VARIABILITY OF SOLAR RADIATION DATA OVER SHORT TIME INTERVALS

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ABSTRACT

In order to evaluate satellite and cloud cover models, it is useful to understand the short-term variability of solar radiation. This article examines at the variability of beam and global solar radiation over short time intervals. First, 5-minute data are compare with data collected 5 and 15 minutes later. Second, data collected during the middle 5-minute period of an hour are compared to hourly average data. These data comparisons show a ‘Nugget Effect’ similar to that observed when verifying satellite modeled solar radiation values with ground-based data.

1. INTRODUCTION

It is difficult to evaluate solar radiation values obtained from models utilizing satellite or cloud cover observation data with solar radiation data measured at a specific location [1]. The satellite modeled data measures solar radiation over a large area, typically from 100 to 10,000 km^2. Ground-based cloud cover observations happen at best once an hour. Ground-based solar radiation measurements are made continuously but from just one location. The mean bias error between satellite-derived and measured solar radiation data can be small, but the standard deviation between satellite-derived and measured data is on the order of 20%. This is called the ‘Nugget Effect’ and represents a limit to the comparison between satellite-derived values and measured data [2].

Even if the satellite-derived values exactly estimate the incident solar radiation for an area, the ground-based measurement in the middle of this area is not expected to match the satellite-derived values. Even over an hour, the ground-based station will not experience all the variations in the cloud cover observed by the satellite. In addition, the satellite modelers typically use one snapshot to represent each hour’s worth of data.

The temporal and spatial variation of the solar resource are somewhat related. Cloud patterns move over a solar monitoring site and produce a variability in the measured solar radiation. While this cloud pattern doesn’t all pass over the ground-based observer and the pattern does change over time, on average it does have characteristics that are indicative of the variability of the solar radiation over the area.

In other words, the variation of the solar radiation over area should have similar properties to the variation of solar radiation over time. Therefore, to better evaluate the comparisons between satellite-derived and measured values, it is worthwhile to examine the short term variability of solar radiation.

Two aspects of the variability of solar radiation over short time intervals are studied in this article. First, the variability of solar radiation from one time interval to another is examined. Second, solar radiation data obtained over a short interval in the middle of the hour are compared to the data obtained over the whole hour. The applicability of these results to satellite modeled and cloud cover modeled solar radiation data is then discussed.

2. SHORT TIME INTERVAL COMPARISON

Before looking at the variability of the data in this study, it is necessary to say a few words about the data. The data come from the solar radiation monitoring station in Eugene, Oregon. The beam data are measured with an Eppley NIP pyrheliometer and the global data are measured with an Eppley PSP pyranometer. Data are sampled at 2-

TABLE 1. COMPARISON OF BEAM DATA TAKEN 5 AND 15 MINUTES APART

Month	Time difference	MBE%	Standard Deviation %
January	5	-3.3	102.1
January	15	11.8	149.8
April	5	-4.5	34.0
April	15	-6.6	64.7
July	5	-2.4	14.6
July	15	4.0	27.2

TABLE 2. COMPARISON OF GLOBAL DATA TAKEN 5 AND 15 MINUTES APART

Month	Time difference	MBE%	Standard Deviation %
January	5	0.0	32.0
January	15	2.8	45.6
April	5	-2.6	17.4
April	15	-4.5	35.0
July	5	-2.2	11.4
July	15	-4.3	20.2

second intervals and the average is stored in buffers every five-minutes. The weather is Eugene is typically sunny in July, partially cloudy in April, and mostly cloudy in January. These are the three months used to make comparisons.

The first comparison looks at data collected during the 5-minutes leading up to the hour and the data collected in the preceding 5-minute interval. An additional comparison is made with the data collected in the interval 10 to 15 minutes after the hour. The results are show in Table 1 for direct normal beam irradiance. To study periods when the maximum direct normal beam values do not change significantly, only hours from 10:00 am to 2:00 pm were used in this analysis. The comparison shows that while the mean bias error (MBE) is small, the standard deviation is large. This results from the fact that it may be sunny during one interval and then cloudy just a little latter. When it is sunny, direct beam is near full scale and when it is cloudy direct beam is near zero. On the average, the mean bias errors are expected to be small because the sunny and cloudy periods will average out while the significant difference between a sunny and cloudy period will lead to large standard deviations between different time intervals.

