A Two-Year Climatology of Radiation Budget and Cloud Properties for the ARM SGP Site

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Introduction

One of primary reasons for the establishment of the ARM Southern Great Plains research site was to obtain long-term records of surface radiation data and the impact of clouds on these data (Stokes and Schwartz 1994). This research project focuses on the creation of a two-year climatology of the surface radiation budget and the impact of clouds on that budget. The period of analysis extends from April 1994 through April 1996.

Surface Radiation Budget

The Baseline Solar Radiation Network (BSRN) instruments at the SGP site include a normal incidence pyrheliometer (NIP) and an unshaded and shaded, upward-looking pyranometers. These three radiometers provide a redundant set of measurements of the downwelling solar irradiance with a temporal averaging period of one minute. From these data, we compute the daily solar insolation.

In order to determine the impact of clouds, we wish to compute the solar cloud forcing, defined as the difference between the clear-sky insolation and the actual insolation. In this study we use an empirical curve fitting technique developed by Long (1996) to determine the clear-sky insolation. We first find periods of hemispherically clear sky using the ratio of diffuse to total downwelling irradiance. Data from these periods are then fit with a simple power law expression of the cosine of the solar zenith angle. Accurate functional fits of the clear-sky radiation can be generated with as few as 110 minutes of clear sky each day. Clear sky solar insolation is then determined during cloudy periods by interpolating the constants of the fitted functions from adjacent clear periods.

The resulting monthly means of clear-sky irradiance, observed irradiance, and surface cloud forcing (clear-sky minus observed irradiance) are shown in Figure 1. This brief time series indicates a tendency for a peak in cloud forcing during the spring season with a minimum in the late summer and early fall. The sharp peak in cloud forcing in May 1995 is perhaps the most notable feature.

While the magnitude of the cloud forcing is greatest in the spring, the maximum insolation is also larger than most other months. An alternate view of the data is provided by calculating the fractional cloud forcing as the ratio of the surface cloud forcing to the clear-sky irradiance (Figure 2). This variable represents the fraction of the clear-sky irradiance that

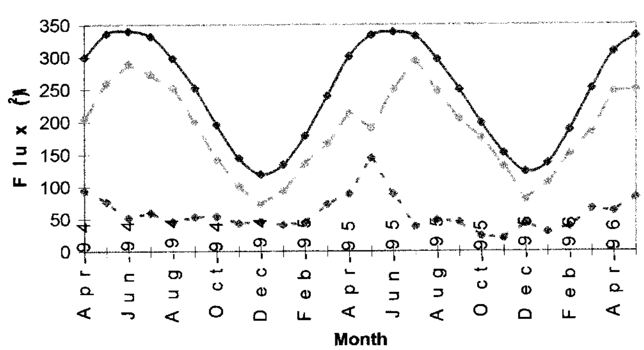

Figure 1. Monthly mean values of clear-sky irradiance (solid), observed irradiance (long dash), and surface cloud forcing (short dash) at the ARM SGP site.

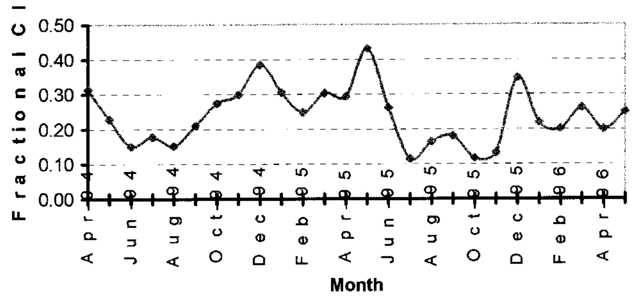

Figure 2. Fractional cloud forcing (cloud forcing divided by clear-sky insolation) at the ARM SGP site.

actually reached the ground. While a peak still exists in the spring, the winter values of fractional cloud forcing are also quite high. In fact, the winter values are slightly greater in magnitude. The average fractional cloud forcing for spring (March, April, May) is 0.29, while the average for winter (December, January, and February) is 0.30.

In addition to the mean cloud forcing, it is instructive to look at frequency distributions of the fractional cloud forcing by season (Figure 3). The frequency distributions were created from 15 minute averages of the cloud forcing over the entire season. As expected, summer tends to favor low values of cloud forcing. The fractional cloud forcing values peak at a small value and very few values greater than 0.35 were found.

