

We thank H.W. Jacobi for his valuable contribution. His careful reading helped us to improve the quality of our paper. We answered below to all his points. His comments are in bold while our answers appear in normal font.

The authors describe the implementation of a detailed snowpack model into a platform to calculate the energy and mass exchanges between the atmosphere and the different types of the Earth surface. This platform also includes a land-surface scheme and, thus, allows the simulation of the exchange of energy and mass in the entire column from the soil through the snowpack to the atmosphere. The different models (CROCUS, SURFEX, ISBA) have been developed and validated previously and have been routinely used by the French meteorological service Météo France in different operational and scientific set-ups. CROCUS is one of only two snowpack models currently available, which include the metamorphism of the snow grains. Therefore, the implementation of the detailed snowpack model replacing previous more simplified representations of the snow in the land-surface scheme appears to be a logic improvement. The snowpack and processes in the snowpack can play an important role in several fields like weather forecast, climatology, hydrology, or even atmospheric chemistry. A better and more detailed simulation of the snowpack can bring major advantages in the performance of models addressing these issues and can deliver unprecedented information about the snow and its role for different applications. Since this model set-up can be coupled to other models of the Météo France family, it may have the capacity to serve as a benchmark model for snow-related issues at different temporal and spatial scales. Although the authors present an example of simulations for Antarctica, a thorough validation of the model in non-alpine environments is still needed in the future, since CROCUS was mainly developed based on alpine observations and conditions. Overall, the paper describes advances in modeling science within the scope of EGU and should be published in GMD. As a previous user of CROCUS, I find that the authors present the model in sufficient detail. I believe that this also applies to a first time user of the snowpack model. For most processes, all necessary information and parameterizations used in the snowpack model, which were spread in several publications or non-existing in the scientific literature before, are presented in an updated form. I recommend this manuscript for publication after the authors address the minor specific comments below.

Specific comments:

P. 2366, l. 21f: I think this statement is a too general because the snow is not always needed for correct weather or hydrological forecasts.

We slightly changed our statement to restrict it to situations when snow is of prime importance:

”Simulating the time and space evolution of the snowpack is key to many scientific and socio-economic applications, such as weather, hydrological (flood predictions and hydropower) and avalanche risk forecasting in snow-covered areas”

P. 2366, l. 25f: My understanding is that Flanner et al. found that on average the land snow cover and the sea ice contribute equally to the radiative forcing of the cryosphere in the northern hemisphere.

We agree with Reviewer 1 that the previous statement was not correct. Flanner et al. (2011) found indeed that cryospheric cooling results from equals contribution of land-based snowpack and sea ice. We changed the sentence in the introduction from:

”Within the cryosphere, the seasonal snowpack is probably the most significant climate forcing”

to: ”Within the cryosphere, the seasonal snowpack is a very significant climate forcing”

P. 2369, 1. paragraph: It should also be mentioned that the major elements of CROCCUS were implemented before in the land-surface scheme of the regional climate model MAR, mainly applied in polar regions (e.g. Gallée, H., G. Guyomarc’h, and E. Brun, Impact of snow drift on the Antarctic ice sheet surface mass balance: Possible sensitivity to snow-surface properties, Boundary-Layer Meteorol. 99, 1-19, 2001.)

We completed the introduction by referring to the study of Gallée et al (2001) : ”The main features of Crocus were implemented in the land-surface scheme of the regional climate model MAR to study snow/atmosphere interactions in polar regions (Gallée et al, 2001).”

P. 2371, l. 4ff: The description here is somewhat difficult to follow. A figure may help to demonstrate the layer numbering and how the projections of the layers and the fluxes are handled and by which component of the model. This figure may be combined with figure 1 or 3? Refer also to chapter 3.2, where the rules for the layering of the snowpack are described.

To clarify Section 2.2, we divided the paragraph mentioned by Reviewer 1 into two parts. The first part describes the layering of the snowpack and

refers to section 3.2 where the rules that govern the layering are defined. The layer numbering has been also included on Fig. 1. The second part describes how the model handles the local slope and its impact on fluxes and simulation outputs.

P. 2372, ch. 2.3: The previous stand-alone version of CROCUS used the cloudiness to divide the radiation into direct and diffuse short-and long-wave radiation. Is this not needed any more? If coupled to an atmospheric model, it can deliver directly the needed radiative fluxes. But what happens if CROCUS/SURFEX is run in the standalone mode?

Cloudiness is not anymore an input variable of Crocus/SURFEX. At present, the model uses as an input the total incoming shortwave radiation (diffuse+ direct) and longwave radiation. In stand-alone mode, the user must provide these two fluxes. In coupled mode, radiative forcing are delivered by the atmospheric model. The incoming radiation is then split by Crocus into three bands using empirical coefficients. As mentioned in the conclusion, the solar radiative transfer through the snowpack will be revisited and it will allow to include forcing from an atmospheric model where incoming shortwave radiation is partitioned into several bands.

P. 2374, eq. 3: In my opinion, in the current form the equation for s_{fall} always returns a value of 0.1.

As noted by Reviewer 1, the expression for s_{fall} in Eq. (3) was wrong. We modified it and used:

$$s_{\text{fall}} = \min [\max(0.08U + 0.38, 0.5), 0.9]$$

instead of:

$$s_{\text{fall}} = \min [\max(0.08U + 0.38, 0.8), 0.1]$$

P. 2375, l. 5f: Give a bit more detail how a thin fresh snow layer is handled in the model. Can it be just one layer or always at least three layers? When does the model switch to the maximum number of layers.

