Reply to Reviewer#2

We sincerely appreciate the reviewer for taking the time to provide valuable comments and suggestions. Below we describe our responses (in blue text) point-by-point to each comment (in black text). In addition, we indicate revisions in the updated manuscript together with new line numbers. Please also refer to the revised marked-up manuscript uploaded in the discussion board.

Summary

This paper introduces a new regional climate model for use over the Greenland ice sheet. The scientific impact is modest, as a) the modelled period is relatively brief, b) there clearly are issues that need to be addressed and c) the model data are not used for improved process understanding. But I presume the authors will at a later stage start using the model for these purposes. The technical quality of the figures is good, as are readability and length (apart from the last section, see below).

Thank you for the comment. The main purpose of this paper is to present a new regional climate model for Greenland. Owing to constructive comments and suggestions provided by all the reviewers, we believe the scientific impact of the revised manuscript has been increased. Now, a long-term climate simulation by NHM-SMAP is ongoing. Obtained results will be presented in the future.

Major comments

l. 166: it is unclear what the physical basis is of a parameterization of ice albedo as a function of density. Ice has a near-constant density?

In the current model, ice albedo is set to 0.55 when surface density is 830 kg m^{-3}, and assumed to decrease into 0.45 that is assigned when surface density is 917 kg m^{-3}. The sentence has been revised as follows:

"The albedo of ice was calculated by a linear equation as a function of density and ranged from 0.55, the typical albedo of clean firn (Cuffey and Paterson, 2010), to 0.45, taken from the MAR model setting as explained by Alexander et al. (2014)."

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"The albedo of ice was calculated by a linear equation as a function of density and ranged from 0.55 for a surface density of 830 kg m^{-3}, the typical albedo of clean firn (Cuffey and Paterson, 2010), to 0.45 for a surface density of 917 kg m^{-3}, taken from the MAR model setting as explained by Alexander et al. (2014). " (P. 5, L. 172-175)

Section 2.2.3 explains how drifting snow sublimation at 2 m is calculated. But what is done with this information? Is a vertical sublimation profile assumed to calculate column blowing snow sublimation? Is the moisture source included in the atmospheric moisture conservation equation, i.e. is the additional water vapour used to moisten the boundary layer? What happens to surface sublimation when drifting snow sublimation starts? Please provide details to answer these questions.

Thank you for the comment. We have included the following description:
“In NHM-SMAP, surface mass loss due to drifting snow sublimation is assumed by Eq. (5); however, it is not used to moisten the boundary layer in the current version, because an interaction between the atmosphere and the snow/firn/ice surface is performed through the medium of albedo and surface temperature as mentioned later in Sect. 2.3.4.” (P. 6, L. 204-208)

l. 197: once drifting snow transport is calculated, the erosion can be simply obtained by taking the divergence of the transport. It is unclear why the authors claim that this is computationally too expensive? If it is not taken into account, the surface mass balance is locally not closed, this must at least be mentioned.

We agree with reviewer that this is an important point for a model that calculates GrIS SMB. We have revised the sentence as follows:
“Although it is ideal to calculate the erosion of drifting snow (redistribution of near-surface snow caused by drifting snow), it was neglected in NHM-SMAP because of computational costs.”
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“Although it is ideal to calculate the erosion of drifting snow (redistribution of near-surface snow caused by drifting snow), tracking changes in physical conditions of snow particles (prognostic variables of SMAP, namely, snow grain size, grain shape, density, and so on) during a drifting snow event and redistributing them in an updated surface field demands substantial computational costs. Therefore, the current version of NHM-SMAP neglects this process, which implies that simulated SMB is not closed locally.” (P. 6, L. 209-214)

l. 210: "Ice sheet area minimum" suggests that ice sheet mask is not constant in time?

Our ice sheet mask is constant in time. The original description might cause misunderstanding, therefore, it has been revised as follows:

"The ice sheet mask for the GrIS was based on Bamber et al. (2001) as updated by Shimada et al. (2016) from 2000 to 2014, including the ice sheet area minimum of summer 2012, on the basis of MODIS satellite images."
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"The ice sheet mask for the GrIS, which is constant in time, was based on Bamber et al. (2001) as updated by Shimada et al. (2016) on the basis of 2000 to 2014 MODIS satellite images." (P. 7, L. 226-228)

Section 3.2: How did the authors deal with the mismatch between SMB observation and model period?

We referred the metadata of PROMICE SMB data and comprehended observation period. The NHM-SMAP calculated SMB data at each PROMICE site were retrieved during the exact measurement period. It is mentioned even in the original manuscript (at the end of Sect. 3.2).

Fig. 3: There is a systematic and considerable underestimation of LWin of up to 50 W m-2, which should lead to too low surface temperature, yet the snow surface temperature is overestimated in the model. I cannot reconcile this?

In the original manuscript, we mentioned possible causes for the discrepancy in terms of only insufficiencies of the model. However, we think there is also a problem in the measurement data. In the revised manuscript, we have discussed the issue as follows:
"On the other hand, observation data for downward longwave radiant flux can also have error especially during the winter period due to riming, which may act to increase measured values. In SIGMA-A, measured 2m air temperature often decreased to about –40 °C during the 2013-2014 winter (Fig. 3a). Although such reductions in 2m air temperature during March and April 2014 were followed by significant reductions in downward longwave radiant flux (Fig. 3e), they did not synchronize in December 2013 and January 2014. These results suggest that observed downward longwave radiant flux especially during December 2013 and January 2014 were affected by riming and forced to increase. A reliable quality control technique for automatic downward longwave radiant flux measurements in the polar region should be developed in the future to perform not only model validation but also climate monitoring accurately." (P. 12, L. 443 – P. 13, L. 452)

In the summary and conclusions section, an additional summary regarding this issue has been added as follows:

"On the other hand, observation data for downward longwave radiant flux can also have error especially during the winter period due to riming, which might affect the evaluation." (P. 18, L. 651-653)

During the revision, we performed additional data quality control for downward longwave radiant flux. What we performed is that rejecting such data as downward and upward longwave radiant fluxes agree exactly. This situation is caused when extreme riming occurs and these two properties are diagnosed only from sensor temperature. However, our discussion was not affected by the reassessment of measurement data.