The variation of the global irradiance is expected to be smaller than that for the beam. While beam radiation can vary between 0 and 1000 watt/m^2 between times when the sun is clearly visible and when a cloud passes in front of the sun, global radiation, which is a combination of beam radiation projected onto a horizontal surface and diffuse radiation, varies over a much smaller range. Even when the cloud is in front of the sun, there is some diffuse irradiance. This difference is most apparent during the mostly cloudy weather in January in Eugene. The percent standard deviation is a factor of three less than that for the beam irradiance. In the summer, when it is mostly sunny, the percentage standard deviation for the global irradiance is only about 20% less than for the beam irradiance.

3. SHORT INTERVAL TO HOURLY COMPARISONS

Typically, satellite or cloud cover derived solar radiation values are obtained from a snapshot of the cloud cover once an hour. This leads to the question of how well this short interval observation can be used to represent the average hourly solar radiation.

Tables 3 and 4 contain comparisons of short interval data to hourly data. Most comparisons are between 5-minute data gathered from twenty-five minutes after the hour to

TABLE 3. SHORT INTERVAL TO HOURLY COMPARISON FOR GLOBAL IRRADIANCE DATA. COVERAGE REFERS TO THE FRACTION OF THE HOUR IN THE DATA INTERVAL.

Month	Coverage	SD	%SD
January	1/12	37.5	29.8
April	1/12	66.8	18.3
July	1/12	70.7	14.0
July	1/6	60.9	12.1
July	1/2	33.1	6.6

TABLE 4. SHORT INTERVAL TO HOURLY COMPARISON FOR BEAM IRRADIANCE DATA. COVERAGE REFERS TO THE FRACTION OF THE HOUR IN THE DATA INTERVAL.

Month	Coverage	SD	%SD
January	1/12	84.9	87.6
April	1/12	86.2	29.0
July	1/12	93.1	17.6
July	1/6	84.0	15.9
July	1/2	45.2	8.5

thirty minutes after the hour. In July, a comparison is also made with 10-minute interval data gathered from twenty-five minutes after the hour to thirty-five minutes after the hour. In addition, half hour interval data from fifteen minutes to forty-five minutes after the hour are compared with hourly data. The first two hours after sunrise and before sunset were not included in the comparisons.

As in the earlier comparison, the percent standard deviations were greatest in the winter, when the cloud cover was most extensive and the standard deviations for the global irradiance were smaller than the standard deviations for the beam irradiance. For the global irradiance, the standard deviation increased while the percent standard deviation decreased with sunnier weather. In the winter, in Eugene, Oregon, the sun is low in the sky and even on clear days, the noon-time global irradiance is only between 400 and 500 watts/m^2. In the summer, the noon-time global irradiance reaches between 900 and 1,000 watts/m^2. Therefore the possible size of the variation from sunny to cloudy periods is greatest in the summer. However, the average global irradiance is nearly five times greater in the summer than the winter and this helps offset the increased variance.

For the beam irradiance, the stand deviation doesn't change much between winter and summer. This partially results from the fact that full sun beam values do not change significantly between summer and winter and hence the maximum size of the variation doesn't change significantly. However, the average beam irradiance is significantly greater in the summer in Eugene, and hence, the percent standard deviation decreases from winter to summer.

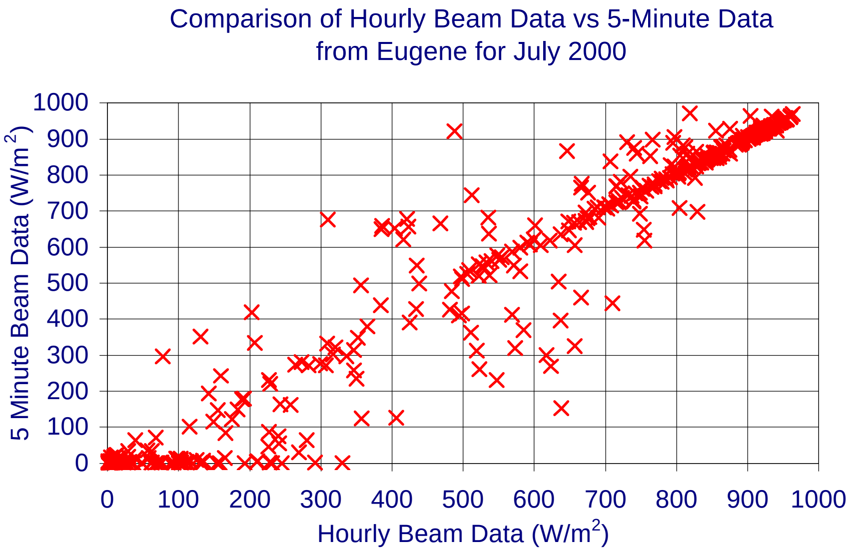

Fig. 1: Comparison of hourly beam data verses 5-minute data. During the clear periods, the 5-minute beam data are a good approximation of the hourly values. During cloudy periods, especially when there is heavy cloud cover with a few breaks in the clouds, the 5 minute beam values typically underestimate the hourly values.

