

On the Contribution of Aerosols and Clouds to Global Dimming and Brightening Using a Radiative Transfer Model, ISCCP-H Cloud and MERRA-2 Aerosol Optical Properties [†]

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Abstract: The interdecadal changes of the incident solar radiation at the Earth's surface (SSR) are mainly driven by changes in clouds and aerosols. In order to investigate their contribution to the SSR changes (global dimming and brightening or GDB), the FORTH radiative transfer model (RTM) is used to compute the SSR fluxes. The cloud input data were taken from satellite observations of ISCCP-H, while aerosols and meteorological data were taken from the MERRA-2 reanalysis dataset. The RTM operates on a monthly basis and in $0.5^\circ \times 0.625^\circ$ latitude-longitude spatial resolution. The GDB was also computed keeping constant at their initial 1984 values, each input parameter that was examined, resulting in a GDB with the 'frozen' parameter. The contribution of each parameter to the GDB is defined as the subtraction of the frozen GDB from the base-run GDB, and the positive/negative values of the contribution indicate that the interdecadal variability of the examined parameter increased/decreased the SSR. The aerosol optical depth (AOD) produced a dimming in India, Amazonia, and S. China, whereas it induced a brightening in Europe and Mexico. On the other hand, the total cloud cover (TCC) changes caused a dimming over the Arctic, Australia, and the South Ocean against a brightening in Europe, Mexico, the Middle East, and South America. The global mean contribution of changing AOD is 0.37 W/m^2 , and for TCC, it is 4.7 W/m^2 , indicating that globally, the counteraction of cloud cover to the overall global dimming is larger. Opposite contributions to GDB from AOD and TCC may occur over specific regions, highlighting the complexity of the causes of the GDB phenomenon.

Keywords: aerosols; clouds; global dimming and brightening; radiation transfer model; MERRA-2; ISCCP-H



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1. Introduction

The surface solar radiation (SSR), which plays a vital role in our planet, undergoes multidecadal changes known as Global Dimming and Brightening (GDB). GDB is mainly associated with the variable transparency of the Earth's atmosphere, being primarily attributed to clouds and aerosols [1,2]. For example, increasing or decreasing loadings of atmospheric aerosols can reduce or increase SSR, a phenomenon that is maximized under clear sky conditions. Ground-based SSR observations suggest that from the 1950s to the 1980s solar dimming has taken place on many locations of the Earth, which has been

succeeded by a brightening observed after the mid-1980s in most stations of global reference radiation networks. This changeover from dimming to brightening is in agreement with changes in aerosol emissions, which also reversed to a decrease since the 1980s, especially in industrialized areas. Since the 1950s, aerosols seem to dominate GDB on multidecadal timescales, while clouds are more relevant to decadal/subdecadal GDB phases [3]. The aim of this study is to investigate the contribution of aerosol optical depth (AOD) and total cloud cover (TCC), which are the main drivers, to GDB during the 35-year period 1984–2018 using the FORTH spectral radiative transfer model (RTM) and state-of-the-art input data.

2. Data, Model and Methodology

The FORTH spectral radiative transfer model (RTM) [4], developed from a radiative-convective model [5] solves the radiative transfer equations using the modified Delta-Eddington method of [6] and computes the upwelling and downwelling solar fluxes at the Earth's surface, at the top of the atmosphere and at 50 levels within the atmosphere. The input aerosol optical properties are computed with data taken from the Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2) reanalysis, as described by [7]. Specific humidity, surface albedo, and ozone concentration are taken from the same reanalysis. The original MERRA-2 resolution is hourly and on a $0.5^\circ \times 0.625^\circ$ latitude-longitude horizontal grid at 72 atmospheric layers. Cloud properties are taken from the International Satellite Cloud Climatology Project H Series (ISCCP-H) originally with 3-h resolution and $1^\circ \times 1^\circ$ latitude-longitude horizontal grid. All input datasets were regridded to the MERRA-2 resolution ($0.5^\circ \times 0.625^\circ$), and their mean monthly values were calculated according to the requirements of the RTM, which operates and computes SSR, constrained by the resolution of the MERRA-2 data on a monthly mean basis. For the evaluation of the RTM SSR fluxes, we use data from 1193 Global Energy Balance Archive (GEBA) stations and 66 Baseline Surface Radiation Network (BSRN) stations.

