

Thank you very much for your constructive comments and suggestions. From the comments of both reviewers, it is clear to us that the explanation of the water cycle in the different experiments was not well done. Therefore, we have now included in Section 2.4 a more elaborate explanation of the experimental set-up and the treatment of water and latent heat. The following two paragraphs have been added to the manuscript.

In the CTRL experiment, the freshwater cycle is closed between the atmospheric model ECBilt and the oceanic model component CLIO. In ECBilt, the precipitation (solid and liquid) is computed every 4 hours and the solid precipitation is added to the snow layer. To prevent the model from piling up too much snow in areas with a positive snow mass balance, the height of the snow layer is not allowed to exceed a pre-defined threshold (10 metres). If the snow layer exceeds this threshold, the amount of snow above it (the so-called excess snow) is melted, and is added to the soil moisture (in a bucket model) and routed into the ocean when the maximum, preset soil water holding capacity is exceeded. The heat needed to melt the excess snow on the Northern Hemisphere is computed in the ocean model and taken up from the surface layer of the ocean cells around the Greenland ice sheet homogenously (Fig. 1), which is done in order to account for the effect of floating icebergs, which are not dynamically computed in CTRL. The solid precipitation that is falling on the ice-sheet is given to GRISLI where it is used to calculate the surface mass balance. However, it is not removed from ECBilt because in CTRL the water cycle between ECBilt-CLIO and GRISLI is uncoupled, implying that GRISLI does not provide any freshwater fluxes to ECBilt or CLIO.

In the calving (CALV), the “fresh”freshwater (FWFf) and the “cold”freshwater (FWFc) experiments, the freshwater cycle is closed between ECBilt, CLIO and GRISLI. Therefore, the precipitation given from ECBilt to GRISLI is removed from ECBilt. GRISLI uses the precipitation to calculate the surface mass balance. At the end of one model year it provides ECBilt with the amount of the computed runoff (surface and basal melt) and CLIO with the ice discharge. In ECBilt the runoff is incorporated into the land routing system and distributed to the ocean. The ice discharge in CLIO is either used to generate icebergs (CALV experiment) or melted instantaneously at the ice sheet border (FWFf and FWFc experiments). The ice discharge has to be melted before being supplied to the ocean as a freshwater flux and the treatment of the heat needed to do this differs between the CALV, FWFc and FWFf experiments. In CALV and FWFc, this heat is taken-up from the ocean cell corresponding to the position where the ice discharge is added to the ocean either in the form of an iceberg melt flux (CALV) or in the form of a freshwater flux at the ice sheet margin (FWFc). In FWFf the ice discharge is melted at the ice sheet border without taking up heat, instead the latent heat related to the excess-snow is taken up homogenously around Greenland (FWFf), identical to the CTRL experiment. This allows us to separate the freshening and the cooling effect of icebergs.

These two paragraphs are now in the section 2.4 (The coupling method and experimental setup) instead of the previous description of the experimental setup.

Reviewer #1 - Specific comments

From the general conclusions in the abstract it is difficult to separate the scientific findings from the particularities of the model set-up. Therefore, it is not clear which findings are physically meaningful and which ones are related to a “virtual” modeling world. For instance, what means in the real world

“taking up the latent heat homogeneously”? Also, the sentences “Yet, : : :” and “Therefore, we conclude: : :” seem contradictory.

All the conclusions described in the abstract are related to the “virtual” modeling world as we do investigate the impact of explicitly modelling icebergs in a coupled atmosphere – ocean – vegetation – ice-sheet model compared to parameterizing icebergs as freshwater fluxes. To state this clearer and to clarify the sentences “Yet:::” and “Therefore, we conclude”, we have changed the abstract:

Yet, in the simulations where the ice discharge is released into the ocean at the calving sites without taking up the heat from the ocean needed to melt the ice, instead cooling the ocean homogeneously, this results in a similar ice sheet configuration and climate as the simulation where icebergs are explicitly modeled. We conclude that in our fully coupled atmosphere – ocean – cryosphere model set-up,...

The introduction is somehow too long, and sometimes unrelated with the paper. In addition, some statements seem wrong: “the potential impact of the GrIS due to interactions with the ocean and the atmosphere (: : :) has never been investigated in a fully coupled global climate-cryosphere modeling framework”. What about Ridley et al. (2005), Vizcaino et al. (2008, 2010)? This work is cited in the manuscript, the statement seems contradictory with the paragraphs below.

