amt-2016-293

Interative comment on "Compatibility of different measurement techniques. Long-term global solar radiation observations at Izaña Observatory" by R. D. García et al.

Anonymous Referee #3:

The manuscript describes the calibration and validation of different instrument types to determine solar irradiance and daily total solar radiation energy. Several of these instruments were used at Izaña Observatory, when pyranometers were not yet available, and the aim of the study was to first derive their uncertainties and second to calculate the solar radiation time-series over the period 1977 to the present. While the sunshine duration instruments can only be used to derive daily totals of solar shortwave radiation, the bimetallic pyranometers provide solar irradiance levels and by numerical integration can calculate the daily totals. The final product is a time-series of daily total solar radiation energy levels for the period 1977 to the present, consisting of bimetallic pyranometers for the first part of the period and different Kipp & Zonen pyranometers for the second part.

Even though the study has been performed with care, I think the study needs to be revised and some concerns addressed before it can be published. My main concerns are listed below:

***Authors*: We appreciate the positive and constructive comments of the Referee. Below we discuss and respond to his/her general and specific comments.**

1. **The results are interesting and produce useful information with regard to the uncertainties one can expect with historical instruments when deriving daily total solar irradiation. However as pointed out by the authors themselves, such studies have been performed previously (see reference list, and especially Coulson, 1975, Garcia et al., 2014c, McArthur, 2005, Garg and Garg, 1993), so that this manuscript essentially confirms the results from these studies (see page 11, line 32) but does not add anything really novel. The authors should stress how their results differ from these previous studies.**

   ***Authors*: This work presents two fundamental novelties respect to previous studies (i.e. Coulson, 1975; García et al., 2014c; McArthur, 2005; Garg and Garg, 1993):**

   1. ***It has been possible to assess and verify the results obtained with different instrumentation by the authors mentioned above in a testbed station (Izaña station) by performing simultaneous measurements under the same environmental conditions. Moreover, our study is based on measurement comparison of an annual cycle using classical and modern radiation and sunshine duration instruments.***
   2. ***An important characteristic of the Izaña station is the wide range of variability found in some key atmospheric parameters and meteorological variables***

throughout the year, i.e., aerosol optical depth, from Rayleigh conditions (< 0.02) to dusty conditions (>0.5), Ångström exponent from >1 to ~0, relative humidity from <5% to 100%, etc… Furthermore, as a subtropical region site the sun reaches very low SZA (5-6°) and provides very high radiation dosis.

3. ***The methodology and the results obtained in this work might be applicable to any other station.***

The authors have added this information in the section: Summary and Conclusions of the final manuscript as follows:

"Assuming GSR_H from BSRN as reference, the measured or estimated GSR_H values show median biases of 2% and 1% for PYR GSR_H and MFRSR, respectively, and of 5% and 2% for CS GSR_H and CSD GSR_H, respectively. These results, as expected, show that the instruments that measure directly GSR_H, such as the PYR and MFRSR, present lower MB and lower scatter than the ones that estimate the GSR_H, such as the CS and CSD recorders. Moreover, median bias values for each instrument are within their corresponding uncertainty, agreeing with results obtained by other authors (Coulson, 1975; García et al., 2014c; McArthur, 2005). The comparison of the daily GSR_H values from PYR and MFRSR showed a good agreement with GSR_H BSRN, obtaining a RMSE of 0.9 ~MJm^{-2} (3%) and ~0.5 MJm^{-2} (2%) for PYR GSR_H and MFRSR GSR_H , respectively, and ~1.7 MJm^{-2} (7%) and ~1.1 MJm^{-2} (4%) for CS GSR_H and CSD GSR_H, respectively. It is worth highlighting the fact that the biases for PYR found in this study are lower than those reported by others authors. For example, Coulson (1975); Garg and Garg (1993) obtained uncertainties between 10 and 20% reduced up to 4-5% by Esteves and de Rosa (1989) and Soulayman and Daudé (1995). These results, obtained with simultaneous observations under the same environmental conditions, provide information about expected GSR_H uncertainties from historical instruments useful for assessing long-term GSRH data series constructed from classical and modern instruments. "

2. **The second objective of the paper was to derive a time-series of solar irradiation levels from historical measurements made at Izaña Observatory. The recovered time series were derived using the bimetallic pyranometers for the period 1977 to 1991 and Kipp & Zonen pyranometers from 1991 to the present (see figure 7). However, sunshine duration meters were deployed at Izaña Observatory since 1917 (page 3, line1) and this study demonstrated that daily total irradiation levels could be derived from sunshine duration meters with comparable uncertainties to the bimetallic pyranometers as shown in Table 3. So why not extend the time-series to 1917 using these instruments?**

Authors:* *One of the main objectives of this paper was to present a GSR data time series at Izaña station only from GSR instruments. From 1917 to 1976 the GSR is obtained by estimations from sunshine duration measurements. The long term GSR data from both measurements and estimations will be the subject of a future analysis.

