LONG-TERM IN GLOBAL SOLAR RADIATION AT THE IZAÑA ATMOSPHERIC OBSERVATORY FROM 1933-2013

R.D García[1,2], E. Cuevas[1], O.E. García[1], V.E Cachorro[2], P. Pallé[3], J.J. Bustos[1], P.M. Romero-Campos[1] and A.M. de Frutos[2]

([1]) Izaña Atmospheric Research Center, Meteorological State Agency of Spain, AEMET, Spain (rgarciac@aemet.es)

([2]) Atmospheric Optics Group, University of Valladolid (GOA-UVA)

([3]) Instituto de Astrofísica de Canarias (IAC), Santa Cruz de Tenerife, Spain

GLOBAL ATMOSPHERE WATCH

Solar radiation controls the energy radiative balance in the Earth and, thus, our weather and climate. For this reason, its study has been one of the main objectives of the research community during the last decades. Recently, the focus is on evaluating the long-term trends of solar radiation reaching the Earth's surface as well as on identifying the variability driven by the climate change. Observational evidences of changes on global solar radiation (GSR) trends have already been reported at a global scale. In this context, the goal of this work is to perform a reconstruction of the GSR time series between 1933 and 2013 at the subtropical high-mountain Izaña Atmospheric Observatory (IZA) located in Tenerife (28.3°N, 16.5°W, 2373 m a.s.l., Spain). For this purpose, we combine GSR estimates from sunshine duration (SD) data using the Ångström–Prescott method over the 1933/1991 period, and GSR observations directly performed by different pyranometers between 1992 and 2013. These results have been recently published (García et al., 2014).

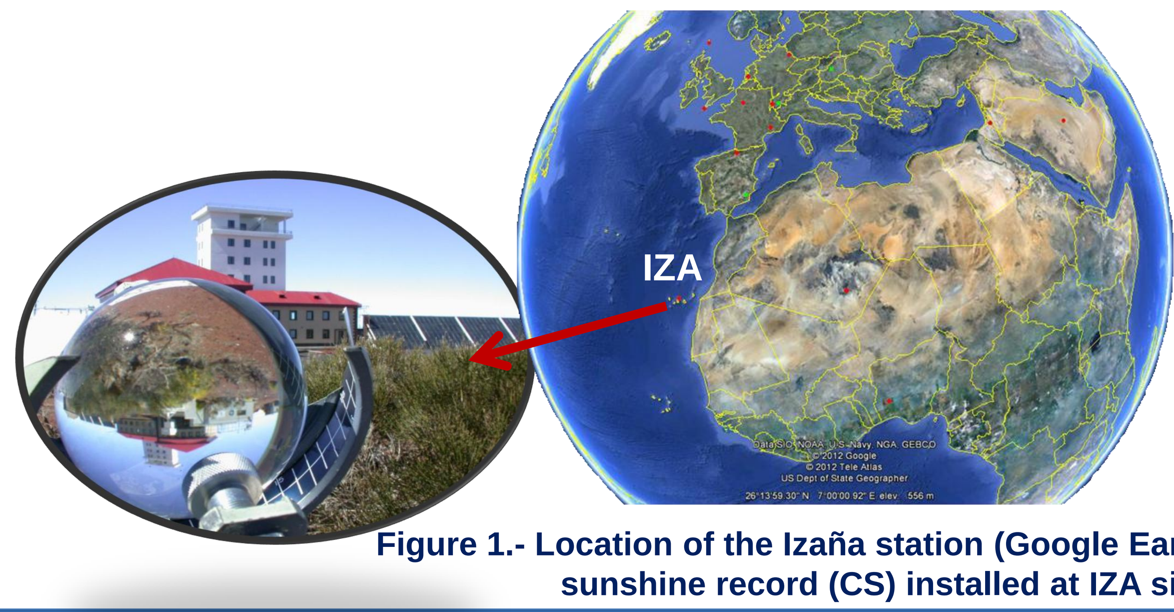

Figure 1.- Location of the Izaña station (Google Earth). Campbell-Stokes sunshine record (CS) installed at IZA since 1933.