Concerning the length of the introduction we have shortened the paragraphs introducing ice sheet models and their coupling procedures. Paragraph (190:10-15) now reads:

Numerical ice sheet models are valuable tools to study the evolution of the ice sheet during different climate states and its impact on climate. Therefore, they are used to better understand and investigate the aforementioned interactions between the GrIS and the other climate components. Most ice sheet models currently used for performing longer-time simulations are three-dimensional thermomechanical models, and based on the shallow ice approximation (SIA), (Hutter, 1983; Morland, 1984).

And (191:3-25):

A further and more complex approach is to couple ice sheet models to Earth System Models of Intermediate Complexity (EMICs, Claussen et al., 2002). In this case, the EMIC and the ice sheet model exchange input (temperature and precipitation) and output (albedo, topography, melting and calving of the ice sheet) fields (e.g. Wang and Mysak, 2002; Kageyama et al., 2004). Therefore, the interactions are two-sided as the ice sheet’s geometry and its freshwater fluxes are used as input for the EMIC, where the runoff (surface and basal melt) as well as the ice discharge are considered as freshwater fluxes that are released into the ocean directly at the coastline (e.g. Bonelli et al., 2009; Goelzer et al., 2010) or over a pre-defined area (Ridley et al., 2005). Therefore, the melt water released due to iceberg calving and the related take up of latent-heat by them is either considered in the same way as the runoff and consequently spatially restricted to the coastline or homogeneously distributed over a fixed region. The most complex approach so far is to couple ice sheet models to general circulation models (GCMs (e.g. Ridley et al., 2005; Vizcaíno et al., 2008). This set-up also allows two-sided interactions, yet, icebergs have not been modelled explicitly so far either. A more complete description of coupled ice sheet – climate modelling can be found in Pollard (2010).

Concerning the fully coupled global climate – cryosphere modeling framework, we were referring to the potential impact of the GrIS mass loss (runoff and calving) on climate that has not been studied in a coupled climate – ice-sheet – **iceberg model** so far. This is now stated clearly:

Although we have clear evidence for major changes of the GrIS in the past and present, our understanding of the potential impact of the GrIS mass loss due to interactions with the ocean and the atmosphere is still limited and has never been investigated in a fully coupled global climate – ice-sheet – iceberg modelling framework.

The calculation of the surface mass balance needs to be explained in the text. How is surface melt calculated? Line 14, page 194 : “through precipitation and surface temperature”. How are you dealing with the resolution gap between the atmosphere and ice sheet components?

The ablation is calculated according to the Positive Degree-Day method following Fausto et al. (2009). It uses the monthly downscaled surface temperatures that are computed using the temperatures at the maximum and minimum GRISLI altitude in one ECBilt cell to compute a linear relationship between the altitude and the surface temperature which is then used to correct the ECBilt surface temperature to fit to the corresponding GRISLI cells. The PDD method accounts for refreezing. The SMB is calculated using the total annual snow fall and the ablation rates. The basal melting is parameterized using a fixed rate. The following information is added to the coupling paragraph 2.4:

After one year the monthly surface temperatures and the total amount of snow fall used are downscaled from the ECBilt to the GRISLI grid and used as input fields calculate the surface mass balance (SMB) that is defined by the accumulation and ablation. To obtain the ablation rates, the Positive Degree-Day (PDD) method of Fausto et al. (2009) is used, which takes into account the dependence of the ice and snow melt rate parameters on temperature as well as the dependence of the refreezing parameter on the altitude. A more detailed description of the coupling between ECBilt – CLIO and GRISLI is given in Roche et al. (2013).

There are too many figures and the size is too small. I recommend to select the key figures to illustrate the main message in the text, and improve the readability of labels in the color bars.

Following the reviewers comments, we have improved the readability of the figures (increased the font of the title and labeling). Moreover, we have re-arranged the order of the figures to make it easier to see the effects of the different experiments on the ocean and the atmosphere (Figures 7+10;8+11;9+12 have been merged). We have substituted the sensible heat flux with the geopotential height to better explain the seen increase / decrease in snow fall. We have tried to decrease the amount of figures, however we have also tried to provide the information that was asked for by the reviewers (surface mass balance and latent heat fluxes).

The definition and treatment of runoff is confusing. Table 1: “runoff=basal and surface melting of the ice sheet”, what about refreezing? Melting and runoff are usually not equivalent.