3. **I have issues with the derivation of the calibration factor F for the bimetallic pyranometers:**

   a) It is derived as a monthly factor using modelled solar irradiance and irradiation as reference (page 6). I do not understand why not use the pyranometer measurements

from the BSRN instrument, which are certainly much more reliable than modeling results?

***Authors**: Garcia et al. (2014c) demonstrate that LibRadtran model to be a very useful tool as a measurement quality control, obtaining that there is a good agreement between measurements and simulations with the mean bias (simulations-measurements) of -0.30 MJm^{-2} (-1.1%) and root mean square error of 0.38 MJm^{-2} (1.3%) for global solar radiation for 386 days between March 2009 and August 2012. Based on these results, we determine the coefficients F_m from the simulated measurements. On the other hand the reference to validate the method is the BSRN GSR and therefore we do not use it to calculate the coefficients F_m.*

Any way, following the referee's recommendation, we have determined the coefficients F_m from the BSRN pyranometer measurements and compared with those obtained with the LibRadtran model simulations. The results obtained are quite similar in both cases (Figure 1) with root mean square error of 0.54 MJm^{-2}(1.15%) (Figure 1b). Thus both coefficients could be used indifferently.

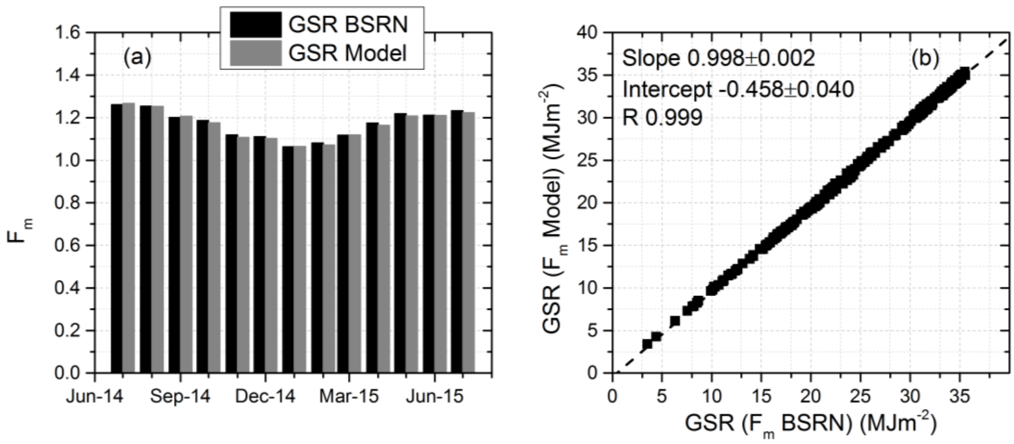

Figure 1.- (a) Annual cycle of F_m coefficients determined from the BSRN pyranometer measurements (black bars) and determined from the LibRadtran model simulations (gray bars). (b) Scatterplot of daily GSR obtained from LibRadtran model simulations versus daily GSR obtained from BSRN pyranometer measurements. The fit coefficients and Pearson correlation coefficient are shown in the legend.

b) I am missing a discussion (and figure) on the amount and source of the variability of F, as I wonder why it is not be an instrument constant instead of a monthly varying factor. I would only expect it to vary slowly in time due to instrument degradation for example.

***Authors**: Figure 1a shows a clear annual cycle of F_m, with lower values in winter and higher in summer. Therefore the use, for example, of an annual mean value of F_m to recover the pyranograph measurements would lead to an important source of error. If we calculate the F_m in the period 1977-1991 by using the model simulations with the*

adequate input variables, the obtained GSR estimations have accuracy within the instrumental error as demonstrated in Figure 1b, and thus we obtain the F_m series showed in Figure 2. In general, every year a similar behavior to that of Figure 1a is observed, but not always, in 1979-1981, 1986, 1987 F_m differs from the annual cycle showed in Figure 1a. Moreover, there is a significant difference in the values obtained before and after 1983, when an instrument change took place.

