Dear anonymous reviewer 3,

We are grateful for your helpful an detailed comments which allowed us to improve our manuscript.

The text in *italic* contains your original comments, the normal text represents our responses to your comments whereas the text in **bold font** shows the modifications made to the manuscript.

Responses to your general comments:

1. *It is unclear what SAR image acquisitions are used in the study. There are discrepancies between the text, Table 1, and figures indicating some data were not used in certain parts of the analysis. If certain data were excluded, this should be made clear and the impacts on the assimilation process and Crocus snowpack evolution explained. Please see the specific comments on this for page 4894.*

   A total of 8 TerraSAR-X acquisitions were used in this study (from January 6th 2009 to March 24th 2009). Table 1 has been modified to detail all the dates of acquisitions.

   Table 1. TerraSAR-X acquisitions parameters

Parameter	**Value**
TerraSAR-X products	Single Look Complex Image
Frequency (GHz)	9.65
Channels	HH
Incidence angle (^{o})	37.9892
Mode	Descending
Acquisition dates (2009)	Jan 6th, 17th, 28th, Feb 8th, 19th, March 2nd, 13th, 24th
Resolution (m)	1.477 x 2.44
Calibration gain (dB)	49.6802

   The results and discussion sections (section 5) have been updated to improve clarity. The following changes have been made:

   - The text from "With pre-set air-snow interface ..." (p4896 line 9) to "...the average value of $\mathbf{R}$ = 0.03" (p4897 line 16) has been moved to the end of data assimilation section (section 3).
   - A figure has been added to show the implementation of the data assimilation process into Crocus and to define the "open loop", "guess" and "assimilated" snow profiles.

     A paragraph has been added to comment on this figure: **Figure 8 presents the implementation of the SAR data assimilation process into Crocus. The top part of the figure shows the Crocus simulation of snowpack without assimilation of SAR data. At instant t, Crocus simulates the snow stratigraphic profile from the previous state of snowpack**

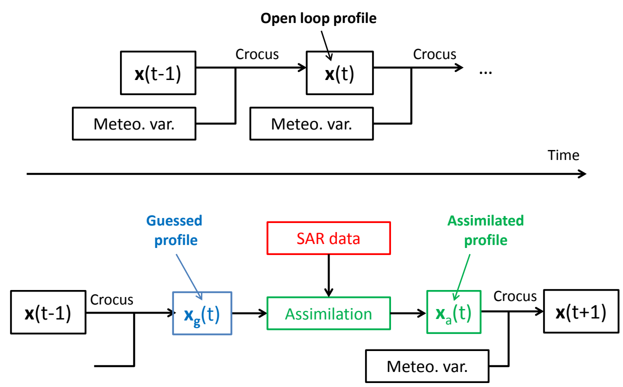

Figure 8. Implementation of SAR data assimilation in the Crocus temporal simulation of a snowpack.

(instant $t-1$) and the meteorological data hourly provided from SAFRAN. The time lag between instant t and instant $t-1$ is therefore one hour. We call this simulation "open-loop". The bottom part of the figure shows the implementation of data assimilation into the execution of Crocus. Each 11 days, a TerraSAR-X acquisition is used to modify the snowpack stratigraphic profile of Crocus through an assimilation process. The snow profile before assimilation is called "guess" and the analyzed snow profile after assimilation is called "assimilated". Consequently, at the date of the first TerraSAR-X acquisition (January 6th), open loop and guess profiles are identical. Once this first SAR acquisition is assimilated into Crocus, guess and assimilated profiles differ. This modification permits to constrain a physical snowpack simulation using external information acquired at different dates.

- Figures 8 and 9 in the original manuscript have been updated with the latest results (using a newer version of Crocus, with all TerraSAR-X acquisitions included). They are now numbered 9 and 10 due to the addition of a figure above. We have also added a table comparing of the RMSE between σ_{snow} (EBM simulations) and σ_{TSX} (TerraSAR-X observations) to highlight improvements made by data assimilation.

  The paragraph of p4898 from line 8 to line 14 has been updated with: **The agreement between TerraSAR-X reflectivity and the output of the EBM using Crocus simulated profiles can be observed in Figure 9, where EBM simulations of assimilated profiles converge gradually with time toward the TerraSAR-X backscattering coefficient. The graph correspond to March 2nd, 2009 shows that the convergence has been reached at all altitudes, as EBM simulations of guess and assimilated profiles are much closer to the TerraSAR-X measurements than the open loop profiles.**

  Table 2 shows a comparison of RMSE between simulated and measured reflectivities for different types of profile: open loop, guess and assimilated. It can be observed that the σ_{snow} converge gradually toward the σ_{TSX} for the guess and assimilated profiles. At the last date of acquisition (March 24th), the RSME for guess and assimilated profiles