To compute the SMB the Positive Degree-Day (PDD) method of Fausto et al. (2009) is used, which takes into account the dependence of the ice and snow melt rate parameters on temperature as well as the dependence of the refreezing parameter on the altitude. We compute the runoff at the end of one ice-sheet model year by computing the difference in ice sheet thickness at the end of the model year compared to the beginning. All the changes in ice sheet thickness are related to calving, surface melt and basal melt. Since we explicitly compute the calving rate, we know the amount of runoff and we do not differentiate between surface and basal melt.

The GRISLI description now reads:

The ice sheet’s runoff (basal and surface melt) is computed at the end of the coupling time step, in our case one year, by calculating the difference in ice sheet thickness between the beginning and the end of the year and taking into account the mass that is lost due to calving. A more detailed explanation of the coupling between GRISLI and ECBilt is given in the section 2.4 as well as in Roche et al. (2013).

In section 2.4:

After one year the monthly surface temperatures and the total amount of snow fall are downscaled from the ECBilt to the GRISLI grid and used as input fields to calculate the surface mass balance (SMB) that is defined by the accumulation and ablation. To obtain the ablation rates, the Positive Degree-Day (PDD) method of Fausto et al. (2009) is used, which takes into account the dependence of the ice and snow melt rate parameters on temperature as well as the dependence of the refreezing parameter on the altitude. A more detailed description of the coupling between ECBilt – CLIO and GRISLI is given in Roche et al. (2013).

The simulations setup is not clear: why is runoff not included in the control simulation?

As indicated at the start of this reply, we have now clarified this in Section 2.4

Why is “excess snow” included? What is the physical interpretation of “excess snow”?

We have also explained excess snow in the new paragraphs in Section 2.4.

How are the effects of runoff and iceberg separated in the comparison of the simulations with the control run? The setup of FWFf and FWFc is not clearly outlined.

The effects of the runoff and icebergs are not separated in the CALV, FWFf and FWFc run because whenever we fully (through topography, albedo AND freshwater fluxes) couple GRISLI to the climate model, we have to consider both, runoff and iceberg discharge to close the water cycle. This is now explained in the experimental set-up.

The model validation/evaluation is very poor, generally based on qualitative assessment. What is the volume of the CTRL ice sheet? What is the surface mass balance? And ice flow? How does the topography compare with the real one? (e.g. thickness anomalies). Even if this is described in other paper, a summary should be given here.

The CTRL ice sheet volume at the end of the 14.000 model years is about one third bigger than currently observed, mainly due to an overestimation of the ice sheet’s extent and its thickness. The excessive extent is particularly visible in the northeast and southwest of Greenland where currently no ice exists (see Fig. 1 and updated Fig. 6 in manuscript). The thickness is overestimated in central and northeast Greenland (by up to 1000m) and over North America. It is important to notice that using present-day observations as input fields to force the ice sheet model instead of ECBilt results in an overestimation of the volume of $4 \times 10^{14} \text{ m}^3$ compared to climatology (Bamber et al., 2001) (Roche et al., 2013). Therefore, dynamically coupling GRISLI to iLOVECLIM results in a 15% overestimation in the ice sheet volume with respect to the computed ice sheet using present-day observations. Both, the overestimated extension and thickness are caused by the SMB that captures the overall pattern of more positive SMB in the south, less in the north and negative at the coast, yet, the positive areas are overestimated (see Fig 2, underneath).

