Detection of SIRS Solar Tracking Problems with Automated Algorithms

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Introduction

Algorithms for assessing Solar Infrared Station (SIRS) broadband solar radiation data quality have been developed to aid automated flagging of the SIRS data streams. Many solar tracking anomalies can be detected by the standard three component comparison technique ("direct" + "diffuse" versus "hemispheric"). This comparison, though, will not be effective during conditions when the solar tracker completely unshades the "shaded" pyranometer and points the pyrheliometer completely off of the solar disk.

An automated algorithm has been developed for use over the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site to help detect these severe tracking errors.

The Problem

Quality control algorithms often take advantage of the "three component comparison" between the unshaded pyranometer (Precision Spectral Pyranometer [PSP]), which measures the total hemispheric downwelling broadband shortwave radiation and that calculated by adding the diffuse radiation component (measured by the shaded pyranometer) to the direct normal radiation component (measured by the pyrheliometer) multiplied by the cosine of the zenith angle.

total downwelling hemispheric shortwave radiation =

the diffuse shortwave radiation + the direct normal radiation * cos (Zenith Angle)

When the difference between these two estimates exceeds 40 W/m^2, it becomes likely, based on operational experience, that a problem has developed with some of the instrumentation that requires standard maintenance or corrective maintenance. Problems that can affect the shortwave data quality include

- calibration errors in the radiometers
- radiometer leveling errors
- malfunction of the radiometers (signal, electrical problems, etc.)
- depletion of radiation due to object obstruction (condensation, frost, snow, rain, ice, insects, birds, etc.).
- enhancement of radiation due to object reflection
- malfunction of solar tracking mechanism causing
  - partial or full unshading of the shaded PSP (too much diffuse radiation measured)
  - partial of full pointing of pyrheliometer of the solar disk (too little direct normal radiation measured).

While the three component comparisons can be very effective in identifying operational problems with the broadband shortwave radiometers, there are occasions in which the three component comparisons are quite good, but severe solar tracking problems are occurring. Figure 1 shows just such a situation in which tracking solar tracking problems affected the E13 SIRS. Early in the day, the pyrheliometer (Normal Incidence Pyrheliometer [NIP]) was pointed completely off of the solar disk while the diffuse pyranometer (PSP) was completely unshaded. Later in the day, the tracking affected the NIP and the shaded PSP individually. During the morning hours, though, the summation of the diffuse and direct component compares to the unshaded PSP to within tolerance; thus, the three component comparisons fails as a quality control tool during this type of severe tracking problem.

Tracking problems of this kind of severe nature require additional tools for review of the data beyond the three component comparisons. This can require comparing the individual components of the radiometers from nearby facilities, and so forth. Since the actual zenith and elevation angles that the tracker is not available in the output data stream, there can be no comparison to theoretical values of the angles based on latitude, longitude and time. The incentive to develop an automated algorithm for detection of these situations comes from

- the desire to automate detection of SIRS problems in order to limit the amount of data needed to review for evaluation of data quality
- the lack of ability of standard algorithms to detect severe tracking problems
- the utility of an automated algorithm in flagging SIRS data streams available to Science Team members.