For snowfall on bare ground, the number of layers, N , in the snowpack depends on the amount of fresh snow and the user-defined maximum number of layers. Its minimum value is the minimum number of layers, set to 3 in Crocus/SURFEX. For more understanding, we mentioned explicitly in section 3.2 the equation that gives N . The number of effective layers in the snowpack then evolves throughout the winter season. It may reach occasionally the maximal number of layers when the snowpack consists in

an accumulation of many layers made of different types of snow grains.

P. 2378, ch. 3.5: If I understand correctly, in the stand-alone runs the blowing snow is actually not transported, but rather the impact on the physical properties of the top layer(s) is considered. Is this also the case in the multi-grid simulations meaning that the transport of snow from one grid cell to another cell is not possible? According to ch. 5.3, if coupled to Meso-NH, snow can be transported. However, the description of the implementation of this process is not very convincing. It lacks many details (especially if compared to the rest of the manuscript) and refers to a 1-page abstract in the proceedings of a conference. I recommend to delete this chapter and to refer inch. 3.5 to the work in progress for the model coupled to Meso-NH.

Yes, the routine SNOWCRODRIFT, described in Sect. 3.5, aims at simulating the effects of snow transport by the wind on the physical properties of the snowpack (density, grain characteristics). In stand alone mode, snow is not redistributed from a grid cell to another even if the simulation is multi-grid (see the simulation over the Grandes Rousses ranges in Sect. 5.2). However, snow transport can be explicitly simulated when Crocus is coupled to a meso-scale atmospheric model (Meso-NH). This work is in progress and its full description falls beyond the scope of this paper. It will be published soon. We changed the structure of this paper as suggested by Reviewer 1. Sect. 5.3 and Fig. 8 have been removed and the future coupling with Meso-NH is mentioned at the end of Sect. 3.5 and in the conclusion:

- Sect 3.5: "Note that, in stand alone mode, Crocus does not handle explicitly wind-induced snow redistribution since grid points are treated independently from each other. A work in progress develops the coupling between Crocus and the meso-scale atmospheric model Meso-NH (Lafore et al., 1998) to simulate blowing snow events in alpine terrain."
- Conclusion: "The coupling of Crocus with the atmospheric model Meso-NH is also in progress and will lead to the inception of a modeling platform dedicated to the simulation of the snowpack evolution during snow-drift events."

P. 2383, l. 5ff: What input information regarding the soil is needed to use ISBA? Does the user need to provide the information?

ISBA requires information concerning the soil texture (root fraction, clay, sand and silt fraction). They can be provided by the user for point specific simulation or taken from global database available at 1km for distributed simulations (ECOCLIMAP : Masson et al., 2003). We added a paragraph

that describes the input data required by ISBA in Sect. 3.8.

P. 2385, l. 3ff: Is there any limit for the flow rate of liquid water from one layer to the next?

Any water in excess of the maximum holding capacity for liquid water is drained into next layer down. The flow rate is not limited and the formation of a capillary barrier is neglected. We added a sentence in section 3.10 to precise this point : "The model considers only gravitational flow and neglects the formation of capillary barriers (Jordan, 1995)"

P. 2388, l. 24f: Give information if and where the file with the input data is publicly available.

We added a reference to the paper of Morin et al (2012) that described the 18-year forcing and evaluation dataset at Col de Porte and its availability.

P. 2390, l. 13ff: What about other parameters like temperature and pressure? Were they also corrected according to topography?

SAFRAN provides meteorological forcing at 300 m elevation steps. Therefore, the meteorological forcing contains already the influence of the topography. The parameters (including temperature and pressure) were then simply distributed at each grid point (elevation h_p) using a linear interpolation of the SAFRAN forcing taken at h_1 and h_2 ($=h_1+300\text{m}$) with $h_1 \leq h_p \leq h_2$.

Technical corrections:

P. 2366, l. 19: ... over the East Antarctic Ice Sheet (Dome C). Correction included

P. 2367, l. 4: ... of the properties of the interior of the snow-pack ... Correction included

P. 2368, l. 6: The ECMWF model has a different name, hasn't it? The model is named HTESSSEL for Hydrology Tiled ECMWF Scheme of Surface Exchanges over Land. We changed the name in the paper.

P. 2369, l. 6: ...the conductive heat flux ... Correction included

P. 2371, l. 3: ... accounted for in CROCUS ... Correction included

P. 2371, l. 11: ... needs to be taken into account ... Correction included

P. 2371, l. 21: These variables ... Correction included

P. 2373, l. 8f: ...described in detail. Correction included

P. 2380, l. 5: I am not familiar with the term “snow browning”. Is it normally used? ”Snow browning” is not commonly used and we decide to remove this term from the paper. We only mention ”the deposition of light absorbing impurities”

P. 2380, l. 13: micro meter, not mm. Correction included

Figures 4 and 6: In the printed form, axis labels and / or legends are not readable. Figures 4 and 6 were modified accordingly.

Figures 8 and 9: These figures are essentially identical to those published in Brun et al., 2011. I don’t think they need to be reproduced. These figures illustrates results of a coupled snow/atmosphere simulation in Antarctica. Since we removed Sect. 5.3 ,it is the only illustration in the paper of the use of Crocus in a coupled mode. Therefore, we preferred keeping these two figures.