NOTES AND CORRESPONDENCE

The Asymmetry of Global Solar Radiation Around Solar Noon

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ABSTRACT

Using approximately 25 years of rehabilitated global solar radiation measurements, an analysis of the asymmetry of global solar radiation around solar noon was performed for three climatic regions of the United States represented by Miami, Florida; Fort Worth, Texas; and Washington, DC.

An asymmetric distribution of the global solar radiation during the summer months was found at all three regions. The most pronounced asymmetry occurred at Miami during July and August: radiation in excess of 12% was received in the morning as compared to the afternoon. At the other stations, the morning totals exceed the afternoon totals by 3%-4%. At Fort Worth, a reversal in the asymmetry was observed during the spring: the afternoon hours received 3% more radiation than the morning hours. Similar analyses were performed using hourly observations of clouds and resulted in consistent findings.

1. Introduction

A valuable result emerging from the last two decades of satellite observations has been improved understanding of the global planetary radiation budgets and atmospheric energetics. Observations from polar orbiting satellites provided the first coherent global estimates of such parameters as planetary albedo, outgoing long wave radiation, net radiation (e.g., Winston et al., 1979; Raschke and Preuss, 1979; Stephens et al., 1981) and atmospheric energetics (Ellis et al., 1978; Oort and Vonder Haar, 1976; Gruber and Winston, 1978). Clouds, the primary modulators of the radiation budget, are known to exhibit diurnal variations. Therefore, the available global radiation budgets as derived from satellites in sun-synchronous orbit (global, but fixed, local hour coverage) could be biased. As yet, observations from geosynchronous satellites have not been utilized for comprehensive studies of this type.

Various attempts have been made to obtain estimates of the diurnal variation in cloud distributions, or of parameters which are affected by the diurnal variation of clouds. Temporal variations in cloud distributions in tropical areas have been documented over the GATE study area (Gruber, 1976; Ball et al., 1980; Ackerman and Cox, 1981). There is also evidence of diurnal cloud variations over continental and oceanic regions in the middle latitudes (Wallace, 1975; Simon, 1977; Short and Wallace, 1980). Most of these studies are of short duration and local coverage. Minnis and Harrison (1984) have used GOES-E data for November 1978 for regions located between 45°N and 45°S lat and 30° to 125°W long to study the diurnal variation in cloud cover. They found that the diurnal variation in the cloud cover was significant in many parts of the area viewed by GOES-E. They conclude that generalization about diurnal cloud variations based on their study may not be appropriate.

An early example of a study on the diurnal variation in parameters affected by the distribution of clouds was given by Kincer (1920) who studied the variation in sunshine duration in the United States. Wallace (1975) used hourly data of the frequency of all types of precipitation events for more than 100 stations to derive statistics on the amplitude and phase of their diurnal cycles. Such statistics are closely related to the temporal distribution of clouds. In a rather unique study, Cox and Griffith (1979) used data from Phase III of the GATE experiment to study the diurnal modulation in the radiative divergence profile. They concluded that the presence of clouds does induce this modulation.

In the present study, an attempt has been made to assess on a climatic time scale the effect of the diurnal variability in cloud distributions on the surface solar radiation. This is of interest, since all previous relevant studies were of short duration. The possibility exists that on a longer time scale, diurnal variability is of no consequence. We used long-term records of global solar radiation at selected climatic regions of the United States as indicators of diurnal cloud variability. Such variability can also cause bias in the planetary radiation budgets, as derived from one satellite observation per day. The data and sites will be described in section 2.


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The results and discussion are presented in section 3, and summarized in section 4.

2. Data and sites

The data used in this study were provided by the National Climatic Data Center (NCDC), Asheville, North Carolina. These are known as the rehabilitated SOLMET (SOLar METeoro logical) data (SOLMET, 1977) and are available for a period of approximately 25-yr. The errors in the radiation data, which necessitated their rehabilitation, were primarily due to instrument sensitivity changes, improper calibration, undocumented instrument changes, different chart scales, and poorly maintained sensor domes. In addition, the solar radiation data were referenced to two different radiation scales: the Smithsonian Scale of 1913 and the International Scale of 1956. Initially, the hourly global solar radiation data were corrected for the temperature response of the sensor and “engineering corrected” for calibration changes as well as scale differences and recorder chart errors. The values were then adjusted for any unresolvable error through comparison with a standard year irradiance model. The time series of radiation observations were serially completed by insertion of modeled values for any missing data. It was this product (claimed to be accurate to within ±5%) together with additional information such as extraterrestrial radiation and hourly meteorological observation of the National Weather Service (NWS) that produced the SOLMET tapes. Since we were interested only in the morning/afternoon relative differences of solar radiation and not in absolute magnitudes, the use of these rehabilitated data seems quite appropriate.

