digital controller calculates required corrections based on the temperature of the thermal reference.

Figure 1. Close-up of the instrument without cover. The infrared detector is visible in the center of the receiver.

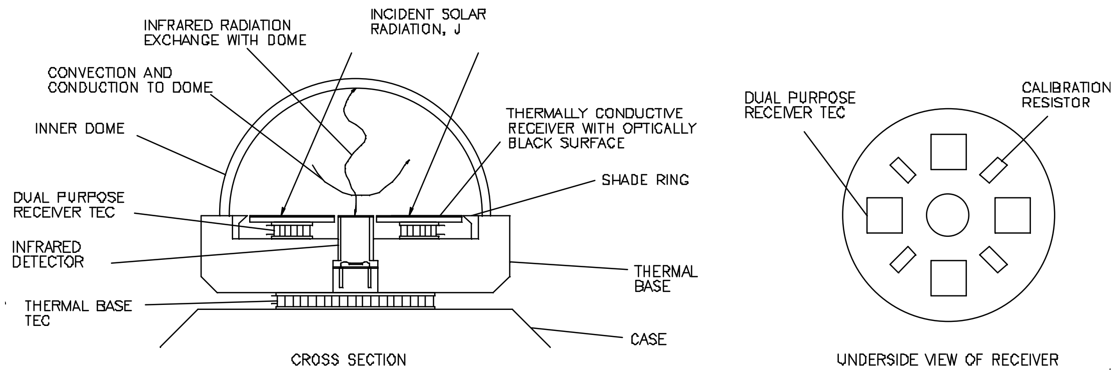

Figure 2. Schematic cross section of sensor and view of underside of the receiver annulus.

3. RESULTS AT THE 2001 DIFFUSE SHORTWAVE IOP

The 2001 Shortwave IOP took place at the Southern Great Plains site of the Atmospheric Radiation Monitoring Program in September and October. Fourteen pyranometers were mounted on trackers with shading spheres. Data was collected with Campbell Scientific CR23x and CR10x recorders and archived (Michalsky *et al.*, 2002); all results presented here are from that data set. Participating instruments and their abbreviations are listed in **Table 1**. Eight of these instruments were unaltered, commercially available models (psp, 848, cm11, cm21, cm22, eko, schenk, cimel), two were commercial models with modifications (pspmh and cm22rp), and four were prototypes (yes, eq08, newepp, tsbr).

1.1 Nighttime Offset

Nighttime offset is any non-zero signal from a pyranometer during the night. Here night is defined as when the elevation of the sun is more that 10 degrees below the horizon. The nighttime outputs of the instruments that Michalsky *et al.*, (2002) found agreed within 1-2 Wm^{-2} during the day (first group: 848, pspmh, cm11, cm22, cm22rp) are shown in **Figure 4.** Also shown are the Isothermal Pyranometer, the psp, and the 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} and the modified instruments (pspmh and cm22rp) show the least offset. The output of the eq08 is nearly centered on zero, but shows considerable scatter. The output of the PSP is offset by –4 to nearly –12 Wm^{-2}. The mean nighttime offsets are shown in the third column of **Table 1**. The average signal from the PIR thermopile for the same period was –88.6 Wm^{-2}, indicating significant radiative cooling.

The nighttime outputs during September 28 of the Isothermal Pyranometer and the five pyranometers of the first group are shown in the left plot of **Figure 4**. The right plot shows the output of some of the instruments in the second group, as defined by Michalsky *et al.* (psp, cm21, eko, schenk, cimel). The Isothermal pyranometer, shown for comparison in both plots, maintains zero output both just before sunrise and just after sunset.

1.2 Capping Test

The capping test took place on the afternoon of September 29, 2001 under clear skies. It consisted of placing opaque caps over the domes of all the (shaded) pyranometers for a period of two to three minutes at intervals of ten minutes. 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

INSTRUMENT	Abbrv.	nighttime mean (Wm^{-2})
Eppley Lab PSP modified by M. Haeffelin (thermistor on dome)	pspmh	0.02
Yankee Environmental Systems Isothermal Pyranometer (prototype)	yes	0.07
Kipp & Zonen cm22 modified by R. Philipona (heated ventilation)	cm22rp	0.13
Carter-Scott Design EQ08-A (prototype)	eq08	-0.20
Schenk Star	schenk	-0.31
Kipp & Zonen CM22	cm22	-0.95
EKO MS-801	eko	-1.12
Eppley Lab model 8-48	848	-1.26
Kipp & Zonen CM11	cm11	-1.67
CIMEL B&W	cimel	-1.81
Eppley Lab new B&W (prototype)	newepp	3.47
Kipp & Zonen CM21	cm21	-3.70
Eppley Lab PSP	psp	-6.83
Scripps (prototype)	tsbr	no data

Table 1. Instruments in the IOP archived data set, their abbreviations, and mean nighttime offset.