The summary and conclusions section can be written up much more concisely: just list the main conclusions.

The first paragraph of the summary and conclusions section have been updated as follows:
"We developed the NHM-SMAP polar RCM, with 5km resolution and hourly output, to reduce uncertainties in SMB estimates for the GrIS. Combining JMA's operational non-hydrostatic atmospheric model JMA-NHM and the multi-layered physical snowpack model SMAP, it is an attempt to take advantage of both short-term detailed weather forecast models and long-term computationally stable climate models. Model output data from NHM-SMAP hold promise for assessing not only long-term climate change in the GrIS, but also detailed diurnal variations of meteorological, snow, firn, and ice conditions in the GrIS. We initialized the atmospheric profile every day by referring to JRA-55 (weather forecast mode) to minimize deviations between the JRA-55 and NHM-SMAP atmospheric fields, while simulating the physical states of snow/firn/ice without any initialization (climate simulation mode). The model, forced by the latest Japanese reanalysis data JRA-55, was evaluated in the GrIS during the 2011–2014 mass balance years using in situ data from the SIGMA, GC-Net, and PROMICE AWS networks, PROMICE SMB data, and ice core data from SIGMA-D and SE-Dome. After updating SMAP by incorporating physical processes for new (polar) snow density, ice albedo, and effects of drifting snow, we validated NHM-SMAP in terms of hourly 2m air temperature, 2m water vapor pressure, surface pressure, 10m wind speed, downward shortwave and longwave radiant fluxes, snow/firn/ice surface temperature and albedo, surface height change, daily melt area extent, and the GrIS accumulated SMB."
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attempt to take advantage of both short-term detailed weather forecast models and long-term computationally stable climate models. The model, forced by the latest Japanese reanalysis data JRA-55, was evaluated in the GrIS during the 2011–2014 mass balance years using in situ data from the SIGMA, GC-Net, and PROMICE AWS networks, PROMICE SMB data, and ice core data from SIGMA-D and SE-Dome." (P. 17, L. 617-623)

Minor and textual comments

l. 167: clean firn -> clean ice

I checked Cuffey and Paterson (2010) again, and confirmed this description is correct. In the book, albedo for clean ice is recommended to be 0.35.

Figure 1: ice mask in Canadian Arctic looks funny.

It is true we did not examine ice mask in Canadian Arctic sufficiently, because we focus the GrIS SMB in the present study. In the revised manuscript, we have mentioned this as follows:
"In the Canadian Arctic Archipelago, considerations for details in the ice sheet mask were nod given in the present study, because we focused the GrIS SMB. Therefore, there is room for improvement on the modelled ice sheet mask, which is a future issue for NHM-SMAP." (P. 7, L. 230-233)

In connection with this point, we recognized that a resolution of Fig. 1 was not enough. Therefore, the quality of Fig. 1 has been improved in the revised manuscript.

l. 287: Why was downward longwave radiation not used from PROMICE stations?

Downward longwave radiation data from PROMICE stations are used even in the original manuscript. Model performance at each PROMICE station are indicated in Table S5. At GC-Net stations, downward longwave radiation data were not employed in the present study, because they were not measured directly during the study period.

l. 320: Why is T2m "the most important climate parameter"? Better to leave out.

Thank you for the comment. We have deleted the sentence as suggested.

l. 473: surface melt -> surface melt extent

It is an important point. We have revised as suggested. (P. 14, L. 520)

l. 478: "were almost the same" This is not very scientific. Please quantify or leave out. The same is true for the discussion in lines 518-520, please provide numbers.

Regarding the former comment, we have revised the sentence as follows:
"The basic geographic patterns of accumulation and ablation simulated for the 2011–2012, 2012–2013, and 2013–2014 mass balance years (Fig. S1) were almost the same as the annual mean SMB map created by RACMO2.3 (Noël et al., 2016)."
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"The geographic patterns of accumulation and ablation simulated for the 2011–2012, 2012–2013, and 2013–2014 mass balance years simulated by NHM-SMAP are depicted in Fig. S2." (P. 15, L. 527-528)

As for the latter comment, we revised the manuscript by referring to the MAR model data provided by Xavier Fettweis (Reviewer #3), and now the description has been updated as follows:
"van den Broeke et al. (2016) reported that in estimates by RACMO2.3, SMB for the GrIS reached its lowest value since 1958 in 2012, then increased greatly in 2013 and decreased slightly in 2014. Our model produced a similar sequence in those years, with accumulated SMBs at the end of each mass balance year of –23, 420, and 312 Gt year^{-1}, respectively (Fig. 9a)."
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"According to simulation results by MAR v3.5.2 forced by JRA-55 (Fettweis et al., 2017), the GrIS SMB during the 2011-2012 mass balance year was relatively low (147 Gt year^{-1}), then increased greatly in 2012-2013 (473 Gt year^{-1}) and decreased slightly in 2013-2014 (403 Gt year^{-1}). Our model, which tends to simulate lower SMB compared to MAR v3.5.2 that uses the bucket schemes with irreducible water contents of 8 %, produced a similar sequence in those years, with accumulated SMBs at the end of each mass balance year of –23, 420, and 312 Gt year^{-1}, respectively (Fig. 9a)." (P. 16, L. 591-596)