Regarding the applied methodology, firstly, we perform RTM runs (base run) under all-sky conditions, and then we calculate the linear slope of the deseasonalized SSR anomalies. The calculated slope is multiplied by the temporal duration (in months) of the time series to compute the SSR changes or GDB in W/m^2 . In the second run, the RTM runs again under all-sky conditions but with constant (frozen) AOD or TCC at their initial values of 1984, and the (frozen parameter) GDB is estimated again. Then, the contribution of these two parameters to GDB is determined by subtracting the frozen GDB from the GDB of the base run. Note that positive/negative values of the contribution of a specific frozen parameter means that the interdecadal variability of this parameter strengthened/counteracted the observed brightening or counteracted/strengthened the observed dimming.

3. Results

The computed base-run GDB (not shown here) revealed mixed tendencies of brightening and dimming globally, even in neighboring regions. Brightening occurs over the Mediterranean, Antarctica, Eastern Pacific Ocean, Mexico, the Middle East, and some other parts of the oceans. On the other hand, the decline of SSR or dimming exists over India, Australia, Amazonia, the Western Pacific, the Arctic and Southern Oceans. On a global scale, a dimming is found equal to -2.2 W/m^2 [8]. The quality of these findings is evaluated by comparing the RTM SSR anomalies to corresponding GEBA and BSRN station data, providing satisfactory correlation coefficients, up to 0.72 against GEBA and 0.8 against BSRN. Overall, the RTM underestimates SSR and SSR trends, with mean biases equal to -4.7 and -14.3 W/m^2 against GEBA and BSRN, respectively [8]. Furthermore, we computed and compared the sign of SSR changes at each station and the corresponding RTM grid point. The agreement against GEBA and BSRN is 63.5% and 54.5%, respectively [8].

After computing the all-sky RTM SSR changes (GDB), we computed the all-sky RTM SSR changes with “frozen” AOD at the initial conditions in 1984, determining the “frozen AOD GDB”. The contribution of (changing) AOD to GDB was quantified by computing

the difference base-run GDB –frozen AOD GDB, and the results are shown in Figure 1. The significant negative contribution of AOD to GDB (greenish and bluish colors) occurs in India, Southern China, Amazonia, the Middle East, and Southern Africa. This means that the changing AOD from 1984 to 2018 produced a dimming over these regions, which is in line with the overall observed dimming, whereas, in the Middle East, the identified negative contribution of the AOD values weakened the estimated brightening. On the other hand, a significant positive contribution exists over parts of Central Africa, Eastern N. America, Central S. America, Europe, and Mexico. At these locations, the interdecadal change of AOD contributes positively to the estimated brightening over these regions. The contribution of AOD interdecadal changes ranges from -32.8 W/m^2 to $+18.5 \text{ W/m}^2$, with a global mean value of $+0.37 \text{ W/m}^2$, which indicates that the changing AOD values during the period 1984–2018 induced a considerable brightening at the global scale which counteracted the overall global dimming (of -2.2 W/m^2).

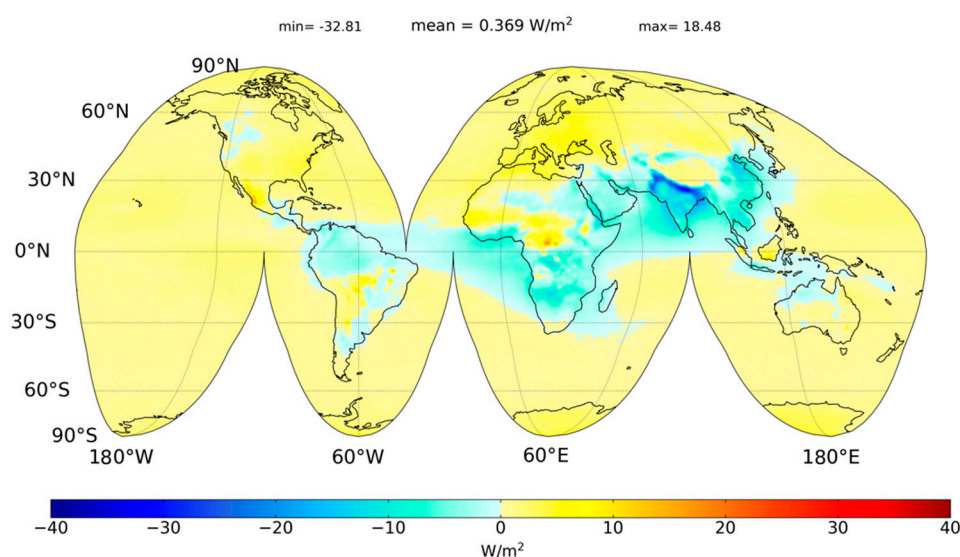


Figure 1. Global distribution of the contribution of AOD interdecadal changes to the RTM GDB in W/m^2 during 1984–2018. Reddish and yellow colors indicate positive, while greenish and bluish colors have negative contributions.

