10.2 DETECTION OF GLOBAL ENERGY BUDGET TRENDS USING SATELLITE AND SURFACE SITES: IS THE CURRENT SURFACE SITE DISTRIBUTION SUFFICIENT?

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1. INTRODUCTION

Several recent studies (e.g., Liepert 2002, Wild et al. 2005) have examined trends in the downwelling solar flux at the surface as measured at ground-based stations in various locations. These studies found a decrease in the received solar flux over the period 1960–1990 with a reversal in this trend in the 1990s. While it seems reasonable to assume that surface sites may detect local trends, a related question is whether the current distribution of surface sites is sufficient to allow detection of global radiative trends. Now that the satellite retrieved flux record extends for over 20 years, we can begin to address this question using both satellite data and ground-based measurements. We are particularly interested in the long-term trend, as this may be related to processes involved in global warming.

The basic approach in this study is to compare time series of measured surface SW fluxes averaged over a set of surface sites to global time series from satellite products. In addition, time series of satellite data from the surface site locations are used as a proxy for the surface measurements in order to estimate the trends that would be detected if no dropouts occurred in the surface measurements.

2. DATA DESCRIPTION

Two surface flux measurement networks were examined in this study: the Baseline Surface Radiation Network (BSRN) and those sites with data in the Global Energy Balance Archive (GEBA). (Both the BSRN and GEBA data are archived at the Swiss Federal Institute of Technology Zürich (ETHZ), under the care of the Institute for Atmospheric and Climate Science.) GEBA, which is maintained under the auspices of the World Climate Programme, is a database of monthly mean fluxes measured at over 3000 stations distributed around the world and dating back as far as 1919. Measurements are recorded by individual observers and transmitted to the ETHZ for archiving.

The Baseline Surface Radiation Network (BSRN), sponsored by both the World Climate Research Programme and the Global Energy and Water Experiment (GEWEX), is a set of surface measurement sites with instrumentation and measurement protocols that meet a set of strict standards. Data is recorded at temporal resolution on the order of a minute, and both longwave and shortwave fluxes are measured. In general, the data in the BSRN archive is expected to be of higher quality than the GEBA data, however, there are fewer BSRN sites (currently 35) and the BSRN record dates back only to 1992.

The satellite surface fluxes used in this study are taken from the GEWEX Surface Radiation Budget (SRB) version 2.5. This product is produced from ISCCP cloud and radiance values using an updated version of the University of Maryland flux algorithm (Pinker and Laszlo, 1992). Other inputs to this algorithm include ozone data from the Total Ozone Mapping Spectrometer (TOMS) and column water vapor from GEOS-4 (Bloom et al., 2005). Although the GEWEX SRB product is produced on a pseudo equal-area grid with a base resolution of 1°, a version of the data averaged up to a 2.5°grid was employed in this study. (This special version fits the data standard of

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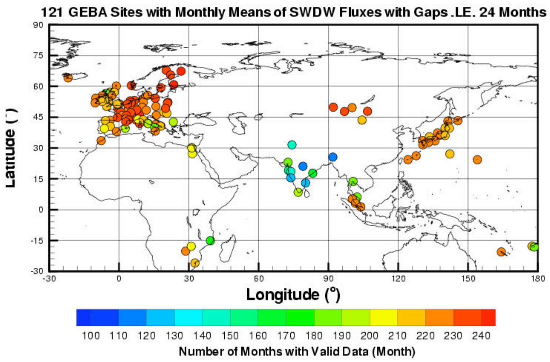

Figure 1: GEBA sites having data during the period July 1983–June 2003 with data gaps no longer than 24 months.

the GEWEX Radiative Flux Assessment.)

3. COMPARISON OF GEBA AND GEWEX SRB SURFACE FLUXES

Since GEBA contains data for the entire 20-year period covered by the GEWEX SRB satellite product, we can compare these two sets of flux values in detail. For this comparison, we restrict our consideration to measurement sites with data for the approximate period of the satellite data record (the twenty years spanning from July 1983 until June 2003) with data gaps no larger than 24 consecutive months. Although 1600 GEBA sites contain some data during this period, only 121 sites meet the continuity criterion. The geographic distribution of these sites is limited, concentrated mainly on Europe and Japan, as shown in Fig. 1.

We begin by comparing the time series of downwelling solar flux at those GEBA sites with the most continuous records to time series for the GEWEX SRB 2.5°cell in which the sites fall. Fig. 2 shows results for two representative sites. For the 28 sites examined, the biases and root-mean-square differences between the GEBA and GEWEX SRB fluxes were generally less that 20 Wm^{-2} in magnitude. Considering the large difference in spatial scale represented by the two data sets, we judge the two to be in good agreement at the sites examined.