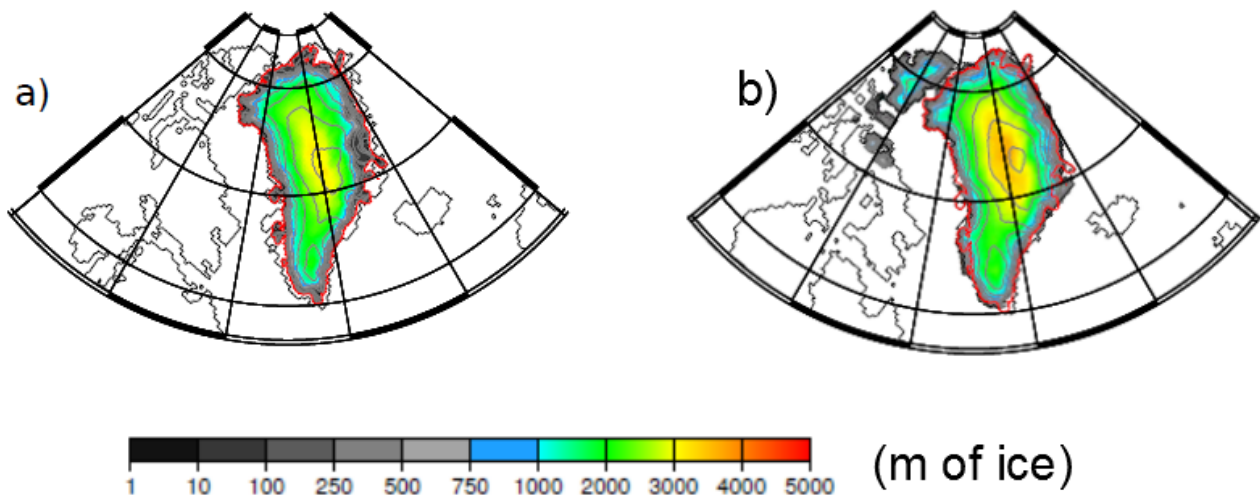


Fig. 1: ice sheet thickness (m); a: observations (Bamber et al., 2001); b: CTRL experiment

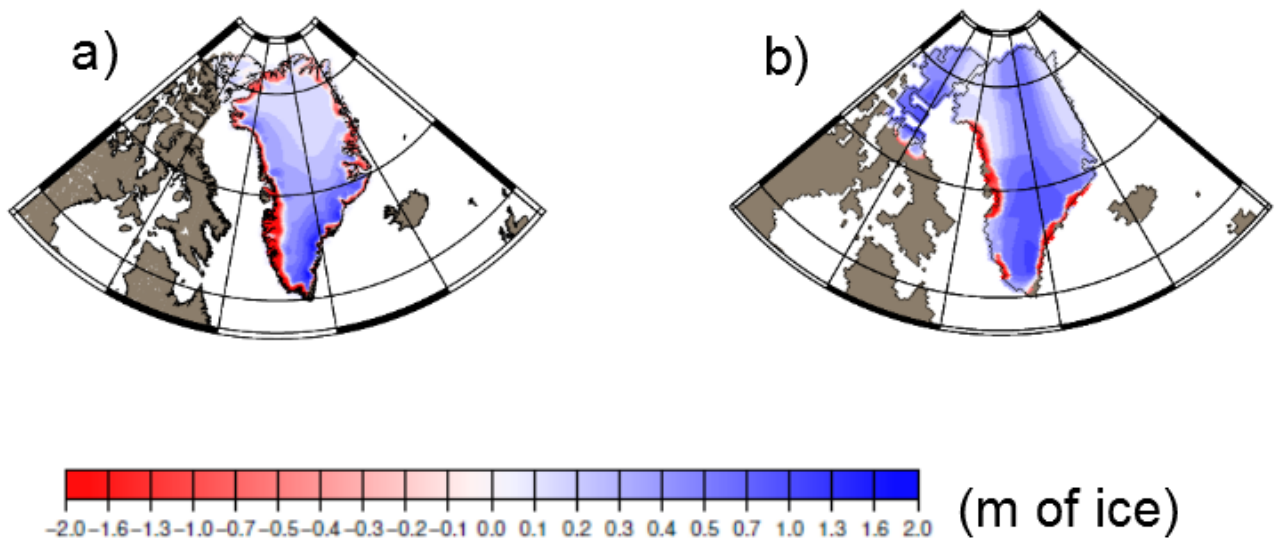


Fig. 2: Surface Mass Balance (m); a: results from the MAR regional climate model at 5km resolution forced by reanalysis (Fettweis et al., 2011); b: CTRL experiment

The values of the SMB, calving and runoff rates are added in the paper in the table 3. We have included the following short description of the CTRL ice sheet in the results section:

Before analyzing our results, we shortly want to summarize the main properties of the CTRL ice sheet as presented in Roche et al. (2013). The resulting ice sheet thickness and extent are overestimated with an excess volume of about $1.05 \times 10^{15} \text{ m}^3$ compared to observations (Bamber et al., 2011). Comparing the CTRL volume to the computed volume using present-day observations as input fields to force GRISLI displays that

dynamically coupling GRISLI to ECBilt results in an excess ice-sheet volume of $4.4 \times 10^{14} \text{ m}^3$. The ice sheet (Fig. 6a) extends almost everywhere up to the Greenland coast even at regions that are currently observed ice free. Further, the CTRL ice sheet is too thick in central and northeast Greenland (up to 1000m) and over Devon Island. This can be explained by the overestimation of the positive SMB by GRISLI. The computed SMB captures the overall pattern of positive SMB in south and less in north of Greenland and negative SMB along the coast, yet, GRISLI overestimates the positive SMB resulting in the excessive extension and ice sheet thickness (Fig. 10a). The mean value of the surface mass balance of the CTRL ice sheet of the last 1000yrs is given in Table 3.

