Sunshine duration data in San Fernando (South of Spain) during 1880s: The impact of Krakatoa volcanic eruption

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Abstract
This article presents the evolution of daily sunshine duration (SD) records at the San Fernando Observatory, a coastal place located in southern Iberian Peninsula, during the period 1881–1890. This period is of great interest because in August 1883, the Krakatoa volcano erupted injecting into the stratosphere large amount of gases and solid aerosol particles. The analysis of these daily SD records shows a considerable reduction in the maximum values of each month from the year 1883, obtaining the minimum values in 1884. In addition, the annual SD values in San Fernando fell around 400–500 hr/year during several years after the eruption. This strong reduction in SD records may be mainly associated with the scattering effects of the injected particles to the atmosphere which remains there for a long time. It must be noted that the signal of the Krakatoa eruption over the SD and, therefore, over the incoming solar radiation is extremely complicated to register due to the limited number of sites with records extending back into the 19th century worldwide. To our knowledge, the results shown in this work are the first evidence of the 1883 Krakatoa eruption effects over SD records.

KEYWORDS
Campbell–Stokes sunshine recorder, Krakatoa volcano, Iberian climate, San Fernando Observatory, sunshine duration

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Sunshine duration (SD) during a given period is defined as the sum of durations of sub-periods for which the direct solar irradiance exceeds 120 W/m² (WMO, 2003). Long and homogeneous series of SD climatological records are scarce, since meteorologists focus more on the records of other variables such as temperature and rainfall. However, the San Fernando Observatory (a coastal place located in southern Iberian Peninsula, 36°27′42″N 6°12′20″W) was a pioneer on the subject and provides one of the oldest SD records in Europe and the oldest one in the Iberia Peninsula (Wheeler, 1992a,b, 1993, 1995). The southern Iberian Peninsula is a region very sunny, with an average annual total sunlight of around 3,011 hr for the period 1933–1995 (Wheeler, 2001). Some average annual can reach values higher than 3,400 hr (Wheeler, 2001). The high frequency of cloud-free conditions was the reason why this region was chosen in the eighteenth century to install Spain’s principal astronomical observatory and naval academy (Wheeler, 1992a). Meteorological studies began around 1800. The annual sunshine regime presents its minimum in winter (527 hr) and its maximum in summer (1,028 hr). The climate of this region belongs to the Csa type (temperate with dry or hot summer) according to Köppen Climate Classification. At this observatory, SD began to be measured on 23 February 1881, until today. The instrument used was a Campbell–Stokes sunshine recorder. This instrument was designed in 1853 by Campbell (1857) and improved to the current version in 1880 by Stokes (1880). More information about the principal stages in the development of the Campbell–Stokes recorder from its initial design to the improvements is described by Sanchez-Lorenzo et al. (2013). Therefore, the Campbell–Stokes sunshine recorder of the San Fernando Observatory was one of the first instruments that began to be used regularly, in dates very close to its invention and development. However, throughout this period, there is a time, between 1900 and 1932, in which the values are unrealistic, since the annual values of sunshine fell from approximately 2,800 to 1,500 hr. The reason for this fall and subsequent recovery is unknown because the Observatory accounts do not provide information about it. Wheeler (2001) suggests that this fall in sunshine values may be due to an obstruction of the observation site due to the growth of nearby vegetation and that in 1933, this obstruction was eliminated or the instrument was relocated.

In this article, we have focused on daily SD records of the San Fernando Observatory during the period 1881–1890. This work is the first in which daily SD data for this period are used, since Wheeler (2001) used monthly data. The main interest of studying this period is due to the fact that in 1883, there was the eruption of Krakatoa volcano in the Netherlands East Indies (Indonesia). In May 1883, this volcanic island erupted, but it was in late August 1883 when a massive explosive eruption occurred, probably the loudest explosion of historic times (Robock, 2000). The eruption of this volcano had worldwide impacts, since a large amount of fine dust and aerosols were thrown into the atmosphere between 40 and 70 km circling the Earth. According to Dörries (2003), months after the eruption, spectacular sunsets were observed across the planet.

