FINAL REPORT

Title **Surface Solar Radiation Data Base**

NASA Global Aerosol Climatology Program GACP

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Objectives

The objective of GACP was the quantitative assessment of radiative forcing caused by atmospheric aerosols over a multi-decadal time period. Therefore we analyzed broadband solar radiation from the Global Energy Budget Archive (GEBA), the National Solar Radiation Database of the United States and a German database. Comparisons with general circulation models have been performed to address possible impact of the indirect and direct effect on surface solar radiation on a 30 years time scale. We focused on comparisons of surface solar radiation climatologies of clear sky and overcast sky conditions, cloud cover and precipitation. The first model experiments utilized are the ECHAM4 GCM with a fully coupled sulfur chemistry and cloud scheme for analyzing the indirect aerosol effect on surface solar radiation, cloud coverage and precipitation. The second simulations stem from GISS GCM model experiments that simulated the direct effect of fossil fuel burning aerosols and their multi-decadal changes. The analysis of surface solar radiation provides an integral perspective in addition to field experiments analyzed by other groups.

Progress Report for the Third Year

In the third year of this project surface solar radiation records of the Global Energy Budget Archive GEBA have been analyzed. The GEBA database consists of monthly means of broadband solar radiation from stations all over the world. Some of these recordings are more the thirty years long. Out of this data set 252 time series with observations covering the time period from 1961 to 1990 have been selected. Composites of decadal mean annual cycles have been calculated for each station and were compared for the three decades 1960s, 1970s and 1980s. Also trend analyses of the United States recordings of solar radiation were carried out. For the three decades from 1961 to 1990 the United States data are available on an hourly resolution including cloud cover information. These records have been separated into clear sky, overcast and opaque overcast conditions on which trend analyses were performed. The results of the analyses will be summarized below.

Project Summary

The GEBA data set revealed an estimated 7W/m^2 or 4% decline in surface solar radiation at sites worldwide from 1961 to 1990 (Figure 1). The strongest decline occurred at the United States sites with 19W/m^2 or 10%. Clear sky solar radiation declined by 8W/m^2 or 3% over the United States from the 1960s to the 1980s (Figure 2). The solar radiation under overcast clouds however, declined in the United States by 18 W/m^2 or 14% from 1961 to 1990 (Figure 2). Though the reduction is higher under optically thick opaque clouds with a decline of 20 W/m^2 or 21% in three decades (Table 1). Hence the observed decreases are most likely caused by increases in cloud optical thickness and to a lesser extend by increases in aerosol optical thickness. To explain at least part of these observed reductions the impact of the direct and indirect aerosol effect on surface solar radiation has been assessed with model studies.

Clear Sky Solar Radiation and Direct Aerosol Effect

Even though the aerosol forcing is stronger in eastern United States compared to the western U.S. the observed reductions are similar (Table 2). The diurnal cycle and the direct to diffuse ratio of solar radiation were used for constraining the observed trends. Increased absorption and declined light scattering seem responsible for the intensified direct aerosol forcing in the United States. While at the same time in Germany both aerosol absorption and scattering must have declined to explain the simultaneous increase in surface solar radiation of 3W/m^2 and the increased direct/diffuse ratio. To estimate the possible anthropogenic portion we compared these observed changes with modeled aerosol forcing scenarios retrieved from the general circulation model of Goddard Institute for Space Studies (Tegen et al., 2000). Modeled surface solar radiation, aerosol optical thickness and single scattering albedo are derived from emission trends of anthropogenic sulfate and carbonaceous aerosols. The emission distributions are calculated from fossil fuel consumption databases. Based on these simulations we suspect that the trends in fossil fuel consumption correspond with the trends derived from the surface solar radiation analysis. Over the United States however, the simulated small increase in the carbonaceous aerosol burden must be exaggerated in order to explain the observed changes in surface solar radiation, diurnal cycle and direct / diffuse ratio of surface solar radiation (Figure 3). In addition, the declining trend of sulfate burden over Germany between 1960 and 1990 was stronger than estimated in the model.