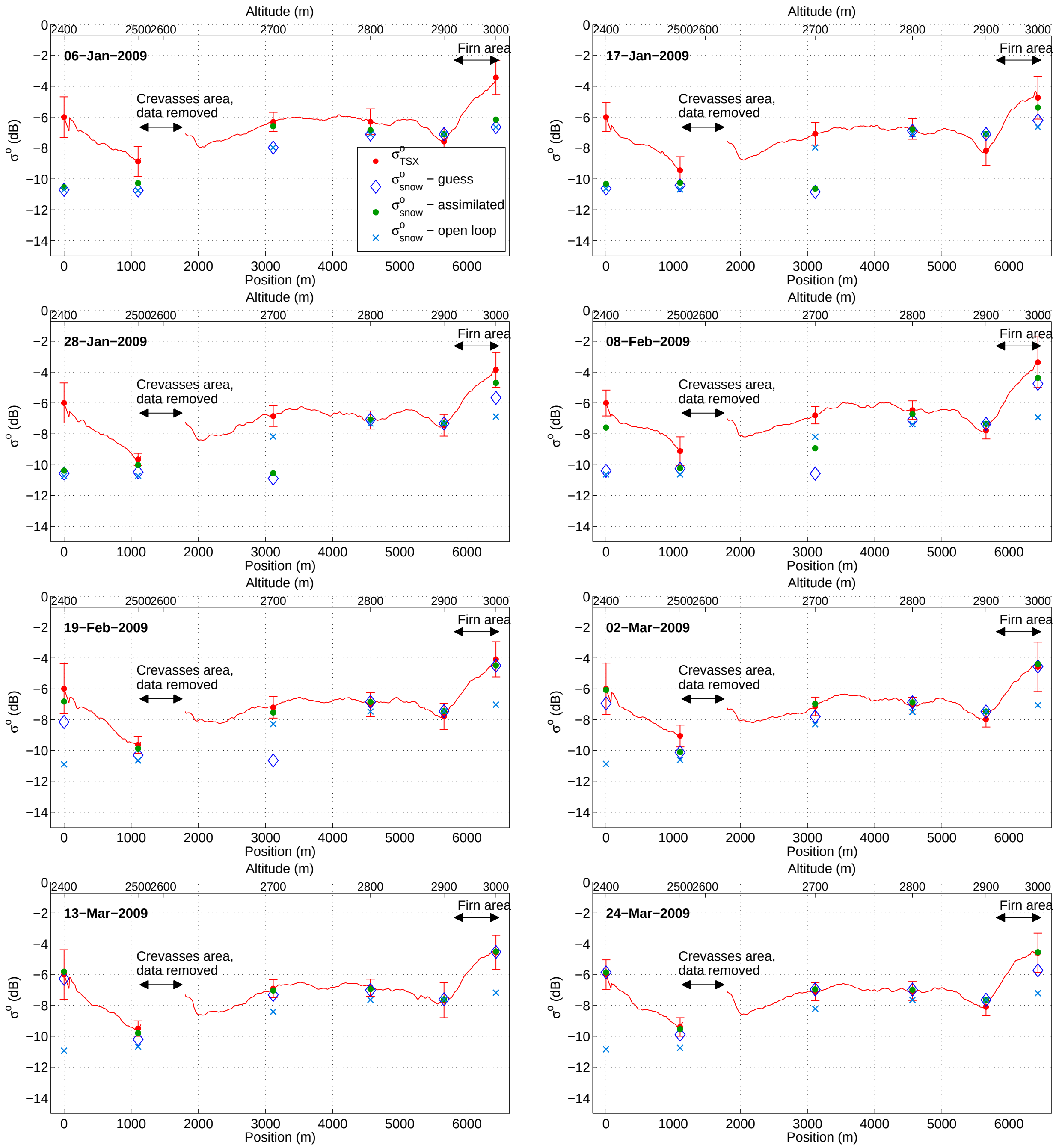

Figure 9. Results of simulation and analysis using TerraSAR-X acquisitions performed on March 2nd, March 13th and March 24th of 2009. σ_{TSX} (red) are mean values obtained from the SAR images over the Argentière glacier (corresponding to the red line of Figure 5). σ_{sim} (blue) represents the output of simulations using Crocus snowpack variables as inputs. Simulations obtained after data analysis are shown in green. Error bars show the standard deviation of the measured reflectivities.

Table 2. Comparisons of RMSE (dB) between simulated, $\sigma_{snow} = H(\mathbf{x})$, and measured, σ_{TSX}, reflectivities for different types of profiles

Date	$\mathbf{x}$ = open-loop	$\mathbf{x}$ = guess	$\mathbf{x}$ = assimilated
Jan 6th	3.6256	3.6256	3.2697
Jan 17th	3.1677	3.3645	3.1302
Jan 28th	3.4697	3.5326	3.3718
Feb 8th	3.4649	3.3619	1.8071
Feb 19th	3.3708	2.6463	1.2729
Mar 2nd	3.6877	1.7992	1.2276
Mar 13th	3.7383	1.2482	1.0652
Mar 24th	3.1840	0.6757	0.4370