It is well-known that SD records can be useful to detect a decrease in the solar radiation at surface due to the increase of the atmospheric aerosols, particularly after powerful volcanic eruptions (Sanchez-Romero et al., 2014). Thus, significant solar radiation anomalies at surface from SD records have been detected after large eruptions in the 20th century such as Santa Maria (1902), Katmai/Novarupta (1912), El Chincón (1982) and Pinatubo (1991) (e.g. Stanhill and Cohen, 2005; Sanchez-Lorenzo et al., 2007; Sanchez-Lorenzo and Wild, 2012; Magee et al., 2014; Antón et al., 2017). However, the signal of Krakatoa eruption on SD records is not found in the literature, being the present article the first evidence of the effects of this eruption over SD records. To our knowledge, only a strong decrease of pyrheliometric data during the period 1884–1886 in Montpelier (France) was reported by Kimball (1924). In this framework, the present study shows the signal of the 1883 Krakatoa volcano eruption on daily SD data measured in San Fernando during the period 1881–1890. It is therefore expected that this article will contribute to the understanding of the effects of this large explosive eruption on the surface solar radiation.

In the following sections, more details about observations and procedures used to digitize the SD records of the San Fernando Observatory are described, and the resulting dataset is presented and briefly analysed during the period 1881–1890.

2 | DATA PRODUCTION METHODS

As already mentioned, SD data were obtained from measurements made with Campbell–Stokes sunshine recorder by the staff of the San Fernando Observatory. Figure 1 shows the Campbell–Stokes installed on the south terrace of the main building of the San Fernando Observatory. The instrument consists of a solid glass sphere that concentrates the sun’s rays on a point of a calibrated paper band, burning it. The paper bands have the convenient division of hours drawn. On these bands, the glass sphere produces a small image of the sun that burns the paper while the sky is clear and there are not barriers that prevented the arrival of solar radiation to the instrument. As the sun blazes across the sky, a burned path is created on paper. The intensity and the position of the burn indicate the strength and the time of the sunshine. When the height of the sun is very low, the impression produced on the paper is inappreciable; but from the moment that, with good atmospheric conditions, said height reaches 4’, a sensible impression is produced on the paper (San Fernando
The Campbell–Stokes sunshine recorder does not need to be adjusted or oriented in the different seasons of the year; it is only adjusted, with respect to latitude, when it is installed. More details about this type of instrument are given by Campbell (1857) and Stokes (1880).

The SD data were recorded in the ‘Anales del Instituto y Observatorio de Marina de San Fernando’ (Annals of San Fernando Marine Institute and Observatory), in the ‘meteorological observations’ section of these yearbooks (San Fernando Observatory, 1882, 1883, 1884, 1885, 1886, 1887, 1888, 1889, 1890, 1891). An example of the cover of the Annals is shown in Figure 2. From these documents, which have been consulted at the historical library and archive of the San Fernando Observatory, daily SD data presented in this study were obtained. Records are distributed in annual tables, such as displayed in Figure 3, in which SD daily values

**FIGURE 1** The Campbell–Stokes sunshine recorder installed on the San Fernando Observatory. It is the original position of the instrument.

**FIGURE 2** Cover of the Annals of San Fernando Marine Institute and Observatory, specifically the meteorological observations section.
were recorded. Once the documentary sources were located, they were photographed in situ with the aim of having the possibility to re-verify the data when the documents were not available. The method for compiling this dataset was transcription from archival sources. Digitization was performed by key input, since the use of optical character recognition programmes often leads to errors (Brönnimann et al., 2006; Tan and Burton, 2014). Basic quality control procedures have been implemented in the analysis. The data repeated on two consecutive days were revised, and it was checked that the values were included between zero hours and the possible maximum sunshine for that day.

