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Short communication

The controversial early brightening in the first half of 20th century: A contribution from pyrheliometer measurements in Madrid (Spain)

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ABSTRACT

A long-term decrease in downward surface solar radiation from the 1950s to the 1980s ("global dimming") followed by a multi-decadal increase up to the present ("brightening") has been detected in many regions worldwide. In addition, some researchers have suggested the existence of an "early brightening" period in the first half of the 20th century. However, this latter phenomenon is an open issue due to the opposite results found in literature and the scarcity of solar radiation data during this period. This paper contributes to this relevant discussion analyzing, for the first time in Southern Europe, the atmospheric column transparency derived from pyrheliometer measurements in Madrid (Spain) for the period 1911–1928. This time series is one of the three longest datasets during the first quarter of the 20th century in Europe. The results showed the great effects of the Katmai eruption (June 1912, Alaska) on transparency values during 1912–1913 with maximum relative anomalies around 8%. Outside the period affected by this volcano, the atmospheric transparency exhibited a stable behavior with a slight negative trend without any statistical significance on an annual and seasonal basis. Overall, there is no evidence of a possible early brightening period in direct solar radiation in Madrid. This phenomenon is currently an open issue and further research is needed using the few sites with available experimental records during the first half of the 20th century.

1. Introduction

Incoming solar radiation is the main factor controlling the energy budget of the earth–atmosphere system (e.g. Stephens et al., 2012; Wild et al., 2013). Hence, studies about long-term records of solar radiation are required for several topics such as climate models, agriculture, water resources and solar energy applications.

Numerous papers have reported a widespread decrease in surface solar radiation from the 1950s to the 1980s, a phenomenon called global dimming (e.g. Stanhill and Cohen, 2001 and references therein; Liepert, 2002; Ohmura, 2009). In addition, a partial recovery of surface radiation values has been detected at many sites from the middle 1980s to the present, being known as the brightening period (e.g. Hatzianastassiou et al., 2005; Wild et al., 2005; Sanchez-Lorenzo et al., 2013). Unfortunately, measurements of solar radiation for the period before the 1950s only exist for a limited number of locations (e.g. Gilgen et al., 1998; Ohmura, 2006, 2009). From these scarce datasets, some authors have suggested an "early brightening" in the first part of the 20th century (Wild, 2009). For example, Ohmura (2006, 2009) reported that global (direct + diffuse) solar radiation generally increased in Western Europe from the 1920s to the 1950s, although only five stations have records available for this period. Equally, Lachat and Wehrli (2012, 2013) analyzed pyrheliometer measurements at Davos (Switzerland) from 1909 to 2010. They identified a period of early brightening up to 1929 with a slight positive trend in the atmospheric transmission (Lachat and Wehrli, 2012), although this increase is not related to changes in aerosol transmission (Lachat and Wehrli, 2013). Stanhill and Cohen (2005, 2008) studied century-scale changes in solar forcing at the Earth's surface in the U.S. and Japan since the end of the 19th century from measurements of sunshine duration, with a significant positive linear trend from about the 1900s to the 1940s.

However, other authors found no significant increase of solar radiation in the first half of the 20th century. For instance, Hoyt (1979a) reported no significant long-term trends in atmospheric transmission between 1923 and 1957 using pyrheliometer records at four locations over the world. Roosen and Angione (1984) showed that the intensity of the direct solar beam was especially steady from the mid-1930s to the late-1940s at Mount Montezuma (Chile) and Table Mountain (California). In a more recent study, Ohvril et al. (2009) analyzed multi-decadal variations in atmospheric column transparency based on measurements of direct solar radiation at several locations in the North and East of Europe for the period 1906–2007. These authors

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suggested that global dimming began as early as 1945, but without any significant variation in the atmospheric transparency between 1910s and 1940s. Finally, Sanchez-Lorenzo and Wild (2012) reconstructed all-sky global radiation from 1885 to 2010 in Switzerland using a homogenous dataset of sunshine duration series. They found no evidence of a possible early brightening from the late 19th century to the 1930s, although a brief and strong increase was observed in the 1940s in line with other areas of Western Europe (Sanchez-Lorenzo et al., 2008).

Therefore, due to the limited number of sites with records extending back into the first half of the 20th century, the existence of an "early brightening" period is an open issue. In this framework, the present paper contributes to this relevant discussion analyzing, for the first time, the evolution of the atmospheric column transparency derived from pyrheliometer measurements of broadband direct irradiance in Madrid (Spain) for the period 1911–1928.

2. Site, instrument and data

The Astronomical Observatory of Madrid (AOM) was founded in 1785. However, the ongoing systematic astronomical observations did not begin until the second half of the nineteenth century due to social and political instabilities in the country. In 1876, AOM staff began the solar observing program carried out during those early years drawing and counting sunspots for the computation of the Sunspot Number as occurred in many other observatories around the world (Vaquero, 2007). This solar program was expanded to other types of observations such as solar protuberances, solar flocculi, and pyrheliometer measurements.

