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The Global and Diffuse Solar Radiation Trends Using GEBA & BSRN Ground Based Measurements during 1984–2018 [†]

Michael Stamatis [1], Pavlos Ioannou [1], Marios-Bruno Korras-Carraca [1,2] and Nikolaos Hatzianastassiou [1,*]

[1] Laboratory of Meteorology & Climatology, Department of Physics, University of Ioannina, 45110 Ioannina, Greece; m.stamatis@uoi.gr (M.S.); ioannoup005@gmail.com (P.I.); koras@env.aegean.gr (M.-B.K.-C.)

[2] Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing, National Observatory of Athens, 11810 Athens, Greece

* Correspondence: nhatzian@uoi.gr

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Abstract: Surface solar radiation (SSR) is a crucial parameter for both the Earth's climate and human activities, and it consists of two components: the direct beam from the sun and diffuse radiation, with the latter being scattered by atmospheric molecules, aerosols, or clouds. The multidecadal variations of SSR, known as Global Dimming and Brightening (GDB), should also arise from a corresponding variability of either the direct or the diffuse radiation. Thus, the determination of the trends of both the direct and the diffuse radiation is important for showing the causes of GDB. In the present study, we estimate the trends of global and diffuse radiation on a global scale during the period 1984–2018, using worldwide reference ground-based measurements from the Global Energy Balance Archive (GEBA) and the Baseline Surface Radiation Network (BSRN). An increasing tendency of SSR is observed over most locations on our planet, while a decreasing trend occurs in India. On the other hand, the diffuse radiation has decreased over Europe and parts of Asia, whereas it has increased over the USA, India, and East Asia.

Keywords: surface solar radiation; global dimming and brightening; diffuse solar radiation; direct solar radiation; ground based measurements

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1. Introduction

Solar radiation reaching the Earth's surface (Surface Solar Radiation or SSR) is the principal energy source that controls a variety of physical, chemical, and biological processes on our planet. The interdecadal changes of SSR, known as global dimming and brightening (GDB), are mainly driven by changes in clouds and aerosols [1,2]. The GDB arises from changes in the direct and diffuse radiation components, which are, respectively, the fractions of SSR coming from the direction of the sun and from other directions in the remaining portion of the sky, scattered by clouds, aerosols, gases, and water droplets in the atmosphere [3,4]. Ground-based SSR observations suggest that from the 1950s to the 1980s, a solar dimming took place on many locations of the Earth, which was been succeeded by a subsequent brightening observed after the mid-1980s in most stations of the global reference radiation networks [5]. Regional studies focusing on the long-term variations of the direct and the diffuse radiation have indicated a general decreasing tendency in direct radiation and an increasing tendency in diffuse radiation during the global dimming phase, and this is attributed to enhanced cloudiness and/or aerosol load. Conversely, during the brightening phase, the opposite trends are observed. These findings have been reported in various world regions, such as Greece [6], Germany [7], India [8], China [9,10], and Spain [11]. The aim of this study is to examine the changes of the SSR and its diffuse component using ground-based stations on a global scale during the years 1984–2018, and the aim is to provide evidence about the causes of GDB on global and climatological scales.