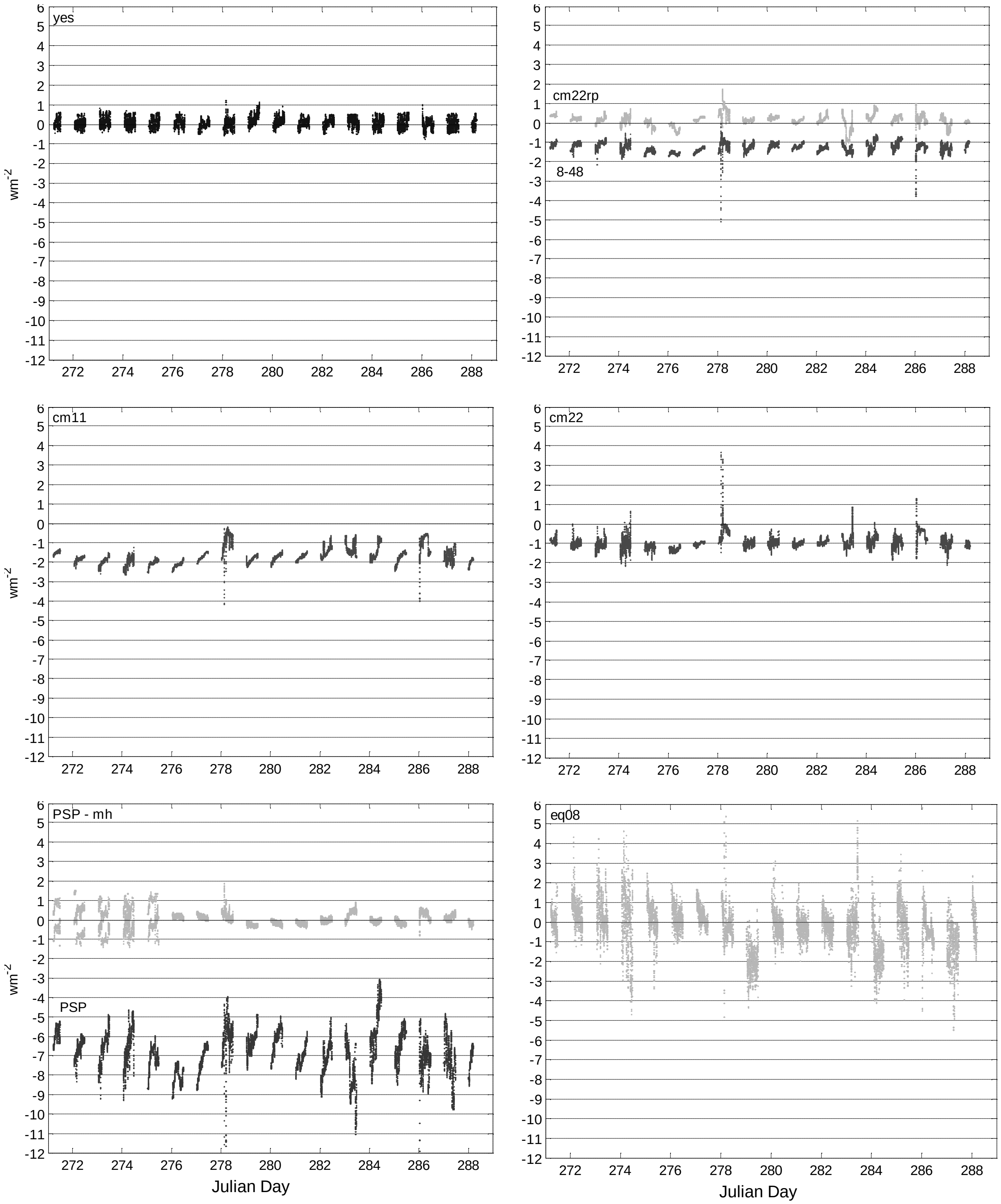

Figure 3. Nighttime offsets during the IOP of eight pyranometers.

