Studies of the Effect of Clouds on Solar Irradiance Using an Automated Clear Sky Detection and Empirical Fitting Algorithm

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Introduction

The effect of clouds on the shortwave (SW) irradiance near the surface is of interest for surface radiative energy budget studies (Long et al. 1994) and investigation of suggested excess SW cloud absorption (Cess et al. 1995, Ramanathan et al. 1995, Pilewski and Valero 1995). One measure of the effect of clouds is the difference between clear (i.e., cloudless) sky irradiance and measured irradiance, or the ratio of the two. Clear sky irradiance can be estimated by empirical fit to clear sky irradiance measurements (for examples of this method, see Waliser et al. 1995, or Cess et al. 1995), which requires the identification of periods of hemispherically cloudless conditions at the instrument site. This identification can be difficult, however, because of the temporal and spatial mismatch between satellite and ground-based observations and the narrow field of view of other ground instruments such as ceilometers, lidars, and cloud radars.

An automated method has been developed (Long 1996a, and Long and Ackerman 1996) that uses only measurements of downwelling broadband total and diffuse SW irradiance to objectively detect periods of hemispherically clear skies. An empirical fitting technique that minimizes absolute deviations (thus ignoring outliers) is applied to all collocated clear sky measurements to estimate daily functions using the cosine of the solar zenith angle as the independent variable. Figure 1 shows an example of the fitting method for October 19, 1994, at Tennant Creek, Australia.

This method for studying the effect of clouds on solar irradiance has the advantage of decreased error.

While the calculated clear sky irradiances have no better absolute accuracy than the measuring instruments themselves, the irradiances *are* what the instruments would have measured had the skies been clear (including the same calibration offsets and cosine response errors). Thus, when taking a ratio or difference between the measured and clear values, a significant portion of the error is removed. This is illustrated in Figures 2 and 3. Figure 2 shows a plot of the the root mean square (RMS) standard deviation between the Solar and Infrared Observing System (SIROS) and Baseline Surface Radiation Network (BSRN) radiometers for increasing

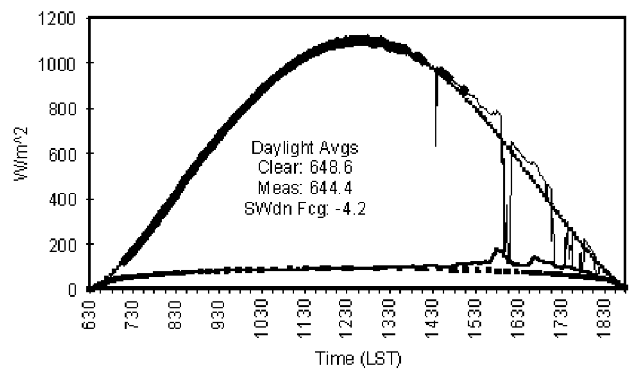

Figure 1. Measured (solid) and clear fit (dashed) total (thin) and diffuse (thick) irradiance for Tennant Creek, October 19, 1994. Diamonds represent detected clear measurements used for fit.

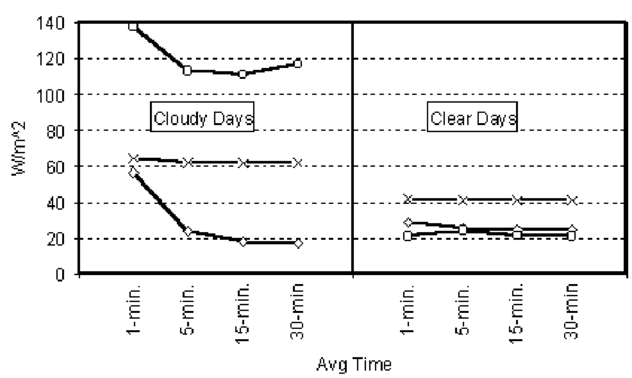

Figure 2: Standard deviation from X = Y for SIROS and BSRN total (diamond), diffuse (x), and normal incidence direct (circle) SW during ARESE.