### 3 | DATASET LOCATION AND FORMAT

The recovered daily SD records of the San Fernando Observatory during the period 1881–1890 are freely available at the World Data Center PANGAEA at https://doi.org/10.5880/2015.PANGAEA.112235.
The database presented includes 3,599 records and a full metadata in the file header. The metadata includes the name of the authors, keywords, location of the observatory, period of the database and the description of the parameters. The parameters are observation time, formatted as YYYY-MM-DD, and SD. SD unit is hours in decimals with one decimal point accuracy. Each parameter is represented in a column, and each record is presented in a separate row.

4 | DATASET USE AND REUSE

Figure 4 shows the temporal evolution of the daily SD values recorded in the San Fernando observatory during the period 1881–1890. There is a clear annual cycle, obtaining maximum values in summer and minimum values in winter, due to astronomical factors. When the variability from year to year is analysed, a significant drop in SD values from 1884 is observed. This decrease in values coincides with the 1883 eruption of the Krakatoa volcano, which, as already mentioned, took place at the end of August 1883. This behaviour is also observed when analysing the annual values of SD records shown in Table 1. Annual values fall from 3,018 hr (1883) to 2,517 hr (1884), and these low values are maintained throughout the decade. This fall of SD records in 1884 is also observed in Figure 5, which shows the maximum monthly SD values for each year of the study period. This figure also shows that the difference between the years is mainly due to the values for the months between April and September, when the SD values are expected to be higher because of the daylight duration is longer during this time of the year. During the other months, there is no clear pattern of decrease in SD values.

Therefore, there was a clear reduction of SD records in San Fernando after the 1883 Krakatoa volcanic eruption, mainly due to the larger scattering of the shortwave solar radiation associated with sulphate aerosol particles (direct effect). Another radiative effect related to these particles is the increasing of the amount of cloud cover (indirect effect).
Both effects likely caused a significant decrease in incoming solar radiation, leading to the cooling at the surface up to 3 years after the eruption (Robock and Mao, 1995). Brunet et al. (2007) observed a significant decrease in temperature in Spain during the period 1882–1892, mainly associated with a decrease in maximum temperature values.

Our SD dataset is compared with climatological data in order to guarantee its validity and quality. Figure 6 shows the evolution of the recovered monthly SD data for the period 1891–1990 together with monthly climatological SD data (mean, minimum and maximum) for the period 1933–1995 and published by Wheeler (2001). The monthly data for the period 1891–1932 are digitized; however, they are not publicly available due to quality issues. It is observed that the monthly SD values from our database are within the maximum (red line) and minimum (blue line) climatological values provided by Wheeler (2001). Additionally, it must be noted that the monthly SD data during the 2 years after the Krakatoa eruption (1884 and 1885) are notably lower than climatological mean values (black line) due to the influence of this eruption as previously was mentioned. Therefore, the SD database used in this study can be considered valid.

The dataset has been presented in this study in order to facilitate a variety of studies relevant to climate research. The recovered SD records at San Fernando from 1881 to 1890 have a great interest for the geoscientific community mainly because these data confirm the marked impact of the Krakatoa eruption on solar radiation reaching at the Earth’s surface in a region very far from the volcano. To our knowledge, our work is the first evidence of the signal of Krakatoa eruption on SD records. In addition, it is well-known that SD records are an excellent proxy measure allowing long-term reconstructions of the surface solar radiation (e.g. Wild, 2009). Hence, the SD data at San Fernando can be used to estimate the solar radiation at this location for a period (the last quarter of the 19th century) with scarce information about the levels of solar radiation reaching at the earth’s surface. For instance, Antón et al. (2017) reconstructed daily solar radiation values from SD records at Madrid from 1887 to 1950. Therefore, the daily SD records shown in our study can help to a better understanding of the solar radiation variability in the Iberian Peninsula for the last part of the 19th century.

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CONFLICT OF INTERESTS
The authors declare that they have no conflicts of interest.

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