A Rotating Shadow Arm for Broadband Hemispheric Radiometers: Instrument Design and Concept Verification Using Atmospheric Radiation Measurement Southern Great Plains Radiometer Measurements

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Measurement of the components of downwelling broadband shortwave (SW) irradiance at the surface can be difficult to accomplish. Because the diffuse irradiance under clear (i.e., cloudless) skies is typically only about 10% of the magnitude of the total SW near local solar noon, instrument inter-calibration offsets can significantly affect the relationship of the diffuse to total SW measured. Both the direct and diffuse measurements involve following the solar disk, which introduces tracking and alignment problems. Thus shading disc systems for diffuse measurements and solar tracking perheliometers measuring the direct normal solar irradiance both tend to need careful monitoring and maintenance. These maintenance requirements often preclude deployment of diffuse and direct instruments in remote locations.

A rotating shadow arm attachment has been designed for use with a standard pyranometer rotating shadowband radiometer (RSR), which allows both the total and diffuse irradiance to be measured by the same detector. This eliminates calibration offset problems typically encountered with multi-instrument systems. The direct component of the irradiance is retrieved by subtracting the diffuse from the total. Using location coordinates and time of day, the solar position relative to the instrument is predicted using an ephemeris algorithm. When the sun is unobscured by clouds, the instrument response characteristics as the arm nears the predicted solar position are used to locate the sun, and then accurately position the shading arm. For more overcast sky, the arm is simply moved to and held at the predicted position. This positioning method makes the RSR ideal for applications in remote areas where intensive maintenance is difficult. As such, the design concept is being considered for use in the tropical western Pacific, included in a network of solar powered sites intended to augment the Atmospheric Radiation and Cloud Station (ARCS) site at Manus, PNG.

The total and diffuse irradiance measurements are output every minute. These values include 30 seconds of measurements for the total irradiance average and 17 seconds for the diffuse. Information on whether the shading arm was positioned by instrument response or prediction, as well as the standard deviation in each measurement, are included in the data output. This information facilitates automatic identification of measurement errors, and estimates of variability during the 1-minute periods which are used for quality assessment.

The RSR design concept has been verified by comparison with Solar and Infrared Observing System (SIROS) and Baseline Surface Radiation Network (BSRN) data taken during the ARM Enhanced Shortwave Experiment (ARESE) at the Atmospheric Radiation Measurement Program (ARM) Southern Great Plains (SGP) central facility. The prototype model was deployed with an Epply solar precision spectral pyranometer (PSP) and was calibrated to the SIROS total SW instrument using clear sky data. Figure 1 shows a comparison of the RSR and SIROS data using 5-minute averages for (a) identified clear sky periods and (b) all-sky.

The standard deviation from perfect agreement (X = Y) is 13.3 Wm^{-2} for clear skies and 22.9 Wm^{-2} for all-sky. Part of this disagreement is attributable to timing differences between the systems. The RSR depended on the onboard computer clock which experienced drift and needed periodic adjustment during deployment. Planned design improvements include incorporation of a global positioning system (GPS) to eliminate this problem. In addition, the SIROS system records a near-instantaneous measurement every 20 seconds (Marvin Wesely, personal communication). Given the rapidly changing hemispheric irradiance under cloudy skies, comparing these instantaneous measurements with those

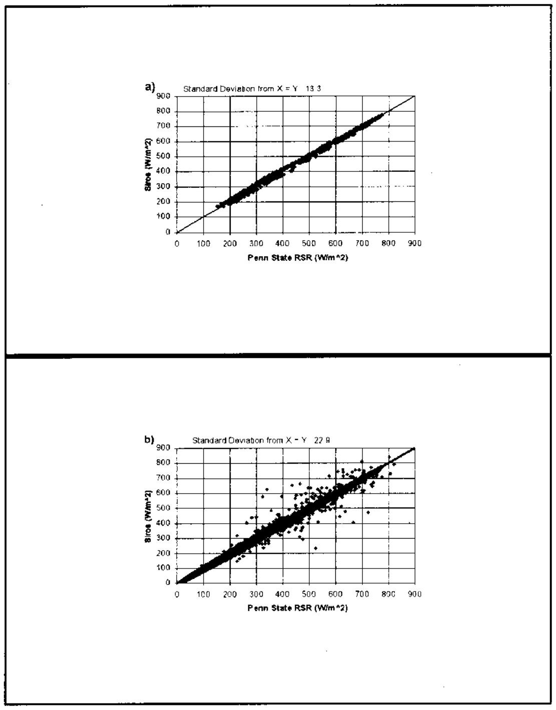

Figure 1. Comparison of RSR and SIROS 5-min. averages of total SW for a) clear and b) all-sky measurements.

