GMD-2017-303

Interactive comment on "Comparison of observed and modelled longwave radiation (2010-2016) at the high mountain BSRN Izaña station" by R. D. García et al.

Anonymous Referee #1:

GENERAL COMMENTS

The manuscript presents a comparison of calculated and observed longwave downward radiation (LDR) for cloud-free conditions at the BSRN Izaña station using the radiative transfer models libRadtran and MODTRAN. Differences(bias ±RMSE)between calculated and observed LDR for 1014 night-time cases in the 2010-2016 period were less than5 Wm-2and hence within the measurement uncertainty with the model calculations being higher compared to the observations. Discrepancies between models and observationsfor1048 cloud-free day cases were slightly higher with the models yielding lower irradiances. These differences in the statistics between day and night are currently not yet understood. Finally, the models confirm the water vapour dependency of observations traceable to the World Infrared Standard Group (WISG) which has been postulated in earlier studies using windowless radiometers (e.g., Gröbner et al., 2014).

The LDR is the second largest component in the radiation budget, directly related to the greenhouse effect and hence of great importance. The accurate calculation of the cloud-free LDR is relevant in many applications. Therefore, the manuscript is significant for the community and hence appropriate for this journal. The manuscripts in general well-structured and clearly written. Graphics and tables are clear and the captions self-explanatory. Therefore, I would recommend publishing the article in GMD after minor–mainly technical -revisions.

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

2.) SPECIFIC COMMENTS

i) Cloud-free detection:

p.5: I wonder if no observational method for night time is available at this site which detects high level clouds more reliably than the Clear-Sky Index (CSI) or APCADA does. Can you comment on that? Moreover, did you really use APCADA (i.e., did you determine the diurnal and annual variability of k and did you calculate fractional cloud cover) or did you just use the original CSI from Marty and Philipona (2000) which only distinguishes between cloud-free and

cloudy skies? Please specify. It seems to me that you used the CSI from Marty and Philipona (2000) if this is true delete APCADA and the corresponding reference in the text.

Authors: ***A SONA total-sky camera (Automatic Cloud Observation System; González et al., 2013) which takes an image every 5 minutes during all day, has been operating at Izaña Observatory during the time period of this study. The SONA's images have been used to check the cloud-free results obtained with the Clear-Sky Index following the Long and Ackerman method. We have reviewed the recorded SONA images by visual examination during the day-time (11 UTC) and night-time (23 UTC), because the camera is sensible enough to observe clouds during night period. We will incorporate this information into the final manuscript as shown hereinafter.***

The referee is right and the method used to detect cloud-free and cloud-skies was the one developed by Marty and Philipona (2000) and not the APCADA (Dürr and Philipona, 2004).

For this reason, the section "Cloud-free detection" has been modified as follows:

> ***"The cloud-free days were detected by using the algorithm developed by Marty and Philipona (2000). A Clear-Sky Index (CSI) is calculated to separate cloud-free days from cloudy days using accurate measurements of LDR in conjunction with air temperature and relative humidity values measured at the station. The CSI index is defined as:***
>
> $$CSI = \frac{\varepsilon_A}{\varepsilon_{AC}} \quad (2)$$
>
> ***where***
>
> $$\varepsilon_A = \frac{LDR}{\sigma_b T^4} \quad (3)$$
>
> $$\varepsilon_{AC} = \varepsilon_{AD} + k({}^{e}/_{T})^{1/8} \quad (4)$$
>
> ***where σ_b is the Stefan-Boltzmann constant, T is the air temperature (K), ε_{AD} is an altitude-dependent emittance of a completely dry atmosphere, e is water vapor pressure (Pa) and k is a constant coefficient dependent on the location. If CSI Index ≤ 1 indicates cloud-free (no clouds) and if CSI Index >1 indicates cloud-sky (overcast) (Marty and Philipona, 2000).***
>
> ***In order to calculate ε_{AC}, this method requires the evaluation of ε_{AD} and k, as shown in equation (4). A sample of known cloud-free days is used to plot ε_{AC} against ${}^{e}/_{T}$ (Figure 2). The cloud-free condition of this sample is assured by applying the Long and Ackerman's method (Long and Ackerman, 2000; adapted for IZO by García et al. (2014)). This method is based on surface measurements of global and diffuse solar radiation with a 1-min sampling period and consists of in four individual tests applied to normalized global radiation magnitude, maximum diffuse radiation, change in global radiation with time, and normalized diffuse radiation ratio variability. We have***

considered the period 2010-2016 at 11 UTC to determine the fitting coefficients of equation (4) obtaining the following relationship (Figure 2):

$$\varepsilon_{AC} = 0.218 + 0.385(e/T)^{1/8} \quad (5)$$

Despite the ε_{AD} depends on the altitude of the station we have obtained for IZO a value of 0.218, similar to the values obtained by Marty and Philipona (2000) for stations located between 2230 and 2540 m (0.22 and 0.211, respectively).