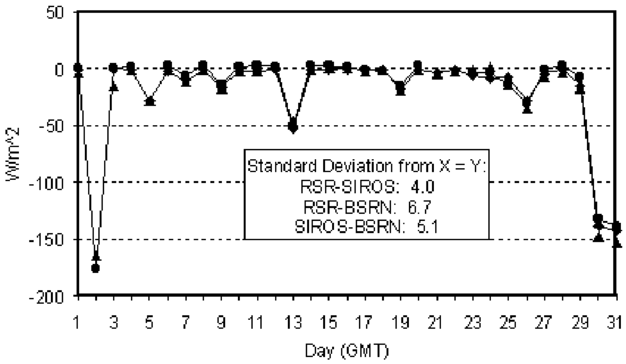

Figure 3: Comparison of Penn State Rotating Shadowband Radiometer (RSR) (circle), SIROS diamond), and BSRN (triangle) daily average downwelling SW cloud effect for ARESE (Oct.) derived using automated detection and fitting method.

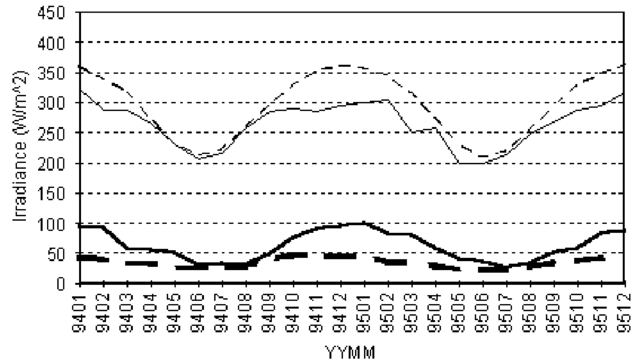

Figure 4: Monthly mean measured (solid) and clear (dashed) total (thin) and diffuse (thick) SW irradiance for Tennant Creek, 1994 to 1995.

averaging times (from Long 1996b). Most of the disagreement shown is due to sampling differences between the two systems. However, note that the total SW agreement converges to about 20 Wm^{-2} for both clear and cloudy skies no matter what the averaging time used. When the clear total SW irradiance is subtracted from the measured to determine the cloud effect, the RMS difference for daily averages decreases to about 5 Wm^{-2} between systems, including a prototype rotating shadow arm system deployed by Penn State (Long et al. 1996), as shown in Figure 3. This represents a substantial decrease in error in determining the cloud effect.

Examples of Results Using the Automated Method

For many sites whose data can be processed, daily clear fit coefficients are possible. For days without enough hemispherically clear sky measurements for fitting, the daily coefficients are interpolated between bracketing clear fit days. Thus, continuous determination of cloud effects are possible for extended data sets. As an example, Figure 4 shows a 2-year plot of the total monthly average and diffuse clear and measured SW downwelling irradiances for Tennant Creek. This station, in north central Australia, exhibits very clear skies during the winter months and relatively small cloud effect during the rest of the year, attesting to the desert-like climate of the area.

Once clear sky periods have been detected, any co-located solar measurements can be fitted with a clear sky function. This provides an opportunity to study the effects of clouds on UV and photosynthetically active radiation (PAR), as well as SW irradiance. Figure 5 shows the measured and clear total SW and ultraviolet-b (UVB) for the Surface Radiation Research Branch (SRRB) Table Mountain SurfRad site near Boulder, Colorado. The peak UVB irradiance lags behind the peak SW by about a month due to the annual ozone cycle: more ozone is produced in the beginning of summer than at the end.

It has long been known that clouds generally affect the UVB less than total SW. However, due to biological hazard considerations, more effort has recently been given to the study of the UVB budget. With the interest in providing the public with UV forecasts, the quantification of the cloud effect on UV has become more essential. The automated detection and fitting method can be used to accomplish this using the SW cloud effect as a comparative tool. Figure 6 shows a comparison of the cloud effect on downwelling total SW, here

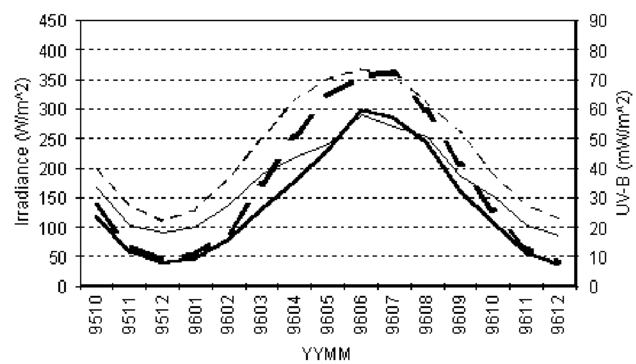

Figure 5. Monthly mean measured (solid) and clear (dashed) total SW (thin, left axis) and UVB (thick, right axis) irradiance for Table Mountain, October 1995 to December 1996.