We performed a similar analysis and estimated the contribution of the total cloud cover changes to GDB, computing the difference between the base-run GDB and frozen TCC GDB, which is shown in Figure 2. The cloud contribution ranges from -34 W/m^2 to $+39.6 \text{ W/m}^2$ with a mean value of 4.7 W/m^2 , which means that changing total cloud cover induced a significant brightening at a global scale that largely exceeds (by one order of magnitude) the corresponding brightening caused by AOD. In general, positive contributions (yellowish/reddish colors) dominate over the globe, which are larger than the contribution of AOD, except for the arctic regions, the South Ocean, and a few tropical areas, where negative contribution exists (bluish colors). In the regions with positive contribution, the interdecadal variability of TCC produced brightening, which contributed positively to the overall brightening in Europe, Mexico, the Middle East, and Southwest USA and negatively (weakening) the dimming in India, Amazonia, and Guinea Gulf. Moreover, the negative contribution of changing TCC contributes positively to the dimming over the Arctic, parts of Australia, Maritime Southeast Asia, and the South Ocean. Note that the artifacts appearing in Figure 2 are caused by artifacts in ISCCP-H cloud data and are connected with changes in the satellite viewing geometries [9], but they are mainly over specific oceanic regions.

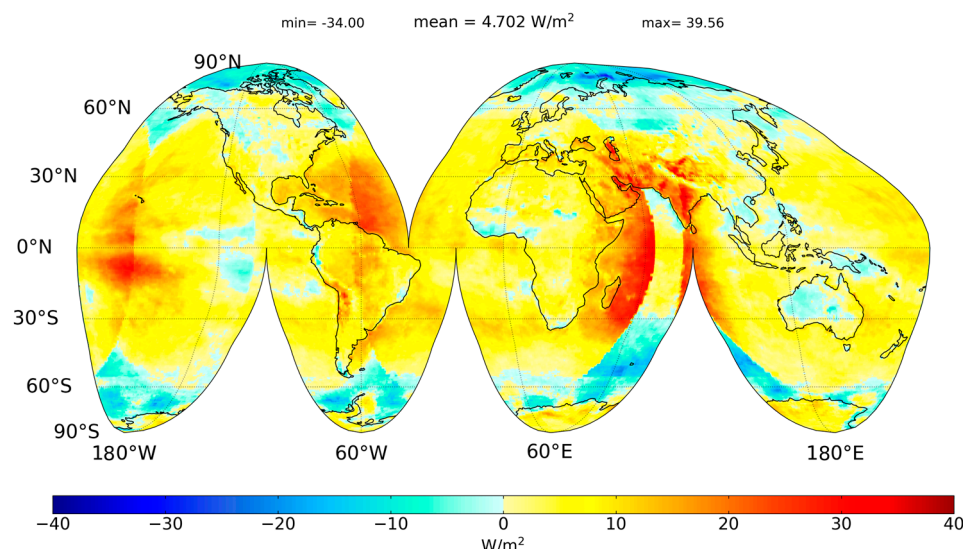


Figure 2. Global distribution of the contribution of TCC interdecadal changes to the RTM GDB in W/m^2 during 1984–2018. Reddish and yellow colors indicate positive, while greenish and bluish colors have negative contributions.

4. Conclusions

In the current study, the contribution of changing AOD and TCC to GDB during the time period 1984–2018 is estimated at a global scale using a radiative transfer model. The changing AOD values over the study period decreased the SSR, producing a dimming in India, Southeast Asia, Amazonia, and the Gulf of Guinea, while it increased SSR, i.e., caused brightening in Europe, Mexico, and Central Africa. On the other hand, the changes of TCC from 1984 to 2018 also increased SSR, as changing AOD did, in regions such as Europe and Mexico, while in India, Amazonia, a large part of Africa and the Middle East the contribution of TCC to GDB is opposite to the contribution of AOD, showing that AOD and TCC can influence in different ways the SSR trends over the same region thus highlighting the complexity of the GDB causes. On a global scale, the contribution of TCC to GDB is much larger than that of AOD (both producing brightening), confirming the dominant role of clouds for surface solar radiation. Note, that these contributions are opposite to the overall observed global mean dimming which (not shown here) is contributed by cloud optical thickness.

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