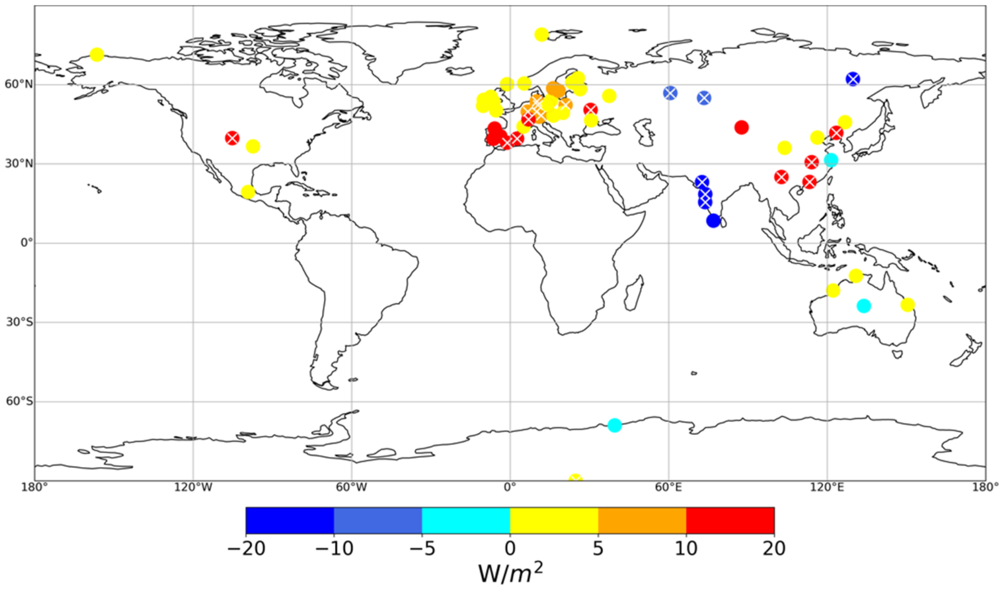
2. Data and Methodology

In the current study, monthly mean SSR and diffuse solar radiation data were obtained from two high-quality ground-based networks—-namely, GEBA and BSRN. In order to improve the reliability of the estimated slopes, an availability criterion was applied, according to which only stations that had more than 70% valid measurements of the total time period for each network (1984–2018 for GEBA and 1992–2018 for BSRN) were used. Therefore, 64 GEBA and 23 BSRN stations were finally used to investigate the tendencies of diffuse radiation and the SSR, from which information was derived about the tendency of direct SSR. Linear regression was applied to the deseasonalized anomalies of SSR and diffuse radiation time-series. The resulting slopes were then multiplied by the number of available months in the time-series in order to compute the changes (in W/m^2), which were also examined for their statistical significance using the Mann–Kendall test. Furthermore, the correlation coefficient between SSR and diffuse radiation anomalies was computed at each station in order to examine the relation between SSR and its diffuse component.

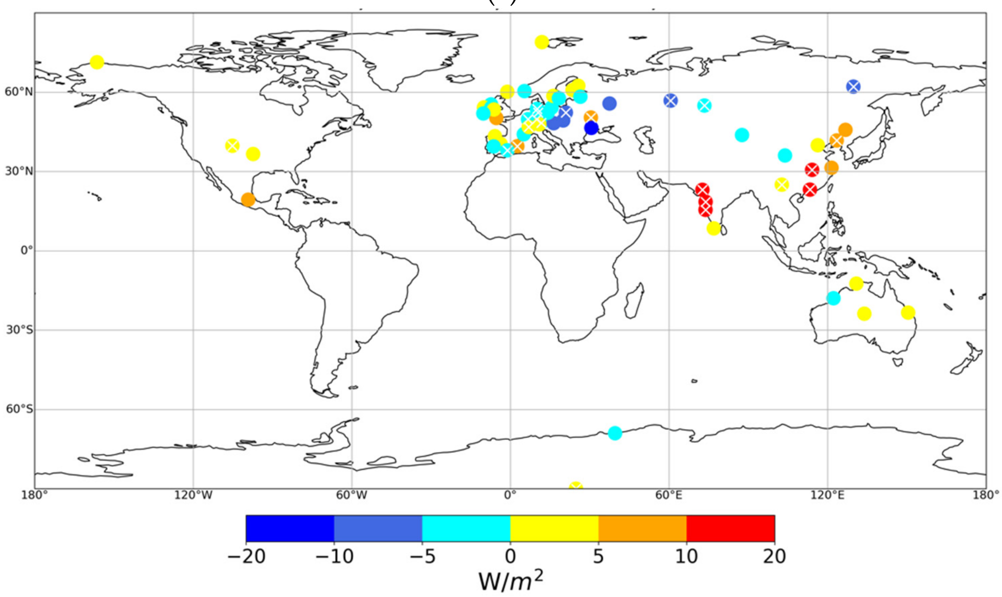
3. Results

The computed SSR changes (or GDB), shown in Figure 1a, reveal a brightening in most stations of the GEBA network (SSR increase up to 28.4 W/m^2), which is statistically significant over Europe and East Asia. On the other hand, a statistically significant dimming (an SSR decrease up to 33.3 W/m^2) occurs in India. Conversely, the diffuse component of the SSR (Figure 1b) decreased over Europe (up to -11 W/m^2) and increased over India (up to 19.6 W/m^2), which is in line with the bibliography referred to in Section 1, and which indicates that the atmosphere over Europe and India is becoming more and less transparent, respectively. Over these two regions, the SSR and diffuse radiation are also negatively correlated (the results are not shown here), which is in line with their opposite changes. However, in East Asia and North America, both SSR and diffuse radiation exhibit an uptrend, which is statistically significant in many stations. Similar findings to these were also found for some stations in China [9,10], but for different time periods, according to which both SSR and diffuse radiation increased, suggesting the complex role of the combination of changes in clouds and aerosols [10] as well as the role of the aerosol single scattering albedo [9], which strongly affects solar radiation.

A similar analysis (shown in Figure 2) was also performed for fewer (23 against 64) BSRN stations, which are mainly distributed in Europe and USA, covering a shorter time period starting from the 1990s. A brightening was observed (Figure 2a) during 1992–2018 in Europe and the USA, ranging from –8.5 W/m^2 to 13.6 W/m^2. On the other hand, the diffuse solar radiation (Figure 2b), whose changes range from –8.5 W/m^2 to 14.3 W/m^2, also showed uptrends in the USA and a mixed pattern in Europe. The findings for the USA are in agreement with those from GEBA, while the results for Europe partly differ with the corresponding ones from GEBA.

