Trends in global radiation between 1950 and 2100

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Abstract

This analysis is based on long time series of global radiation with a duration of at least 40 years and the forecasts of global radiation till 2100, based on results of IPCC [1]. For the mean and most of the individual 25 examined sites the dimming for the period 1950 – 85 and the brightening [2, 3] for the period 1985 – 2009 is statistically significant. The negative trend during the dimming period is clearly stronger (approx. factor 2) than the positive trend during the brightening phase. The individual regions and groups of measurement sites show a great variety of different trends for the analyzed sub periods. The variation depending on the duration of measurement is also quite different from site to site. Most sites have a standard deviation of 5 – 7% for a 12 month mean which goes down to 2-4% at 10 years and 2% at 20 years. The biggest decline happens in the first 5 years.

The future changes are relatively small. On an average the global radiation will decrease slightly. However, in the Mediterranean region the trend is positive (+ 2 – 3 % till 2100).

1. Introduction

The knowledge of the means, variations and trends of global radiation is important for planning solar applications. This analysis is focused on long time series of global radiation with a duration of at least 40 years within the period 1950 - 2009. Like this work lies in-between the analysis for worldwide (satellite) data with approximately 20 years of duration and those for some few sites with very long measurements.

2. Method

A total of 25 sites based on the Global Energy Balance Archive (GEBA, http://proto-geba.ethz.ch) have been used. These 25 sites have been grouped to 10 regional clusters including 2 – 13 stations (Table 1).

The time series have been corrected for the seasonal effects. This has been done by adding the difference between the yearly means and the monthly means to each month. The results have been tested (using a f-test) for each site separately and for groups of sites.

Table 1: Ten groups of stations used for the analysis.

Nr	Group	Stations
1	All	All stations (25 stations)
2	Europe	All European sites (14 stations; Weissfluhjoch excluded)
3	Northern Europe	Uccle, London, Aberporth, Eskdalemuir, Lerwick, Stockholm and Hamburg (7)
4	Germany / Austria	Hamburg, Braunschweig, Würzburg, Trier, Potsdam and Salzburg (6)
5	Switzerland	Davos, Weissfluhjoch and Locarno-Monti (3)
6	United Kingdom	London, Lerwick, Aberporth and Eskdalemuir (4)
7	Asia	Akita, Fukuoka, Kagoshima, Sapporo, Beijing, Ahmadabad, Madras and Poona (8)
8	Japan	Akita, Fukuoka, Kagoshima and Sapporo (4)
9	India	Ahmadabad, Madras and Poona (3)
10	Canada	Edmonton and Toronto (2)

The following three questions have been investigated:

• Trend of the time series of monthly data (full period and several sub periods)

• Trends of 5, 10 and 20 year means

• Dependence of the variability on the length of a measured period.

Additionally the results of the fourth report of IPCC [1] have been analysed to get an idea about the future changes till 2100.

3. Trends of monthly values

For the whole period between 1950 and 2009 and all sites a negative and statistically significant trend of -1.4 W/m^2 per decade could be found. For most grouped sites no significant trend is visible. Nevertheless for Germany / Austria a slightly positive trend can be seen and for Switzerland, Asia, India and Canada a negative trend. For the two sub periods 1950 – 1985 and 1985 – 2009 a significant trend could be found for most groups and stations. For the first period 1950 – 1985 only negative trends were found. For the second period 1985 – 2009 (including data for most sites up to 2006) all regions except India and Canada showed a positive trend.

The phenomenon of global dimming and brightening [2, 3] could be approved (Table 2). For the mean of all sites the dimming for the period 1950 – 85 and the brightening for the period 1985 – 2009 is statistically significant. The negative trend during the dimming period is clearly stronger (approx. factor 2) than the positive trend during the brightening phase. The individual regions and groups show a great variety of different trends for the analyzed sub periods. The negative trend found in [4] for the period after 2000 could be found only at 2 stations out of the 25.

