7.1 COMPARISON OF DIFFUSE SHORTWAVE IRRADIANCE MEASUREMENTS

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1. INTRODUCTION

Solar irradiance measurements have improved significantly with recent contributions from the Atmospheric Radiation Measurement (ARM) and Baseline Surface Radiation Network (BSRN) communities as scientists have pushed for better measurements to rigorously test models of radiative transfer. Models and measurements of the direct normal irradiance generally agree to within measurement and modeling errors [Kato et al. 1997, Halthore et al. 1997]. Since the direct is measured with a small uncertainty using an absolute reference instrument (the self-calibrating cavity radiometer), model and measurement agreement gives us some assurance that the model inputs are reasonable. A significant problem arises, however, when we use these same model inputs to calculate the diffuse horizontal irradiance. Model irradiances persistently exceed measured irradiance for the cleanest sky conditions [Kato et al. 1997, Halthore and Schwartz 2000].

Diffuse horizontal irradiance sensors are pyranometers that are mounted on solar trackers and have direct normal solar irradiance blocked using a tracking ball or disk. In ARM these pyranometers are calibrated in full sun by comparing to a reference system that measures direct and diffuse horizontal components separately and adds to obtain a reference measurement. The pyranometer signal under test is ratioed to the summed components on clear days when the sun is within 5° of solar elevation 40°.

Large negative offsets using single-black detector pyranometers can amount to 20-30% of the diffuse irradiance in clean, clear skies [Bush et al. 2000]. A black and white pyranometer that eliminates most of this offset has replaced the single black detectors in ARM, but the ultimate solution for measuring diffuse irradiance remains elusive. The main difficulty is that there does not exist an absolute standard for the diffuse horizontal irradiance as exists for the direct normal irradiance.

As an first step in establishing a working reference, we conducted an intensive observation period (IOP) in September and October 2001 to compare pyranometer measurements of diffuse irradiance using representative commercial pyranometers plus four prototypes. The goal was to determine whether there was a consensus using different instruments calibrated independently.

2. EXPERIMENTAL DETAILS

Table 1 is a list of the instruments in the comparison. Ten representative commercial pyranometers and four prototypes were mounted on Sci-Tec 2AP two-axis trackers. The tracking during the experiment was flawless. The instruments were all mounted with the surface of the detector horizontal and with the blocking balls at the same distance from the radiation-sensing surfaces. While the shading was sufficient to block the direct beam for every instrument the detectors vary in

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size, leading to differences in measured diffuse of 1-2 W/m^2 caused by geometry.

On one of the trackers we also measured downwelling infrared radiation using an Eppley PIR pyrgeometer that was shaded from direct beam irradiance. These measurements are used to correct the **cm21** and **psp** offsets using the algorithm proposed in Dutton et al. [2001].

TABLE 1. Instruments in comparison

Instrument -- **symbol**
Carter-Scott Design EQ08A (prototype) — **eq08**
Eppley PSP dome & case temperature — **psp-mh**
CIMEL black&white – **cimel**
EKO MS-801 — **eko**
Kipp & Zonen CM 11 — **cm11**
Kipp & Zonen CM 22 — **cm22**
CM22 heated ventilation — **cm22-rp**
Eppley 8-48 — **8-48**
Eppley (prototype black & white) — **new_epp_bw**
Kipp & Zonen CM 21 — **cm21**
Schenk Star — **schenk**
Eppley PSP — **psp**
Yankee Isothermal Pyranometer (prototype) — **yes**
Scripps (prototype) — **tsbr**

3. RESULTS

After examining the data collectively we found the most consistent results among five of the pyranometers, moderate consistency among five others and less consistency among the prototypes. Our focus was initially on clear-day measurements since those are expected to be the most likely to disagree because of offsets and asymmetric skylight distributions convolved with imperfect cosine responses. Figure 1(a) contains data from the clear day of 28 September 2001 (day of year 271). The data plotted are for solar elevations greater than –10°. Time is local standard time. The **psp-mh** data are corrected according to the procedures outlined in Haeffelin et al. [2001]. The four others have no corrections. The three Kipp & Zonen (**cm**xx) pyranometers have very high volume ventilation relative to the other pyranometers in this experiment; the **cm22-rp** has the only vented air that is heated. The **psp-mh** and the **8-48** have modest ventilation to keep dew from forming on the outer window. The one-minute difference of each measurement from the mean of the five is plotted in the bottom of Figure 1(a) (use the left-hand-side (lhs) ordinate). The standard deviations among the five are plotted as a function of time according to the right-hand-side (rhs) ordinate of the bottom figure. The range in standard deviation for this day was 0.24 -1.46 W/m^2 with an average deviation of 0.63 W/m^2.

