Answer to Referee #2

- **Summary**

This paper examines radiation data from satellite and model products for their potential use in snowpack modelling. Following the approach of Hinkelman et al., 2015, the general accuracy of the longwave and shortwave irradiances from a forecast model (AROME), a reanalysis product (SAFRAN), and satellite-related data sets (DSSF and DSLF from the LSA SAF) is first assessed through comparisons to measurements at in situ stations in the French Alps and Pyrenees. After this assessment, the various irradiance data sets are used as inputs to a snowpack model (CROCUS) and the accuracy of the respective model runs is evaluated. Based on these analyses, the authors conclude that the most accurate shortwave irradiance values are those in the satellite-related irradiance product while the longwave irradiance products all perform similarly in comparisons to measurements. The snow depth was overestimated in all of the CROCUS runs, with the worst overestimation occurring when the satelliterelated data was used as input.
In general, although this study closely follows the lines of Hinkelman et al., 2015, it is useful to show results from different conditions, i.e., different satellite products, different location, different snowpack model, to confirm the results of that study. In addition, detailed evaluation of a number of different irradiance data sets against ground-based measurements and discussion of analyses in terms of altitude are new and useful. I find no major issues with the manuscript and recommend publication after the following comments are addressed. A marked copy of the manuscript with suggested English corrections has been returned to the authors.

We thank the referee for the time dedicated to this review and his insightful comments. We answered below to all his points. His comments are in bold while our answers appear in blue. Changes in the manuscript appear in red. We are also grateful to the referee for the suggestions of English corrections; unfortunately, we have not received the marked copy of the manuscript (see previous comment in the interactive discussion).

- **Comments**

Lines 141-151. What type of method is used to calculate the shortwave fluxes from the satellite data? I would at least like to know whether it's an explicit radiative transfer calculation, a parameterisation, or something else.

According to the Product User Manual of DSSF (available at: https://landsaf.ipma.pt/GetDocument.do?id=449) and Geiger et al. (2008b), the shortwave fluxes are calculated with a parameterisation of the atmospheric transmittance as a function of the concentration of atmospheric constituents in case of clear sky, and with a simple physical model of radiative transfer using the observed top-of-atmosphere reflectance in case of cloudy sky. We have briefly mentioned these methods in the new manuscript.

--- CHANGES IN MANUSCRIPT (lines 147-155) ---
Two separate algorithms are then applied. In the clear-sky method, derived from Frouin et al. (1989), the effective transmittance of the atmosphere is parameterized using the total column water vapour content (TCWV) forecast by the European Centre for Medium-Range Weather Forecasts (ECMWF) Integrated Forecasting System (IFS), the ozone amount from the Total Ozone Mapping Spectrometer climatology, a constant visibility and the surface albedo taken from the LSA SAF albedo product (Geiger et al., 2008a). In the cloudy-sky method, derived from Gautier et al. (1980) and Brisson et al. (1999), the top-of-atmosphere reflectance observed by MSG/SEVIRI is used in addition to the former set of variables to apply a simple

physical model of radiative transfer.

Lines 153-161. Calling the DSLF a satellite product seems a stretch, considering that the underlying algorithm is the Prata parameterisation and the only satellite input is cloud fraction.

We fully agree with reviewer 2: meteorological variables taken from ECMWF forecasts have a significant weight in the calculation of the DSLF. A sentence recognizing it has been added in the description. However, for the sake of brevity, DSSF and DSLF are called "satellite-derived products" in the rest of the manuscript, including the title.

--- CHANGES IN MANUSCRIPT (lines 168-170) ---
The DSLF can therefore be described more accurately as a longwave irradiance parameterisation using satellite observations of the cloud mask rather than a satellite product.

Lines 150-151 and 160-161. Can you say whether these targets have been met?

The target accuracy of 10% is not reached most of the time, which is not surprising since it was derived from comparisons at reference plain stations (Trigo and Viterbo, 2009). The performance of satellite-derived products remains satisfactory, compared to AROME and SAFRAN. It has been mentioned in the discussion.

--- CHANGES IN MANUSCRIPT (lines 473-476) ---
Thus, the performance of LSA SAF irradiance products remains satisfactory compared to previous evaluations of these products in plains, even though they generally do not reach the target accuracy (Sect. 2.2.3), derived from reference plain stations.

Line 175. What is the source of the -6.5 Kkm^{-1} temperature gradient used in computing DSLFnew?