Albedo changes are shown in the figures and mentioned in the text, but the albedo calculation is not described in the text.

The albedo changes described in the text mainly relate to changes in sea ice thickness and the ice-sheet. Therefore, they are either computed by CLIO considering the state of the sea ice or by ECBilt following the ice mask provided by GRISLI. We now stated this in the CLIO

The formulation of the surface albedo of the sea ice takes into account its state (frozen or melting) and the thickness of the snow and ice covers (Goosse et al., 2010)..

and GRISLI description:

After one model year, GRISLI provides the updated topography and ice mask to ECBilt to calculate the surface albedo.

In the evaluation (3.1), colder conditions in the preindustrial climate and lower calving rates are linked. What is the link in the model between colder temperatures and lower calving rates?

In the evaluation (3.1) the lower calving rates are linked to an underestimation of the ice sheet thickness in South – East Greenland. We changed the sentence to:

Only at the sites south-east of Greenland too little ice is calved, probably caused by the underestimation of the ice sheet thickness there compared to observations (Roche et al., 2013).

Please quantify calving rates, freshwater fluxes and heat fluxes, surface mass balance, etc. for all simulations.

We added the mean (last 1000 years) calving rates, freshwater fluxes, surface mass balance, sea ice volume and area in table 3. Moreover, we substituted figure 1 that displayed the region where the take-up of heat was parameterized in CTRL with a figure that displays the amount of heat taken up in the CTRL experiment. Moreover, we added two figures that display the take up of latent heat in the CALV set-up versus the FWFc set-up to figure 5 (c and 5d). The maximum values in FWFc are much higher in FWFc than CALV which is also due to the higher calving fluxes (0.026 SV compared to 0.017SV, Table 3). Moreover, it is visible from the figures, that the impact of the FWFc experiment is restricted to the coastal areas around Greenland whereas the icebergs impact the ocean over a wider area as has already been seen in the freshwater fluxes (Fig. 5a and 5b).

We adapted the results description (section 3.2):

In CALV more heat is taken up (Fig. 5d) close to the coast west of Greenland, but along the North American coast and in Davis Strait less heat is used to melt the bergs than parameterized in CTRL. The comparison of Fig. 5c and 5d clearly shows that the parameterisation used in CTRL overestimates the latent heat take up further away from shore, but underestimates it along the coast of Greenland. Additionally, the higher sea

surface salinities (SSS) in the CALV set-up in the Baffin and Hudson Bay region (Fig. 7b) indicate that less freshwater is released by the icebergs than by the excess snow used in CTRL since the amount of freshwater is not defined to be the same in the performed experiments but depend on the prevailing climate. A different pattern is seen in the Greenland Sea where the icebergs freshen the ocean’s surface due to the major calving sites along the east coast of Greenland and in the Labrador Sea where they cause a decline in SSS as well as a decrease in convection depth (Fig. 7d) whereas in the GIN (Greenland – Iceland – Norwegian) Seas the centre of the deep convection site is shifted northward in the CALV experiment, without a change in convective activity. The strongest impact on sea ice is found along the east coast of Greenland where it becomes thicker due to the lower SST (Fig. 7c). The total sea ice volume is one third higher in CTRL (Table 3) than in CALV due to the thicker sea ice west and north of Greenland (Fig. 7b).

	Calvflux (GRISLI) (10^{-2} Sv)	Surface Mass Balance (GRISLI) (10^2 m ³)	Runoff (GRISLI) (10^{-4} Sv)	Sea Ice Volume (10^3 km ³)	Sea Ice Area (10^{12} km ²)
CTRL	-	-1.7	-	24,69	11,89
CALV	1,7	-0.87	2,1	16,18	11,05
FWFf	1,8	-1.89	3,9	25,09	11,99
FWFc	2,6	-2.2	1,3	24,36	11,76

Table 3: summary of computed ice discharge (CALVFLUX) as calculated in GRISLI, Surface Mass Balance (SMB) of the Greenland ice sheet, runoff as calculated in GRISLI, Sea Ice Volume and area as computed in CLIO; all values plus standard

3.2. Please quantify the changes in sea ice thickness in terms of total area and volume.

This information is now given in Table 3 and added to the results description (as stated above).