Table 2: Results of the regional trend analysis 1950-1985 and 1985 – 2009.

Region	Trend [W/m2 10y]	R^2	P (T-Test)	Trend [W/m2 10y]	R^2	P (T-Test)
Time period	**1950 – 1985**			**1985 – 2009**		
average	-4.7	0.409	0.000	1.8	0.160	0.019
Europe	-1.9	0.145	0.009	4.1	0.248	0.000
Germany	-1.2	0.070	0.206	4.6	0.211	0.001
Switzerland	-7.7	0.465	0.000	3.1	0.162	0.003
Asia	-5.9	0.430	0.000	1.4	0.133	0.177
India	-6.5	0.356	0.000	-5.4	0.331	0.001
Canada	-1.9	0.168	0.001	-0.2	0.008	0.909

Figure 1 shows seasonally corrected time series with smoothed values over 1 and 5 years. In this figure a gentle oscillation of the radiation values can be seen. Local maxima are visible around 1970 and 2003 (heat wave over Central and Western Europe).

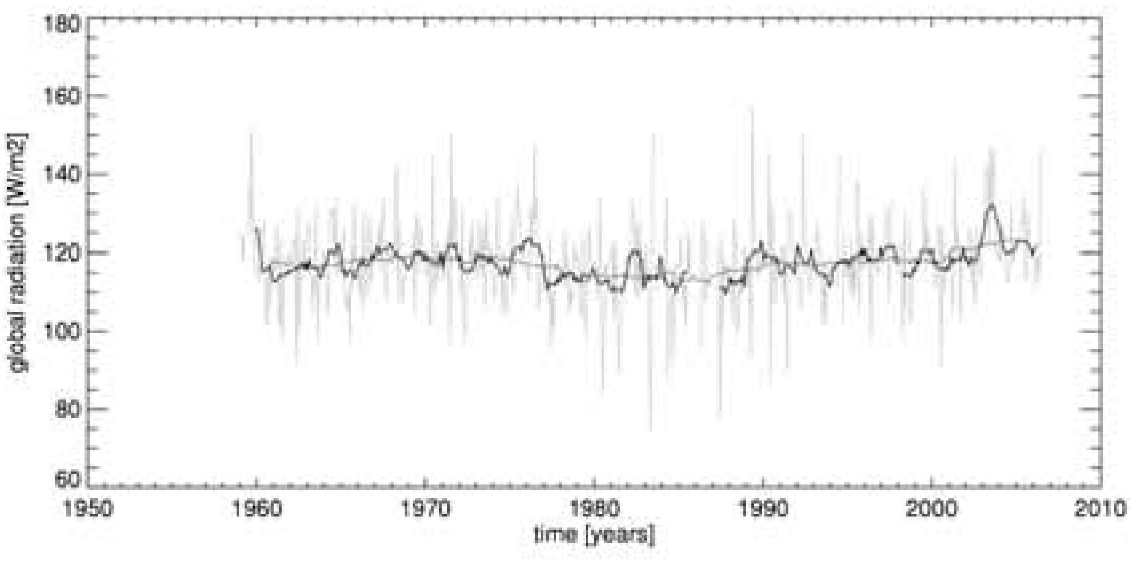

Figure 1: Seasonally corrected time series with moving averages for 1 and 5 years for Europe.

4. Trends of 5, 10 and 20 year means

Similar to the trends of the monthly values also the trends of the 5, 10 and 20 year means show a big dependence on the station (Figure 2). Also here the dimming and brightening phase is clearly visible. For 20 year means most sites show variations lower than 5-10%. However some sites in India, Beijing and Weissfluhjoch (Swiss mountain top station) show a big negative trend with a decline of more than 20% during the analyzed period. Whereas in Beijing the growing aerosol loads are the main reason for the decline, the reason for the changes in Weissfluhjoch are not known at the moment.

