

Review of

Characteristics of the contemporary Antarctic firn layer simulated with IMAU-FDM v1.2A (1979-2020)

by Veldhuisen et al.

Reviewer: Vincent Verjans

This study presents a modeling approach to simulate the evolution of the Antarctic firn layer. The manuscript reviewed is the second iteration of the reviewing process.

Firstly, I commend the authors for their thorough work on addressing the comments from the other reviewers and me. I appreciate their efforts, and I find this revised version much improved compared to the initial manuscript. In particular, I find the sensitivity analysis and the ice-sheet-wide uncertainty estimates much better than previously. In my view, this study now has the scientific quality to be published in *The Cryosphere*. However, I still believe that some sections of the text should be clarified and/or better explained. I address these concerns in this review.

My review is separated in one Minor comment, and Specific line-by-line comments. Please note that line numbers are with respect to the updated manuscript without tracked changes.

Minor comment

1) Section 6 still needs some work, and the last two paragraphs in particular. I have read this section several times, and I still do not understand how the statements presented can be derived from the results. I specify these statements here:

-(1516-517) *“In non-spin-up experiments, the uncertainty is only 4 % of the total surface elevation change.”*
Is this 4% value calculated at the end of the time series? Or averaged over the time series? Or something else?

-(1517) *“This uncertainty is smaller than the 40 % that can be derived from Table 3.”*
I do not understand how this can be derived from Table 5 (note that the Table number is wrong in the text). Can the authors please clarify how they calculate the 40% value?

-(1524-525) *“It indicates that imposing an uncertainty in the experiments mostly has an impact on the high-density, low-FAC part of the firn column.”*
I understand that the uncertainty in FAC is lower than in dH/dt . However, I disagree that this necessarily implies that mostly high-density firn is affected by uncertainties here. For example, density could be higher at all vertical levels (due to higher temperatures) but compensated by a larger total firn column thickness (due to higher accumulation). This can result in similar FAC values (i.e., low FAC uncertainty) but with density values affected throughout the firn column. Therefore, the authors should support this statement quantitatively, and using extra figures in the supplements that show that low-density firn is unaffected by the sensitivity tests.

-(1525-526) *“The spatial pattern in FAC change uncertainty for the spin-up experiments is different from that of surface elevation uncertainty (Fig. S6)”*
This is not clear to me when I compare Fig. 10b and Fig. S6. In contrast, I find the patterns generally similar.

-(1527-528) *“We attribute this to the fact that in high-accumulation regions, the imposed uncertainty has an effect on the entire firn layer much more quickly.”* Why is that? Can the authors clarify how they reach this conclusion?

-(1533-534) *“It suggests that the ice-sheet-wide uncertainty due to uncertainty in the spin-up climate is lower than suggested in Figure S7c.”*

Do the authors mean that their uncertainty estimates provided in Table 2 overestimate the actual uncertainty? In this case, this contradicts the references that are provided in Table 2.

Specific line-by-line comments

-Title

I suggest: “Characteristics of the 1979-2020 Antarctic firn layer simulated with IMAU-FDM v1.2A”

-12

Here and elsewhere in the manuscript, I suggest replacing “*ice thickness*” by “ice mass”.

-16-7

“*seasonal and decadal surface height variability is due to variations*”: replace is by are.

-17

Add: “firn mass, respectively”.

-134-35

Replace: “in mass- and density-change components”.

-135

Correct: “an ice-dynamical”

-137

Add comma: “climate, enhanced”

-152

Replace “*while*” by “but”.

-172

Replace: “characteristics”.

-Table 1

Include FDM v1.2G

-1108

Replace “*depositing*” by “deposition”.

-1113

Please specify: “to simulate the fresh snow density, here applied to the top-most model layer (typically xx cm thick)” OR “to simulate the fresh snow density, here applied to the top 0.5 m of the model domain”, depending on the modeling procedure.

-1114

Replace “*include*” by “perform”.

-1123

Replace “*measure*” by “proxy”.

-1124

Replace “*assuming that the accumulation rate is constant*” by “approximating the accumulation rate as constant”.

-1128

Replace “*by deformation, sublimation and diffusion*” by “by deformation, recrystallization and molecular diffusion”.

-1141

Replace “*include*” by “perform”.

-1151

Is it only retained meltwater that is allowed to refreeze? I believe that meltwater reaching a subfreezing layer is allowed to refreeze even if it is not retained through the irreducible water content before.

-1187

Replace “*retuned cloud scheme and snow properties*” by “retuned schemes for clouds and for snow properties”.

-Section 2.5

Is it possible to describe better how the separation between calibration and evaluation cores was decided?

-1214

I think that “*method and citation*” should be plural.

-1221

Add comma: “15 cm, depending”.

-1230

Typo: “is currently too short”.

-1242

“excluding five sites that were later added for evaluation”: this is not clear. Is it meant that five additional sites were later added for evaluation?

-1247

Replace “a model sensitivity test, which includes” by “a range of model sensitivity tests, which include”.

-1248

Is the fresh snow density varied independently at each time step?

-1252-254

Similar question: are the temperature variations applied independently at each time step?

-1257

Change: “isotope”.

-1258-259

A citation is needed for this statement.

-1259

Replace “about typically” by “approximately”.

-1268

Please specify “we also performed two tests”.

-1272

Replace “a steady-state firn layer” by “a firn layer in steady-state”.

-1272

Replace “this simulation” by “these simulations”.

-1274

Specify: “and/or temperature”.

-1275

Why “randomly”? Please clarify.

-1278

Replace “included” by “shown”.