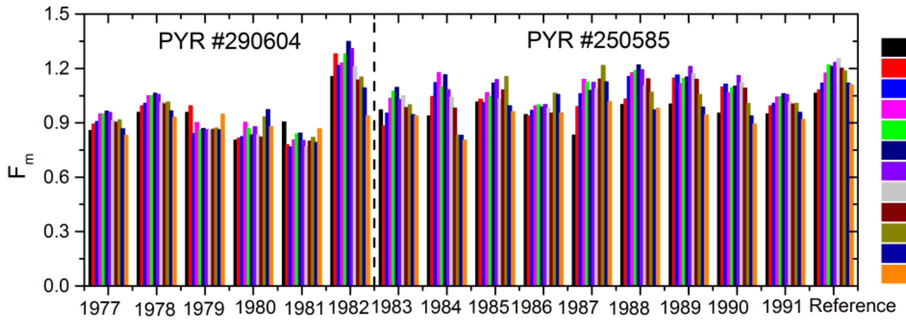

Figure 2.- Time series F_m ($MJ/m^2/cm^2$) in the period 1977-1991 and reference indicates the period 2014-2015.

Many works pointed that the main source of variability in the bimetallic pyranograph measurements is its strong temperature dependence and its degradation with time (Coulson, 1975; Garg and Garg, 1993; Esteves and de Rosa, 1989). From Figure 3 we observe there is no dependence of S, and H_{ci} on temperature (Figures 3a and 3b) for the reference period (2014-2015). However there is a clear dependence of the (H_{ci} / S) ratio with the temperature (Figure 3c) in this period, explaining the annual cycle.

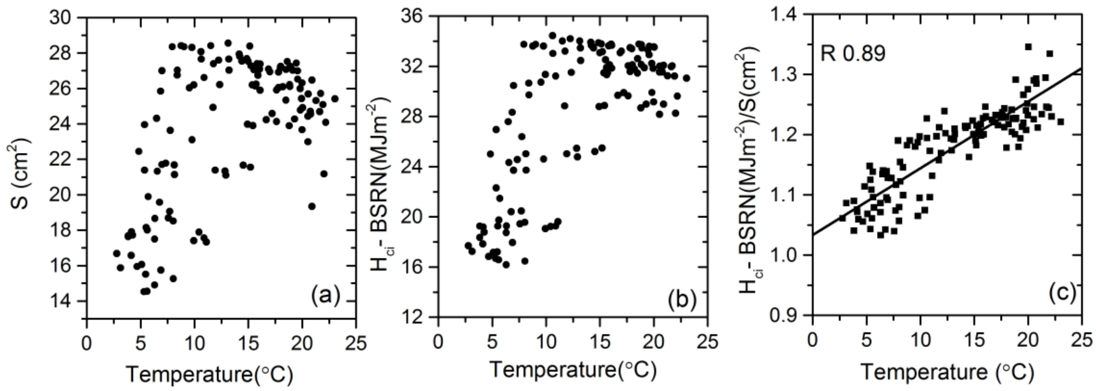

Figure 3.- (a) Area (S; cm^2), (b) GSR BSRN ($H_{ci;}$ MJm^{-2}) and (c) ratio between H_{ci} from GSR BSRN and area (MJm^{-2}/cm^2) versus temperature (°C) for the period 2014-2015.

The higher the temperature, the higher the ratio values, coinciding with higher F_m values. When if we calculate the differences between the mean monthly temperature for each year in the period 1977-1991 and the reference period (2014-2015), the Figure 4a is obtained. Most of years present mean bias in the range ±5° but there are years with months that present mean bias as higher as +20° or -10° against the reference period. These differences in the temperatures respect to the reference period along

with the instrument degradation lead to the necessity of recalibration of the instrument every month.