Once we have adjusted the coefficients, the cloud-free cases were selected with a combination of Long and Ackerman and CSI methods. At day-time, we have used the Long and Ackerman one, taking into account for each day the period 11-13 UTC. At night-time the CSI was applied in the period 23-01 UTC. These results have been checked by visual examination of 5-minute total sky images obtained with a SONA camera (Automatic Cloud Observation System; González et al., 2013) installed at IZO. We found that both methods detect 97% of the visually selected cases. A total of 1161 and 1083 cases were detected for day-time and night-time, respectively, in the period 2010-2016 "

ii) Solar effect on the LDR and differences in the bias between the day and night comparisons of observed and calculated LDR:

I assume that the LDR observations used in this study were shaded (according to the guidelines of BSRN), i.e. both pyrgeometers were installed on a solar tracker? It is a bit confusing because the authors state (on p.4,line4, based on McArthur (2005)) that the CG4 filters all solar radiation and hence no shading is necessary (I see this statement anyways a bit more critical: the longwave irradiance in the direct beam of the sun is measured by any pyrgeometer and its magnitude depends on the cut-on of the filter and the solar insolation and hence on atmospheric conditions (e.g., water vapor content, cloudiness).In fact, a CG(R)4 has a higher cut-on (approximately at 4.5µm) compared to a Eppley PIR (approximately at 4µm)and hence the CG(R)4 measures less longwave irradiance from the sun which has been already reported in previous studies (e.g., Meloni et al., 2012). Nevertheless, a few Wm-2 originating from the long-wave irradiance in the direct beam of the sun will be observed by a CG(R) 4 and thus it should be also operated in shaded mode).In any case, state clearly if your pyrgeometers were shaded (e.g., on p.3, line 30: '…with a shaded and ventilated broadband Kipp & Zonen…', or on page 4, line 4 after the reference of McArthur (2005)).

If the pyrgeometers were not shaded (unlikely), the long-wave irradiance in the direct beam of the sun could be a possible explanation for the small differences in the bias between the results of the day and night comparisons of measured and calculated LDR (p.11, lines20-21/p.12, lines 1-2and Fig. 4 or Table 4) which are in fact consistent with the results in Dürr et al, 2005. If the observations are shaded, it is reasonable that the differences between day and night are caused by additional measurement inaccuracies during daytime as stated by the authors. However, an underestimation of the models due to inaccuracies in the model input parameters during day time (e.g., inaccuracies in the observed temperature/humidity profiles due to different heating of the radiosonde sensors by solar radiation) could be also possible

(instead of instrumental inaccuracies). Could you comment on that? I would add this option at the end of the paragraph (p.12, line 2).

Authors: ***The authors appreciate these interesting comments and remarks.***

The LDR observations have been performed with CGR4 pyrgeometers installed on a solar shaded tracker. This information has been added to the final manuscript in Pag. 3 Line 30 as follows:

> ***"The LDR measurements used in this study have been performed at the Izaña BSRN (#61, IZA; http://www.bsrn.aemet.es) (García et al., 2012) with a ventilated broadband Kipp & Zonen CG4 pyrgeometer (onwards, CGR4) mounted on a sun tracker equipped with dome shading. This instrument uses a specially designed silicon window which provides a 180° field of view (although not hemispherical) with good cosine response. A diamond-like surface protects the outer surface of the window, while the inner surface filters most of solar radiation. The design of the instrument is such that solar radiation absorbed by the windows is conducted away to reduce the solar heating effect. This fact reduces the need for dome heating correction terms and shading from the sun (McArthur, 2005)."***

Pag 12 Line 2:

> ***"The small differences observed in the evolution of the bias with the PWV (close to the instrumental error) found between day-time and night-time may be associated with instrumental measurements (Ohmura et al., 1998; McArthur, 2005) and we do not preclude they could be also related to inaccuracies in the model input parameters during day-time, e.g., inaccuracies in the observed temperature/humidity profiles due to different heating of the radiosonde sensors by solar radiation. Dirksen et al. (2014) studied the effects on the RS92's temperature and humidity measurements and they estimated this uncertainty to be 0.15 K for night-time temperature measurements and approximately 0.6 K at 25 km during daytime. "***

Pag 14 Line 4:

> ***"The differences between day and night-time are currently not understood. Further specific analysis are needed to identify and quantify the contribution of the different possible causes for the observed differences which are outside the scope of this work."***

SUMMARY:

p.3, line 30 or p.4, line 4: Specify if the LDR observations were shaded or not.

