*AMTD-2014-93*

*Interactive comment on "Re-construction of global solar radiation time series from 1933 to 2013 at the Izaña Atmospheric Observatory" by R. D. García et al.*

*Referee #1:*

**The paper is acceptable for publication. In this paper "Re-construction of global solar radiation time series from 1933 to 2013 at the IZO" the global solar radiation has been re-constructed combining Global solar radiation estimates from sunshine duration measurements using the Ångström-Prescott method. The resulting annual time series confirms an early brightening period (30-50), a period of dimming (1950-90), followed by a period of brightening in the most recent decades. The present manuscript contains useful results, which are of great concern in the scientific community. The presentation is well structured and clear, all in all, this is an excellent paper and I recommend publication. But, in my opinion the "estimation of global SDR from SD" section 4, must be revised.**

**Authors**: We appreciate the positive and constructive comments of the Referee, and in the following we discuss and respond to his/her specific and minor comments.

***Specific comments:***

1. **In the paper the term Shortwave Downward Radiation SDR added the two components of solar radiation come to the Earth surface. One component comes directly from the Sun (direct solar radiation) and the other the diffuse solar radiation. Global solar radiation consists of direct and diffuse solar radiation. I prefer the term global solar radiation.**

   **Authors R1**:

   Following the referee's recommendation, the term "shortwave downward radiation (SDR)" will be changed by "*global solar radiation (GSR)*" in the final manuscript.

2. **In Angström-Prescott formulation H/Ho = a + b (n/N). Where H and Ho are, respectively the global solar radiation (MJm$^{-2}$day$^{-1}$) and the extraterrestrial solar radiation (Angot's value); n and N are, respectively, actual sunshine hours and maximum possible sunshine hours; and a and b are regression constants determined empirically. The sky is overcast when the ratio n/N is zero, so (a x Ho) represents the diffuse radiance, and therefore "a" may be considered as the fraction of the extraterrestrial solar radiation received during that day; whilst the term (b x Ho x(n/N)] is a measure of the direct radiance. The**

**angstrom –Prescott formula use bright sunshine duration data, this are readily available in many parts of the world (measured mainly by simple Campbell-Stokes sunshine recorders). The CS and CSD instrument produces similar sunshine duration data, however the electronic sensor tends to show more "sunshine hours n" than the Campbell-Stokes. The difference may amount higher, especially on days with maximum global solar radiation. The CSD sensor reacts quickly to radiation, especially for the first hour after sunrise and before sunset. Differences in sunshine duration depend on the nature and thick of clouds. The threshold sensitivity of the Campbell-Stokes recorder of 120 W/m$^2$ which results in underestimates of n (sunshine hours), in the recorders based on photoelectric measuring techniques the threshold value of 120 W/m$^2$ is implemented artificially to meet a WMO convection. In my opinion, for the Angstrom-Prescott formulation the Campbell Stokes sunshine recorder remains the best instrument for measurements.**

__Authors R2__: Thank you very much for your detailed comment. It will be included in section 2.3 of the final manuscript as follows:

"…The CS presents several disadvantages against CSD record, being the most important ones: (1) the instrument must be operated manually and a new card strip mounted every morning before sunrise, (2) *the card strip reacts more slower than the electronic CSD sensor to solar irradiance variations (especially at sunrise and sunset) as well as responds in a different manner whether the ambient air is humid or dry* (3) the burning of band are not well defined at sunrise and sunset, (4) different operators reading the same cards may get very different totals…*."*

*"…*Furthermore, the CS design by using a glass sphere that concentrates radiances coming from the whole sky on the card (not only the direct solar irradiance) may cause differences between CS and direct SDR simulations. *These differences may amount higher, especially on days with maximum GSR values, and depend on the nature and cloud thickness."*

3. **As I see it the variations of solar constant (and extraterrestrial solar radiation) are not adequate for explaining, in the last 10000 years, abrupt climate shifts. But it only should be applied to short periods the transitions of solar irradiance can be considered. The solar constant, Isc = 1367 W/m$^2$, recommended by the World Radiometric Center (WRC), is the generally accepted one for estimating solar radiation and evaluating empirical, the solar constant, but is variable . The intensity of the Sun varies along with the 11-year sunspot cycle; when sunspots are numerous the solar constant is high (about 1367 W/m2); when sunspots are scarce the value is low (about 1365 W/m2). The solar constant can fluctuate by 0.2% to 0.6% over 100 years. The solar radiation at the entrance into the Earth atmosphere is known as extraterrestrial radiation. The intensity of extraterrestrial solar radiation is variables because of the change in distance between the Earth and Sun and because of the Sun activity.**

**<u>Authors R3</u>**: Following the referee's recommendation, we have estimated the global solar radiation from sunshine duration considering the temporal variability of the solar constant. Particularly, we have used the monthly average solar constant in the study period (1933-2013). The results are very similar to those obtained with a constant value for Isc of 1367 $W/m^2$ (see Figure 1), with a mean difference and standard deviation of 0.03 and 0.01 $MJm^{-2}$, respectively.