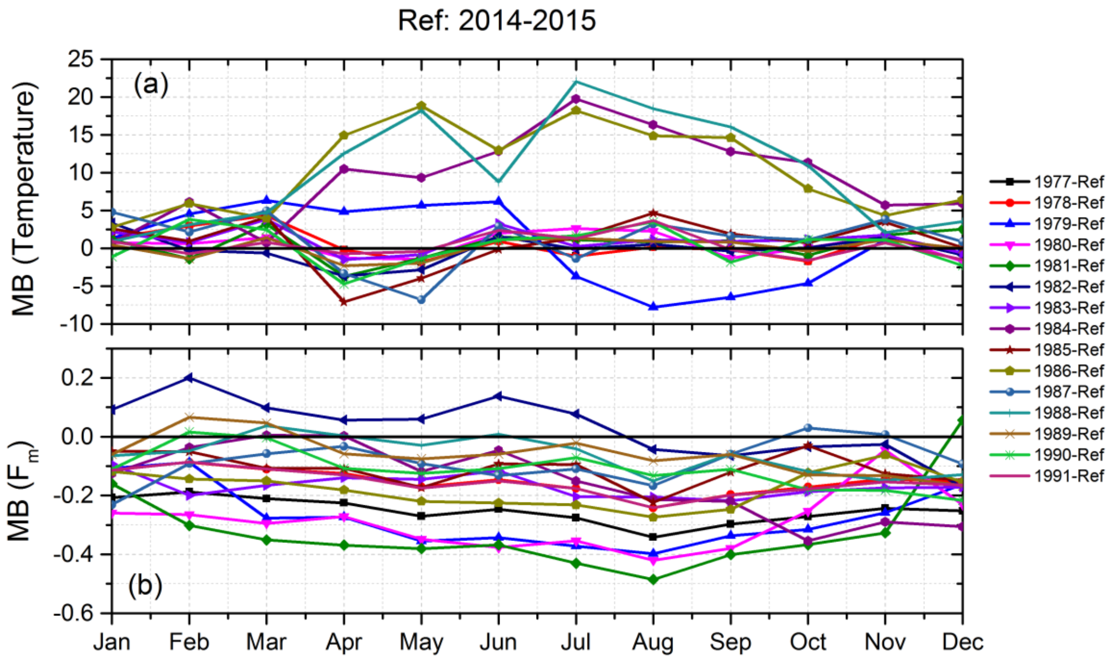

Figure 4.- Monthly averages bias (a) of temperature (°C) and (b) F_m (MJm^{-2}/cm^2) respect to the period 2014-2014 between 1977 and 1991.

In Figure 4b we have plotted the bias of the F_m computed with the model for each month of each year with respect to the F_m computed in the reference period. It is clear that the F_m is very different from year to year and even in the same month in different years leading to very different F_m annual cycle.

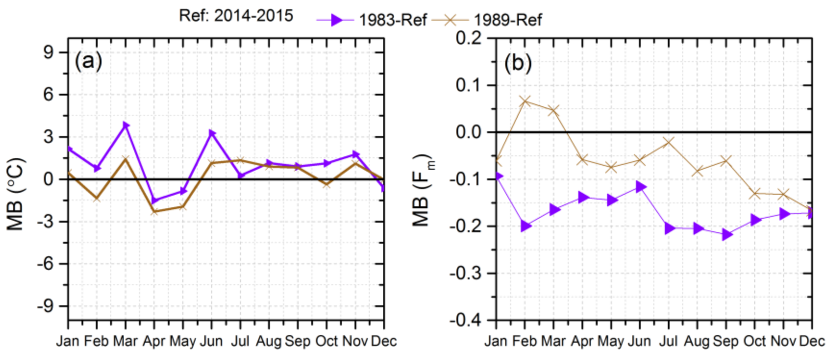

Figure 5.- Monthly averages bias (a) of temperature (°C) and (b) F_m (MJm^{-2}/cm^2) respect to the period 2014-2014 for 1983 and 1989.

Besides, as can be seen in Figure 5, for example, in 1983 and 1989 the temperature mean bias does not differ so much from the reference period but the F_m values differs between -10% and -20% in 1983, and between -5% and -15% in 1989, when a similar values for both F_m annual cycles were expected. Probably the instrument degradation causes this effect, because the instruments was measuring until 1991, thus the degradation level in 2014-2015 is closer to the degradation level in 1991 than in 1983.

We have to take into account that the F_m were calculated by selecting for each month a set of days that are cloud-free and the input parameters to the model are well known, in order to obtain a reliable GSR to calculate the F_m. For the rest of days the F_m calculated is used to derive the GSR without any other consideration, as in any other calibration procedure.

c) There seems to be a circular reasoning in the method used to derive the time-series from 1977 to 1991 (see page 10, last paragraph). The method uses modelled GSR data to retrieve the instrument calibration factors over this time-period, and then applies these calibration factors to the data to derive the solar irradiation from the instruments. But then, how can the solar irradiation levels recalculated from the bimetallic pyranometers contain any more information than the modelled radiation used in the first place to derive the calibration factors? I would suggest to carefully analyse the variability of F, and check if the calibration factors derived in 2014-2015 could not be used for the period 1977-1991.

Note that Fm factors are computed on a monthly basis only for clear skies days, as "calibration factors". So, the information provided by the bimetallic pyranometers, that is, the daily radiation curves formed by instantaneous radiation values, which are recorded on strip cards, constitute the main experimental information since they contain the effects of the diurnal variation of clouds and aerosol of each day. Monthly Fm factors only provide the calibration of the instrument.