All Sky Surface Solar Radiation and Indirect Aerosol Effect

The observations of solar irradiance at the surface, total cloud cover and precipitation rates for the United States have been used to evaluate aerosol-cloud-interactions in the ECHAM4 GCM. The model runs were for a 5-year period with fully coupled sulfur chemistry - cloud scheme (Lohmann and Feichter, 1997). We studied two experiments - one with an annual mean sulfate load of 0.36Tg S for the pre-industrial simulation and one with 1.05Tg S for the present day simulation. Our goal was to indirectly confirm the existence of the indirect aerosol effect by finding indices for a better agreement of observations with the present day experiment compared to the pre-industrial experiment. We were able to draw such a conclusion only for the German data but not for the United States. The model correctly predicts the annual means of the total cloud cover in Germany and the United States, whereas global solar radiation is underestimated. This deficiencies stem from clouds which are either optically too thick or the vertical distribution of clouds is erroneous. The modeled overcast solar irradiance is 27W/m^2 lower than observed whereas for the clear sky agrees. The modeled cloud cover is too low over the Central United States in July and August and consequently the solar irradiance exceeds the observations during these months (Figure 5). The opposite occurs in winter when the model overestimates the cloud cover and thus underestimates solar irradiance (Figure 5). On the other hand, this drying out effect of the inner continent is not as pronounced in coastal regions and in particular, the comparisons for the German grid-box provide indications for the validity of the indirect aerosol effect. The modeled annual cloud cover and solar radiation cycles for the present day aerosol load are in better agreement with observations. Furthermore, the model shows an interesting shift from low cloud reduction to cirrus formation in spring as a consequence of the indirect aerosol effect, a result confirmed by observational data.

References

Lohmann, U. and J. Feichter, 1997: Impact of sulfate aerosols on albedo and lifetime of clouds: a sensitivity study with the ECHAM4 GCM. *J. Geophys. Res.*, **102,** D12, 13,685-13,700.

Tegen, I., D. Koch, A. A. Lacis, and M. Sato, Trends in tropospheric aerosol loads and corresponding impact on direct radiative forcing between 1950 and 1990: A model study, *J. Geophys. Res.*, 105, D22, 26,971-26,989, 2000.

Reviewed Papers of the Project

Liepert, B. G., 2002: Observed Reduction of Surface Solar Radiation at Sites in the United States and Worldwide from 1961 to 1990. Submitted.

Liepert, B. G. and I. Tegen, 2001: Multi-Decadal Solar Radiation Trends in the United States and Germany and Direct Tropospheric Aerosol Forcing. *J. Geophys. Res.*, accepted.

Liepert, B. G. and U. Lohmann, 2001: A Comparison of Surface Observations and ECHAM4-GCM Results relevant to the Indirect Aerosol Effect. *J. Climate*, 14/6, 1078-1091.

Other Papers of the Project

Liepert, B. G., 2001: Multi-Decadal Solar Radiation Observations and their Relevance to Cloud and Aerosol Changes. *Proceedings (in print) 1. Intl. Conf. On Global Warming and the Next Ice Age, Halifax, Canada, August 19 - 24, 2001*.

Liepert, B.G., 2000: Solar Radiation, Cloud Cover and Precipitation Observations Compared to ECHAM4-GCM Experiments. *Int'l Radiation Symposium 2000: Current Problems in Atm. Radiation.* Eds. W.L. Smith, Y.M. Timofeyrv, St. Petersburg, Russia.

Table 1. Surface solar radiation G 10-year annual means for various regions and cloud cover conditions. All stations, NH northern hemisphere records, FSU former Soviet Union records, United States and Germany.

Stations	All	NH	FSU	United States			Germany	
Cloudiness Conditions	All Sky	All Sky	All Sky	All Sky	Overcast	Opaque Overcast	All Sky	Overcast
1961-70	189	163	125	200	128	95	124	47
1971-80	186	160	123	194	121	84	122	44
1981-90	182	156	123	181	110	75	120	42

Table 2. Decadal means of observed global solar radiation (G) and decadal range of modeled global solar radiation (G), aerosol optical thickness (AOT) and single scattering albedo (SSA) for three aerosol scenarios.