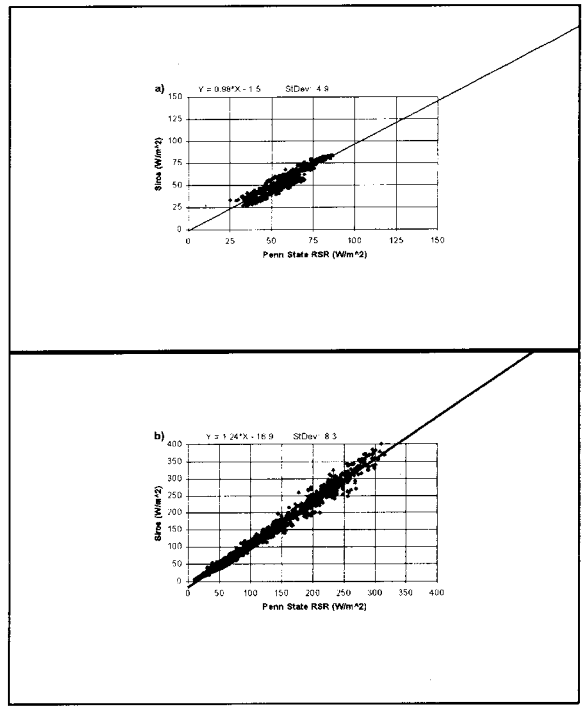

Figure 2. Comparison of RSR and SIROS 5-min. averages of diffuse SR for a) clear and b) all-sky measurements. Standard deviations are calculated from linear fit shown.

logged as longer time averages like the RSR and BSRN systems use leads to significant disagreement (Long 1996). Thus the increase in standard deviation for the all-sky case is not surprising.

The diffuse irradiance is relatively slowly changing compared to the total SW, thus the difference in standard deviation from clear to all-sky is also less. No shading arm correction algorithms have yet been developed for the RSR. As such, the RSR diffuse measurements are underestimated by about 8-10% at local solar noon. This underestimate decreases rapidly with increasing arm angle (from zenith), since the arm correction factor is a function of the cosine response of the pyranometer. To compare the diffuse measurements, the standard deviation from a linear fit has been calculated. Figure 2a shows excellent agreement for clear skies with a standard deviation of only 5 Wm^{-2} from a linear fit with slope near 1 and a modest offset of a few Wm^{-2}. For all-sky (Figure 2b) both the slope and offset increase due to the uncorrected RSR measurements. The standard deviation increases due to data logging differences (Long 1996).

Figure 3 shows the direct SW comparison for clear sky. The SIROS direct normal measurements have been converted to the direct SW component using the cosine of the solar zenith angle. The standard deviation from perfect agreement of 20.0 Wm^{-2} for the clear data includes calibration offset, the inclusion of part of the circumsolar disc due to the 5° field of view of the SIROS perheliometer, and uncorrected shading arm errors from the RSR. The standard deviation increases to 27.4 Wm^{-2} for the all-sky case (not shown), which includes the disagreement due to data logging systems.

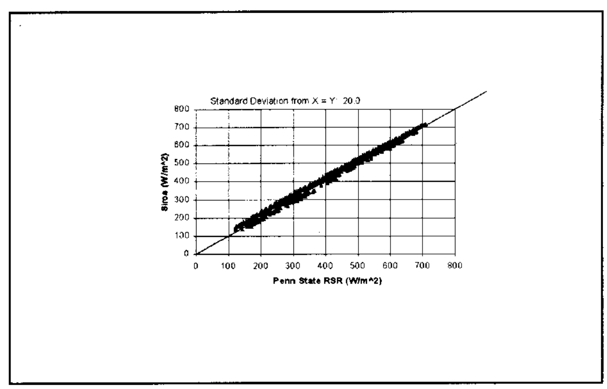

Figure 3. Same as Figure 1a, but for direct SW component.

Comparisons of the RSR with BSRN data from the Central Facility have proven difficult, even though the BSRN logging system of full 1-minute averages is more comparable to the RSR system. The BSRN data logging, direct normal instrument, diffuse shading disc, and total SW offset drift problems during ARESE have been documented by Long (1996). However, where comparison was possible, the agreement was similar to that with the SIROS data for clear skies and better for cloudy skies.

In summary, the RSR system under development is shown to effectively measure the components of surface SW irradiance, while eliminating instrument inter-calibration problems. The system design includes features that greatly enhance and simplify data quality control. During the period of ARESE deployment, the system performed continuously with no maintenance required after the initial installation, though the pyranometer dome was cleaned daily. The system uses a rotating arm and motor assembly that a standard pyranometer is attached to. Thus, for a moderate expense, this system can be affixed to any existing radiometer installation currently collecting only total hemispheric data. The system will be deployed during the DISCO experiment at Manus, PNG, in March of 1996 for further testing and evaluation.

Reference

Long, C.N., 1996: *Report on Broadband Solar Radiometer Inconsistencies at the ARM SGP Central Facility During ARESE*, unpublished manuscript.