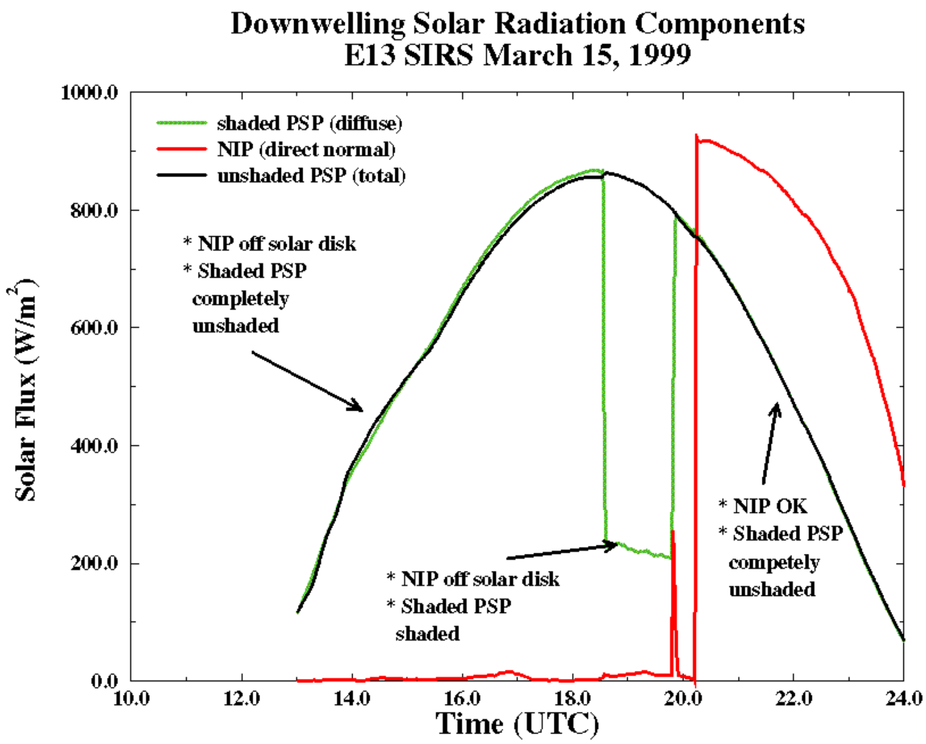

Figure 1. The three broadband solar radiation components during a day in which the solar tracking mechanism had severe malfunction. The direct and diffuse were both affected for various portions of the day, and it is noted that the three component summation comparison would not have indicated a problem early in the day.

A Partial Solution

Comparison of the ratio of the direct versus total downwelling shortwave radiation to the total radiation was tested for use as an indicator of severe tracking problems. Figure 2 depicts this comparison for E9 and E20 during a period in July 1998. E9 had been predetermined to be of good quality by visual inspection, while E20 had severe problems with the solar tracking device. A clear difference in the distribution of data points is noted, especially in the lower right-hand corner of the graph where the graph is populated with data from E20 but not E9. The difference in data distribution is due to E9 data being of good data quality, while E20 is suffering from tracking problems. The E20 ratio of direct/total is unusually low given the amount of total radiation.

The E20 SIRS indicates ratio values near 0.0 W/m^2 where the total radiation value is above 1000 W/m^2. In order for this to be physically valid, the solar disk would need to be blocked nearly completely while still allowing for 1000 W/m^2 radiation to reach the surface via diffuse radiation. This is unlikely given cloud radiative properties in the shortwave. On the other hand, there becomes a point whereby near 0.0 ratios are plausible based on the properly operating instrumentation; this point is near 600 W/m^2.

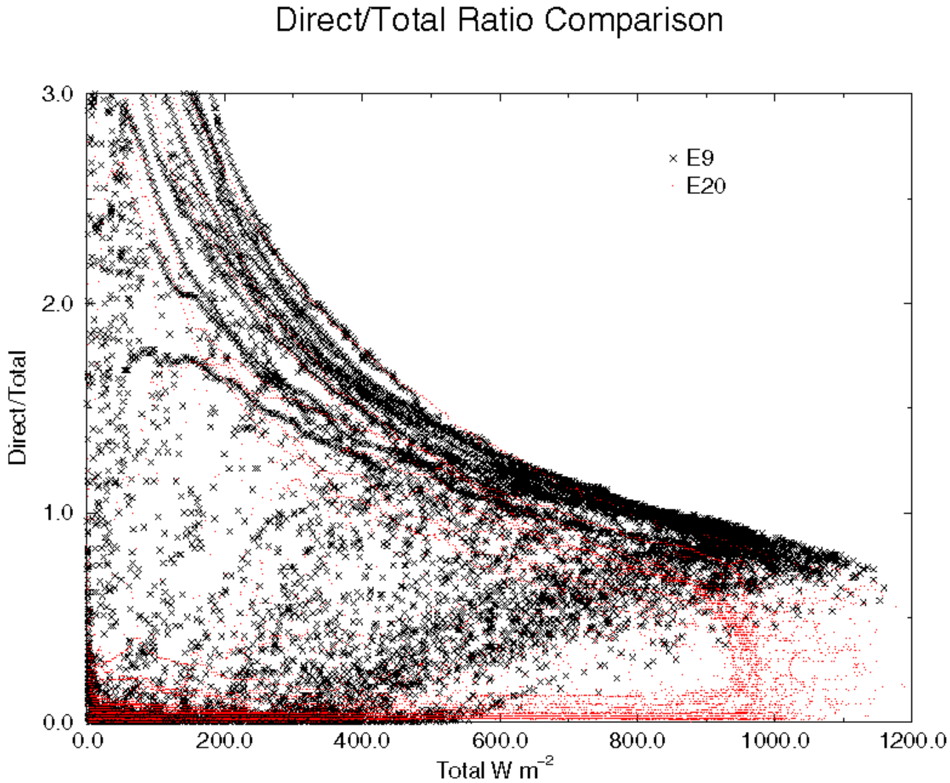

Figure 2. Comparison of the ratio between the direct and total shortwave flux as a function of the total flux for E9 and E20. E9 data quality was considered good during this period, while E20 had noted tracking problem. E9 and E20 populate different portions of this graph as a result of the difference in data quality.

Data from other SIRS instrumentation at other extended facilities validated the general distribution of good data in Figure 2. Based on this distribution, a line was drawn whereby data that falls on one side is considered plausible and data that falls on the other side is considered unreasonable. This line was then converted into a simple automated algorithm to detect severe tracking problems.