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 5** 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. Normalized responses of the cm22rp, yes, and 848

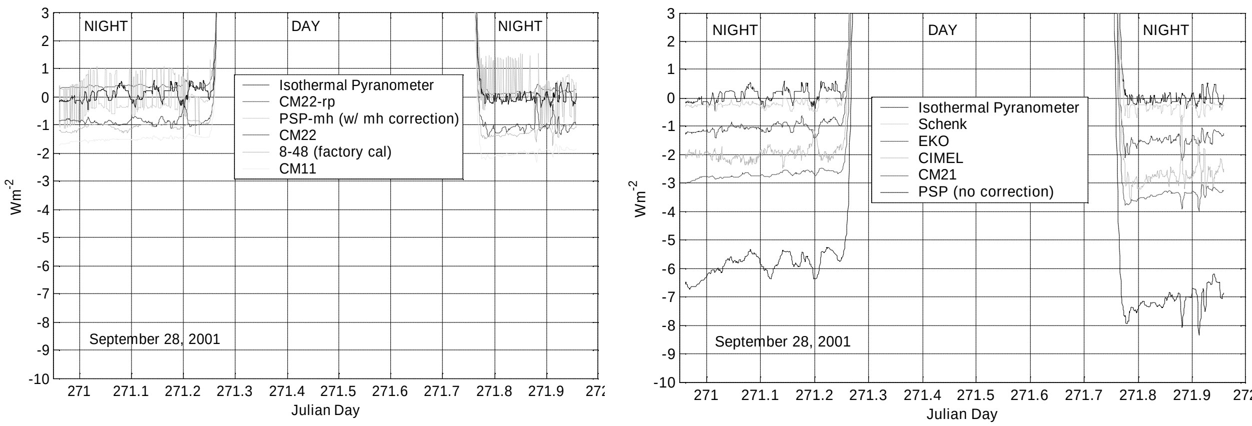

Figure 4. Expanded views of September 28, 2001 showing nighttime readings. At left, the Isothermal Pyranometer and five instruments in the group with closest agreement; at right five other, commercially available, instruments.

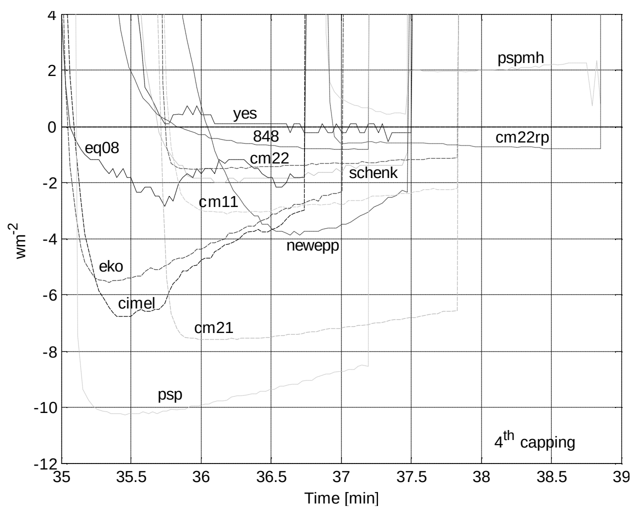

Figure 5. Output of all instruments while capped.

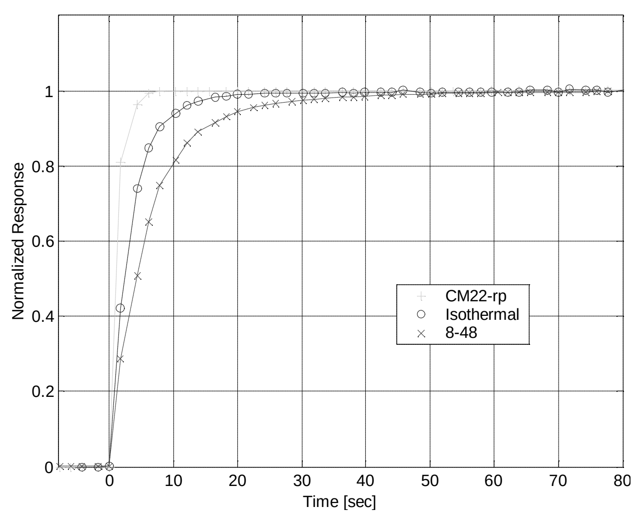

Figure 6. Normalized step responses.

when the cap was removed are compared in **Figure 6.** The Isothermal Pyranometer has a 1/*e* time constant of 3 seconds compared to the range from just over 1 second (cm22) to more than 5.5 seconds (848). A thinner receiver disk is planned which will reduce the time constant of the Isothermal Pyranometer.

4. 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. This performance is due to the isothermal environment around the receiver that prevents extraneous heat flows. Thus the Isothermal Pyranometer has eliminated a major source of error in the measurement of diffuse solar radiation.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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