	Western United States		
	1960s	1970s	1980s
G W/m^2 Obs.	244	243	236
G W/m^2 Model	253 - 254	253 - 254	252 - 253
AOT Model	0.11 - 0.14	0.12 - 0.16	0.13 - 0.18
SSA Model	0.946 - 0.923	0.948 - 0.922	0.947 - 0.917
	Eastern United States		
	1960s	1970s	1980s
G W/m^2 Obs.	236	235	229
G W/m^2 Model	230 - 232	229 - 231	229 - 230
AOT Model	0.15 - 0.20	0.17 - 0.23	0.18 - 0.26
SSA Model	0.952 - 0.922	0.955 - 0.922	0.953 - 0.916
	Germany		
	1960s	1970s	1980s
G W/m^2 Obs.	190	190	193
G W/m^2 Model	171 - 178	173 - 180	177 - 181
AOT Model	0.21 - 0.45	0.22 - 0.41	0.20 - 0.37
SSA Model	0.940 - 0.885	0.948 - 0.895	0.950 - 0.898

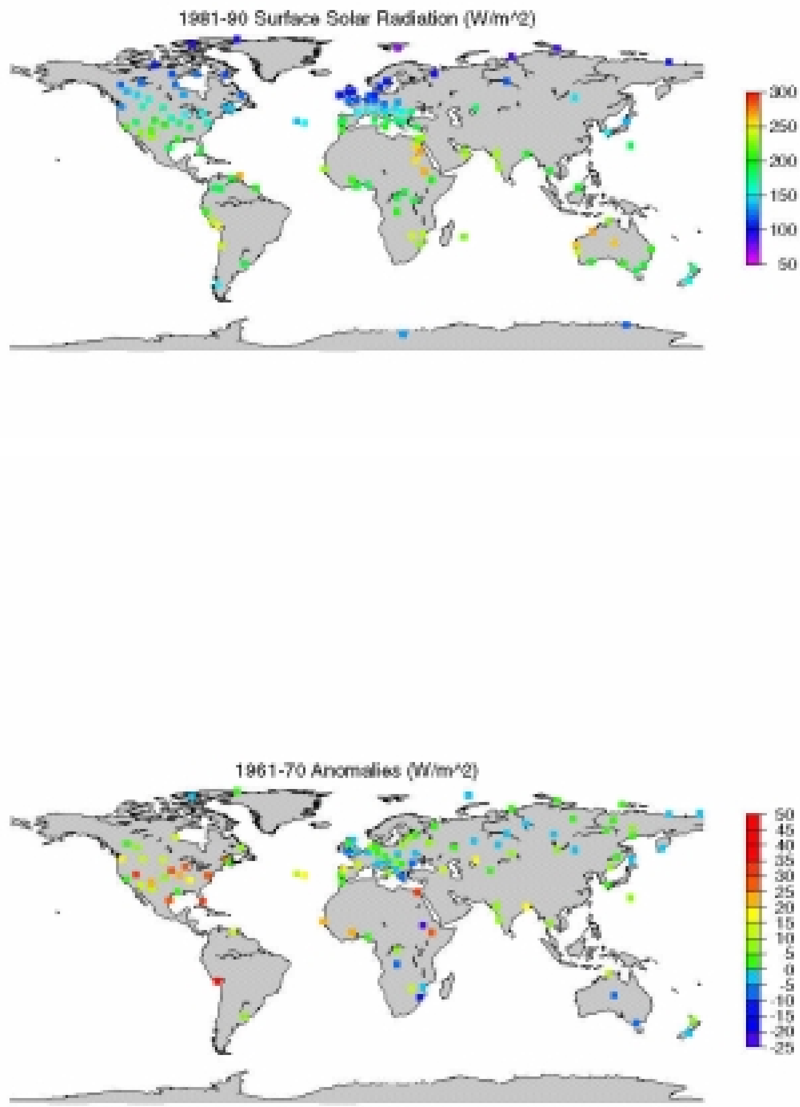

Figure 1. Distribution of annual mean surface solar radiation for 10-year average from 1981 to 1990 (upper panel) and anomalies of the 1961 to 1970 period from the 1981 to 1990 period (lower panel).