Discussion

It becomes obvious from the philosophy used to detect the severe tracking problems that the algorithm will not be able to detect tracking problems when the total radiation is below about 600 W/m^2. It is at this point where the clouds over the SGP, climatologically, can cause near total blocking of the direct solar irradiance even though the total radiation values may be moderately high. This limitation is most severe during the winter months when solar zenith angles are low. Even with the limitation of the algorithm application to higher total radiation values, this approach has been able to detect enough solar tracking failures to be of utility for advisement to site operations of instrument servicing needs. Figure 3 is a replication of a real-time graphic that was made available on the SGP Site Scientist Team web page

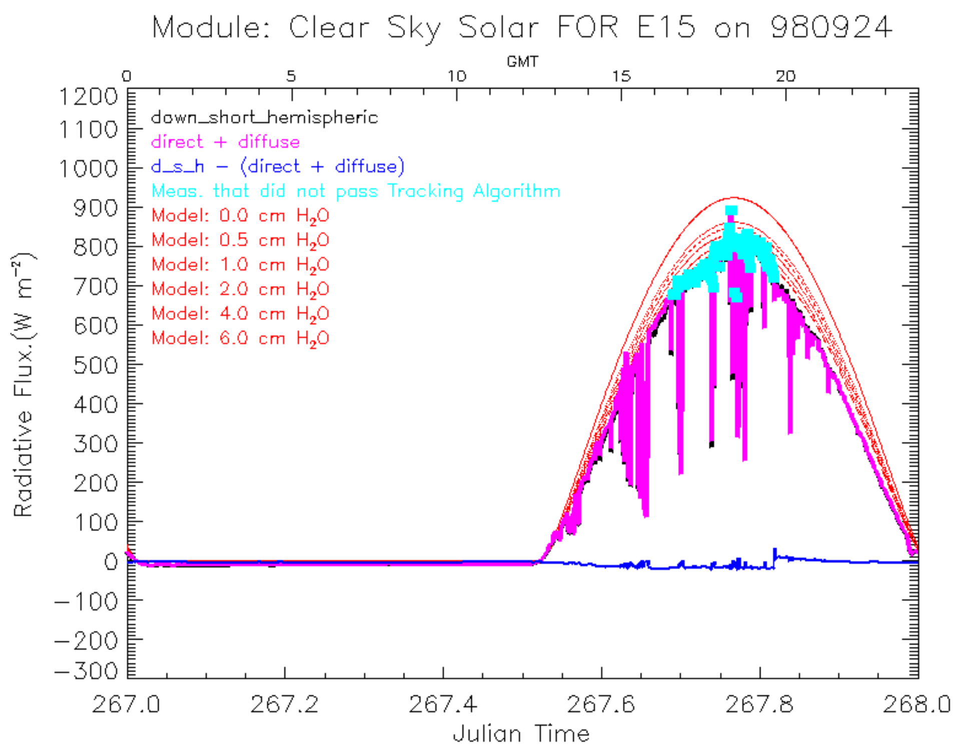

Figure 3. The Site Scientist Team data quality graphic for the shortwave indicating periods (red highlighted data points) in which the tracking algorithm was tripped.

for which a data quality problem was detected with the new algorithm. Figure 3 depicts the total radiation, the summation of the direct and diffuse radiation, the difference between the total and "direct + diffuse," as well as highlighted measurements that did not pass the automated tracking algorithm (in red). This particular site was suffering from a severe tracking problem until late in the day. The new algorithm flags data complimentary to the three component checks, which would not have detected outliers of significance for this event. This figure also demonstrates how the algorithm is used to help condense data quality information into a single graphic, limiting the number of analyses required for evaluation of data quality.

The algorithm developed has been integrated into the near real time quality control monitoring by the SGP Site Scientist Team. Each morning quality control algorithms are applied to the previous day's SIRS data and graphical displays are created (of which examples have been shown) as well as email notification of tracking problems. An example of the email notification text follows with the number of bad observations noted, as well as the year to date (ytd) number of days in which the algorithm detected a problem:

Subject: SIRS E13 Tracking Algorithm Violation

E13

Date	Number of Bad Meas.	Total Meas.
990315	243	642

YTD days with violations 2

The near real-time plots of SIRS shortwave data quality are available on the Site Scientist web page at http://www.res.sgp.arm.gov/sst/dq_monitor/DISPLAYS.html.

The automated algorithm developed here, while not capable of detecting tracking problems under all conditions, adds substantial value for operational detection of solar tracking problems. The algorithm has been added to the suite of tools used by the SGP Site Scientist Team to inform site operations of corrective maintenance needs in a timely manner. Automated detection of severe tracking problems not captured by the current algorithm (when the total shortwave flux is <600 W/m^2) will likely need a different approach.