The vertical temperature gradient of -6.5 K km^{-1} comes from the International Standard Atmosphere, now mentioned in the manuscript. We used this value since it is used in the original DSLF product when adjusting ECMWF forecast.

--- CHANGES IN MANUSCRIPT (lines 188-191) ---
The possible altitude difference between AROME grid points and LSA SAF grid points was mitigated thanks to a vertical temperature gradient of - 6.5 K km^{-1} according to the International Standard Atmosphere, similarly to the method applied to ECMWF IFS forecasts.

Lines 192-195. The quoted 5-8% accuracy of the Meteo-France pyranometers is probably based on laboratory measurements, not field tests. It would be easier to estimate the actual performance of the Meteo-France instruments if the maintenance regimen was described. It seems unlikely that the uncertainty of these measurements would be the same as those made using better instruments with regular maintenance at Col de Porte.

After verification, the 5-8% accuracy of Meteo-France pyranometers is indeed the value based on laboratory measurements. According to the classification of Météo-France stations (Leroy and Leches, 2014), as part of the Radome network, these stations have a required quality of 10% for hourly means. They are classified as category "B" in terms of maintenance, which corresponds to a biennial calibration and a maintenance at least every week if there is staff, every six months otherwise, according to Leroy (2010). In absence of more details concerning each station, we have mentioned in the revised manuscript that the uncertainties may be higher than 10% at these stations.

--- CHANGES IN MANUSCRIPT (lines 208-212) ---

The pyranometers from Météo-France network (Kipp&Zonen CM5, CM6B and CM11) meet the good quality standards of the World Meteorological Organization (WMO, 2014), hence an uncertainty of hourly total SW↓ irradiance of 10% (Leroy and Leches, 2014). Due to their location in altitude, the maintenance may not be systematically weekly so that uncertainties of 10% are probably too optimistic.

Line 225. Why were the impact of slope and aspect on the solar irradiance not taken into account in the modeling? Using horizontal irradiances in the comparisons makes sense because all of the data sets provide values in this form, but surely this would have a large impact on the model results. (Incidentally, "supposed to be" suggests that they should meet these conditions, but not that they necessarily do.)

The snowpack simulations are carried out on a 2.5 km grid spacing. This resolution does not enable to reproduce the distribution of slopes and aspects found in a given mountainous area. Therefore, these simulations are made ideally on flat terrain and supposed to provide the mean state of the snowpack over the pixel. Previous distributed snowpack simulations at kilometric scale using Crocus model have been made in this configuration (Vionnet et al., 2016; Quéno et al., 2016). To this end, the meteorological forcing (including the solar and longwave irradiance) has to be provided in the same topographical conditions. In particular, the solar irradiance is provided over a flat terrain, which discards the need to take into account slope and aspect. The influence of local topography on incoming radiation and its impact on snowpack evolution is the scope of finer scale simulations. As this concern was also a part of the other referee's major comment, a new section of the discussion has been added to tackle it.

For comparisons to snow depth measurements, the stations are located on flat terrain: the slope of the concerned pixel could be different if taken into account in the simulation. The main limitation for comparisons to snow depth stations is the local terrain shadowing which cannot be taken into account in the simulation with a 2.5 km grid.

(The expression "supposed to" has been removed, thank you for your remark.)

--- CHANGES IN MANUSCRIPT (lines 510-531) ---

At sub-kilometric scale, the local topography strongly influences the solar and longwave irradiance variability. Oliphant et al. (2003) identified the following surface characteristics as causes of radiative flux variability, by order of importance: slope aspect, slope angle, elevation, albedo, shading, sky view factor, and leaf area index. These local factors are not taken into account in AROME, SAFRAN and LSA SAF irradiance products. This study aims at assessing the practical benefits of different irradiance datasets to be used as radiative forcing for distributed snowpack simulations at 2.5 km resolution in mountains. In the context of representing the mean state of the snowpack over a considered flat pixel, at a given altitude and a given location in the mountain range, the terrain influence on the radiation does not need to be taken into account in the radiative forcing. However, to capture the sub-kilometric variability of the snowpack, it will be necessary to consider sub-grid effects of the surrounding terrain on the radiation, and thus a topographical correction of irradiance products (e.g. Helbig and Löwe, 2012) as done for MSG satellite-derived solar fluxes by the HelioMont method (Stöckli, 2013; Castelli et al., 2014).