Authors: ***See previous answer (SPECIFIC COMMENTS ii).***

p.4, line 2: Replace 'all solar radiation' by 'most of the solar radiation'
Authors: ***Done.***

p.11, line 13-21: I would re-arrange this paragraph and start with the night-time results first, i.e. with line 16 (in the night the uncertainties are in general smaller because of the absence of solar radiation). Then describe the results for day time.

Authors: *The authors think it is not convenient to discuss night-time results before day-time results, for consistency with the rest of the manuscript.*

p.11,lines20-21/p.12, lines 1-2: If the LDR observations were not shaded the previously mentioned impact of the longwave irradiance in the solar spectrum on the LDR observations should be stated and the publication of Meloni et al. (2012) cited. If the observations are shaded, I agree with the content (but I would use '…with additional instrumental inaccuracies during daytime' on p.11 line 21/p.12, line 1). In addition, I would add a sentence about possible inaccuracies in the model input parameters during day time which may result in an underestimation of the models.

Authors: *See previous answer (SPECIFIC COMMENTS ii).*

3.) TECHNICAL CORRECTIONS

p.1, title: add 'cloud-free' between 'modelled' and 'longwave'.

Authors: *Done.*

p.1, line 4 and throughout the manuscript: 'libRadtran' instead of 'LibRadtran'.

Authors: *Done.*

p.1, line 4: Revise sentence: 'Results show an excellent….and simulations using the radiative transfer models (RTM) libRadtran and MODTRAN V6.'(delete 'similar for both models').

Authors: *Done.*

p.1, line 7: '…useful tools for the quality control of LDR observations…'

Authors: *Done.*

p.1, line 16: cloud cover is only one aspect; I would add 'cloud type'. Furthermore, water vapor is missing.

Authors: *We fully agree. Following the Referee's recommendation, the authors have added the underlined information into the following paragraph:*

> *"The longwave downward radiation (LDR) at the Earth's surface is a key component in land-atmosphere interaction processes, and is crucial in the surface energy budget and global climate change, because the changes in the LDR values may be related to changes in cloud-cover, cloud type, water vapour, temperature, and the increase of anthropogenic greenhouse gas concentrations in the atmosphere (Wild et al., 1997; Marty et al., 2003)."*

p.2, line 2: The CG4 is nowadays termed CGR4 use 'CG(R)4 series'

Authors: *Done.*

p.2, line 2: put the reference of McArthur (2005) at the end of the sentence.

***Authors:* Done.**

p.2, lines 3-4. I would delete this sentence. The specifications for the CG(R)4 from Kipp & Zonen may not be representative for the other types of pyrgeometers listed previously.
***Authors:* Done.**

p.2, line 6: delete here the reference of Ohmura et al. (1998).
***Authors:* Done.**

p.2, line 9: Reference should be Ångström, also in the reference list.
***Authors:* Done.**

p.2, line 11, use ‘e.g.,’ instead of ‘i.e.’
***Authors:* Done.**

p.2, line 17, ‘Stefan-Boltzmann constant’
***Authors:* Done.**

p.2, line 27: I would put ‘as model inputs’ at the end of the sentence.
***Authors:* Done.**

p.3, line 28: I would term Section 3 as ‘Observational Data and Methods’, then Section 3.1 ‘Instrument and Measurements’ and Section 3.2‘Cloud-free detection’
***Authors:* Done.**

p.3, line 4: ‘…with values of +1.5and –3.2Wm-2for night-time….’
***Authors:* Done.**

p.3, line 12: rather use‘…uncertainty assessment…’than ‘…quality assessment…’
***Authors:* Done.**

p.3, line 13: ‘…temporal stability of the LDR observations…’
***Authors:* Done.**

p.3, line 17: use ‘location’ instead of ‘situation’.
***Authors:* Done.**

p.3, line21: I would use ‘…it has been actively contributing…’
***Authors:* Done.**

p.3, line 21 and throughout the manuscript: an abbreviation should be define at its first occurrence in the manuscript, e.g.,‘…such as the Network for the Detection of Atmospheric Composition Change(NDACC; http://www.ndsc.ncep.noaa.gov/)since 1999,the Aerosol Robotic Network(AERONET, http://aeronet.gsfc.nasa.gov/) since 2004, the Total Carbon Column Observing Network (TCCON, http://www.tccon.caltech.edu/)since2007,…’. Later, just use the abbreviation.
***Authors:* Done.**

p.3, line 26: Revise reference (also in the reference list). Should be read ‘WMO’ or ‘CIMO’, I guess.
***Authors:* Done.**

p.4, line 6: '…at the Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center (PMOD/WRC).'

Authors: Done.

p.4, line 9: The reference is from 2002, I guess. Revise also in the reference list.