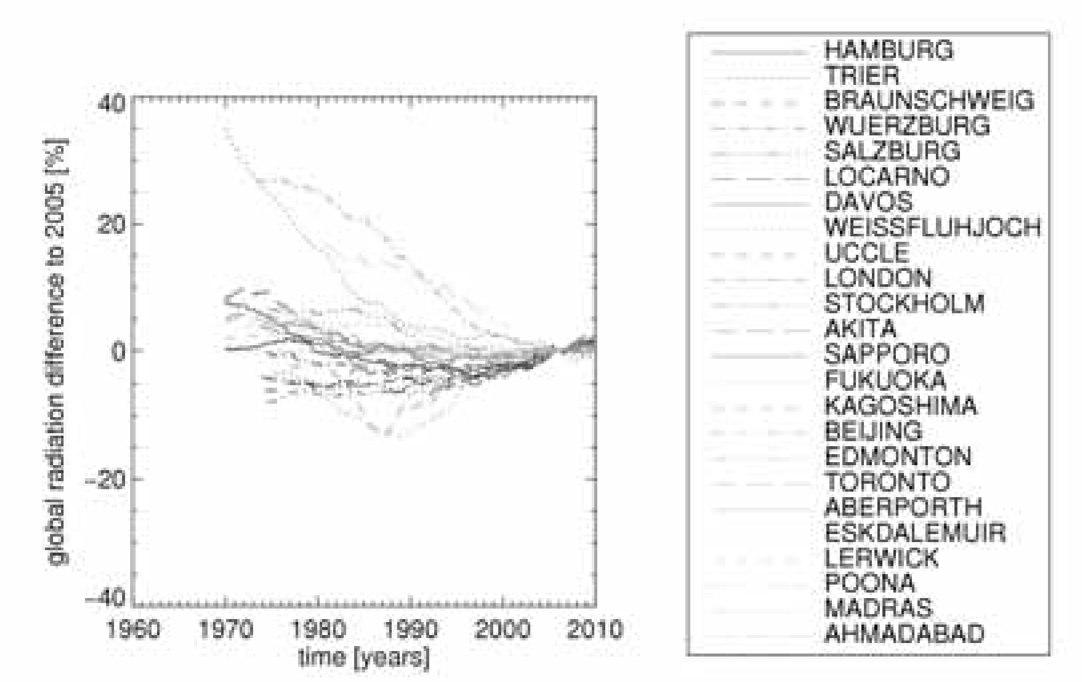

Figure 2: Variation of 2-decadal means in % compared to 1986-2005 for all sites. Time shows the end point of the **20 year** period.

5. Dependence of the variability on the length of a measured period

The variation depending on the duration of the measurement period is also quite different from site to site. Most sites have a standard deviation of 5 – 7% for a 12 month mean which decreases to 2 – 4% at 10 years and 2% at 20 years (Figure 3, Table 3). The biggest decline happens in the first 5 years. As a general rule it can be stated, that a climatology of global radiation should include at least 10 years. Only for regions with very high trends (more than 5 W/m^2 and decade) it makes sense to get as current data as possible.