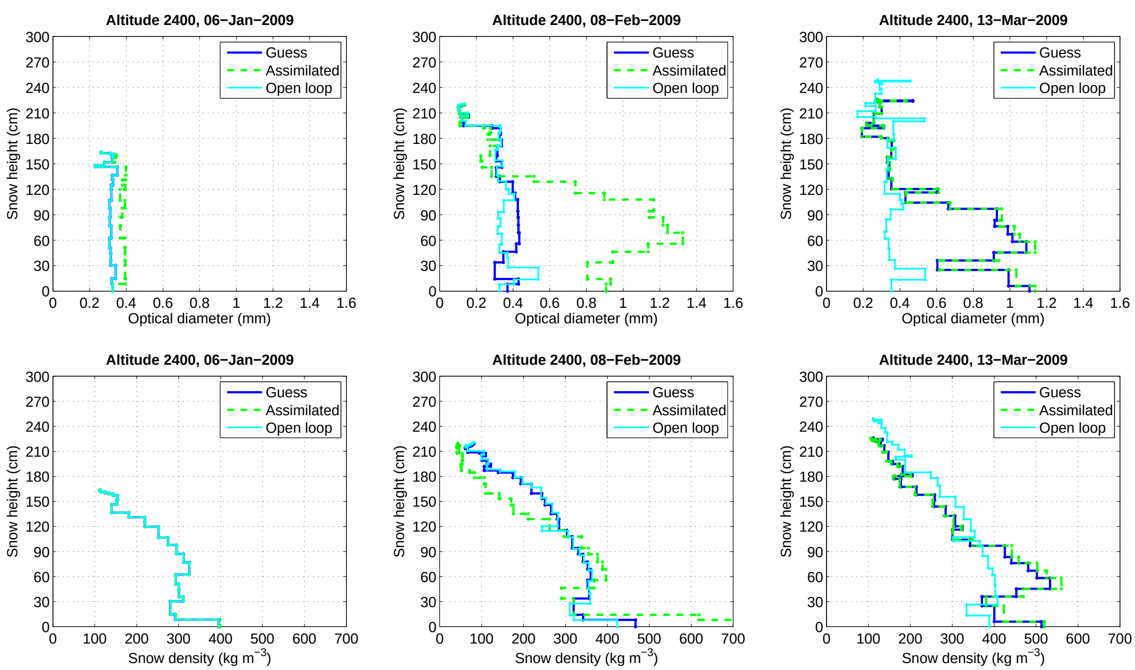

Figure 10. Results of 1D-VAR data assimilation on some Crocus profiles, which show changes made by the data assimilation algorithm on grain optical diameter (top) and snow density (bottom) on January 6th (left), February 8th (middle) and March 13th (right). Note that the assimilation only affects directly the grain optical diameter and snow density. These direct modifications are injected into Crocus, propagate in the subsequent simulations, and may then lead to open-loop and assimilated profiles with different snow heights.

are below 1 dB while the open loop profile still gives a RSME higher than 3 dB.

The discussion paragraph of p4898 from line 15 to line 28 has been updated with a new discussion of the results and a conclusion: **Figure 10 shows a detailed analysis of the modifications of the optical diameter and density of each layer due to data assimilation on January 6th, February 8th and March 13th, 2009 at the altitude of 2400 m. It can be observed that the assimilation algorithm tends to modify the grain optical diameter and density in the deep layers which have the strong influence on the backscatter intensity and whose slight modification reduce significantly the discrepancy between TerraSAR-X observations and Crocus simulations. The speed of densification process is therefore faster in the Crocus simulations with assimilation. The snow profile on February 8th records a large change in the optical diameter (from 0.4 mm to 0.8-1.3 mm in the layers from 0 to 100 cm of snow height), which results in a variation in the simulated backscattering coefficient for the assimilated profile, which can be observed in figure 9 at 2400 m. Note that this large increase in the diameter results in a large discrepancy between open loop and guess profiles on March 13th. It can also be noted that there is a difference of 20 cm in total snow depth between open loop and close loop simulation on March 13th, which shows that the modifications of optical diameter and snow density made by data assimilation also modify indirectly others physical properties of the Crocus simulated snowpack.**

These results show that we have combined three models (Crocus, EBM, adjoint model) and the TerraSAR-X data to constrain spatially and temporally the snowpack evolution. It is the first time that active X-band radar data are not used directly to perform an assessment of snowpack properties, but used to estimate physical parameters of each snow layer through a data assimilation algorithm. This algorithm needs to be further validated in the future using in-situ measurements and advanced 3-D imaging techniques (Ferro-Famil et al., 2012).

- The first paragraph of the conclusion section has been rewritten: **This study presents a new system using data assimilation and a multilayer snowpack backscattering model based on the radiative transfer theory to constrain the evolution of a snowpack simulated by the snow model Crocus. The proposed new backscattering model adapted to X-band and higher frequencies enables a fairly accurate calculation of EMW losses in each layer of the snowpack. Through the use of 1D-VAR data assimilation based on the linear tangent and adjoint operator of the EBM, we are able to modify in a physically consistent way the snowpack profiles calculated by the snowpack evolution model Crocus. This process has been applied to a time series of TerraSAR-X images and Crocus simulations during the winter of 2008-2009 over the Argentière glacier. Results show that SAR data can be taken into account to efficiently modify the evolution of snowpack simulated by Crocus. This process can be further developed and used in real application such as large-scale snow cover monitoring or snowpack evolution through a long period of time.**

2. *Some justification is needed for the choice of snowpack parameters in the sensitivity analysis (section 4.3). In particular, grain sizes used are quite large (0.5-1mm) and roughness values describing the correlation length and rms height are taken from a study examining these parameters for bare soil, not snow/ice surfaces. Please also see specific comments for page 4895.*

The optical grain diameter from 0.5 to 1 mm correspond to the optical radius of 0.25 to 0.5 mm. These values correspond to the densified snow layers, which represent the main contributors to backscattering at X-band. The sensitivity test has been rerun for wider range of optical diameter (0.2-1 mm). The roughness of snow-glacier interface (rms height and correlation length) hasn't been studied in the literature and its definition is rather delicate. The paper of Lacroix et al. (2008) measures only the air-snow surface roughness, which gives low contribution in the total backscattering at X band. We have therefore chosen the a priori values of rms height and correlation length from the paper of Oh et al. (1992). These values correspond to a smooth interface of air-snow and a rough interface of snow-ice.

In the manuscript, the sensitivity test of the EBM now consists of two figures, which show the sensitivity of the EBM to optical diameter and snow density.