ESTIMATION OF GSR FROM SUNSHINE DURATION

At IZA, the SD observations started in 1933 with a Campbell-Stokes sunshine record (CS)(see Figure 1) through 2000. Several types of regression models have been proposed for estimating GSR on a horizontal surface at the Earth's surface from SD records. One of the most extended and used approaches was developed by Ångström (Angstrom, 1924,1956) and later modified by Prescott and Rietveld (Prescott,1940). This model allows the GSR from SD to be determined by using the following equation:

$$\frac{H}{H_o} = a\frac{n}{N_d} + b \quad (1)$$

where H_o is the extraterrestrial solar radiation on a horizontal surface ($MJm^{-2}day^{-1}$), n and N_d are the number of hours measured by the SD recorder and the maximum daily SD, respectively, and a and b are empirically determined regression constants (see Table 1).

The SD records, and thus the fraction of clear sky (FCS), defined here by Eq. (2), depend on solar direct irradiance, cloud cover, water atmospheric column and atmospheric aerosols (mainly mineral dust particles at IZA).

$$FCS = \frac{n}{N_d} * 100 \quad (2)$$

They also depend, in a lesser extent, on meteorological variables as temperature and humidity, although this dependence is very minor and purely instrumental. All of these factors account for the stratification found for FCS in Figure 2a, where five regions (in intervals of 20 %) can clearly be distinguished, with a very low overlapping among them. Similar stratification is observed in the measured GSR time series (Fig. 2b). Therefore, the subsequent estimation of GSR from SD records will be performed considering the dependence on FCS.

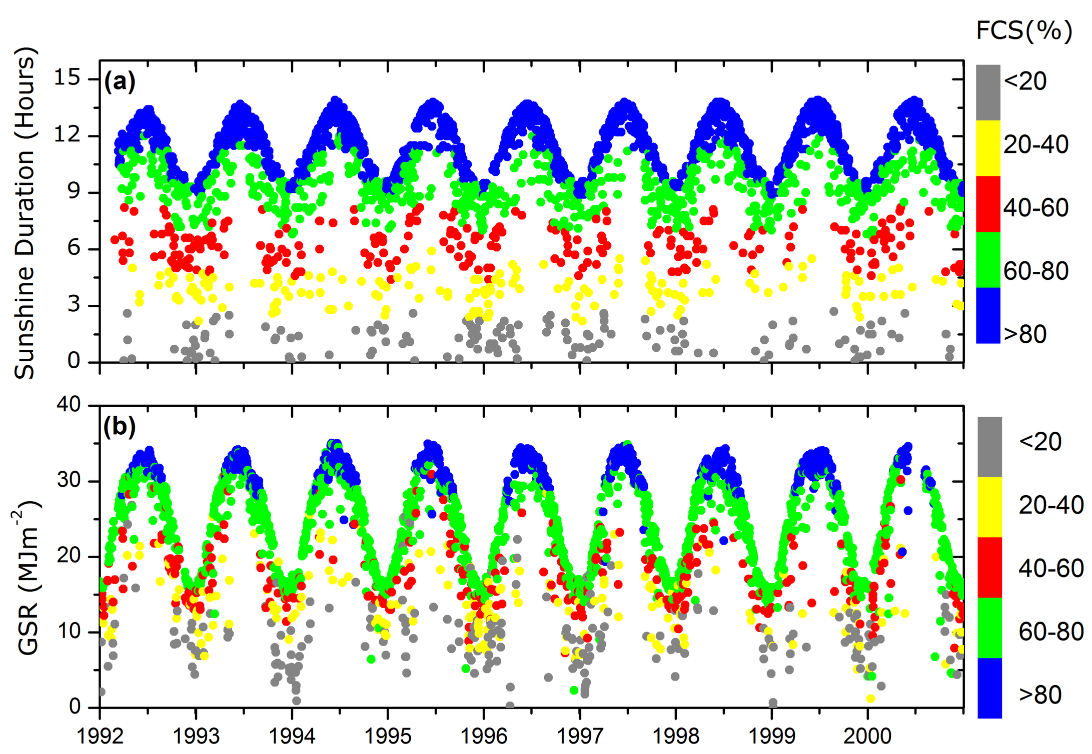

Figure 2.- Time series of (a) the sunshine duration (hours) (b) GSR from 1992 to 2000 at IZA. The color scale indicates the FCS values (%)

VALIDATIONS GSR ESTIMATIONS

We have split the SD series (1992-2000) in two periods:

1) **1992-1996: "calculation period", calculating the Ångström-Prescott's coefficients (Eq. 1; Table 1)**
2) **1997-1999: "testing period" (Fig. 3)**

The comparison shows a good agreement (see Table 1 and Figure 3), obtaining a correlation coefficient and a RMSE of 0.96 and 2.16 MJm^{-2} (9.2%), respectively.