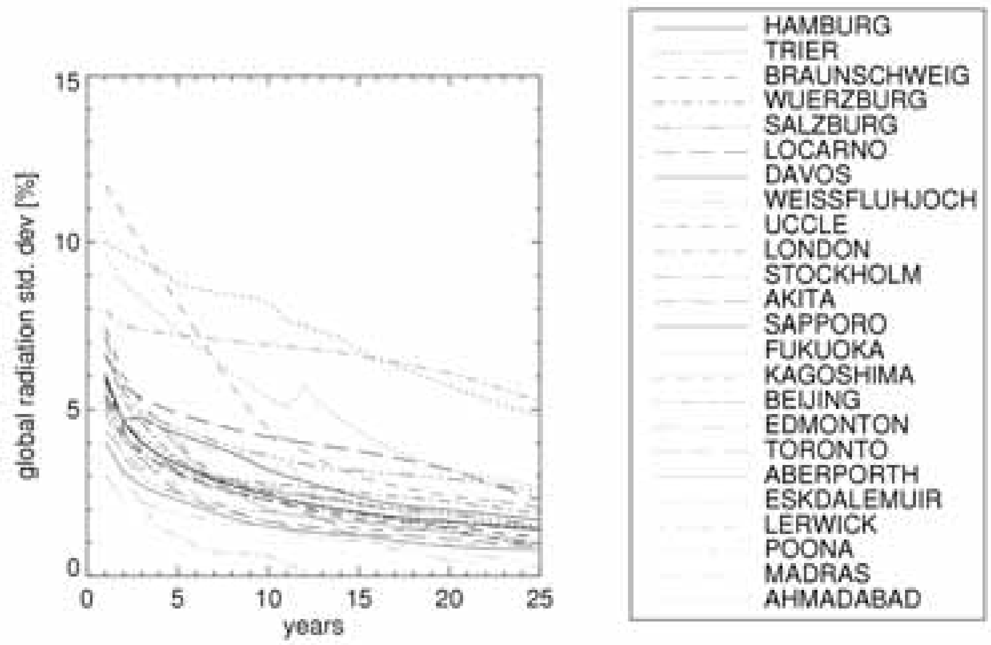

Figure 3: Variation of measurements depending on duration of measurement.

Table 3: Relative standard deviation in percent depending on the duration of the time period of selected sites.

Name	**1 year [%]**	**2 years [%]**	**3 years [%]**	**5 years [%]**	**10 years [%]**	**20 years [%]**
Salzburg, AT	5.86	4.64	4.07	3.20	2.53	1.87
Uccle, BE	7.46	6.01	5.21	3.99	2.40	1.48
Potsdam, DE	5.37	4.06	3.57	3.16	2.53	1.77
London Weather Station, UK	6.69	5.27	4.61	3.52	2.77	2.24
Stockholm, SW	7.19	5.54	4.94	4.44	3.61	2.93
Locarno-Monti, CH	6.64	5.73	5.34	4.88	4.18	3.18
Davos, CH	5.33	4.71	4.73	4.27	3.19	1.98
Weissfluhjoch, CH	9.99	9.66	9.39	8.76	8.22	5.72
Akita, JP	5.41	4.28	3.55	2.51	1.63	1.11
Fukuoka, JP	9.61	8.76	8.30	7.35	5.36	3.26
Beijing, CN	7.94	7.51	7.39	7.26	6.96	6.11
Madras, IN	3.03	2.28	2.23	1.89	1.44	0.41
Toronto, CA	4.38	3.75	3.18	3.13	2.66	1.67

6. Future changes of global radiation

From IPCC results [1] we took the average of all approximately 18 available models. We used the three scenarios B1 (low), A1B (mid) and A2 (high). In order to make an average, we regridded all individual model anomalies to a 1x1° grid. The forecasted changes of global radiation until 2100 with all scenarios are relatively small compared to temperature changes. They are in the range of one tenth of a percent until some percents. The differences between the three scenarios are also relatively small (Table 4 and Figure 4). On an average the global radiation will decrease slightly. However, in the Mediterranean region the trend is positive (+ 2 – 4 % till 2100). The changes of the last 25 years go in the same direction but are already bigger than the forecasted anomalies for the period until 2030. However it has to be noted, that the variations in the past 50 years (global dimming and brightening) has been underestimated by the climate models.

Table 4: Change of mean global radiation values in scenario A2. Means 1981-2000 according Meteonorm 6.1.