The three stations used in this study were selected from the 12 metropolitan regions recognized as major climatic regions for the United States. They are

1) Miami, Florida
2) Fort Worth, Texas
3) Washington, DC

The period of record for each station varied. Twenty-five years of data (1953–78) were available for Miami, Florida. Fort Worth’s record, observed at Greater Southwest International Airport, contained 20 yr of observations (1953–73). The data from the Washington, DC area came from two locations. Seven years of observations were taken at Silver Hill, Maryland beginning in 1953. In December 1960, the station was moved to Sterling, Virginia where observations were taken for 15 yr.

3. Results and discussion

In order to get a quantitative estimate of the asymmetry around solar noon in the distribution of the received global solar radiation, the percentage difference between the morning (0900–1200 solar hours) and afternoon (1300–1600 solar hours) radiation amounts were calculated for each month. By subtracting the total afternoon (A) radiation from the total morning (M) radiation and dividing the result by the first quantity, 100(M – A)/A, the percentage difference is obtained. Positive differences indicate an excess of radiation in

![Graph](https://via.placeholder.com/150)

**Fig. 1.** The annual variation of the average (1952–76) percentage difference between morning and afternoon global solar radiation (left scale, solid line) and the annual variation of the average (1983–87) difference between morning (as observed at 700 and 1000 LST) and afternoon cloudiness (as observed at 1300 and 1600), when the latter is expressed in tenths (right scale, single dots) for Miami, Florida. Positive values indicate an excess in morning radiation or afternoon cloudiness; negative values indicate an excess in afternoon radiation or morning cloudiness.
the morning and negative differences indicate an excess in the afternoon (Figs. 1–3).

As seen from Fig. 1, Miami receives more radiation in the morning throughout the entire year. The largest excess occurs during the summer months of July and August when the mornings receive 12.7% and 7.0% more radiation, respectively, than the afternoons. In contrast, at Fort Worth (Fig. 2), the morning radiation exceeds the afternoon radiation for 3 months only. During July–September, the morning hours receive between 3.1% and 4.2% more radiation than the afternoon hours. From November through May a complete reversal in the percentage difference occurs. During these months the afternoon is receiving between 2.2% and 4.1% more radiation than the morning, the largest percentage difference occurring from mid-winter to early spring. The only months when the distribution of solar radiation was symmetric around solar noon were June and October. The percentage differences between the morning and afternoon radiation for the Washington, DC area is displayed in Fig. 3. Symmetry in the radiation distribution from November to January

![Graph](image)

**Fig. 2.** As in Fig. 1 for Fort Worth, Texas using radiation data for (1953–73) and cloud observations for 1953–73. The morning cloudiness is represented by observations taken at 0600 and 0900 LST, and the afternoon cloudiness is represented by observations taken at 1200 and 1600 LST. The squares represent differences based on data from 1956–66. Here the morning cloudiness is represented by observations taken at 0700, 0800, 0900, 1000, and 1100, and the afternoon cloudiness is represented by observations taken at 1200, 1300, 1400, 1500 and 1600.

![Graph](image)

**Fig. 3.** As in Fig. 1 for the Washington, DC area using radiation data for 1953–75 and cloud observations for 1966–86.
and from April to June is evident. In February and March the morning hours are receiving 1.2% and 2.1% more radiation than the afternoon hours while from July through October the morning excess is greater than 3%.

The major climatic factors responsible for asymmetric distribution in hourly solar radiation at Miami are associated with late afternoon convective activity, leading to thundershowers. These showers are often heavy and last only 1–2 h. They usually occur between 1500 and 1600 LST, the hottest part of the day (Frank et al., 1967), and the time of maximum surface convergence over the Florida peninsula (Gruber, 1970). Day-long summer rains associated with tropical disturbances are rare. Even in the wet season the rainfall duration is generally less than 10% of the day.

The climate of Texas and the central United States is characterized by frequent changes in air masses and by a nocturnal maximum of thunderstorm activity. These storms, possibly associated with a “low level jet” (Bonner, 1966), occur between 0000 and 0800 LST. The cloud bands associated with these storms are large and persist well into the morning hours. This would suggest the possibility of an asymmetry in the Fort Worth region due to reduced solar radiation in the morning hours.