The spring and fall distributions are slightly bimodal distribution, with the major peak occurring at a small positive value, and a secondary peak occurring at a quite large value. One possible explanation for this distribution would be thunderstorms, which occur in Oklahoma most frequently in the spring and the fall. Cumulonimbus clouds can reach a thickness of 10 kilometers or more. Such large, deep clouds have a very large optical depth and therefore produce a high fractional cloud forcing.

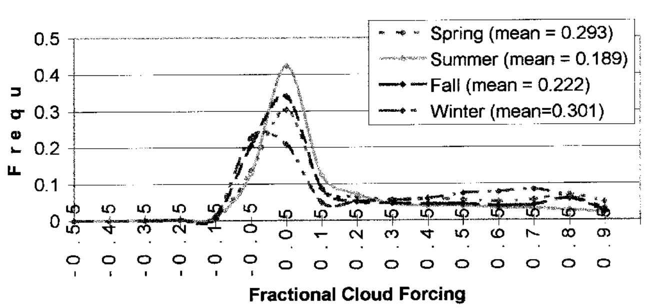

Figure 3. Frequency distribution of fractional cloud forcing by season for the ARM SGP site.

The winter distribution is the most surprising. It has both the greatest percentage of high fractional cloud forcing events and the most significant percentage of positive cloud forcing events. The frequency of fractional cloud forcing values between 0.6 and 0.85 is twice as high in winter as in summer. The low sun angles in winter probably account for the bimodality of this distribution. Stratus decks are common in winter. These decks are highly reflective for low sun angles. In addition, direct beam irradiance penetrating through breaks in the decks can produce positive cloud forcing events.

Cloud Forcing versus Liquid Water Path

The statistics of cloud forcing provide interesting insights but cannot by themselves be linked to specific cloud properties. The suite of measurements being acquired at the ARM site, however, does allow us to take this additional step. As an example, we have focused on the relationship of cloud liquid water path and cloud forcing. Using a cloud climatology based on the ceilometer and micropulse lidar data (see Mace et al., this document), we identified periods of continuous cloud cover with cloud bases below 2000 m. We define continuous here as 45 minutes of continuous cloud base detection by either system. We then used the central 15 minutes to create a data base of cloud forcing and liquid water path (LWP). The latter was measured by a microwave radiometer at the site.

The resulting data set shows considerable scatter (Figure 4), but with a definite logarithmic relationship. As expected, high LWP values result in large values of cloud forcing. At very large LWP values, the curve asymptotes to a cloud forcing value of around 0.95. This probably is a combination of a

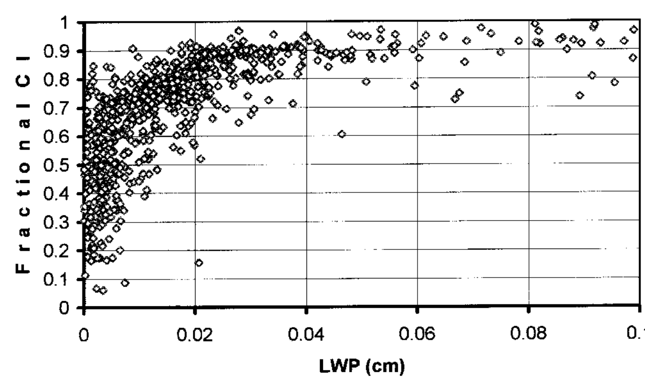

Figure 4. Scatter plot of 15-minute averages of liquid water path (in cm) and associated fractional cloud forcing values.

number of effects, including the spatial variability of even uniform decks and the inclusion of some deep convective clouds in our data set. For very small values of LWP, a very large range of cloud forcing exists. Again, this probably arises for a number of reasons. The microwave radiometer cannot detect ice. Thus, some of our data points undoubtedly are mixed phase clouds that experience additional attenuation of solar radiation by ice. Also, the microwave data typically has some background level that can produce a substantial uncertainty at small values of LWP. The range of fractional cloud forcing values is much less for LWP values greater than 0.01 cm, than for values less than 0.01 cm, suggesting that fractional cloud forcing can be estimated quite accurately from LWP measurements greater than about 0.01 cm.

Summary

We have presented a 2-year climatology of the solar irradiance and associated solar cloud forcing at the SGP site. The monthly mean cloud forcing values are typically between 50 and 100 W/m^2. The fractional cloud forcing tends to be a maximum in winter and spring and a minimum in summer and early fall. The seasonal frequency distributions show some interesting features, including a bimodality and a tendency in winter towards both positive cloud forcing and very large negative values. As an example of further directions for this research, we show a scatter plot of LWP compared to cloud forcing. The recently acquired millimeter radar data will significantly improve our ability to carry out this type of research.

References

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