-1287

Rephrase: “extent (bias = 10.3 kg m^{-3}). It is the update in the atmospheric forcing that causes a poorer (...)”.

-1296

If this is correct, please specify: “is reduced by 18 kg m^{-3} on average”.

-1299-301

In my view, these two sentences can be removed.

-1302-303

How can do the MO values influence the rho0 parameterization? Is it not the other way around?

-Table 3

The R2 values do not agree with the R2 values of Fig. 2.

-Table 4

First, MO coefficients have no units, and thus the last column should be unitless. Second, RMSE should be replaced by RMSD (root mean squared deviation) because this quantifies the deviations with respect to the fitted function, and not errors. Finally, RMSD values should be given in all rows.

-1316

The comparison with FDM v1.1p1 and FDM v1.1p2 is unfair. These models were not calibrated with the data of this study, whereas FDM v1.2A was calibrated with (almost) all the data used for evaluation. This must be specified.

-1324

Correct: “asymptotically”.

-1324

To avoid any confusion, please specify: “asymptotically towards zero, but less rapidly than FDM v1.2A-log”.

-1330

Replace “68” by “0.68”.

-1348-349

Please quantify: “ *The patterns vary spatially across climatic regions with temperature as a primary driver and accumulation and surface melt as secondary drivers.*”

-1353

Please specify: “in younger, thus less densified”.

-1360

“*If we compare this to observations*”: which observations give firm age?

-1360-361

“*On average, the RMSE is 25 %*”: is this really the RMSE (i.e., the mean across all the errors) or rather the average ratio between the individual absolute errors and their corresponding observed value?

-1361

“*In comparison, RMSE of z830 is 15 % of the observed values*”: same question as comment just above.

-1366

Replace “*would be*” by “*was*”.

-1371

Specify: “Community Firm Model”.

-1375

Replace both instances of “*new*” by “*updated*”.

-1378

I think that “*FDMv1.2A*” should be replaced by “*FDMv1.1*”.

-1383

Correct: “*contribute*”.

-1387

Correct: “*values*”.

-Section 4.3

Is it possible to provide maps of mean accumulation, melt, and sublimation in the Supplementary Information?

-1415

“*as the annual average accumulation is low*”: I do not understand why this causes low seasonal amplitude.

-1421

Replace “*its components*” by “*the components of the latter*”.

-1424

Replace “*long time scale*” by “*slower response timescale*”.

-1426

Typo: vfc is all in subscript.

-1430-432

Note that this difference is also explained by the high sensitivity of firm compaction to temperature variability for firm at low temperatures.

-1432

Correct: “*variabilities*”.

-1435

Specify: “*total surface elevation change variability*”.

-1451

Please remove “*which compares well with the FDM seasonal amplitudes*”, and replace it by a new sentence:

“*This suggests that our results of AIS-wide seasonal amplitude lie within the range of observational uncertainty.*”

-1480

Remove “*relatively*”.

-1482:

Typo: “*reduced*”.

-1484-485

Break the sentence: “*depth (Schröder et al., 2019). On the other hand,*”.

-1487 vs. 1490

Make sure to be consistent in using brackets or not around the location numbers.

-1495

If this is correct, specify: “are on average 41% lower”.

-1497-498

Replace “*is needed*” by “we used”.

-1498

Refer to Fig. S3.

-1505

Typo: “a surface elevation”.

-1506

Typo: “*of of*”.

-1507

I do not understand “0.7/0.8”.

-Table 5

Specify periods in the caption: 2015-2020 for dH/dt, and averaged over 1979-2020 for FAC I think.

-1517

Replace “*Table 3*” by “Table 5”.

-1518

Replace “*amplifying*” by “compensating”.

-Figure 10

Specify periods in the caption: 2015-2020 for dH/dt, and averaged over 1979-2020 for FAC I think.

-1519

Replace “*Table 3*” by “Table 5”.

-1522

Replace this sentence by “We expand ice-sheet-wide averaged estimates of uncertainty into time series, shown in Figure S7c.”

-1529-530

Replace here: “The finding that imposing an uncertainty in spin-up climate has low impact on FAC uncertainty”. (see my Minor comment).

-1537

Replace “*minus the spin-up sensitivity test*” by “minus the transient run spun-up with the sensitivity test”.

-1539

“*we assume the underlying ice to have responded to the changing climatic conditions*”: does this mean that advection if ice at the lower boundary has changed? And is this equivalent to saying that v_{ice} cannot be assumed constant?

-Section 7

I would appreciate adding a couple of sentences about larger uncertainties in melt-affected areas. Can the authors also provide the quantitative results of the evaluation at the 10 wet cores?

-1543

Specify: “has been used over the AIS”.

-1544

Correct format of citation.

-1546

Specify: “the mass change associated with surface processes”.

-1548

Correct: “updated climatic forcing, as is shown”.

-1553:

Specify: “ compared to the error range of the altimetry observations and model uncertainties”.

-1558

Replace “*decadal*” by “inter-annual”.

-1561

Remove comma after “*factor*”.

-1565

Replace: “not recommended in combination”.

-1577-578

See my comment on l316.

-1582

Phrasing: “as a primary, and accumulation and surface melt as secondary drivers.”

-1585

Replace “*As variations in FAC and firn thickness have a similar phase, 63 to 68 %*” by “Variations in FAC and firn thickness have a similar phase, and 63 to 68 %”.

-1591

Replace “*which violates*” by “violating”.

-Caption of Figure S4

(h) should be for the accumulation spin-up experiments.

-Caption of Figure S5

(h) should be for the accumulation spin-up experiments.

-Caption of Figure S7

Specify: “the estimated ice-sheet-wide averaged surface elevation change”.