We next compare the mean, deseasonalized signals from the two data sets for the entire 20-year period. First, we determine in which SRB grid cell each GEBA site falls. Because of the large number of sites in Europe, there are several cases in which multiple GEBA sites fall within the same grid cell. To avoid having

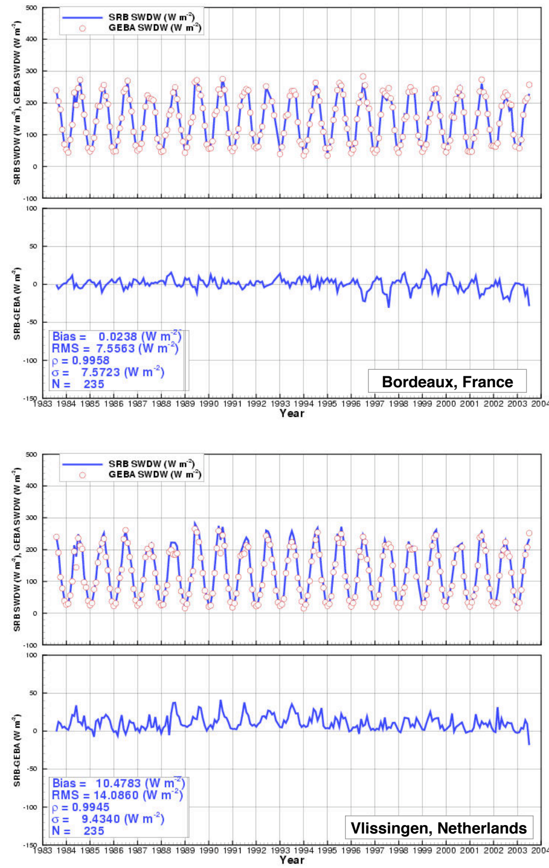

Figure 2: Comparison of downwelling solar fluxes at example GEBA sites and the corresponding GEWEX SRB grid cell means.

different numbers of sample points in the two time series, we combine the neighboring sites into "composite" sites, averaging the corresponding flux values together. The monthly flux values at the resulting 101 surface locations are then averaged together to create a single GEBA time series. SRB values for the times and locations where GEBA values are available are also averaged to create a matched SRB time series. The two time series are then deseasonalized independently.

The GEBA and matched SRB anomaly time series, shown in Fig. 3, have fluctuations that match well in both magnitude (RMS difference of just 2.9 Wm^{-2} despite up to 35 Wm^{-2} deviations in the time series) and timing (correlation of 0.882). As a result of this and the site-by-site comparisons, we judge the SRB flux estimates to be a reasonable proxy for the GEBA data. However, we are somewhat concerned about the large fluctuations in both signals during the last year of the record. Since the two signals track together, it seems unlikely that these spikes are caused by bad data in one

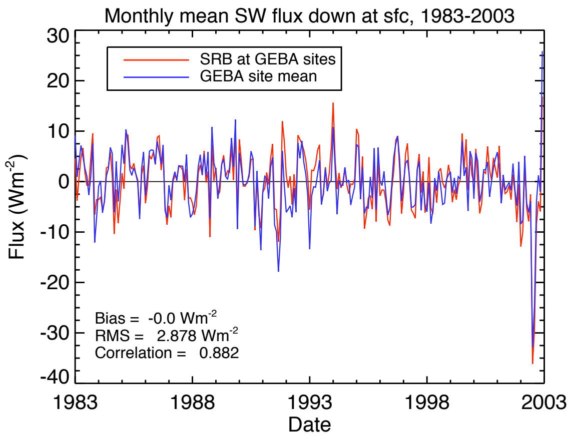

Figure 3: Comparison of average downwelling SW surface fluxes from GEBA sites and matched data from the GEWEX Surface Radiation Budget v. 2.5.