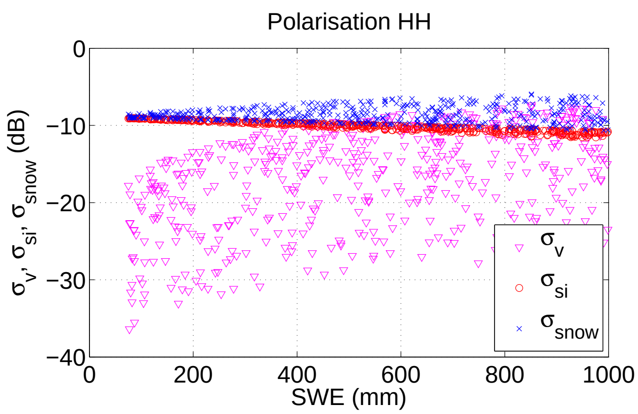

Figure 3. Test of EBM simulations on X-band, HH polarization for varying snow depth and optical diameter: snow density 250 kg m^{-3}, optical diameter 0.2-1 mm, snow depth 30-400 cm. The glacier roughness is fixed at $\sigma_{si} = 0.9\ cm$ and $l_{si} = 8.6\ cm$.

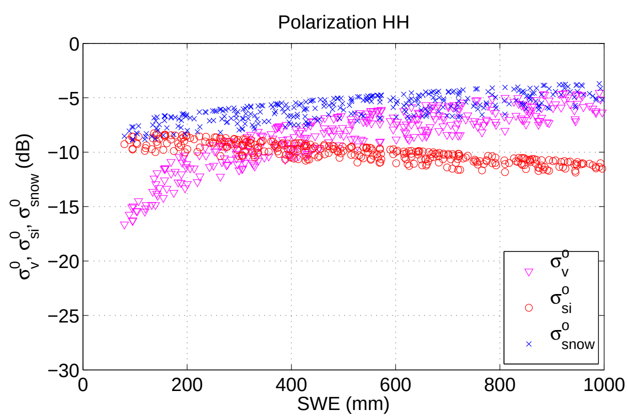

Figure 4. Test of EBM simulations on X-band, HH polarization for varying snow depth and density: snow density 200-600 kg m^{-3}, optical diameter 1 mm, snow depth 30-400 cm. The glacier roughness is fixed at $\sigma_{si} = 0.9\ cm$ and $l_{si} = 8.6\ cm$.

The text has been updated accordingly.

P4895, line 17 - P4896, line 7: **In order to assess the sensitivity of the EBM outputs with**

respect to the different properties of a snowpack, a set of simulations were run for various snowpack structures. A random dataset was generated corresponding to a snow height varying from 30 cm to 400 cm (SWE from 75 to 1000 mm with snow density set at 250 kg m^{-3}). Measurements of the roughness parameters of air-snow interface and snow-ice interface are not available, therefore empirical values for the correlation length l and the rms height σ from Oh et al. (1992) have been used. The values of $\sigma_{as} = 0.4\ cm$ and $l_{as} = 8.4\ cm$, equivalent to a slightly rough surface, are used for the air-snow interface; whereas $\sigma_{si} = 0.9\ cm$ and $l_{si} = 8.6\ cm$, corresponding to a rough surface, are chosen for the snow-ice interface due to the characteristic of ice beneath the snowpack over the study area.

The results of EBM simulations are plotted vs SWE in figures 3 and 4. In figure 3, snow density is fixed at 250 kg m^{-3} while the optical diameter is varied from 0.2 to 1 mm. The backscattering contribution at the air-snow interface, being inferior to -40 dB, is not represented here. As the SWE increases, the volume backscattering coefficient becomes more important until it reaches a value comparable to the snow-ice interface backscattering. The vertical dispersion of the volume backscattering represents the sensitivity of the EBM to optical diameter. Lowest values correspond to an optical diameter of 0.2 mm, whereas the highest ones correspond to an optical diameter of 1 mm.

In figure 4 where the optical diameter is fixed at 1 mm and snow density varies from 200 to 600 kg m^{-3}, the vertical dispersion of the volume backscattering represents the sensitivity of the EBM to snow density. By comparing figures 3 and 4, we can observe that the EBM is strongly sensitive to the optical diameter and moderately sensitive to the snow density.

3. *The results from this study need to be better contextualized with the existing literature. Much work has been performed on assessing snowpack properties from radar observations. How are the techniques presented here advancing this knowledge? This should be included in the results/discussion or conclusions section.*

The results section has been modified to address the novelty of this study: **These results show that we have combined three models (Crocus, EBM, adjoint model) and the TerraSAR-X data to constrain spatially and temporally the snowpack evolution. The use of data assimilation on SAR data to predict certain physical properties of snowpack has been developed in Nagler et al. (2008); Takala et al. (2011). However, It is the first time that active X-band radar data are not used directly to perform an assessment of snowpack properties, but used to estimate physical parameters of each snow layer through a data assimilation algorithm. This algorithm needs to be further validated in the future using in-situ measurements and advanced 3-D imaging techniques (Ferro-Famil et al., 2012).**

[Nagler et al., 2008] Nagler, T., Rott, H., Malcher, P., and Muller, F.: Assimilation of meteorological and remote sensing data for snowmelt runoff forecasting, Remote Sensing of Environment, 112, 1408 1420, Remote Sensing Data Assimilation Special Issue, 2008.