FCS(%)	a ±SEM	b ±SEM	% days	RMSE (MJm^{-2})	R
≤20	0.503±0.155	0.342±0.015	9	4.19(12.1%)	0.51
20-40	0.458±0.178	0.362±0.062	6	3.33(4.9%)	0.69
40-60	0.476±0.103	0.358±0.058	9	2.54(3.6%)	0.83
60-80	0.369±0.045	0.434±0.037	23	1.81(4.2%)	0.92
≥80	0.433±0.039	0.386±0.037	53	1.65(4.5%)	0.96
Total	-	-	-	*2.16(9.2%)*	*0.96*

"Caculation Period" ***"Testing Period"***

Table 1.- Coefficients a and b between 1992 and 1996 as a function of the FCS. SEM is the standard error of the mean. The root mean square error (RMSE) and the correlation coefficients (R).

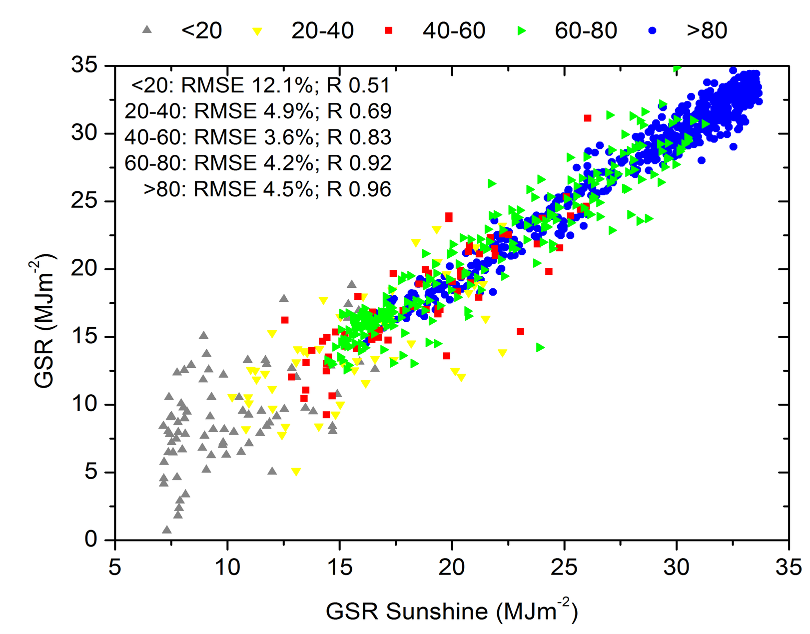

Figure 3.- Scatterplot of the GSR observations versus GSR estimations from SD. Between 1997 and 1999. The root mean square error (RMSE) and the correlation coefficients (R) are shown in the legend. The color indicates the FCS values (%).

1933-2013 TIME SERIES OF ESTIMATED GSR

The GSR time series between 1933 and 2013 has been successfully reconstructed combining:

1) **GSR estimations from SD measurements (1933-1991)**
2) **GSR observations performed by different pyranometers at IZA between 1992 and 2013.**

The reconstructed IZA GSR time series between 1933 and 2013 confirms change points and periods of increases/decreases of solar radiation at Earth's surface observed at a global scale, such as the *early brightening*, *dimming* and *brightening* (see Figure 4):

- **Yellow Zone: *EARLY BRIGTHENING* From the 1950s to the early 1960s**
- **Cyan Zone: *DIMMING* From the 1960s to the ending of the 1990s a gradual decrease of GSR is observed**
- **Orange Zone: *BRIGTHENING* From the ending of the 1990s onwards.**