Cooling translates into reduced ice thickness due to precipitation changes, but what about surface melt?

The surface mass balance of the CTRL, CALV and FWFc experiments displays that there is a positive SMB in south-east Greenland, but that it is clearly the strongest in FWFc. Therefore, the reduced melting due to lower temperatures does not balance the reduced precipitation. We added the SMB of the CTRL, CALV and FWFc experiment to Figure 13 (now Figure 10).

3.2. The differences in the set-up of control and CALV simulations is not clear. How different are total freshwater and heat fluxes in both simulations? How can you separate the effect of the differences in the amount and distribution of these fluxes? The text seems to attribute the differences only to the distribution. But there is no runoff or ice flow in control, so the amount of fluxes should be different as well, and the seasonality.

It is correct that the amount of fluxes is different but this is on purpose as we investigate the impact of modeled icebergs explicitly compared to parameterized icebergs. Therefore, the differences arise due to the different amount of freshwater applied and the distribution effect, this is correct and was not stated clearly in the text. The seasonality is included in both experiments due to computation of the snow fall. We added this information:

Additionally, the higher sea surface salinities (SSS) in the CALV set-up in the Baffin and Hudson Bay region (Fig. 7d) indicate that less freshwater is released by the icebergs than by the excess snow used in CTRL since the amount of freshwater is not defined to be the same in the performed experiments but depend on the prevailing climate.

The analysis of the sensitivity studies (3.3) should be quantitative. This sub-section is full of vague statements. Instead, the authors need to quantify the energy and mass fluxes.

We have added a quantitative evaluation in Table 3 and the figures displaying the take up of latent heat and have partly re-written the section 3.3 :

3.3.1 The freshening effect (FWFf – CTRL)

Releasing the calving fluxes instantaneously into the ocean, without forming icebergs, does not alter the climate strongly compared to CTRL. In the FWFf experiment, the calving flux (1,8 10²⁵V, table 3) is released instantaneously at the calving sites, consequently freshening the ocean surface but without cooling it, since the FWFf and CTRL set-up share the same parameterisation of homogeneous take-up of latent heat. At the end of the experiments, FWFf and CTRL result in a very similar ocean and atmospheric state, as well as ice-sheet configuration (not shown). Therefore, the impact of the freshwater fluxes (freshening effect), related to calving under pre-industrial equilibrium conditions, is small.

3.3.2 The freshening and cooling effect (FWFc – CTRL)

Applying the calving fluxes in the form of instantaneous freshwater fluxes that do take up the latent heat needed to melt them at the calving sites both freshens and cools the ocean close to the GrIS margin (Fig 8a). Therefore, they cause warmer and saltier GIN Seas as well as a cooling and freshening in the Davis Strait and Labrador Sea (Fig 8d).

The location of the freshwater fluxes has quite distinct impacts. To the west of Greenland it promotes an increase in sea ice thickness (Fig. 8b) because of the strong freshening. In the GIN Seas however, there is a decrease in sea ice thickness because of the increased SST (Fig. 8a). The freshwater flux released in FWFc (0.026 SV) is confined to the GrIS margin, as is the related cooling effect (Fig. 5d). Therefore, it does not reach the convection site in the Gin Seas which results in a more extensive convection activity and the inflow of relatively warm and saline Atlantic waters that further enhance the sea surface temperature and salinity (Fig. 8a, 8d).

The sea surface temperature, as well as salinity (Fig. 8a, 8d). The freshwater flux along the west coast of Greenland causes a shift of the convection site south of Greenland eastwards (Fig 8c). To the North of Greenland the freshening and cooling effect of released ice flux results in a thicker sea ice. Despite the big differences North of Greenland is the overall sea ice volume and area comparable between CTRL and FWFc (Table 3).