[Takala et al., 2011] Takala, M., Luojus, K., Pulliainen, J., Derksen, C., Lemmetyinen, J., Karna, J.-P., Koskinen, J., and Bojkov, B.: Estimating northern hemisphere snow water equivalent for climate research through assimilation of space-borne radiometer data and ground-based measurements, Remote Sensing of Environment, 115, 3517 3529, 2011.

[Ferro-Famil et al., 2012] Ferro-Famil, L., Leconte, C., Boutet, F., Phan, X., Gay, M., and Durand, Y.: PoSAR: A VHR tomographic GB-SAR system application to snow cover 3-D imaging at X and Ku bands, in: Radar 720 Conference (EuRAD), 2012 9th European, pp. 130133, 2012.

4. *Figures 1 and 2 are taken from other studies. At minimum, this should be made clear*

   Corrected: The original work from which figure 1 has been sampled is now properly cited. The authors gave us the right to use this figure. Figure 2 has been removed from the manuscript since it was not necessary.

5. *The overall importance or relevance of SAR assimilation into snowpack models is not made very clear. The introduction section could more directly identify existing knowledge gaps/limitations (i.e., few in-situ observations exist necessary to evaluate, inform, and adjust snowpack models... which are critical for snow cover forecasting, water resource monitoring, and avalanche prediction) and the provided value/contribution of this study (SAR observations may potentially be incorporated into snow models, thus improving confidence in their results!). Without revision here, the purpose of the study remains somewhat ambiguous.*

   The main goal of the study is to constrain the Crocus snow model using SAR data, because Crocus is currently running without any constraint from in-situ measurements. The lack of in-situ measurements is due to the geographical and meteorological difficulties on the high altitudes of the Alps. The SAR acquisitions can provide dense information both spatially and temporally and therefore can help us overcome these difficulties The introduction has been updated with the purpose of the study. The new text of the introduction section is shown below.

6. *The introduction section would benefit from reorganization and revision. The first paragraph gives the problem statement, which concludes on the general techniques employed in the study. In particular, the techniques could be more explicitly stated and summarized (the backscattering model, SAR platform, and snowpack model should all be introduced in (or near) the first paragraph with note that they are more thoroughly introduced in the following paragraphs and/or the methods section). Here, referencing Figure 3 (which is incredibly useful!), would be ideal. I suggest the authors consider moving Figure 3 to become Figure 1. Otherwise, the reader is tasked with attempting to visualize this flow chart without knowing that it later depicted as a figure!*

   The entire introduction section has been revised, the schematic figure has been moved to the introduction section. The new text of the introduction section is shown in the answer to comment number 6 above.

   Accurate knowledge of snowpack internal structure is critical for better understanding the snowpack evolution over time, and is essential to snow forecasting, water resource monitoring and prediction of natural hazards, such as avalanche warning. For this purpose, snow metamorphism models, such as Crocus (Brun et al., 1992; Vionnet et al., 2012), are developed in order to simulate the evolution of snowpack based on meteorological variables. These models are currently limited due to the lack of in-situ snow stratigraphic measurements. For example, in the French Alps, the network of snow and meteorological observations contains about 150-180 stations, which is not enough to adjust a snow model to predict the state and the spatial variability of snowpack at small scale (20 m). This limitation results in potential divergences, accumulated errors and limited spatial resolution of the model. Therefore,

exogenous data are crucial in order to constrain the simulator and improve its performance over time.

On the other hand, the radiometric properties of a snowpack measured at high frequencies depend strongly on its main physical parameters, like its depth, snow grain size, density. The Electromagnetic Backscatttering Model (EBM) initially developed by Longepe et al. (2009) based on Dense Media Radiative Transfer (DMRT) theory, allows to simulate the backscattering coefficient σ^0 of dry snow from C-band (5 GHz) to Ku-band (14 GHz). The air-snow σ_{as} and snow-ground σ_{sg} (or snow-ice σ_{si}) interfaces backscattering components are calculated using the Integral Equation Model (IEM) developed by Fung and Chen (2004). The snow permittivity is calculated using the Strong Fluctuation Theory (SFT) (Stogryn, 1984), which was validated on snow by Wang et al. (2000) for frequencies from 5 GHz to 37 GHz. With this model, we can calculate the total backscattering coefficient σ^0_{pq} for different polarization channels (p, q = H or V) from the physical features of each snow layer, the roughness of air-snow and snow-ice interfaces, and specific radar illumination (frequency, incidence angle).

The new generation of Synthetic Aperture Radar (SAR) satellite data provides images with metric resolution and short revisit time. The TerraSAR-X satellite, with 1.477 m x 2.44 m resolution and 11 days revisit time, gives dense information both spatially and temporally on snowpack evolution. In this study, we propose a new process which uses these multi-temporal images of TerraSAR-X to constrain the Crocus model through data assimilation.

Data assimilation has been widely used in meteorological studies (Courtier et al., 1998; Uppala et al., 2005) and land surface modeling (Slater and Clark, 2006; De Lannoy et al., 2010; Toure et al., 2011). Data assimilation using physically-based multilayer models has been initiated in recent studies, using passive microwave radiance (Toure et al., 2011) or albedo observations (Dumont et al., 2012). The advantages of assimilation using SAR images are the low sensitivity to atmospheric conditions, the higher resolution and the volume-sensitive backscattering. The assimilation techniques have proven effective in combining observations and *a priori* information to more realistically simulate snowpack conditions (i.e., an *a posteriori* state). The *a priori* information is often referred to as "guess parameters", whereas the *a posteriori* state is called "the analysis". The guess parameters in this study are the physical properties of each snowpack layer simulated using a snow evolution model. The analysis is obtained by modifying the guess information based on the backscattering coefficient obtained from SAR acquisitions, according to the error statistics of both model and observations. The algorithm then re-initializes the snow model with the modified snowpack physical parameters, allowing it to continue the simulation of snowpack evolution, with adjustments based on remote sensing information. The intermittent assimilation algorithm is carried out each time a new SAR acquisition is available, therefore the assimilation is propagated over time, which allows us to constrain the snowpack simulation using remote sensing observations.