In Figure 1(b) the **psp** has been corrected using the method outlined in Dutton et al. [2001] where the offset is determined using nighttime pyranometer data (sun lower than –10°) regressed against the net PIR signal with the intercept forced through zero. This was also used for the **cm21**. The Meteorological Services of Canada (MSC) algorithm produces a correction that did not do as well; it is based on an average night correction using the data just before sunrise and just after sunset on each day. The MSC network does not include pyrgeometers at most of its sites, which precludes the routine use of the Dutton et al. [2001] method. The **cimel**, **eko**, and **schenk** were not corrected. The **psp** and **cm21** were ventilated to prevent dew formation, but the **cimel**, **eko**, and **schenk** were not. These five measurements are plotted in the top of Figure 1(b). The mean of the five measurements in Figure 1(a) is included for comparison. The bottom of Figure 1(b) is a plot of the differences between the mean in Figure 1(a) and each of the pyranometers of Figure 1(b).

The four prototypes that were included in the experiment (**eq08**, **new_ep_bw**, **yes**, and **tsbr**) are plotted in the top of Figure 1(c) along with the mean from Figure 1(a), and the difference from this mean is plotted in the bottom of Figure 1(c). It appears that some improvement could be achieved with a better calibration and/or offset correction although it is not clear that this would work for every prototype.

On 5 October 2001 (day of year 278) we had opaque clouds in the morning. Figures 2(a-c) are plots for the same sets of instruments as presented in the previous two sets of figures for the part of the day (2.4 hours in length) that is known to be overcast based on direct beam data. There is a fairly tight grouping in Figure 2(a) of the five that had the best consistency in earlier figures. The standard deviation (bottom) is only slightly higher than it was for the clear day in Figure 1(a) with the differences fairly constant in time. The next most consistent group in Figure 2(b) shows a larger spread than they did for clear skies. In the bottom of Figure 2(b) the deviations from the mean in Figure 2(a) are plotted. In the bottom of Figure 2(c) the prototype differences from the mean in Figure 2(a) are consistent with those shown for the clear day in Figure 1(c).

4. SUMMARY

Fourteen measurements of diffuse horizontal irradiance were made simultaneously over a two-week period in September and October 2001. Tracking to keep the instruments shaded was excellent. Five of the measurements were consistently within 1-2 W/m^2 of their mean for both clear and cloudy conditions. Five other measurements were slightly less stable with most measurements within 2-4 W/m^2 of this mean. The prototypes showed poor agreement, and the most consistent

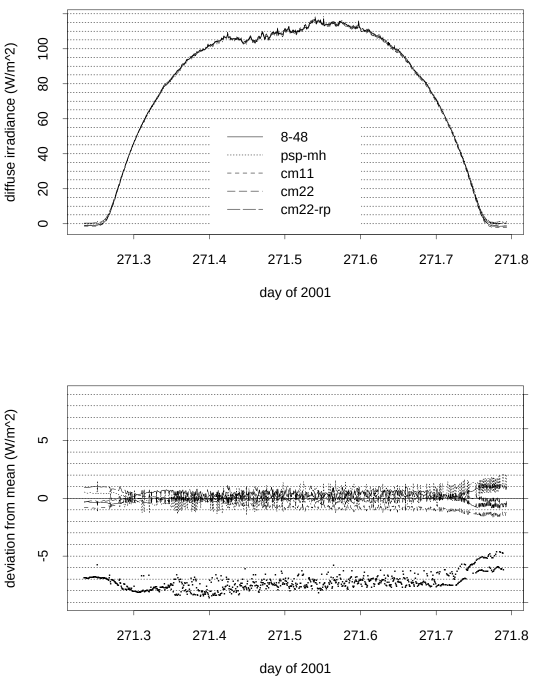

Figure 1(a). Five most consistent diffuse irradiance measurements. Top is over plot of five, and bottom is difference from mean and standard deviation (rhs axis).