The main limitation implied by local topography effects regards the evaluation of the irradiance products and the snowpack simulations through in situ comparisons. Indeed, in situ irradiance and snow depth measurements are affected by these effects. The location of stations in flat and open fields reduces the impacts of slope, aspect and vegetation. The evaluation of solar irradiances at periods when the sun is not masked by the surrounding topography enables to discard the terrain shadowing effect on direct solar radiation. However, this effect is not considered for snow depth comparisons. Additionally, the limited sky view and the reflection effects on diffuse solar radiation are not taken into account, as well as the limited sky view and terrain thermal radiation effects on longwave irradiance.

Line 253 says that topographic shading was included in the comparisons to measured irradiance despite the previous statement that slope and aspect could be ignored when running CROCUS. This seems to be a contradiction. Was the shading correction applied to all

of the data sets? Was there, in fact, topographic shading at these locations? The method used to make this correction could affect the comparison results.

The topographic mask is computed at stations to account for the effect of topographic shading on irradiance in situ measurements. It is applied to all the SW irradiance products (DSSF, AROME and SAFRAN) which do not take into account this effect: the comparison with in situ measurements is only made when the sun is above the calculated horizon. This mask only regards the evaluation of SW irradiance products at stations. It has been clarified in this part of the manuscript, and the new discussion section also tackles this topic.

--- CHANGES IN MANUSCRIPT (lines 273-277) ---

To account for topographic shading on irradiance in situ measurements, a topographic mask was computed with a 5° interval size after a 25 m resolution digital elevation model (DEM) of IGN (French National Institute of Geographical and Forest Information), and applied to the SW↓ irradiance products at all stations except Andorre and Envalira, because the DEM of IGN was only available on the French territory. The SW↓ irradiance products were only evaluated when the sun was above the horizon, or when the observed value was higher than 20 W m^{-2} at Andorre and Envalira stations (to discard periods when the sun is masked by the terrain).

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The main limitation implied by local topography effects regards the evaluation of the irradiance products and the snowpack simulations through in situ comparisons. Indeed, in situ irradiance and snow depth measurements are affected by these effects. The location of stations in flat and open fields reduces the impacts of slope, aspect and vegetation. The evaluation of solar irradiances at periods when the sun is not masked by the surrounding topography enables to discard the terrain shadowing effect on direct solar radiation. However, this effect is not considered for snow depth comparisons. Additionally, the limited sky view and the reflection effects on diffuse solar radiation are not taken into account, as well as the limited sky view and terrain thermal radiation effects on longwave irradiance.

Lines 267-268. It might be useful to list standard deviations along with biases and RMSEs to allow explicit distinction of the contribution of bias and random error to the RMSE, as was done by Geiger et al., 2008b, Trigo et al., 20ll, and Hinkelman et al., 2015, among others.

As standard deviations of errors can be derived from the values of biases and RMSEs, we have decided not to burden the text, tables and figures with redundant metrics, especially as they do not provide additionnal explanation.

Lines 295-296. Based on the shape of the bias plots, it appears that DSSF is out of phase with the measurements. Perhaps you should check the meaning of the time stamps in the satellite data. Misinterpretation could cause the data to be shifted in time relative to the measurements.

We have double-checked the meaning of the time stamps of each dataset and they were not misinterpreted. DSSF is not really out of phase since the SW daily maximum corresponds to the maximum of the observations. The problem seems to come from an underestimation of SW by DSSF in the afternoon, which we could not explain.

Line 318. How can a West-East mountain chain provide a barrier to westerly winds, to create differences on the north and south sides?

The Pyrenees indeed provide a barrier to the northwesterlies and not the westerlies. It has been corrected.

--- CHANGES IN MANUSCRIPT (lines 341-343) ---
The heterogeneity of DSSF is even more marked in the Pyrenees (Fig. 6e) where the West-East chain acts as an orographic barrier to the prevailing northwesterlies coming from the Atlantic Ocean (Quéno et al., 2016).

Lines 403-404. Please define AL_{SW}-Cro and AL_{LW}-Cro.

AL_{SW}-Cro and AL_{LW}-Cro are now defined in Sect. 2.3.1, as well as in Table 2.

--- CHANGES IN MANUSCRIPT (lines 247-252) ---
The radiative components of the forcings were extracted from the different irradiance datasets: a) AROME irradiance forecasts (simulations named A-Cro hereafter), b) SAFRAN irradiance reanalyses (simulations named AS-Cro hereafter), c) DSSF and DSLFnew (simulations named AL-Cro hereafter), d) DSSF and AROME LW↓ irradiance (simulations named AL_{SW}-Cro hereafter), e) DSLFnew and AROME SW↓ irradiance (simulations named AL_{LW}-Cro hereafter).