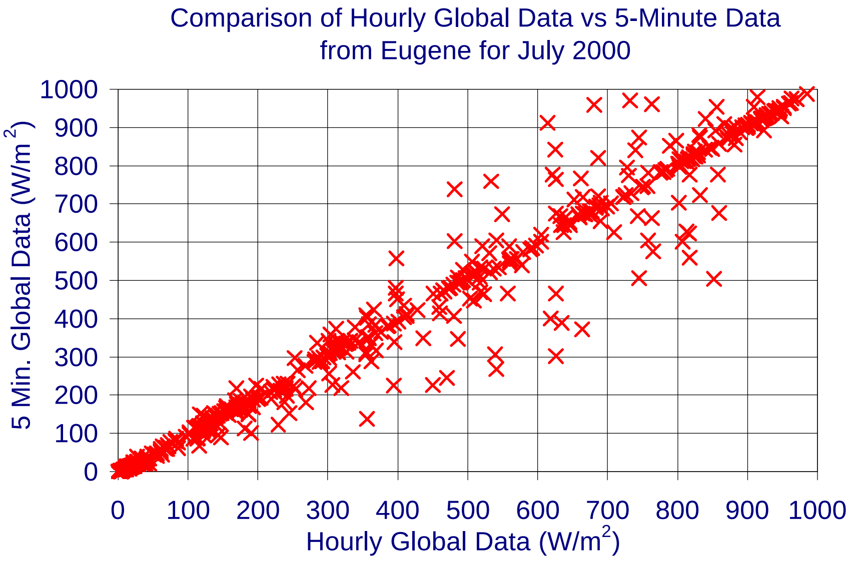

Fig. 2: Comparison of hourly global data verses 5-minute data. During clear periods, the 5-minute global data are a good approximation of the hourly values. During periods of heavy cloud cover, the 5-minute data are also a good approximation of the hourly values.

Fig. 1 shows the comparison between 5-minute beam data and hourly data for July. When it is sunny, the five-minute interval data are a good representation of the hourly values. When there are a few clouds present, 5-minute interval data are a significantly less reliable indication of the hourly data. When there are but few breaks in the clouds, most five-minute data tends to underestimate the hourly value. This can be seen in the data points where the five-minute values are near zero and the hourly values range up to 300 watts/m^2.

Fig. 2 shows the comparison between 5-minute global data and hourly data for July. When it is sunny, the five-minute interval data are a good representation of the hourly values. When there are a few clouds present, there is a considerable variance between the five-minute interval data and the hourly values. A comparison of Figs. 1 and 2 shows that the variance in the global data is less than that in the beam data. When it is very cloudy, as indicated by small global values, the 5-minute interval data are again a good indicator of the hourly values.

While Figs. 1 and 2 illustrate the variance of the 5-minute interval data from the hourly data, it is also of interest to look at the data for different time intervals. Five-minute data covers 1/12 of the hourly interval. Tables 3 and 4 contain comparisons of 10-minute and hourly data. The 10-minute data covers 1/6 of the hour and the half hourly data covers half of the hour. As the time interval increases, the standard deviation between the short time interval and hourly data decreases in a nearly linear manner. Of course, the standard deviation goes to zero as the time interval increases to an hour.

Fig. 3 plots the trend as the percentage of the hour covered by the short time interval data decreases from 100% to 8.3% for July beam data from Eugene, Oregon. Extrapolating the curve down to an instantaneous measurement would give a percent standard deviation of about 20%.

For the comparison between short interval measurements and hourly values, the MBE bias errors were very small. This is to be expected since the method is taking small samples from the middle of an hourly interval.

The information in these tables is meant to illustrate trends and patterns. The data are from one site and only for selected months for one year. The comparison of short interval data with hourly data will likely vary with the amount of cloud cover and latitude for the global data. However, the overall trends are likely to persist even as the values will vary from year to year and site to site.