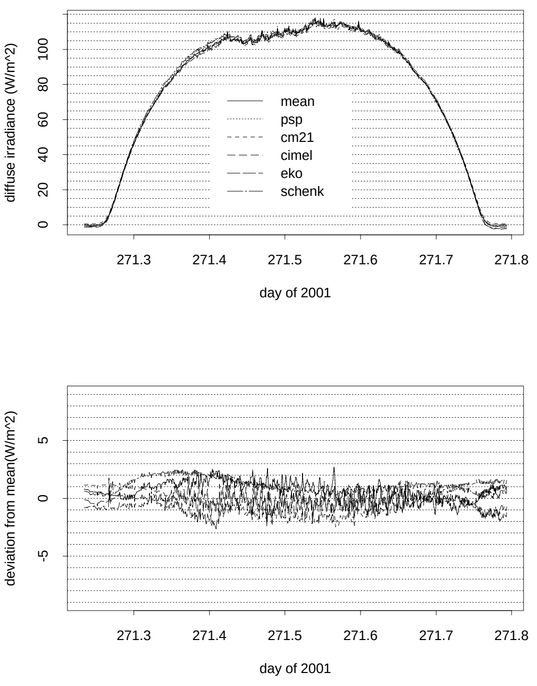

Figure 1(b). Next five most consistent diffuse measurements. Top is over plot of five plus mean of Figure 1(a), and bottom is deviation from that mean.

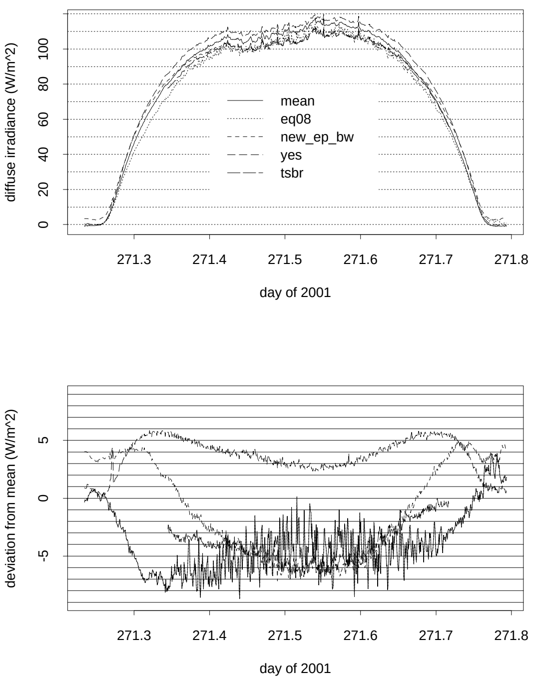

Figure 1(c). Top is over plot of prototype measurement of diffuse irradiance. Bottom is deviation from mean in Figure 1(a).

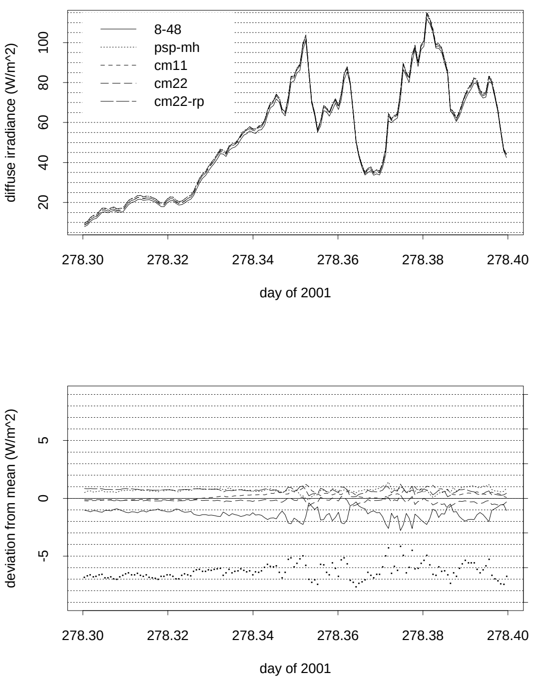

Figure 2(a). Cloudy day irradiance over plot of five most consistent diffuse measurements. Bottom is deviation from the mean and standard deviation (rhs axis).