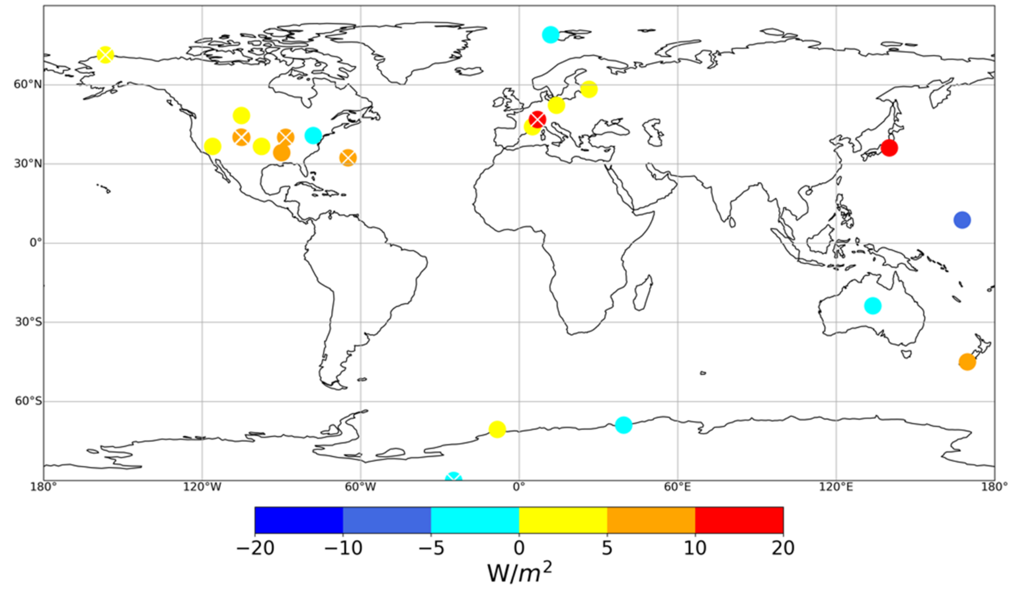


(**a**)



(**b**)

Figure 1. Global distribution of changes in (**a**) SSR and (**b**) diffuse radiation (in W/m^2) during the years 1984–2018 at 64 globally distributed GEBA stations. Reddish and yellow colors indicate increasing trends, while bluish colors indicate decreasing trends. The statistical significance of each trend is denoted by embedded "x" symbols.



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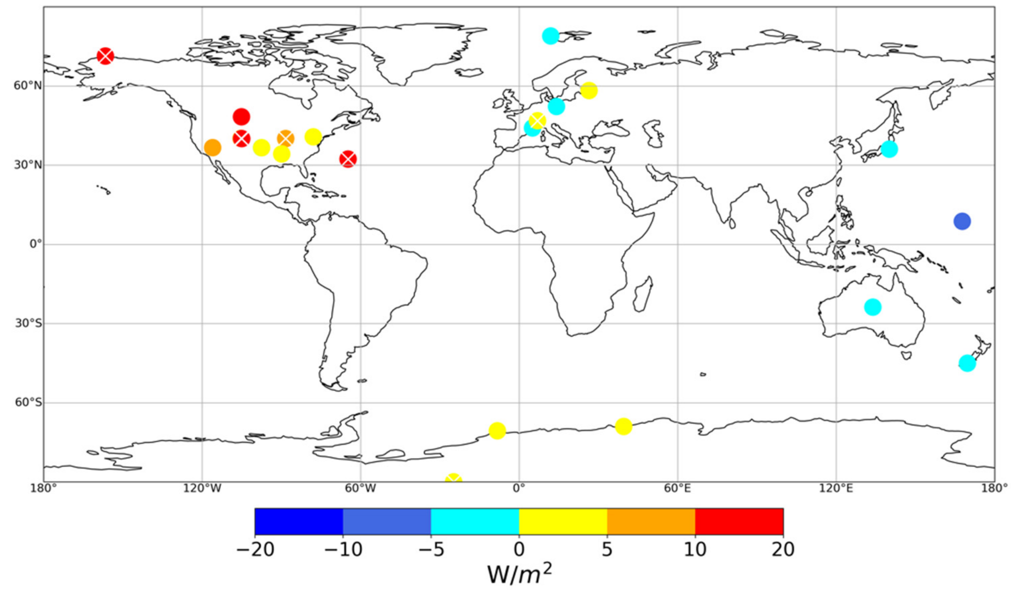

(**b**)

Figure 2. The global distribution of changes in (**a**) SSR and (**b**) diffuse radiation (in W/m^2) during the years 1992–2018 at 23 globally distributed BSRN stations. Reddish and yellow colors indicate increasing trends, while bluish colors indicate decreasing trends. The statistical significance of each trend is denoted by embedded "x" symbols.

4. Conclusions

In the current study, the changes of SSR and its diffuse component are investigated using ground-based observations from 64 GEBA stations during the years 1984–2018 and using 23 BSRN stations for the period 1992–2018. Increasing tendencies are computed for SSR over Europe, USA, East Asia, and Australia, and decreasing tendencies are computed over India. The diffuse solar radiation decreased over Europe and some locations in Asia, while it increased over the USA, East Asia, and India. The computed tendencies of SSR and diffuse radiation indicate that over Europe, the atmosphere is getting more transparent, while over India, it is getting less transparent. Moreover, in other regions, such as East Asia and the USA, the combination of cloud and aerosol changes is occurring in a way that leads to an increase in both SSR and diffuse radiation.

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Conflicts of Interest: The authors declare no conflict of interest.

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