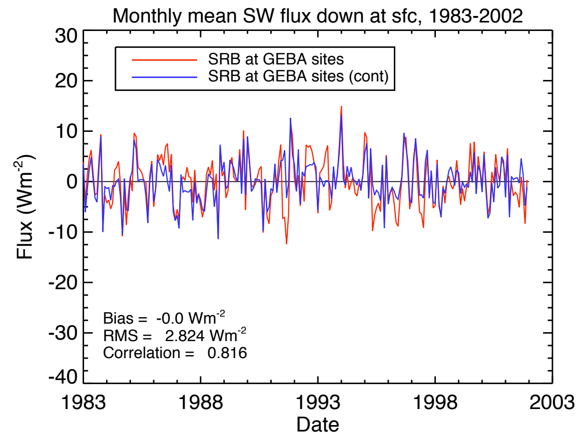

Figure 4: Comparison of average downwelling SW surface fluxes for the GEBA sites from the GEWEX Surface Radiation Budget v. 2.5: data matched to actual measurements vs. continuous records.

of the series. Further examination reveals that only 1/3 of the GEBA sites used in this analysis had transmitted measurements for the 2002-2003 period to the archive by the time of this study. Thus the differences are due to reduced spatial sampling during this period.

To determine the effect of the spikes at the end of the series on the fitted trends, we independently compute the best-fit lines for each set of data over the 1983-2003 and 1983-2002 periods using least-mean-square-error techniques. As we expect from the time series plots, the trends computed for the orignal GEBA and matched SRB time series match well for both periods, but the choice of time series end points is quite significant. Over the 20-year period, the GEBA and matched SRB trends are -1.59 and -1.61 Wm^{-2} decade^{-1}, respectively. For the 19-year period, these change to -0.95 and -0.40 Wm^{-2} decade^{-1}. From this we conclude that the inconsistent values at the end of the 20-year record dominate the trends computed for that period. As a result, we restrict the rest of our analysis to the 19-year interval from July 1983 to June 2002.

4. FURTHER TREND ANALYSIS

For the remainder of our analysis, we employ only GEWEX SRB surface fluxes. This remove measurement source differences and data gaps from consideration, allowing us to focus on how spatial sampling affects trend detection. One important question is whether gaps in the surface measurement records detract from the usefulness of this data. We assess this by comparing the GEBA-matched SRB time series to a second series made up of continuous SRB records at the same locations. Although the two series (shown in Fig. 4) are quite similar, the corresponding trends are of opposite sign: 0.67 Wm^{-2}decade^{-1} for the continuous data versus -0.40 Wm^{-2}decade^{-1} for the series with temporal gaps. This suggests that instrument maintenance is crucial to obtaining meaningful long-term surface measurements.

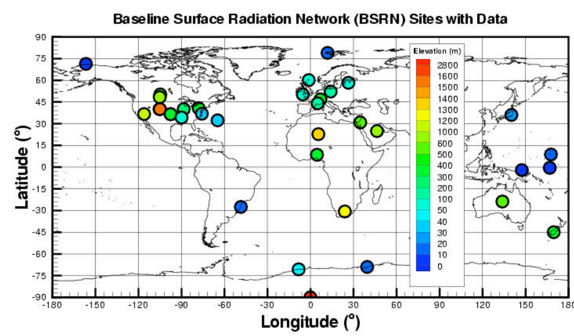

Figure 5: Location of active BSRN sites as of 2003.

Although the Baseline Surface Radiation Network archive does not contain 20 years of data, we can approximate what the average time series from these sites would be using the SRB fluxes. As illustrated in Fig. 5, the 35 currently active BSRN measurement sites are less clustered than the 121 GEBA sites treated above, but two (BIL and E13, at the ARM Central Facility in Oklahoma) are separated by only 100 m. We eliminate site E13 and create a mean time series from the SRB fluxes at the remaining 34 locations. At the same time, we produce a global mean time series using the SRB data. Both deseasonalized series are shown in Fig. 6.

Even though the proxy time series for the BSRN has different low-frequency components than the GEBA se-

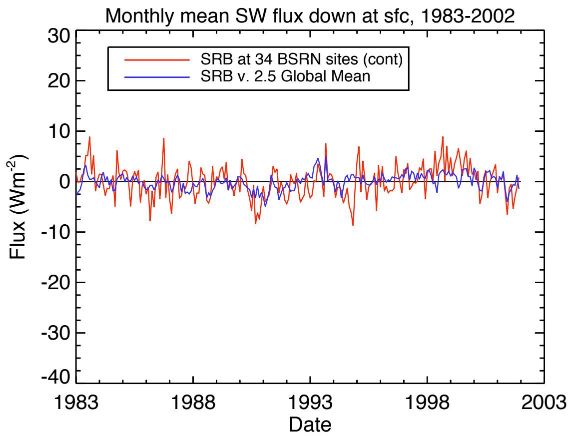

Figure 6: Average downwelling SW surface fluxes for the BSRN sites and entire globe from the GEWEX Surface Radiation Budget v. 2.5.

ries, the overall variance of these time series are similar ($\sim$10 Wm^{-2} maximum excursions.) However, the variability of the global series is significantly lower, with maximum deviations of only $\sim$5 Wm^{-2}. The limited range of the global time series fluctuations is likely due to averaging over a greater number of samples at each time step. The trends computed for these series are 0.67 and 0.48 Wm^{-2}decade^{-1}, respectively.