Even though, in Baffin Bay the release of the calving flux and the take up of heat needed to melt it causes lower SST (fig) and consequently increases the sea ice thickness and albedo, the warmer ocean conditions in the GIN Seas cause higher air temperatures over the whole North Atlantic region (FIG). The increase in surface albedo and the related cooling west of Greenland provoke an enhanced high pressure system over the western GrIS and North America (Fig. 8h) and the opposite effect is seen east of Greenland. Due to the decrease in sea ice in the GIN Seas, the low pressure system transports more humid air to central Greenland. This is reflected in the resulting ice sheet thickness, which over eastern (western) Greenland is up to 300 m increased (decreased) compared to CTRL (Fig. 6f). This is also seen in the surface mass balance (SMB) (Fig. 10a compared to Fig. 10c) and the accumulation (Fig. 10d compared to Fig. 10f).

The comparison of the FWFc with the CTRL experiment shows that the absorption of latent heat from the ocean and the location of the take-up of latent heat have a stronger impact on the climate and consequently on the evolution of the ice sheet than the input of freshwater.

3.3.3. The distribution effect (CALV – FWFc)

Using the calving mass calculated by GRISLI to generate icebergs (as in CALV) instead of applying this mass in the form of direct freshwater fluxes (as in FWFc), has an almost opposite effect on climate and the GrIS. Due to the movement of the bergs and their slow release of melt water, their impact on climate is over a wider area with less water being directly released at the calving sites than in FWFc (Fig. 5c). Therefore, the CALV experiment results in a much fresher and cooler Denmark Strait (Fig. 9a,d) with a reduced convection depth than seen in FWFc (Fig 9c). This is due to the release of melt water in this area by the icebergs, which is not the case for the directly applied freshwater fluxes. In the GIN Seas the decrease in SST and SSS in the CALV run are linked to a spatially smaller deep convection area compared to the FWFc set-up (Fig. 9d). It is interesting to notice that in Baffin Bay the instantaneous release of the calved mass provokes a stronger cooling and freshening than the slow release of melt water by icebergs. Even though they release more freshwater there (Fig. 5c) icebergs take up less heat than the directly released freshwater fluxes (Fig. 5d compared to Fig 5e)..

The thinning of the sea ice thickness west and north of the GrIS and its thickening south east of Greenland in CALV results in a decreased sea ice volume compared to FWFc (Table 3). Moreover, it causes a two-sided response in albedo (Fig. 9f) and the geopotential height, resulting in less precipitation over central Greenland in CALV (Fig. 9g,h). Thus, the air temperature is reduced over the GrIS and increased over the Arctic (Fig.9e). The different effectiveness of direct freshwater fluxes and icebergs leads to different ice sheet geometries at the end of the simulations with a up to 300 metres higher western and lower eastern GrIS in the CALV set-up (Fig. 6e). This is a consequence of the mass balance (Fig. 10f).

From our studies we conclude that the main effect of calving on the climate is due to spatial distribution of the take-up of latent heat absorbed to melt the calved mass. Using local freshwater and latent heat fluxes cause a thicker ice sheet volume and higher melting rates (0.026SV in FWFc compared to 0.017 SV in CALV, Table 3). Therefore, the use of local freshwater and latent heat fluxes does not represent the effect of icebergs well and it strongly underestimates the distribution effect of the icebergs. In our model and under pre-industrial conditions, the FWFc experiment reveals the most similar results to the CALV run (not shown) as it includes the wider spread, parameterised take-up of latent heat and the local freshening.

The discussion (section 4) does not always relate the results of this manuscript with previous work, instead it describes previous work. This could be done in the introduction, but in the discussion a

comparison must be done. This section is lengthy and does not serve the point to relate this work to previous work. Instead, please answer the question: why didn't other studies find an important role of the latent heat exchange from icebergs?

So far, only Jongma et al. (2009, 2013) directly addressed the effect of the take up of latent heat of icebergs on climate. They found that including this effect results in a stronger impact of icebergs on the ocean. The other studies concerning iceberg modeling have not analysed the effect of the take up of latent heat.

We re-wrote the discussion to stronger relate our work to previous work and discussed our findings concerning the importance of the take-up of latent heat.