The Washington, DC area averages 30 thunderstorms per year with 75%–80% of these occurring between May and August (Moyer, 1968). July is the peak season with about 25% of the annual total number. The preferred occurrence is in the afternoon.

In Figs. 1–3, we presented differences between the morning and afternoon surface solar radiation and attempted to explain them on the basis of known climatic controls. In order to directly relate these differences to cloud distributions, we examined long-term cloud cover records as given in the Local Climatological Data (LCD) monthly summaries. The available cloud data did not always correspond to the years for which global solar radiation was available, nor were they of comparable length of record. For Miami, only 5 yr (1983–87) of cloud observations were available. For Washington, DC, 20 yr of data (1966–86) as observed at the National Airport, were used. For Fort Worth, 20 years of data (1953–73) as observed at the Greater Southern International Airport were available. The time of cloud observations at the three locations was not always the same. For Miami and Washington, DC, monthly averaged values of cloud cover (in tenths) are listed for every 3-h interval (i.e., 0100, 0400, 0700, 1000, 1300, 1600, 1900, and 2200). For Fort Worth (during 1965–73), observations are also listed as monthly averaged values of cloud cover (in tenths) for every 3-h interval, starting at 0000 (i.e., 0000, 0300, 0600, 0900, 1200, 1500, and 1800). For the earlier period (1953–64), observations were taken every hour and are reported for each hour as the number of days per month having cloudiness in the following ranges of tenths: 0–3, 4–7, and 8–10. In our study we considered the cloudiness as the average value in each interval, i.e., 1.5; 5.5; and 9. We computed the climatological mean cloudiness for the morning (represented by the 0700 and 1000 LST observations) and for the afternoon (represented by the 1300 and 1600 LST observations) and subtracted the morning values from the afternoon values, for each month. For Fort Worth during the period of 1965–73, the mean cloudiness for the morning was represented by the 0600 and 0900 LST observations and for the afternoon, by the 1200 and 1600 LST observations. A difference of 2 would indicate that, on the average, the cloud cover in the afternoon will exceed the cloud cover in the morning by two tenths. Positive (negative) differences indicate excess in afternoon (morning) cloudiness. These differences are also presented in Figs. 1–3 and should be referenced to the right-side scale. As evident, the two patterns are consistent in spite of the fact that there were only two cloud observations for each half day; the cloud and radiation observations were not always co-located, and the lengths of records did not always overlap. The poorest agreement between the asymmetry in global solar radiation and cloud distributions was found for Fort Worth during the winter time. If, indeed, the lower insolation in the morning is related to the nocturnal cloudiness known to persist until around 0800 LST, the analysis of the cloud data based on observations at 0600 and 0900 LST might not be representative of the morning conditions. During 1953–64, cloud observations at Fort Worth were made every hour. (However, they were reported only as frequency distributions in three broad cloud categories). We reanalyzed the data from this period. The morning and afternoon cloudiness was now characterized by observations taken at 0700, 0800, 0900, 1000, 1100, and 1200, 1300, 1400, 1500 and 1600, respectively. The resulting morning/afternoon differences are also presented in Fig. 3. As evident, a better agreement with the corresponding differences in the global solar radiation was obtained.

4. Summary

Diurnal cloud cycles occur in many areas. The magnitude of the daily cloud oscillations are poorly documented, but recognized to be a source of bias in the present estimates of the planetary radiation budgets. The need to determine the magnitude and temporal and spatial extent of the diurnal variation has been recognized and led to the International Satellite Cloud Climatology Project (ISCCP) (Schiffer and Rossow, 1985). In the present study, an attempt has been made to estimate the long-term effect of the diurnal variability in cloud distributions, by quantifying the asymmetry in the distribution of global solar radiation around solar noon.

It was found that an asymmetric distribution in the global solar radiation during the summer months exists
at all the three locations investigated. The most pronounced asymmetry occurred at Miami during July and August when radiation in excess of 12% was received in the morning as compared to the afternoon. Fort Worth exhibits a reversal in the asymmetry in the solar radiation. In the spring, the afternoon receives 3% more radiation than the morning, but by the summer, the morning receives 3% more radiation than the afternoon. In the Washington, DC area, the excess in the amount of radiation received in the morning compared to the afternoon is 3%. These findings indicate that concern about asymmetric distributions of clouds should also be of concern on a climatic time scale.

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REFERENCES