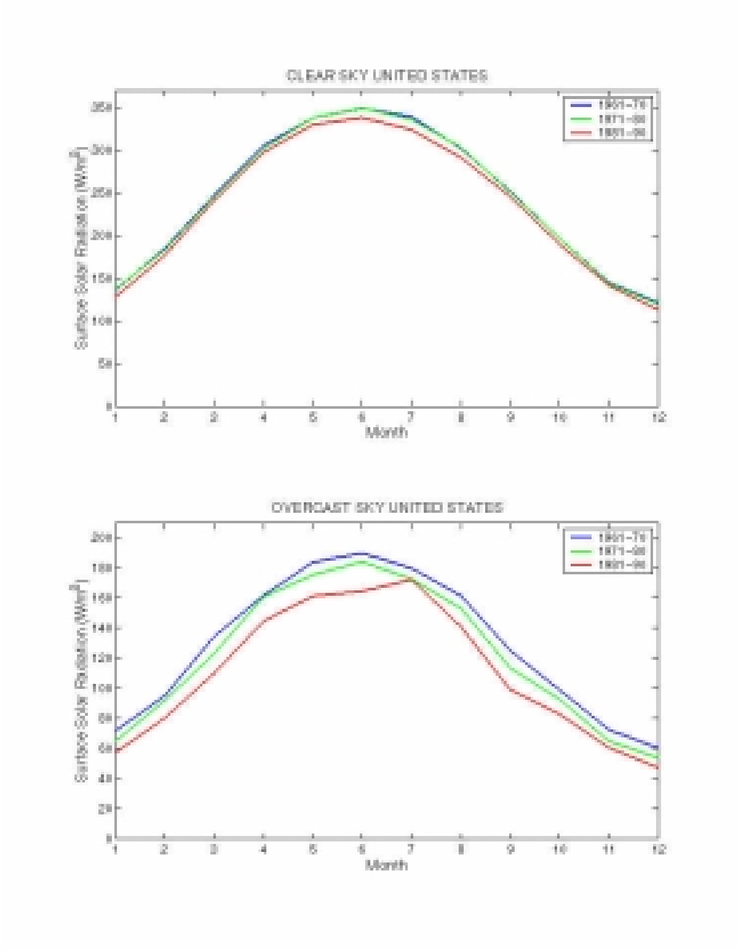

Figure 2. Monthly mean surface solar radiation of United States. Blue line represents 1961 to 1970, green 1971 to 1980 and red 1981 to 1990 period for (upper panel) clear sky and (lower panel) overcast sky conditions.

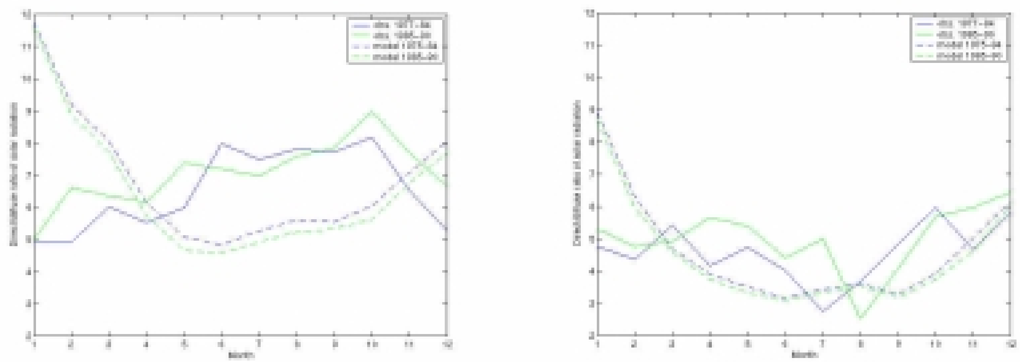

Figure 3. Decadal mean direct / diffuse ratios of clear sky solar radiation for the western and eastern United States. Solid lines are the observations and dashed lines are the modeled monthly mean ratios.

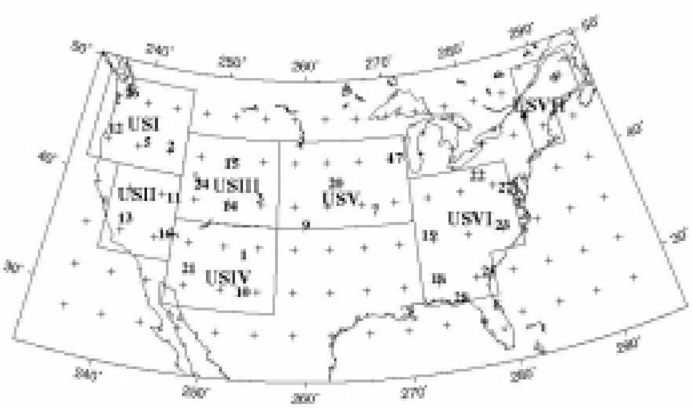

Figure 4. The Distribution of the observational sites and of the seven model boxes and the model grid points for the United States.