Some more technical comments:

4) The use of the term global solar radiation (GSR) by the authors is very confusing: Sometimes it is used for the global solar irradiance (W/m^2), at other times it represents daily total irradiation (J/m^2). The authors should clearly distinguish between these two different parameters, and not use the same term GSR.

Authors: Following the referee's recommendation we have distinguished between GSR_H and GSR_E following the recommendations of the WMO (2008):

- *Daily Global solar radiation (GSR_H) for the global solar radiation measured in MJ/m^2 and that it represents daily total irradiance.*
- *Instantaneous global solar radiation instantaneous (GSR_E) for the global solar radiation measured in W/m^2.*

5) page 10, section 5: Can the neural networks track sahara dust events and volcanic eruptions (Pinatubo in 1991 and El Chichon in 1982), which are unpredicted events with significant influences on the GSR and the largest sources of aerosols at Izaña observatory, for otherwise low AOD background conditions?

Authors: Yes, the ANNs may predict Sahara dust events and volcanic eruptions. In Figure 6 we have the comparison between AOD observations performed with Mark-I (Barreto et al., 2014)

and ANN AOD estimates at 769.9 nm between 1991 and 1993 at Izaña station (see Figure 5 in Garcia et al. 2016) during Pinatubo period. The results show a good agreement for the daily values with R = 0.915.

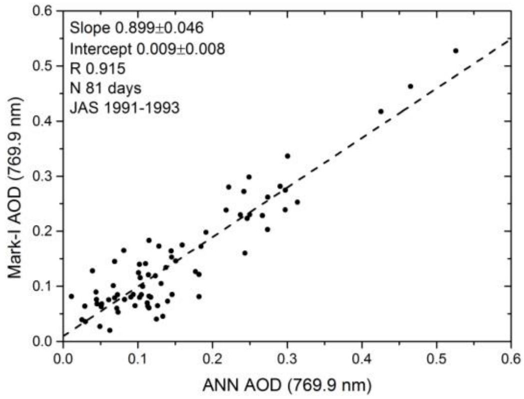

Figure 6.- Scatterplot of daily Mark-I AOD at 769.9 nm vs. ANN AOD estimates for all cloud-free days (oktas = 0) for months July, August and September (JAS) between 1991 and 1993 (Pinatubo period). The least-square fit parameters are shown in legend.

Barreto, A., Cuevas, E., Pallé, P., Romero, P. M., Guirados, C., Wehrli, C. and Almasa, F.: Recovering Long-term Aerosol Optical Depth Series (1976–2012) from an Astronomical Potassium-based Resonance Scattering Spectrometer, Atmospheric Measurement Techniques, Atmos. Meas. Tech., 7, 4103–4116, doi:10.5194/amt-7-4103-2014, 2014.

Abstract: Please define SD here, not later in the text.

Authors: Done

Page 4, line 12: Please explain the method by which the pyranometer performs the diffuse and global measurements (simultaneously?).

Authors: The pyranometer CM-21 Kipp & Zonen does not simultaneously measurements the global and diffuse radiation. The global and diffuse solar radiation are measured with unshaded and shaded, respectively.

The authors have clarified this sentence as follows:

"… The GSR_H at Izaña BSRN is measured with a Kipp & Zonen CM-21 pyranometer (Table 1). Pyranometers integrate radiation hemispherically over a horizontal surface covering a spectral range from 310 to 2800 nm (95%)…"

Page 6, line 2: As mentioned previously, why not use the BSRN Pyranometer here, instead of the modelled solar irradiance using libradtran?

Authors: Please see the question (3a, page 3)

Page 10, line 22, add bimetallic, in "…with two pyranometers: "

***Authors**: Done*

References: Please remove Garcia et al., 2014a as it is only AMTD and a duplicate of Garcia et al., 2014b.

***Authors**: We think it is correct to leave in the final manuscript the reference García et al. (2014a), because in AMTD the authors analyze the behavior of the Sunshine Duration sensor (CSD) and perform a comparison with Campbell Stokes (CS) records. In that work, the authors following the referee's recommendation removed everything related to CSD records in the final manuscript, therefore this analysis is not in García et al. (2014b).*

Table 1: I suggest to define the basic parameter shown as magnitude for MFRSR and CM21 as solar irradiance (W/m^2), from which solar irradiation (J/m^2) can be derived.

***Authors**: Done*

Figure 3: There is a mistake in the bottom figures: OND should probably be corrected to SON?

***Authors**: This typo has been modified in the final manuscript.*