This study reports for the first time, on a new process based on the DMRT model (Longepe et al., 2009) and the one-dimensional variational analysis (1D-VAR) (Courtier et al., 1998)

to assimilate the TerraSAR-X data into the snow model Crocus (Vionnet et al., 2012). A global schematic of this process is presented in figure 1. Section 2 introduce the Crocus snowpack evolution model. Section 3 described the DMRT electromagnetic backscattering model. The 1D-Var data assimilation method is presented in section 4. Section 5 contains the study of simulations and sensitivity of snowpack at X-band. Section 6 presents the first results and discussion of data assimilation method in the particular case of the Argentière glacier, where the ground beneath the snow consists of ice.

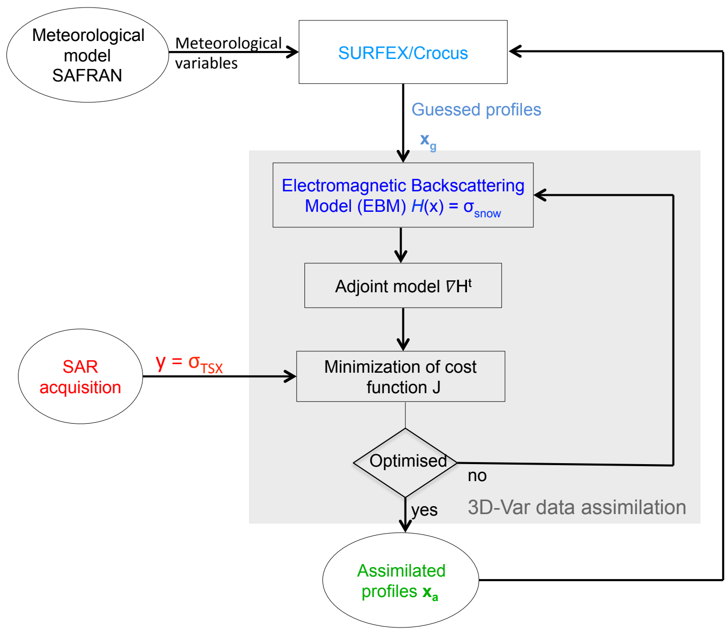

Figure 1. Global schematic of the data analysis used in this study. The inputs of the process are the SAR reflectivities, σ^0 (observation) and the snowpack stratigraphic profile calculated by Crocus (guess). The output is the analyzed snowpack profile $\mathbf{x}$ that minimizes the cost function.

7. *Snowpack modeling is mentioned throughout the introduction section, but not in the first paragraph (as the other methods are noted). Further, the specific model used (Crocus) or how these models function is nowhere stated in the introduction (as the EBM and assimilation techniques are explained). I would suggest the authors explicitly state within the first paragraph that this study uses TerraSAR-X, Crocus, an EBM, and assimilation techniques. Then, in the following introduction paragraph(s), briefly introduce each method and their context with relevant studies. I suggest considering scaling back methods details within the introduction section. Much material is presented here that is later repeated in the methods sections. Instead, I would suggest synthesizing this content into one or two sentences for each method and then put this into in a single paragraph in which you describe the overall method of the paper (and reference the flow chart figure 3). As a potential problem for the current layout, ?guess? variables/parameters and ?the analysis? are defined in the introduction (p 4884 lines 4-5) and then referred to in the methods section (p 4892 line 23). Readers unfamiliar with this terminology may get confused and need to flip back to the introduction to get their definitions.*

The entire structure of the introduction has been modified (see response to your comment 6).

8. *Along the same lines, the difference between open loop and closed loop Crocus runs needs to be better explained. Only is the open loop method (i.e., without any SAR assimilation) defined in the text. It should be made clear in the text that "closed loop" is the same as the "analysed" situation (i.e., with SAR backscatter assimilation), if I am understanding this correctly. As it stands, the reader is left to decipher the differences. Please use a consistent terminology for the different model cases throughout the paper text and figures. These different model set-up scenarios need to be made clear. Per- haps consider adding a table to define the cases (guessed/Crocus, analysed/closed- loop/SAR-assimilated, open-loop Crocus). Alternatively, Figure 3 could be updated showing the different experimental set-ups.*

   A schematic (figure 8) has been added to clarify the implementation of the assimilation process into Crocus. In this schematic, the open loop, guessed and assimilated notations were explained more clearly. The modifications on the result section can be viewed in the answer to the first general comment.