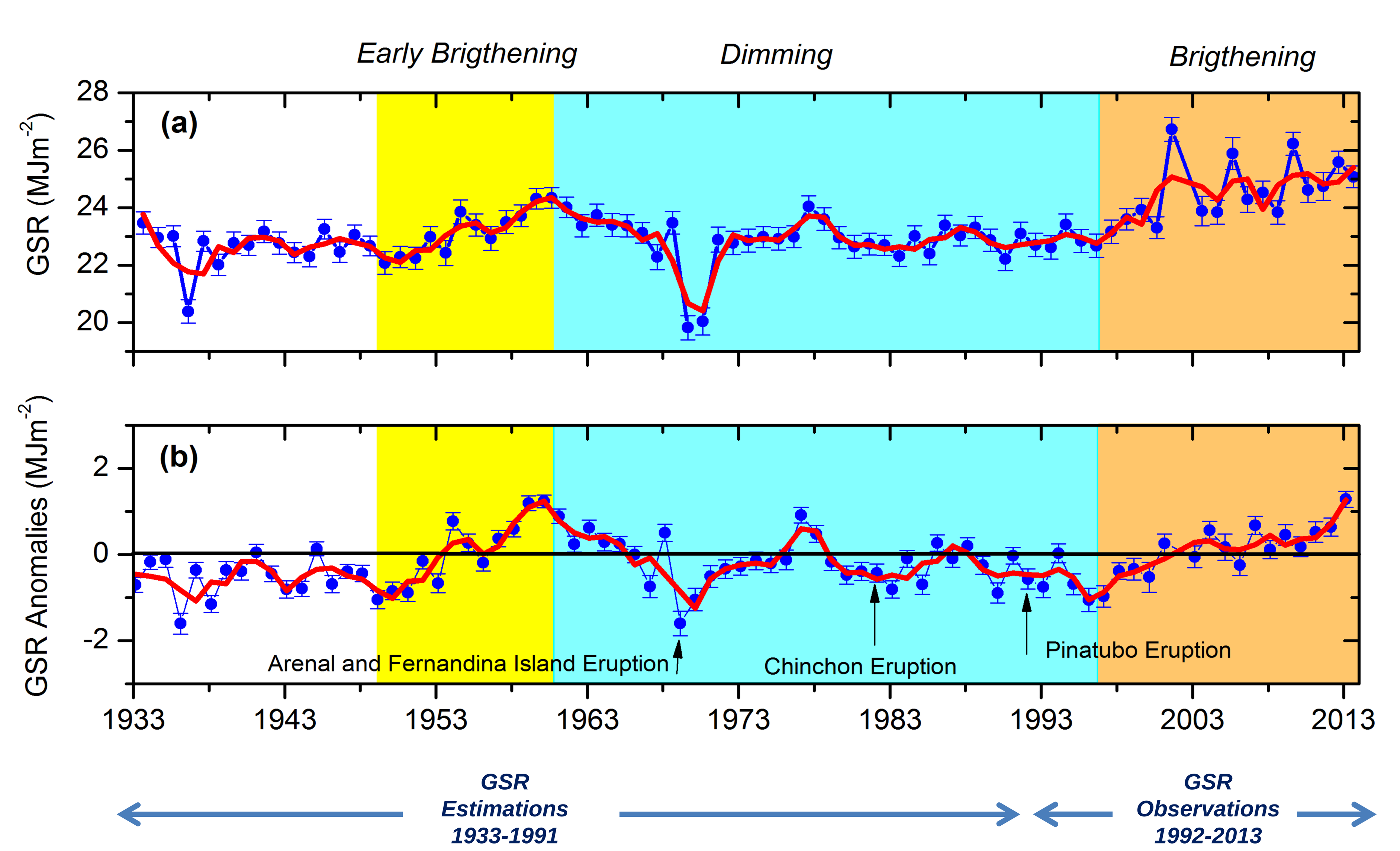

Figure 4.- Time series of the annual means of the (a) GSR and (b) GSR anomalies from 1933 to 2013 at IZA. The error bars indicate ±1 SEM (standard error of the mean) The arrows indicate the eruptions of Arenal and Fernandina (1968), Chinchón (1982) and Pinatubo (1991). Five-yr moving average is shown in red. (Time series has been deseasonalised by subtracting the averaged GSR annual cycle, obtaining the annual mean anomalies time series).

CONCLUSIONS

The results show that using the Ångström-Prescott 's method can be reconstructed with a notable accuracy time series of GSR from measurements SD at IZA. We obtain an overall root mean square error (RMSE) of 2.16 MJm^{-2} (9.2%), and an agreement between the variances of SDR estimations and SDR measurements within 92% (correlation coefficient of 0.96).

The resulting annual time series GSR confirms a period of early brightening from the 1950s to the early 1960s, a period of dimming from the 1960s to the ending of the 1990s followed by a period of brightening in the most recent decades. However, we observe a delay of between 5 and 10 years for the transition *from early brightening, dimming* and *brigthening*. All of these findings indicate the consistency of the IZA GSR time series presented in this work, which may be a reference for solar radiation studies in the Subtropical North Atlantic Region. These results are comparable with those of other studies carried out in other regions.

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