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Interactive comment on "On the assimilation of optical reflectances and snow depth observations into a detailed snowpack model" *by* L. Charrois et al.

Anonymous Referee #1

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SUMMARY OF THE PAPER

The study is motivated to examine how assimilation of remotely sensed reflectance data (visible and near-infrared) might benefit snow model applications, the limitations, and the advantages of also assimilating snow depth data. This is different from prior works, which have focused on assimilation of retrieved products (e.g., snow covered area) instead of basic reflectance data. The authors conduct the analysis at the Col du Lautaret site in the French Alps over five hydrologic years. They use the Crocus multi-layer snow model, which was updated with a radiative transfer model to output spectral reflectances for comparison/assimilation with remote sensing data (TARTES). While

the analysis focuses on MODIS spectral bands and overpass frequency (daily updates available), actual MODIS data are not used and instead synthetic data are applied. They create 300 Crocus ensembles assuming that the errors in the model are due to meteorological uncertainty and vary errors in meteorological variables and impurity deposition using first-order auto-regressive models and errors observed from comparing reanalysis at a nearby site (CdP). The authors then apply the Sequential Importance Resampling particle filter and consider multiple possible scenarios of data assimilation. The scenarios include: (0) no assimilation of any data, assimilation of (1) reflectance data only during clear sky periods (baseline), (2) reflectance data during all days in the year, (3) reflectance data only during October-December, (4) reflectance data only during January-April, (5) reflectance data after long snow-free periods but right before new snowfall, (6) reflectance data after those snowfall events, (7) snow depth data during clear sky periods, and (8) assimilation of both reflection data and snow depth (clear sky periods). The results show that reflectance assimilation improves simulation of SWE and snow depth over the case of no assimilation. Furthermore, the timing of reflectance assimilation is important and daily updates are not necessarily warranted as long as the available data are timed appropriately. Finally, assimilation of both reflectance and snow depth improves snowpack simulations relative to just assimilating reflectance.

GENERAL COMMENTS

- I think the authors have conducted a valuable and interesting analysis. To my knowledge, the assimilation of reflectance data is novel and the authors demonstrate a clear benefit for this practice. They have established a basis for future work that may have a greater impact, including the use of real-time remote sensing data from MODIS and operational implementations. I think the paper should be published pending attention to a suite of minor revisions.

- The manuscript lacks substantive discussion of the results, and this is the main weakness of the study in my opinion. I think the authors need to place some attention on

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contextualizing their results, comparing their results to prior research, and anticipating future work.

- I think it would be beneficial for the authors to discuss what is necessary to include a radiative transfer model like TARTES in a snow model (instead of an albedo parameterization). This is important because it seems that the only way to assimilate remotely sensed reflectance into an existing model is to ensure that it has the capability of outputting reflectance data at different wavelengths. Many, if not most, existing snow models do not have this capacity. So it would be useful to have some discussion about the changes required in the model structure, runtime, and operation, and what level of complexity is needed in order to achieve the methodologies demonstrated with Crocus.

- In several places in the manuscript, the authors use the word “envelops” as a noun, but it is a verb. I think they mean “envelopes” instead in some (but not all) of these cases. Please rectify this word usage.

SPECIFIC COMMENTS

1. The second paragraph of the abstract (page 6830, lines 11-22) does not make it consistently clear that MODIS data are not actually used in the study. The first sentence suggests MODIS reflectance data are used, but the subsequent sentences refer to MODIS-like data. The authors need to include additional clarification here.

2. The biases in shortwave and longwave radiation are of opposite sign (Table 1, left column). Does this reflect some specific shortcoming of SAFRAN, such as problems with a low bias in cloud conditions or a high bias in atmospheric transmissivity? In other words, are the radiation errors linked in some physical way, or is it just by chance that the biases are positive for shortwave and negative for longwave? Does vegetation/topographic shading at the CdP site factor into the positive SAFRAN shortwave bias, and does this influence the longwave estimation in any capacity? I recommend addressing these questions in the paragraph that discusses the discrepancies between

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SAFRAN and observations (page 6838, Lines 9-17). This paragraph currently focuses on temperature, precipitation, and wind speed but could be improved with more attention to the radiation components.

3. I am unsure why the shortwave perturbations are additive while the longwave perturbations are multiplicative (page 6839, lines 8-10). Please clarify the logic behind this decision.

4. The authors rightfully attempt to maintain physical consistency amongst the meteorological variables (page 6839, Lines 16-19). Are any efforts made to examine the physical consistency between shortwave and longwave radiation? For example, a high shortwave value and a high longwave value might not be physically realistic because the high shortwave implies no cloud cover whereas the high longwave value can imply cloud presence.

TECHNICAL CORRECTIONS

- Page 6830, Line 5: Uncertainties can never be ruled out in any type of dataset; they can only be identified and reduced through improved datasets. Please rephrase.

- Page 6830, Line 11 and Page 6832, Line 11: The full name of MODIS is “MODerate-resolution imaging spectroradiometer”. Please correct these lines.

- Page 6831, Line 9: Replace “reducing” with “reduce”.

- Page 6833, Line 6: Should read “statistics”.

- Page 6833, Line 25: Replace “including” with “includes”.

- Page 6835, Line 21: Replace “first” with “top” to be more specific to the location of these layers.

- Page 6837, Line 15: The phrasing would sound better as “other physical parameterizations”.

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- Page 6839, Line 21: Should read “captures”.

- Page 6840, Line 4: Based on Table 1, I think this should read “58.3” instead of “70”.

- Page 6841, Line 17: What do you specifically mean here by the “spread” in the melt-out date? Is this the range (max-min) or the variance or some other statistic? A definition of uncertainty in melt-out date appears later (page 6844, Lines 13-14), so it might be helpful to bring this definition earlier in the text.

- Page 6843, Line 16: Add “to” before “presenting”.

- Page 6846, Line 1: Should read “simpler” instead of “simplest”.

- Page 6847, Line 8: Add “to” after “according”.

- Page 6849, Line 6: Should read “cloud coverage” instead of “clouds coverage”.

- Page 6850, Line 13: Rephrase to say “The ensemble spread retrieves almost the same value as. . .”

- Page 6854, Line 21: Add “as” before “MODIS”.

- Page 6854, Lines 22-23: Rephrase to say “Combining reflectance assimilation with SD assimilation at 4 dates during the snow season leads to. . .”

- Page 6855, Line 11: Replace “what” with “which”.

- Page 6855, Line 18: Should read “through” instead of “though”.

TABLE AND FIGURE COMMENTS

- Figure 1c: The upper limit of the vertical axis cuts off the SWE ensemble. Please extend so the entire ensemble can be seen.

- Table 2: The understandability of this table would be improved if the column headings not only included the Figure reference, but also a brief description of what is represented in each experiment. For example, the “Fig. S2” column should also have a

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heading that says something like “Reflectance – all days” while the “Fig. S7” column should have a heading saying “SD – clear sky days”, etc. This will help the reader by not requiring them to keep searching for what is tested in each scenario.

Interactive comment on The Cryosphere Discuss., 9, 6829, 2015.