In the presented study the coupling between the ice sheet model GRISLI and the earth system model of intermediate complexity iLOVECLIM and the dynamical iceberg module was further developed. This set-up was used to investigate the impact of icebergs on climate and the ice sheet itself in a fully coupled low resolution model. To model iceberg calving is a complex task as small scale processes are involved, which we cannot expect to be represented with the 40 x 40km resolution of GRISLI. Still, the calculated calving sites fit reasonably well with observations as do the modelled iceberg trajectories. Moreover, we are interested in the impact of the icebergs on the climate and the ice sheet, and especially in the mechanisms behind this impact, which are independent of the model resolution. We have to keep in mind that refreezing of the melt water, as well as splitting up of bergs is not accounted for in our setup. Excluding this latter process probably leads to an underestimation of the spread of the fresh anomaly, but an overestimation of the near-shore freshwater input, as has been reported by Martin and Adcroft (2010) and could explain the less wide spread iceberg melt flux in our simulations compared to theirs. Despite the mentioned shortcomings, this model set-up is a valuable tool to investigate the effect of icebergs on the Northern Hemisphere climate and the GrIS. Especially as the EMIC is coupled to a dynamically computed ice sheet model and therefore changes in calving rates and positions are taken into account. This is of particular interest for the study of past climate changes at relatively long time-scales (centuries to multi-millennia), when also large changes in ice sheet geometries can be expected.

In the prevailing study the resulting climate conditions and ice sheet geometries differ between the experiments even though they were done under pre-industrial conditions where the calving rates are relatively constant and small. The impact of icebergs on the ice sheet's development is thought to be stronger during colder climate conditions with higher calving rates.

So far, icebergs have mostly been parameterised using freshwater fluxes to save computation time. To study the impact of such parameterisations, we compared dynamical included icebergs to freshwater fluxes released at the same locations and according to the same seasonal cycle as the icebergs and found noticeable differences. Icebergs facilitate the formation of sea ice especially in the GIN seas compared to the freshwater fluxes being applied at the calving locations together with homogeneous take-up of latent heat around Greenland. This is comparable to the findings of Jongma et al. (2009) who performed sensitivity studies under pre-industrial conditions, where they investigated the different impact of icebergs compared to homogeneously distributed freshwater fluxes in the Southern Ocean. They found that the effect of icebergs is restricted closer to shore than that of the freshwater fluxes and that the sea ice formation is facilitated by icebergs. Yet, when we apply local freshwater fluxes that cool the ocean locally due to the take-up of latent heat needed to melt, these fluxes are more efficient in producing thicker sea ice than icebergs. This is in agreement with Martin and Adcroft (2010) who investigated the impact of interactively coupled icebergs in an AOGCM and also compared it to directly applied freshwater fluxes. They find a decrease in sea ice thickness almost everywhere around Antarctica besides a few regions when generating icebergs when generating

icebergs. Also Hunke and Comeau (2011) investigated the interactions between sea ice and both giant and small icebergs in the Southern Ocean using a stand-alone ocean model with explicitly included icebergs that are moved according to the ocean currents and the atmospheric forcing applied. They revealed that the bergs locally affect the sea ice thickness and area, but conclude that on a global scale these dynamically induced differences are negligible. In our study the effects on sea ice are locally confined, yet, the feedback on the atmosphere and consequently the development of the ice sheet indicates more extensive impact. The CALV experiment is the only one in which the sea ice thickness enhances east and south of Greenland, in all the other runs the sea ice thickness increases only west of it. This different impact on the sea ice and consequently on the atmospheric state results in different ice sheet geometries. In our experiments we find that the effect of icebergs on the climate is due to both the freshening and the cooling effect, as the bergs take up the latent heat from the ocean. These findings coincide with the results of Jongma et al. (2013), who looked at the impact of icebergs on climate during Heinrich events. They show that including icebergs as melt water fluxes and take up of latent heat has a stronger impact on climate than as just melt water fluxes.

The presented coupled model set-up offers a great approach to conduct long term experiments to better understand the role of icebergs and the interactions between the different climate components during abrupt climate changes. This is feasible with the presented model since the computation time for 1,000 model years is about two days in the fully coupled set-up. A useful next step could be to use this model set-up to study Heinrich events in detail, as the crucial question how the icebergs' feedback was on climate under colder and more instable times has not yet been fully addressed.

Technical corrections

GIS is used for "Geographical Information Systems", I advice to use GrIS instead.

We changed GIS to GrIS

P191I22: "short" (i.e. a few centuries). The cited work describes complete deglaciation, and the scenarios are multi-millennia. I would not call this short, and it is definitively beyond "a few centuries".

This is correct, we stated it wrong and changed it.

P197, I23: "besides" do you mean "except"?

Yes, this has been changed.