Pyrheliometer measurements began in 1903 and were abandoned in 1934. The AOM had three Ångström electrical compensation pyrheliometers made by Rosse (Uppsala) with reference numbers 25, 136 and 782. The observations started with instrument number 25, which was replaced by instrument number 136 in September 1910. Instrument number 136 was used until February 1929 when it was replaced due to failure by instrument number 25. Instrument number 782 was used only for observation campaigns outside Madrid, particularly in summer months. Thus, AOM staff made pyrheliometer observations from the Observatory building, placed in the center of Madrid in the South part of the Retiro Park, in clear sky conditions for over thirty years. The results of these observations were published in the "Anuario del Observatorio de Madrid" and the "Boletín Astronómico del Observatorio de Madrid" (López Arroyo, 2004).

In this work, we have collected all published data. However, we only use data from pyrheliometer number 136 (September 1910–February 1929), since the data collected using instrument number 25 are highly variable due to a strong dependence of the instrumental constant with temperature. To our knowledge, this series can be considered as one of the three longest continuous pyrheliometer datasets during the first quarter of the 20th century in Europe together with Davos, Switzerland (Lachat and Wehrli, 2012, 2013) and Pavlovsk, Russia (Ohvril et al., 2009) and the only one in Southern Europe.

3. Atmospheric column transparency

In this work, the atmospheric column transparency is characterized by the Atmospheric Integral Transparency Coefficient (AITC) defined as

$$\mathrm{AITC}_m = \left(\frac{I_m}{I_0}\right)^{1/m} \tag{1}$$

where I_m is the experimental broadband direct irradiance in a cloud-free solar disk at relative optical air mass m, and I_0 is the extraterrestrial broadband solar irradiance (1367 W/m^2) corrected to the actual Sun–Earth distance. This transparency parameter, also called the Bourger atmospheric transmittance coefficient, is derived from the pyrheliometric formula which is based on the Bouguer–Lambert law (e.g. Kondratyev, 1969; Kasten, 1980). AITC has been used by numerous authors to characterize the atmospheric column transparency in different locations worldwide (e.g. Russak, 1990, Abakumova et al., 1996; Alados-Arboledas et al., 1997; Ohvril et al., 1999; Olmo et al., 1999, Ohvril et al., 2009; Russak, 2009; Kannel et al., 2012).

AITC represents the atmospheric column transmission averaged over the entire solar spectrum of a direct solar beam which changes throughout the day even in the case of a stationary and azimuthally homogeneous atmosphere. Therefore, AITC depends on solar elevation causing the diurnal variation of the atmospheric (broadband) column transmission, a phenomenon known as the Forbes effect (Ohvril et al., 1999). This effect is related to the high wavelength-dependence of solar radiation in its way through the atmosphere during the day. Thus, longer wavelengths contribute proportionately more to direct irradiance as the solar elevation decreases due to the substantial attenuation of shorter wavelengths by Rayleigh scattering. Consequently, the peak contributions shift to longer wavelengths where the solar rays become more penetrating and, therefore, the broadband coefficient of transparency increases.

To remove the dependence of AITC on solar elevation caused by the Forbes effect, all their daily values were reduced from the actual optical air mass m to optical air mass $m = 2$ (solar elevation of 30°) by the expression proposed by Mürk and Ohvril (1990) and subsequently used by different authors (e.g. Alados-Arboledas et al., 1997; Ohvril et al., 1999; Olmo et al., 1999; Ohvril et al., 2009; Russak, 2009; Kannel et al., 2012):

$$\mathrm{AITC}_2 = \mathrm{AITC}_m \left(\frac{2}{m}\right)^{\frac{\log \mathrm{AITC}_m + 0.009}{\log m - 1.848}} \tag{2}$$

4. Results and discussion

Firstly, the day-to-day changes in the atmospheric column transparency over Madrid during the study period were analyzed. For this goal, the relative variation in AITC$_2$ was calculated as follows:

$$(\Delta \mathrm{AITC}_2)_i = 100 \times \frac{\left|\mathrm{AITC}_2^{i+1} - \mathrm{AITC}_2^{i}\right|}{\mathrm{AITC}_2^{i}} \tag{3}$$

where AITC_2^i and AITC_2^{i+1} are the Atmospheric Integral Transparency Coefficients for two consecutive days i and $i + 1$. The mean (median) value of ΔAITC for all cases was 3.7% (2.2%), which indicates that the atmospheric column transparency over Madrid showed on average small day-to-day changes. Nevertheless, punctual large day-to-day variations were found, reaching the 95th and 99th percentile of ΔAITC a value of 12.3% and 23.2%, respectively. These large day-to-day fluctuations could be associated with desert dust intrusions from Northern Africa and local aerosol sources like smoke plume from occasional forest fires nearby.

To minimize the effect of day-to-day turbidity fluctuations, monthly mean time-series dataset, $M(t)$, was derived from the averages of the daily AITC$_2$ data. The evolution of these monthly AITC$_2$ values for the period from January 1911 to December 1928 in Madrid is shown in Fig. 1 (top). A buildup of AITC$_2$ values during winter can be seen, while a decline is observed through summer. On average (± one standard deviation), the maximum monthly AITC$_2$ is reached in December (0.76 ± 0.05), and the minimum value in July and August (0.71 ± 0.04), while the annual mean using all the available monthly data has a value of 0.74 ± 0.04. This annual cycle is anticorrelated with cycles of integrated water vapor content and aerosol concentration which are the main factors responsible for the atmospheric transparency variation in the case of an unscreened solar disk (e.g. Hoyt, 1979b; Lachat and Wehrli, 2012, 2013). For instance, Bennouna et al. (2013) analyzed the seasonal