Authors: Done.

p.5, line 1: Here, I would use only the reference of Dürr and Philipona (2004) but only if you have really used APCACA (see my previous comments). Insert the reference of Marty and Philipona inline 4 (after 'at the station').If you have used the CSI from Marty and Philipona (2000) replace APCADA and the corresponding reference with 'Clear-Sky Index (CSI) (Marty and Philipona(2000)'in line 1, p.5.

Authors: Done. See previous answer (SPECIFIC COMMENTS i).

p.5, line 10: 'Stefan-Boltzmann'

Authors: Done.

p.5, line 10: εAD is an altitude-dependent emittance of a completely dry atmosphere (εAC is the apparent emittance of a cloud-free sky)

Authors: Done. See previous answer (SPECIFIC COMMENTS i).

p.5, lines11/12: Revise this sentence, e.g.: 'A CSI Index ≤1 and >1indicates cloud-free and cloud-sky, respectively.'

Authors: Done. See previous answer (SPECIFIC COMMENTS i).

p.5, line 16: '…consists of…'

Authors: Done.

p.5, line 28: delete 'models'.

Authors: Done.

p.6, line 7: Hasn't the band model used in MODTRAN 6 a resolution of 0.1cm-1?

Authors: Yes, MODTRAN 6 has resolution of 0.1 cm^{-1}, but we use a resolution of 1 cm^{-1} in order to reduce de computational time, taking into account that the integrated LDR using 1 cm^{-1} resolution differs not significantly from the 0.1 cm^{-1} one.

p.7, line 10: The site of the radiosonde launch is located at sea level, more than 2000 m lower the IZO. I assume that you cut the profiles at the altitude of IZO to assimilate the profiles into the RTM?

Authors: Yes. The radiosonde profiles have been used from the altitude of IZO (2373 m a.s.l.). The authors have been added the following sentence:

> *"In this work, we have used the AEMET's meteorological radiosondes dataset. Radiosondes are launched twice a day, at 11 and 23 UTC at the Güimar station (WMO GRUAN station #60018, 105 m a.s.l.). This station is located at the coastline, approximately 15 km to the southeast of IZO. Vertical profiles of pressure, temperature and relative humidity were measured using Vaisala RS92 radiosondes (Cuevas et al., 2015; Carrillo et al., 2016). We have used the radiosonde profiles from the altitude of IZO (2373 m .a.s.l.)"*

p. 7, line 18: NDACC has been already defined on p. 3.

Authors:* *Done.

p.7, line 31: delete 'one'.
Authors:* *Done.

p.8, line 15: delete 'the'.
Authors:* *Done.

p.10, line 5: Did you average the observations over a certain time period (e.g., 30 minutes) in order to validate the RTM calculations? Or did you use the 1 min observations? Specify.

Authors: Yes. We have averaged in a 30 minutes period the LDR observations from 11:00 to 11:30 and from 23:00 to 23:30 UTC to match the flight time of the radiosonde over IZO. This information has been added to the final manuscript as follows:

> ***"In this section, we present the comparison between LDR measured with BSRN and simulated with LibRadtran and MODTRAN, considering the available and coincident cloud-free BSRN at day-time and night-time, and the inputs indicated in section 4.1 at IZO between 2010 and 2016. A total of 1048 measurements at day-time, and 1014 measurements at night-time were used. The observations were averaged in a time period of 30 minutes, in order match the flight time of the radiosonde over IZO. In particular, we averaged over 11:00-11:30 UTC and 23:00-23:30 UTC periods, for day-time and night-time measurements, respectively. .."***

p.10, line 7: you may better use '…and R of 0.999, and are more consistent during nighttime'.

Authors:* *Done

p.11, Table 4 (Caption): The number of day-time calculations given here (1075 cases) is not consistent with those given in the abstract, Section 5 (1048, p.10) and Section 6.

Authors:* *Done

p.12, line 11: Could you specify what was changed in the location of the instrumentation in 2012?
Authors: Due to improvement works at IZO the instrumentation was moved for a short period of time (approximately a month) from the tower to a nearby platform at ground level. Once the works ended the instrumentation was reinstalled in its original location. This information has been added to the final manuscript as follows:

> ***"… When analyzing the BSRN LDR and the simulated LDR data time series separately, we do not observe any change in the simulated LDR, but a change point in the BSRN LDR data time series at both day-time and night-time. This change point (October 2012) coincided with a change in the location of the instrumentation within the IZO facilities. The instrument was moved to ground level during approximately a month, until the works ended…."***

p.14, line 3: 'supports'.

***<u>Authors:</u>* Done**

p.14, line 4: I would add 'However, the differences between day and night are currently not yet understood.'

***<u>Authors:</u>* The authors have been added this sentence to the final manuscript (See previous answer (SPECIFIC COMMENTS ii).**

p.17, line 37: Specify journal/meeting event of publication/presentation of Redondas and Cede.

***<u>Authors:</u>* Done**