4. RELEVENCE TO SATELLITE AND CLOUD COVER MODELING

Comparisons of satellite-derived solar radiation values and ground-based measurements is difficult because there are spatial and temporal differences between the measurements. Satellite modeling uses a picture at a given point in time to estimate the solar radiation of an area. The solar radiation varies from point to point in the area, and from time to time.

The first comparison made between solar radiation data taken during one period with another is similar to examining the variation of the solar radiation over an area. The cloud cover moves, and what was over one spot earlier moves over the ground-based site. So knowledge of how the solar radiation varies over time is somewhat analogous to how the solar resource is varying over an area. The standard deviation from one period to the next describes the type of cloud cover experienced. If it is a clear day, the correlation between one time period and the next is very high. If it is a very cloudy day, with no breaks in the cloud, the correlation is also very good. In both situations, the spatial and the temporal variations of the solar radiation is small, and satellite and/or cloud cover modeling of the solar resource should be expected to produce results comparable to ground based measurements.

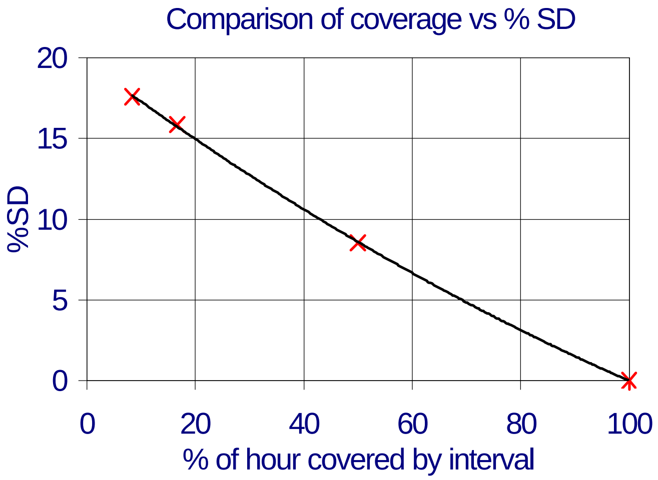

Fig. 3: Plot of percent standard deviation verse the percentage of a hour covered by the time interval used for data comparison. This plot is for July beam data from Eugene, Oregon. At 100% coverage, the standard deviation is zero. As the time interval decreases, the standard deviation increases. At about 8.3% coverage (5-minute data) the percent standard deviation is nearly 18%.

Once there are breaks in the clouds, the spatial and temporal variations increase significantly. It is during these periods that the comparisons between satellite modeled values and ground measurements have a much larger variance. They are truly measuring different patterns and the variance should be the greatest. It is these periods that produce the 'Nugget Effect' that results in a minimum standard deviation between satellite-derived values and ground-based measurements.

The size of the ground-based temporal variations should provide an idea of the size of the variance between ground-based and satellite-based values. More work is needed to quantify this relationship.

In the second comparison, the differences resulting from determining an hourly value from a short interval measurement or observation are examined. Both satellite data and ground-based cloud cover observations depend on pictures or observations that are not taken on a continuous basis. Typically cloud cover and satellite observations are made an hourly basis. Therefore, the question arises as to how well a short interval measurement can represent a value obtained over an hour.

Again, it is the partially clear periods that lead to the large deviation between the short interval measurements and the hourly values. These comparisons show in a temporal sense that there is a limit as to how small the standard deviation can be reduced between an observation taken once an hour and continuous measurements.

While the ground-based measurements can determine a minimum standard deviation, the exact relationship to the minimum standard deviation expected from cloud cover or satellite-derived models is complicated because the cloud cover or satellite observations cover a large area and the equivalence to time interval is not direct or obvious. Whether these observations are best represented by 1-, 5-, 10-, or 15-minute data intervals comparisons is not known. Perhaps with the knowledge of the average wind speed one might be able to estimate the temporal interval that matches the observational limits.

More likely, the appropriate time interval will be found by model testing and seeing a trend in the reduction of variance as models improve.

In general, one should not be overly concerned by the standard deviation between satellite modeled solar radiation values and ground-based measurements. Different standards should be applied when evaluating satellite model data. Good matches during clear and totally cloudy periods should be expected. However, during partially cloudy periods, it might be best to test the mean bias error and match the variations in the data, rather than just examine the standard deviations.

5. ACKNOWLEDGEMENTS

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