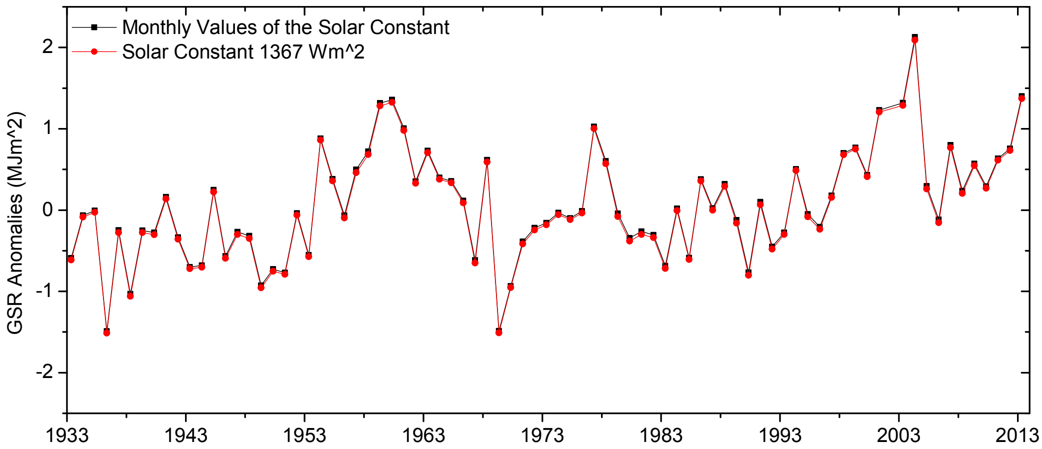


Figure 1. Time series of the annual means of the global SR anomalies ($MJm^{-2}$). The black dots represent the global SD obtained considering the monthly values of the solar constant and the red dots represent the global SD obtained considering a constant value of the solar constant, 1367 $Wm^{-2}$.

The temporal variability of the solar constant will be considered in the estimation of the global solar radiation from sunshine duration observations (section 4) and included in the final manuscript as follows:

"... The value of $H_o$ is calculated as:

$$H_o = \frac{24}{\pi} I_{sc} E_o [\omega_s (\sin\delta \sin\emptyset) + (\cos\delta \cos\emptyset \sin\omega_s] \qquad (4)$$

*where* $I_{sc}$ *is solar constant,* $E_o$ is the eccentricity correction factor of the Earth's orbit (Eq. 5) and $\omega_s$ is sunshine hour angle *(Spencer, 1971). Note that we have used the monthly values of the solar constant instead of a constant value to account for the 11-year sunspot cycles during the study period..."*

***<u>Minor comments</u>:***

**<u>p.364</u> reference Prescott and Rietveld . Is better only Prescott 1940. The first author who employed a linear relationship between global radiation and sunshine duration was**

**Angström (1924): H/Hc = k + (1- k) (n/N) where H: amount of global radiation; Hc: global radiation under a real atmosphere in completely clear days; k: empirical constant, determined by Angström as k= 0.25 from Stockholm data; n: number of hours measured by a sunshine recorder; and N: maximum possible number of hours of sunshine. The modified version of the Angstrom's correlation has been the most convenient and widely used correlation for estimating the global radiation (Prescott, 1940): H/H0 = a + b (n/N) where H0: extraterrestrial solar radiation on a horizontal surface ($MJm^{-2}day^{-1}$), and a and b: empirically determined regression constants.**

__Authors R1__: Following the referee's recommendation, we will only use the reference of Prescott (1940) in this section of the final manuscript.

__**p. 381**__ **is 0.00148? Declin. = (180/3.1415926) (0.006918 - 0.399912 cosR + 0.070257 sinR - 0.006758 cos2R + 0.000907 sin2R - 0.002697 cos3R + 0.00148 sin3R). The solar declination in degrees can be computed from the Spencer formula (Spencer, 1971): where the day angle R (radians) is given by R = 6.283185 (nday-1)/365 where nday is the number of the Julian day of the year, starting from the first of January. I prefer, for the eccentricity correction factor, the expression (Spencer, 1971) E0= 1.00011 + 00034221 cos R + 0.00128 sin R + 0.000719 cos 2R + 0.000077 sin R In your manuscript: How does one calculate the maximum daily sunshine hours on a horizontal surface at a given location?**

__Authors R2__:

1) In the equation (5) the value "0.000148" was a typographical error and it will be conveniently corrected in the final manuscript.

2) The equation (4) will be corrected in the GSR estimations and in the final manuscript following the referee's recommendation as follows:

$E_o$ = 1.00011 + 00034221 cos R + 0.00128 sin R + 0.000719 cos 2R + 0.000077 sin R

3) Regarding the maximum daily sunshine hours on a horizontal surface, they have been calculated with the following expression:

$$N_d = \frac{2}{15}\, cos^{-1}(-\tan \emptyset\; tang\ \delta)$$

where $\emptyset$ is the geographic latitude and $\delta$ is solar declination. This expression will be included as equation 3 in section 4 of the final manuscript.