

Interactive comment on “Assimilation of passive microwave AMSR-2 satellite observations in a snowpack evolution model over North-Eastern Canada” by Fanny Larue et al.

Fanny Larue et al.

fanny.larue@usherbrooke.ca

Received and published: 10 September 2018

General comments of the reviewer:

RC1. This paper evaluates the assimilation of AMSR-2 brightness temperature observations at 11 GHz, 19GHz and 37GHz into the Crocus/DMRT-ML models to analyse snow water equivalent. Results are evaluated against in situ data obtained from 12 sites representing different land cover types in Québec, Eastern Canada. This study is very relevant for the scientific community as assimilating radiances to analyse snow conditions in physical snowpack models is of high interest for hydrology and numerical weather prediction applications. The paper shows promising results for moderate veg-

C1

etation cover and the method opens larger scale applications possibilities. The text has a number of language issues and grammar mistakes, some of which are listed below. The manuscript should be checked by a native English speaking colleague.

AC1: The paper was checked by a native English speaking colleague.

RC2. However the paper is very well organised, results are presented with appropriate figures and tables, and very interesting discussion and conclusion sections are provided. I suggest this paper to be accepted for publication in HESS after the comments below are accounted for.

Page 9 lines 11-12: " To generate a three hourly-continuous meteorological forcing database for running Crocus, successive GEM forecasts were taken from the +09 forecast hour to the +18 forecast hour provided at the 00 and 12 UTC analysis time of each day." It is not clear to me what it means. Did the authors take forecasts at 00 UTC steps covering 09UTC to 12UTC and at 12UTC steps covering 18UTC to 21 UTC? Does it match the AMSR2 pass at 1pm local time? The authors should clarify in the text and also it would be clearer to use UTC everywhere, also when describing the AMSR data both UTC and local time could be provided (page 5 section 2.2 and page 7 section 3.1.1).

AC2: We deleted this part since it was already introduced in the previous section, Page 5, line 20: 'The three hourly-continuous atmospheric forcing database provided by the Global Environmental Multiscale weather prediction model (referred to as 'GEM'; Côté et al., 1998) was used to drive the multi-layer Crocus snowpack model (described in Sect. 3.2.1).' This section 3.2.1 focuses on the coupling Crocus/DMRT-ML, and the GEM inputs used are well detailed in Larue et al., 2018 (section 2.2): 'It provides forecasts of meteorological variables every 3 hr and can make predictions of up to 48 hr. Forecasts are updated daily at 00 and 12 UTC analysis times. To generate a 3-hourly continuous meteorological forcing database for running Crocus, successive GEM forecasts were taken from the +09 forecast hour to the +18 forecast hour provided

C2

at the 00 and 12 UTC analysis time of each day.'

The GEM forecasts were taken in order to match the 1 pm local time. We replaced hours in UTC everywhere. Section 2.2, page 6, line 1: " The Crocus model updates the snowpack every 15 minutes by interpolating meteorological inputs, but in this study we used daily Crocus outputs (SWE, snow depth, density, etc.) computed at 14:00 local time (19:00 UTC), in agreement with the AMSR-2 pass (Sect. 3.1.1)."

RC3. Page 10 lines 18-20: " Hence, as soon as a snowfall is detected with GEM precipitation data, the IL firstly added on the top of the surface was positioned 4 cm from the surface in the simulated snow profile. The maximum number of detected IL was fixed at two. In this case, the first detected IL was 20 positioned at 8 cm from the surface and the second at 4 cm after a snowfall was detected." please clarify/reformulate this part. From the first sentence the reader understands that the first IL is at 4cm depth, but from the second and third sentences it is indicated that the first one is at 8cm depth and the second at 4cm.