9. *While EBM-produced and SAR-observed backscatter are in better agreement, it remains unclear to what extent the snowpack is better represented (i.e., the overarching goal of the study) without in-situ validation. Furthermore, there is no attempt to quantify the differences between observed backscatter and that modeled by Crocus (with and without assimilation). This is critical, as it is unclear which method (Crocus with "guessed" profiles, EBM "analysed" profiles (aka closed loop), or the Crocus "open-loop" profiles (without assimilation) works best or if there is any real (statistical) difference between the methods. Which best matches the observed backscatter? How does this vary over space and time? I feel this needs to be quantified.*

   The study has been improved since the submission of the paper. A newer version of Crocus has been updated and some bugs in the implementation of the data assimilation algorithm have been fixed. New results have been calculated and presented in figure 9 and 10 in the answer of the first general comment. These results represent better the effect of data assimilation on Crocus. We have added a table of statistical comparisons of RMSE between EBM simulations of "open-loop, guess and assimilated" profiles to TerraSAR-X measurements (Table 2), which shows that the EBM simulations of guess and assimilated profiles converge toward TerraSAR-X backscattering coefficients. In order to verify that the modifications made by assimilation is better than Crocus open-loop, we need to validate the whole process against snow stratigraphic in-situ measurements or using 3-D SAR measurement (Ferro-Famil et al., 2012).

10. *In figure 9 it is clear that the guessed and analysed profiles are nearly identical, whereas the open-loop profile does not match the other two. My understanding is that the dark blue lines (guessed profile) is from the SAFRAN-forced Crocus input into the EBM, whereas the green (analysed) profiles then incorporate the SAR data in the assimilation method to modify snowpack properties in Crocus. If this is the case, and there is little to no difference between modeled and SAR-incorporated snowpack parameters, then what is the value of the whole method of assimilating SAR observations?*

    A figure has been added to clarify the different between open-loop, guess and assimilated snow profiles (figure 8). The updated results and the RSME table show the improvement of data assimilation in order to reduce the discrepancy between EBM simulations and TerraSAR-X measurements. The new text of the result section is detailed in the answer of the first general comment.

Responses for your specific comments:

1. P. 4882 Line 2: ”structure” replaced with ”physical”

2. P. 4882 Line 6: Changed to ”These snowpack properties”

3. P. 4882 Line 8: ”calculates the simulated” replaced with ”simulates”

4. P. 4882 Line 12: ”structure” replaced with ”physical”

5. P. 4882 Line 14: corrected

6. P. 4882 Lines 14-16: Sentence changed to ”Results of data assimilation using TerraSAR-X images on specific site Argente‘re glacier (Mont-Blanc massif, French Alps) show that we can take into account the SAR data in the evolution of snowpack simulation.”

7. P. 4882 Line 18: ”essential” replaced with ”critical”

8. P. 4882 Line 19: corrected

9. P. 4882 Line 19: corrected

10. P. 4882 Line 19: Replaced ”provides greater benefit” with ”is essential”

11. P. 4882 Line 20: Replaced ”snow avalanches warning” with ”avalanche warning”

12. P. 4882 Line 21: corrected

13. P. 4882 Line 23: corrected

14. P. 4882 Line 23: The limitation of Crocus is detailed more clearly

15. P. 4882 Lines 23-25: The abstract and introduction sections have been improved

16. P. 4883 Line 1: corrected

17. P. 4883 Line 1: Replaced ”analyze” with ”evaluate”

18. P. 4883 Line 1: Replaced ”calculated” with ”simulated”

19. P. 4883 Line 2: Removed ”these”

20. P. 4883 Line 2: Replaced ”values” with ”snowpack properties”

21. P. 4883 Line 11: Replaced ”model” with ”EBM”

22. P. 4883 Line 15: Replaced ”strong variations of various” with ”highly variable”

23. P. 4883 Line 16: Snowpack layer thicknesses stated.

24. P. 4883 Line 19: Replaced ”cover maps” with ”mapping”

25. P. 4883 Line 20: Changed to ”inverting the EBM”

26. P. 4883 Line 21: Inserted "snowpack" before "properties"

27. P. 4883 Line 26: Replaced "meteorology" with "meteorological"

28. P. 4883 Line 27: Inserted "and" before "land"

29. P. 4883 Line 28: corrected

30. P. 4883 Line 29: Replaced ", related to snow" with "utilizing"

31. P. 4884 Line 1: replaced "or" with "and"

32. P. 4884 Line 1: Replaced "assimilation" with "observations"

33. P. 4884 Lines 1-3: Sentence changed to "Such assimilation techniques have proven effective in combining observations and a priori information to more realistically simulate snowpack conditions (i.e., an a posteriori state). "

34. P. 4884 Line 4: "guess parameters" has been put in quotes

35. P. 4884 Line 5: "the analysis" has been put in quotes.

36. P. 4884 Line 6: Changed to "a snow evolution model"

37. P. 4884 Lines 11-12: Changed to "permits informing snowpack simulation using. . ."

38. P. 4884: The schematic figure has been improved in detail and moved to the introduction section.

39. P. 4884 Line 14: Replaced "The" with "A"

40. P. 4885 Line 1: EWM defined as "Electromagnetic Wave"

41. P. 4885 Line 17: RT defined as "radiative transfer (RT)"

42. P. 4885 Line 17: Changed to "The first order solution of the radiative transfer (RT) equation. . ."

43. P. 4885 Line 17: Replaced "a total" with "the total"

44. P. 4886 Line 2: Replaced "over" with "from"

45. P. 4886 Line 2: Replaced "ground" with "snow-ground interface"

46. P. 4886 Lines 2-3: Abbreviations used in the figure have been corrected

47. P. 4886 Line 9: Changed "Fung et al. (Fung and Chen, 2004)" to "Fung and Chen (2004)"

48. P. 4886 Lines 21-22: Changed "(Fung and Chen, 2004)" to "Fung and Chen (2004)"

49. P. 4887 Lines 9-10: Replaced "strong variations of various" with "strongly variable"

50. P. 4887 Line 17: Reference style corrected.

51. P. 4887 Line 17: Replaced "such medium" with "such a medium"

52. P. 4887 Line 18: Changed ”effect” to ”effects”

53. P. 4889 Line 11: Added ”(attenuation)” after ”intensity loss”

54. P. 4890 Line 2: Added reference to figure 1 after ”the thickness of layer k”

55. P. 4891 Line 4: Changed the sentence to ”In this study within the French Alps, these meteorological conditions are taken from the SAFRAN reanalysis, which combines. . .”