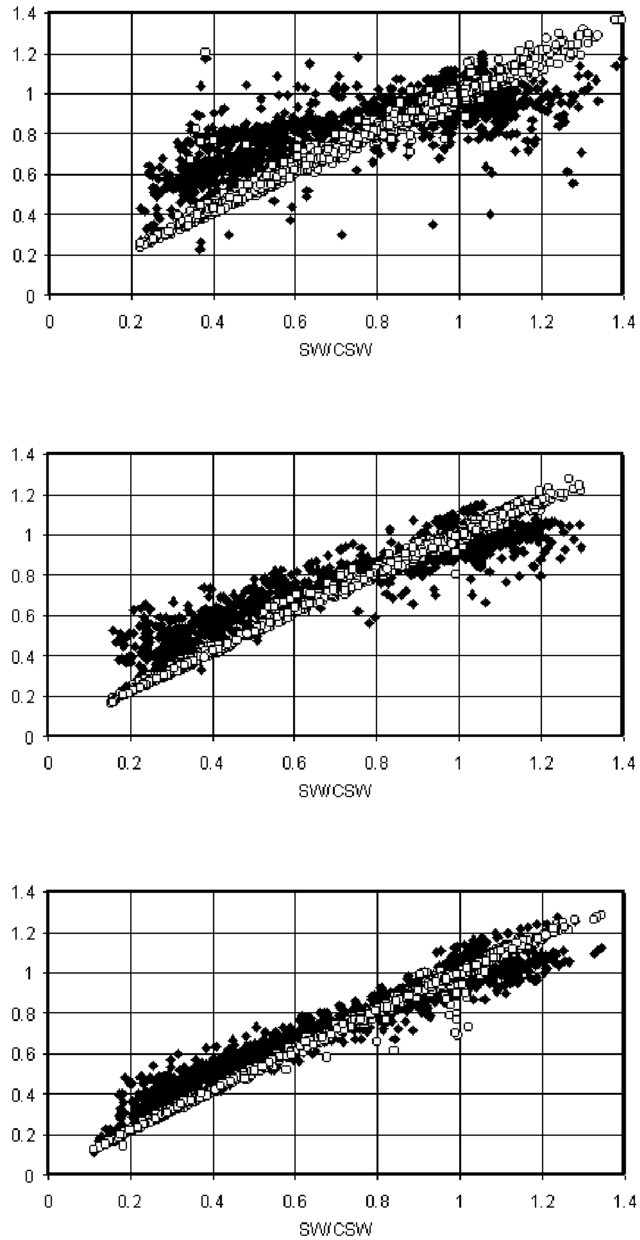

Figure 6. Comparison of the ratio of measured over clear PAR (circles) and UVB (diamonds) to total SW (X axis) for solar zenith angles of 60-75º (top), 45-60º (middle), and 0-45 º (bottom) from Table Mountain for days with enough clear measurements for fitting during 1996.

represented as the ratio of the measured over the clear values, to the same ratios for PAR and UVB from Table Mountain. While the PAR cloud effect is virtually the same as that for total SW, i.e., the ratio values are about equal, the ratio values for UVB show less attenuation compared to total SW during periods on negative cloud effect, and less enhancement during positive effect episodes. Also, this difference is zenith-angle dependent, with the difference being greater at a greater solar zenith angle. Forecast models can already fairly accurately predict clear sky UV irradiance given inputs such as column ozone amount and top of the atmosphere (TOA) irradiance. Quantification of the cloud effect can be used to further refine the forecast for UVB reaching the surface under various cloud conditions and zenith angles.

Summary

An automated clear sky detection and fitting method has been developed for use in studying the effect of clouds on solar irradiance. This method will be incorporated in the NOAA/ARL/SRRB SurfRad data stream in the near future to produce cloud effect values as an operational product. The SurfRad data archive can be accessed at: http://www.srrb.noaa.gov. The method is offered to the ARM community as a research tool by contacting the author at: long@srrb.noaa.gov.

The method has been shown to decrease the uncertainty in calculating the cloud effect compared to the absolute uncertainties in the irradiance measurements themselves (Long 1996a, Long and Ackerman 1996). Research in progress using the method includes quantifying the UVB cloud effect, climatological studies of cloud effect using long-term data sets from the Australian Bureau of Meteorology, SurfRad, and ARM, and a study of the spatial variability of cloud effect and the relation to General Circulation Model (GCM) scales using data from the ARM SGP network.

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