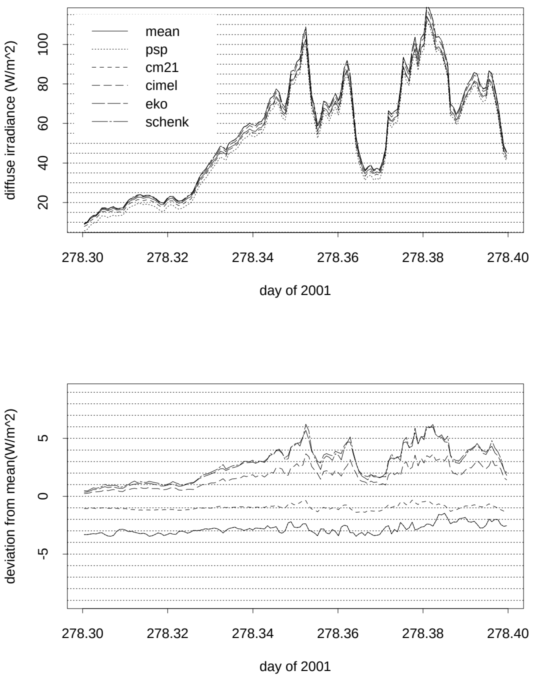

Figure 2(b). Next most consistent group of diffuse measurement for a cloudy day. Bottom is deviation of each in top of figure from mean of Figure 2(a).

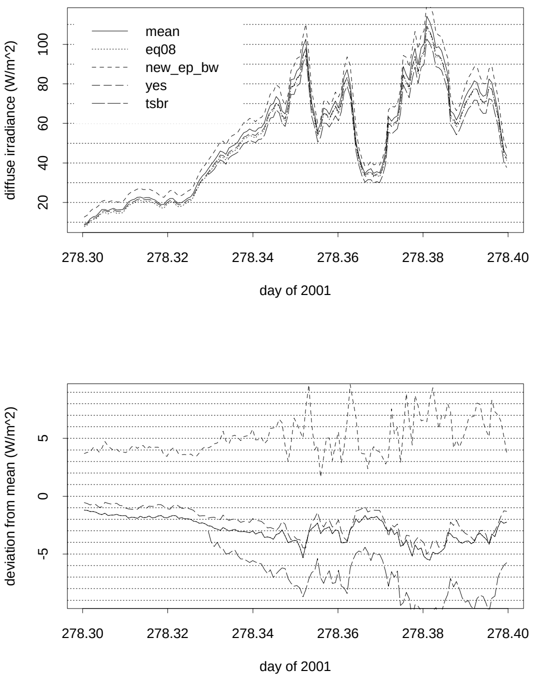

Figure 2(c). Prototype diffuse measurements on a cloudy day. Bottom is deviation of each from mean of Figure 2(a).

Measurement were from the commercial instruments.

There are still unresolved issues regarding calibration. The current procedure in ARM produces 3 to 4% higher diffuse irradiances than are measured by the most consistent group of five.

There are geometry differences in the radiometer detectors. Since all were shaded similarly with the same size blocker at a fixed distance, the larger detectors receive more diffuse radiation from the penumbra than the smaller detectors. Calculations suggest that the differences between the largest and smallest detectors are less than 2 W/m^2 for the data shown here.

Based on this study, it appears that we should be able to establish a set of instruments that we can maintain as a working diffuse standard group for ARM. However, the question of how close this standard is to the true absolute value will remain elusive until an absolute diffuse radiometer is developed.

This research was supported by the Biological and Environmental Research Program (BER), U.S. Department of Energy, Grant No. DE-FG02-90ER61072.

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