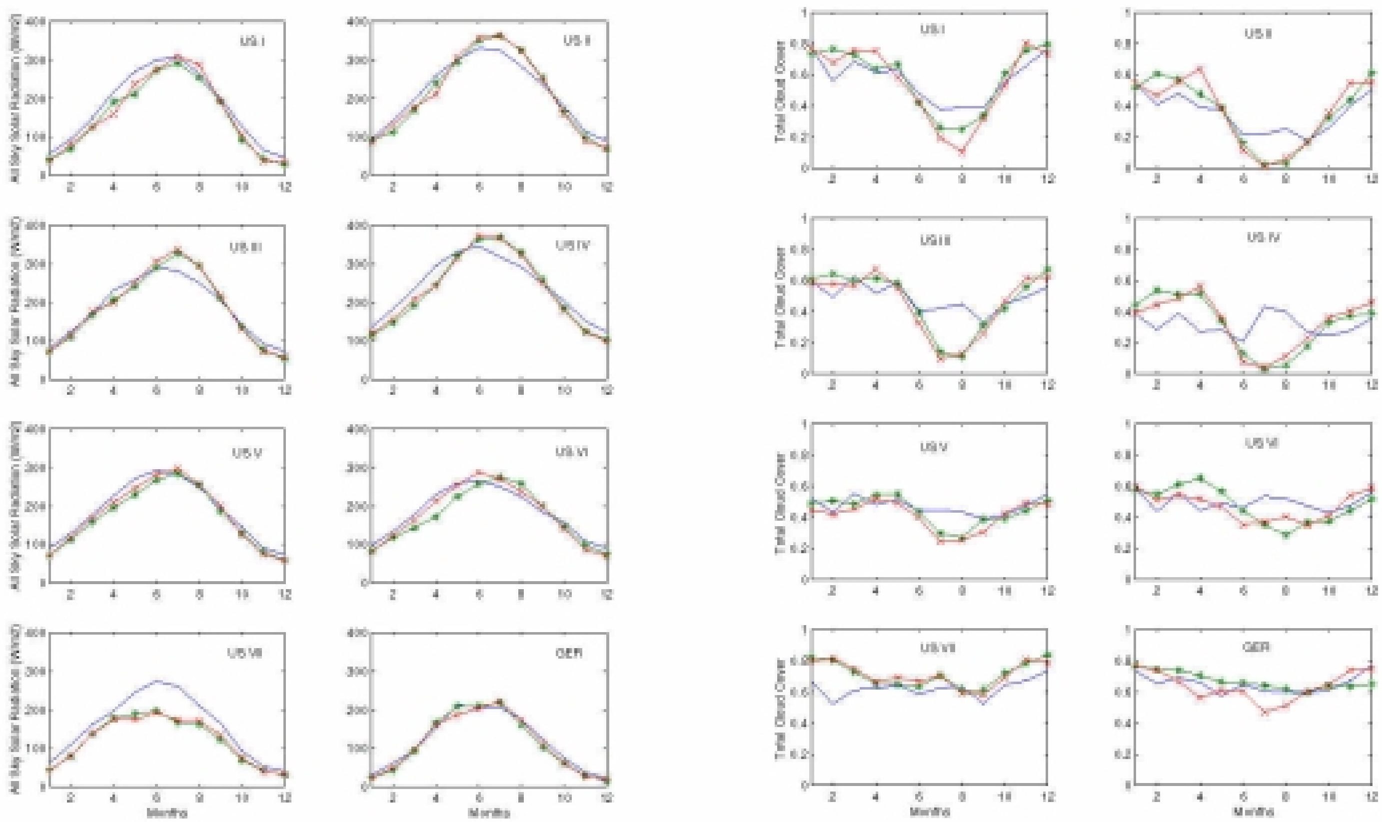

Figure 5. The annual cycles of solar radiation (left) and total cloud coverage (right) for the eight regions as shown in fig. 4. The blue line represents the observations, the green the present-day and the red the pre-industrial experiment.