5. SIGNIFICANCE OF DETECTED TRENDS

Table 1 summarizes the least-mean-square-error linear trends computed for all of the time series examined in this study. Before drawing conclusions from these values, however, we must consider their statistical significance. For this reason, we include the 95% confidence limits determined from the standard deviations of the estimated trends according to Equation 2 in Weatherhead et al. (1998). This equation takes into account both the variance and autocorrelation in the signals from which the trends are estimated.

The first observation we can make regarding the trend confidence intervals is that they all span a range of both positive and negative values. This means that we cannot determine even the sign of the trend in surface solar fluxes at the 95% confidence level from the data series examined here. However, we note that the total width of the confidence intervals decreases as the number of sample points used in the flux averages increases, from about 3 Wm^{-2}decade^{-1}) for the discontinuous GEBA data to just 1.5 Wm^{-2}decade^{-1} for the global satellite time series. While the confidence intervals narrow, they also shift toward the positive range until the range is almost entirely positive for the global series. Based on this trend, it is likely that the true trend in global downwelling solar flux at the surface is positive.

Given the width of the confidence intervals shown in Table 1, we cannot define the surface solar flux trend to better than $\sim$0.7 Wm^{-2}decade^{-1} with a high degree of confidence. [Note: This implies that the precise agreement between the trends for the continuous SRB series at the GEBA sites and the global SRB series is probably coincidental.] Greater confidence can be obtained by extending the data records. We can estimate the sample duration needed to produce trends that are significant at the 95% confidence level using Equation 3 from Weatherhead et al. (1998). In the column labeled "Std. Trend," we show the sampling duration which we are 90% certain will be enough to yield 95% significance for a trend of 1.0 Wm^{-2}decade^{-1}, assuming that the characteristics of the signals remain constant. This value ranges from about 35 years to 22 years as the level of noise in the time series decreases. Since the trends detected are all less than 1.0 Wm^{-2}decade^{-1}, the expected time until the actual trends are significant is longer than the figure given in this column. We show the estimated necessary sampling periods for the detected trends in the column labeled "Actual Trend". These values range from about 30 to 65 years.

6. CONCLUSIONS

We have examined solar surface flux trends for the period July 1983 to June 2002 from satellite and ground-based measurements using different geographic sampling distributions. The number of sample points and the degree of continuity in the data record affect both the estimated trends and their level of significance strongly. Despite the dominance of Northern Hemisphere land sites in the GEBA and BSRN measurement networks, continuous records from these locations are expected to yield trends similar to the global mean record. However, the trends computed from available GEBA data give quite different results due to the spottiness of the records. Thus we must emphasize that surface networks need to provide continuous reliable measurements in order to be useful to long-term studies.

It is difficult at this time to make definitive statements regarding the sign or magnitude of any linear trend in the solar surface flux from the available data, but our estimates indicate that the satellite records should be long enough to make such statements within the next decade. In the mean time, we can work on decreasing the noise level in our flux records by improving satellite flux retrieval algorithms, trying to detect and remove features in the data record that are due to known phenomena such as ENSO or volcanic

Table 1: Summary of trend statistics. "Years for significance" are computed for a standard trend of 1.0 $Wm^{-2}decade^{-1}$ ("Std. Trend") and for the fitted slope ("Actual Trend") of each data set.

Data set	Fitted trend ($Wm^{-2}decade^{-1}$)	95% Confidence interval ($Wm^{-2}decade^{-1}$)	Years for significance	
			Std. Trend	Actual Trend
GEBA data	-0.952	[-2.479, 0.575]	35.2	36.3
SRB at GEBA sites	-0.395	[-1.956, 1.166]	35.7	66.3
SRB at GEBA sites (cont.)	0.671	[-0.466, 1.808]	28.9	37.7
SRB at BSRN sites (cont.)	0.482	[-0.619, 1.583]	28.3	46.0
SRB global mean	0.671	[-0.076, 1.419]	21.9	28.5

erruptions, and improving instrument calibration and maintenance.

In the future, we plan to improve our understanding of flux trends by comparing trends observed in various satellite data sets. We will also further examine surface station siting by studying the geographic separation needed between two sites in order for their signals to be independent and the trends detected over different geographical regions. This will allow us to provide guidance regarding optimal surface network configurations for the detection of long-term global surface solar flux trends.

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