56. P. 4891 Line 5: Changed ”radioprobes” with ”radiosondes”

57. P. 4891 Line 11-12: Replaced ”. . . ” to ”etc.”

58. P. 4891 Line 18: Replaced ”observation” with ”observational”

59. P. 4891 Line 21: Changed to ”searching for a solution”

60. P. 4892 Line 13: R has been put in parentheses

”61. P. 4892 Line 13: Changed to ”of the model (B; i.e., the guess error covariance).”

62. P. 4893 Line 5: Replaced ”of natural” to ”of a natural”

63. P. 4893 Line 5: Changed ”by a specific” to ”by specific”

64. P. 4893 Line 10: Changed to ”in the case of a snowpack. . .”

65. P. 4893 Line 14: Changed to ”impractical”

66. P. 4893 Line 16: Unclear expression removed

67. P. 4893 Line 17: Changed ”as guess” to ”as guess variables”

68. P. 4893 Line 19: Changed ”guess” to ”guess variables”

69. P. 4894 Line 3: Changed ”on” to ”in”

70. P. 4894 Line 4: The time series contains 8 images TerraSAR-X from 6 January to 24 March, with the revisit time of 11 days. The dates of acquisitions in table 1 have been modified to include all dates.

71. P. 4894 Line 5: Changed to ”Table 1 shows”

72. P. 4894 Line 16: Changed to ”a Frost filter”

73. P. 4894 Line 17: Changed to ”at an altitude of 2700 m”

74. P. 4894 Line 19: Changed to ”triangles”

”75. P. 4894 Line 20: Changed to ”circles”

76. P. 4894 Line 21: changed to ”decreased between successive observations”

77. P. 4894 Line 22: Changed to ”crosses”

78. P. 4894 Line 25: The figure has been modified to contains the comparison of three different altitudes. A chart of snow precipitation on these periods has also been added in order to relate the changes in TerraSAR-X backscattering coefficient with the state of snowpack.

79. P. 4895 Line 3: Changed "consists of the number" to "consists of a number"

80. P. 4895 Line 7: Placed tau in parentheses.

81. P. 4895 Line 11: Spelling corrected

82. P. 4895 Line 11: Removed "is" before "largely"

83. P. 4895 Line 13: Changed to "snowpack stratigraphy"

84. P. 4895 Line 14: Spelling corrected

85. P. 4895 Line 17: Spelling corrected

86. P. 4895 Line 18-19: Changed to "A random dataset was generated corresponding to . . ."

87. P. 4895 Line 21: 0.5 - 1 mm in optical diameter is equal to 0.25 - 0.5 mm in optical radius, which correspond to densified dry snow on the study site (French Alps), to which the X-band waves are sensitive.

88. P. 4895 Line 23: The glacier (snow-ice interface) roughness values stated in the text has been corrected to match the figure description. The answer for snow-ice interface has been given in the responses of general comments above.

89. P. 4896 Lines 4-6. The study on the sensitivity of the EBM to snowpack parameters has been improved.

90. P. 4896 Line 16: Changed to "At the first iteration . . ."

91. P. 4896 Lines 17-18: The definition of guess variables have been added

92. P. 4897 Line 1: Replaced "are" with "is"

93. P. 4897 Line 5: Replaced "splitted" with "split"

94. P. 4897 Line 9: Removed ", i.e."

95. P. 4897 Line 10: Replaced "differences in" with "varying" 96. P. 4897 Line 10: remove comma after "inputs"

97. P. 4897 Line 11: Replaced "have been" with "were"

98. P. 4897 Line 17: corrected

"99. P. 4897 Line 19: Changed to "times and locations"

100. P. 4897 Line 19: Replaced "experiment" with "analysis"

101. P. 4897 Line 19: Changed "percent" to "%"

102. P. 4897 Line 22: Changed "two" to "three"

103. P. 4897 Line 23: Changed to "2600 m elevation"

104. P. 4898 Lines 1-5 (and lines 24-26 on previous page): Paragraph has been improved

105. P. 4898 Lines 10-12: The sentence has been improved

106. P. 4898 Line 33-34: Paragraph has been rewritten for more clarity

107. P. 4898 Line 26: Changed "difference" to "different"

108. P. 4899 Line 2: Paragraph has been rewritten for more clarity

109. P. 4899 Line 9: Paragraph has been rewritten for more clarity

110. Table 1: Table edited with all the dates in the time series

111. Figure 1: Figure modified.

112. Figure 2: Figure has been reduced in size and the author has been referenced

113. Figure 3: Figure modified to be more specific, also the figure has been put on the introduction section

114. Figure 4: Figure modified

115. Figure 5: Figure modified

116. Figure 7: Roughness parameters were corrected in the text

117. Figure 8: The figure has been modified to include the data assimilation on all the dates of the time series.

Sincerely yours,
Xuan-Vu Phan
on behalf of all co-authors