Site	**Long-itude**	**Lat-itude**	**Mean [kWh/m^2]**	**Anomalies 2011 – 2030 [kWh/m^2]**	**Anomalies 2046 – 2065 [kWh/m^2]**	**Anomalies 2080 – 2099 [kWh/m^2]**
Germany	10	50	1087	7 (0.6 %)	14 (1.3 %)	38 (3.5 %)
South Spain	-5	37	1796	18 (1.0 %)	28 (1.6 %)	51 (2.8 %)
Turkey	30	37	1952	15 (0.8 %)	34 (1.7 %)	69 (3.5 %)
Sahara	0	30	2163	-9 (-0.4 %)	-11 (-0.5 %)	-14 (-0.6 %)
World	-	-	1500	-10 (-0.7 %)	-21 (-1.4 %)	-29 (-1.9 %)

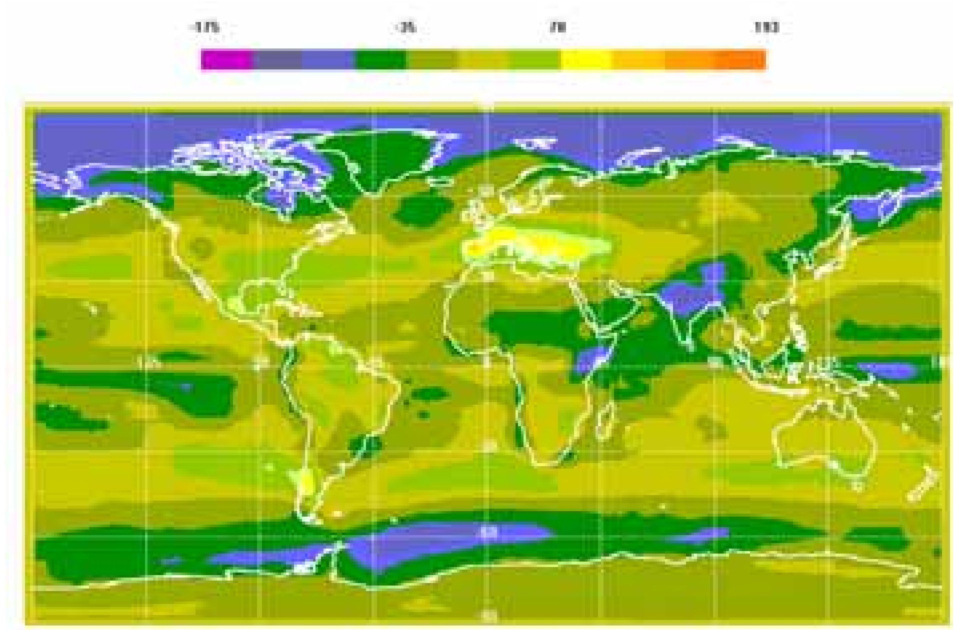

Figure 4: Anomalies of global radiation in kWh/m^2 compared to 1961 – 90 for the period 2080 – 99 with IPCC scenario A2.

7. Conclusions

The phenomenon of global dimming and brightening could be approved in this analysis. The positive trend since 1985 is visible in Europe until last year and is in the range of 4 W/m^2 and decade. However there are signs of a decline of the trend after 2005.

Looking at the moving averages with smoothing lengths of e.g. 20 years, the changes are generally small. The standard deviation of a 20 year mean is in and around Germany in the range of 1.5 – 2.0% - what's below the uncertainty of the measurement itself. The use of the 20 year mean 1981 – 2000 leads in Germany to a underestimation of 2 – 3 % compared to the time period 1986 – 2005. In most other regions the trends are smaller or – like in China – even reversed.

As the changes in aerosol concentration based mainly on industrial processes (which is dependent on the production and air pollution control) are one of the main reasons for brightening and dimming this conclusions are not astonishing. In India and China industry and power production based on coal still has a strong growth, whereas in Europe and Japan industry has lowered the output of aerosols after 1985. As aerosol loads are now quite stable in Western Europe and will presumably grow in Asia, the brightening phase will presumably not be prolonged in the future.

The modelled changes in global radiation for this century are relatively small and are mostly in the range of a few percents. In opposition to temperature, there are no big changes in radiation foreseen. On a global average the radiation will diminish slightly. In the Mediterranean region however the trend is positive.

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