AC3: This section 3.1.2 was rewritten, Page 10, line 12: " In this study, an IL was added on the top of the simulated snowpack if the AMSR-2 PR(11) was above 0.06 (Roy, 2014). This IL was represented as a 1-cm layer with a density of 900 kg m⁻³ and with snow grain radius set to zero (Roy et al., 2016). The difficulty is to know how to evolve this IL in the snowpack. The Crocus snowpack model has not yet been adapted to integrate the formation of ILs and evolve them in a coherent way (Quéno et al., 2016). Nevertheless, it was shown in Larue et al. (2018) (from field measurements) that an IL of 1 cm located at 4 cm from the surface of the simulated snowpack minimized the bias of DMRT-ML simulations due to the presence of an IL (regardless of its real location in the snow profile). Hence, the IL first added at the surface of the snowpack was moved to 4 cm from the surface as soon as a snowfall was detected with GEM precipitation data or, if not, after five days to take into account the snowpack transformations (percolations, sublimations, etc.). The maximum number of detected IL was fixed at two. When a second IL was detected (IL2), IL2 was added at the surface

C3

while the first detected IL (IL1) was left at 4 cm. After the next snowfall (or after five days otherwise), IL1 was moved to 8 cm from the surface and IL2 to 4 cm. For instance, during winter 2014-2015, one IL was detected at sites 1 and 12 (22 December 2014 and 15 December 2014). At Site 9, two ILs were detected: one on 10 December 2014 and another on 1 January 2015. "

RC4. In section 3.4.2 it would be very useful to include a table with the list of experiments with a short name for each and indicating in the caption the experiment period and sites. So that the reader would have centralised in the table the experiment set-up information. For example experiment names like "DA1_TB19-37", "DA2_TB19-37,TB11-19", "DA3_TB_11,19,37". Using these short names in Section 4 when presenting the results would be much clearer.

AC4: We added a new Table (table 3) with acronyms. We used the new acronyms in section 4 to be clearer.

RC5. Also the first sentence of the section 3.4.2 starts with "In a first step,...", it should be followed by "In a second step," probably page 15, line 17 when introducing the experiment on all sites. It is not a problem to reveal the fact that the best configuration will be DA of TB11,19,37 at this stage, it will only make the paper clearer. Page 18: section 4.2.1, first paragraph: there is no need to repeat in the results section the experiments that were conducted: please remove the first sentence of section 4.2.1.

AC5: Done, these sections were checked to be clearer and the first sentence of section 4.2.1 was removed to avoid repetitions.

RC6. Finally, even the last experiment, with free snow stickiness and forest parameter, presented in Section 5, should be described in Section 3.4.2 and included in the experiment list table. It is surprising for the reader to be informed in Section 5 that another experiment was conducted. In other words, the paper should not necessarily follow the chronology of the research developments. It should present the experiments and the results/discussion without holding new experiment description for the results and

C4

discussion sections.

AC6: Done, we moved it in the result section, and introduced it in the method as the 'experiment C'. see new section 3.4.2.

RC7. Page 20 line 6 and Figure 6: The way it is formulated page 20 and in the caption, it is not straightforward to understand the meaning of "SWE ensemble obtained with the DA of the three frequencies (referred to as 'SWEDA')". The reader may wonder why this one is called SWEDA whereas the DA of TB 11, 19 37 GHZ had no specific name. Please use experiment names and provide a table in section 3 (see comment above).

AC7: Done, we used experiment names introduced in new table 3 (section 3).

Minor comments of the reviewer:

RC8. table 1 Caption: replace: "Characteristics of the nivometric stations: SWE (in kg m-2) data, Latitude (Lat.),..." by "Characteristics of the nivometric SWE stations: Site number, Latitude (Lat.),"

AC8. Done

RC9. Table1 caption: GEM is used here but only defined later in section 2.2. So, define it on its first occurrence in Table 1's caption.

AC9. Done

RC10. Page 5, line 11: remove "further"

AC10. Done

RC11. Page 5 line 13: replace "1pm" by "1pm local time"

AC11. Done

RC12. Page 5 last paragraph: make sure tenses are consistent: line 12: "Crocus computes" and line 13-14: "The DMRT-ML ... was used to "

C5

AC12. Done

RC13. Page 6 line 13: ".." -> "."

AC13. Done

RC14. Page 8, table 2, caption: clarify if the winter period January to March as indicated in the caption, or if it is 1 January to 1 March as indicated in the text page 7 line 18.