--- CHANGES IN MANUSCRIPT (lines 427-429) ---
The relative impact of DSSF and DSLFnew is represented in dashed lines (simulations AL_{SW}-Cro and AL_{LW}-Cro, as defined in Table 2).

Lines 464-490. The discussion of possible errors in the Crocus model is appreciated.

Thank you.

Lines 491-493. How would using an ensemble of simulations eliminate systematic biases? Do you mean an ensemble of simulations from a number of different models or just one?

ESCROC is the multiphysical ensemble system of the snowpack model Crocus (Lafaysse et al., 2017). The ensemble of simulations is thus based on different physical laws for each process within the snowpack, which could eliminate systematic biases. For instance, ESCROC uses several laws for solar radiation absorption and albedo: computing it in three spectral bands (Brun et al., 1992) or using the radiative transfer scheme TARTES (Two-streAm Radiative TransfEr in Snow, Libois, 2014). We have specified in the new manuscript the multiphysical character of this system.

--- CHANGES IN MANUSCRIPT (lines 560-562) ---
These results endorse the idea that snowpack ensemble simulations are necessary to mitigate error compensations, as recently developed for Crocus with the multiphysical ensemble system ESCROC (Ensemble System Crocus; Lafaysse et al., 2017).

Lines 500-501. I don't understand why the greater importance of LW irradiance relative to SW would be "specific to high latitudes." Solar irradiance is also low during the winter in the midlatitudes, so the LW should be of greater importance, at least during the accumulation season.

We thank the referee for this remark, the sentence was indeed badly formulated. It has been reformulated.

--- CHANGES IN MANUSCRIPT (lines 569-570) ---
However, the prevailing effect of LW↓ compared to SW↓ is more marked at high latitudes, because of the lack of solar insolation in winter.

It seems odd that the study by Lapo et al. (2015) is cited in lines 512-514 but then discounted. Although that paper discusses the importance of albedo to the effect of SW irradiance, it also assumes that the changes in the LW and SW energy inputs are similar. Looking at Figure 11, I would not say that the SW is more important than the LW because the albedo is lower in the spring (lines 513-514). Rather, there is a very large SW bias in DSSF (-56 W/m2) and no bias in the DSLFnew LW, such that the total bias is -56 W/m2 relative to AROME. This contrasts with the situation in SAFRAN in which the LW bias offsets that in the SW, yielding a total bias of -18 W/m2.

The reviewer is right to underline this issue. No conclusion can be deduced from Fig. 11 about the albedo effect on the SWE impact of SW and LW biases, because the energy inputs of both terms are indeed very different. Considering this reasoning was wrong and the fact that the outcomes of Lapo et al. (2015b) could not be properly verified in our case with different SW and LW biases, this part of the discussion has been removed.

Lines 553-554. The study did not show that "there is a clear benefit of using LSA SAF satellite products of incoming radiation for snow cover modelling in mountains." To the contrary, the model performed worse when the LSA SFA products were used. Consider changing this to say that, until snowpack models are improved, the LSA SFA products could be used to improve understanding of the models as well as in other snowpack related studies because they provide irradiance data of reasonable quality in mountainous areas (without measurement stations).

The reviewer is right: the last sentence of the conclusion did not reflect the results obtained in the study. It has been modified according to the reviewer's suggestion.

--- CHANGES IN MANUSCRIPT (lines 619-623) ---
Until such improvements are performed in the AROME-Crocus modelling context, the LSA SAF products of incoming radiative fluxes can be used to improve understanding of snowpack models as well as in other snowpack-related studies, because they provide irradiance data of reasonable quality in mountainous areas.

- **Note**

The word "radiation" can be considered either to refer to a process, and hence derived from a verb form (like "differentiation" or "automation"), or a noncountable noun (like "granite" or "wheat.") As such, it is generally not pluralized. Note that it is also not measureable. Like water, only its characteristics can be measured. The relevant SI quantity is irradiance, measured in units of W/m2. It would thus be better in most cases to stick with "irradiance" or the historically used term "(radiative) flux" unless it is being discussed in general (e.g., "Radiation is important to many land surface processes.")

We thank the reviewer for this comment. The text has been corrected accordingly, including the title.

The word "score" usually refers to a tally of points and is thus usually a unitless integer. It isn't really appropriate to refer to RMSEs or means as "scores." As used in this paper, a better word would be "statistics," or possibly "metrics."

Thank you for this comment, which has been taken into account.

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