AC14. Done

RC15. Page 8 line 17 "formulations in" -> "formulations of"

AC15. Done

RC16. Page 10 line 24: reformulate by something like: "The PMW brightness temperature (TB) emitted at the scale of the AMSR-2 product can be written as (2) for each grid cell as"

AC16. Done

RC17. Page 11 line 15: "the expression of TB TOA in boreal areas was described by the Eq. (2)" for consistency please update Eq 2 (page 10) by replacing "TB=" by "TB TOA="

AC17. Done

RC18. Page 12 line 3: remove "throughout the year"

AC18. Done

RC19. Page 12 line 7: "In the Eq.7"-> "In Eq. 7"

AC19. Done

RC20. Page 12 lines 17-20: update the text to ensure tenses consistency. For example lines 17-18: "Forest parameters (I, _) depend on the forest characteristics, such as the

C6

biomass and the structure of the canopy for each site. To take into account the temporal variations of these characteristics, the forest parameters were linked to the LAI." can be replaced by: "Forest parameters (ω , σ) depend on the forest characteristics, such as the biomass and the structure of the canopy for each site. They also depend on LAI which allows to account for the seasonal cycle in the forest emission". Also check the rest of the paragraph.

AC20. Done

RC21. Page 12 line 31: replace "value couple" by "set of values", replace "(considered constant in frequency)" by ", defined at each frequency (11 GHz, 19 GHz and 37 GHz)", and replace "for each frequency (at 11, 19 and 37 GHz) in V-pol" by "at V-pol".

AC21. Done

RC22. Page 12 line 32 / page 13 line 1: This sentence is not clear, it should be reformulated. Do you mean that the parameters were optimised also at H-pol or that the V-pol set of parameters were tested at H-pol?

AC22. Done; We used V-pol only since H-pol is very sensitive to the stratigraphy of the snowpack and to the presence of ILS. Section 3.4.2: "We used V-pol TB because H-pol TB is more sensitive to the stratigraphy of the snowpack and to the presence of ILS (Mätzler, 1987)". Moreover, this section was rewritten to be clearer, Page 12, new line 29: ' the two frequency-dependent parameters ($\eta\nu$, $\beta\nu$) and two frequency-invariant parameters (ω , σ s) were inverted with a two-stage calibration by permuting all possible combinations of the two frequency invariant parameters. Specifically, ω values varied from 0.02 to 0.16 in steps of 0.01, and σ s varied from 0.01 to 1.1 in steps of 0.05. This yields a total of 300 possible combinations of the frequency invariant parameters. Then, for each possible combination of the frequency-invariant parameters, a calibration of the frequency-dependent parameters, $\eta\nu$ and $\beta\nu$, was performed for each frequency. A total of 900 frequency-dependent calibrations were thus computed. Finally, for each possible combination of the frequency-invariant parameters, the total post-calibration

C7

TB RMSE across all three frequencies was computed. The combination of frequency-invariant parameters resulting in the lowest TB RMSE was chosen.'

RC23. Page 13 lines 9-12: the 3 sentences on observation errors and ensemble inflation technics should be removed because they are not well formulated and the description given on the next page (page 14) is very clear.

AC23. Done

RC24. Page 14, lines 19-21: This sentence repeats lines 12-13: " Hence, to avoid a 20 degeneracy problem, the weight of the 25-th selected particle (wekeep) must always be larger or equal to the inverse of the ensemble size (N=150)." Please update the text to avoid repeating sentences.

AC24. Done

RC25. Page 15, first paragraph, last sentence: this statement should be placed earlier in the paragraph, before the three experiments are described.

AC25. Done

RC26. Page 14 line 30 and page 15 line 8: The information on the DA experiments length and period should not be spread in the text. It should be clearly stated once.

AC26. Done. This section was rewritten.

RC27. Page 16 line 5: remove "(constant in frequency, Sect. 3.3.3)"

AC27. Done

RC28. Page 16, section 4.1: update the text to use consistent tenses.

AC28. Done, we checked all the tenses in the text.

RC29. Page 18 line 19: replace "according to the studied period" by "for the studied period"

C8

AC29. Done

RC30. Page 27 lines 14-15: replace "explain" by "explains" and "up to" by "larger than".

AC30. Done

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., <https://doi.org/10.5194/hess-2018-95>, 2018.