***Interactive comment on* "Representing icebergs in the *i*LOVECLIM model (version 1.0) – a sensitivity study" *by* M. Bügelmayer et al.**

Anonymous Referee #2

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In "Representing icebergs in the iLOVECLIM model (version 1.0) – a sensitivity study" Bügelmayer, Roche and *Renssen* discuss results from simulations with a recently ex- tended earth system model of intermediate complexity (EMIC) that now also includes interactive ice sheets as well as icebergs. The new model is also presented in Roche at al. (2013) and Bügelmayer et al. (2014) of which the former paper has been ac- cepted while the latter is still under review/discussion.

The present manuscript focuses on the sensitivity of the EMIC to the iceberg component. However, considering the two publications above and that the iceberg component has been applied to various sorts of model environments before (see references in Section 2.3) the work presented here lacks novelty.

Besides this issue I am also not comfortable with the experimental set up. The authors study the influence of atmospheric and oceanic forcing on the ice- berg momentum balance by comparing the large-scale spatial distribution of icebergs between simulations in which the one or the other forcing is artificially neglected. How- ever, the spatial resolution of the model grid used (atmosphere: 5.6 deg and vertical 3 layers; ocean: 3 deg and 20 layers) is hardly sufficient to resolve local characteris- tics of winds and currents around Greenland and to draw conclusions that would be applicable beyond this particular model. The model set up further lacks Antarctic ice sheet and icebergs that, however, may well influence the Atlantic Meridional Overturn- ing Circulation and hence imprint on the climate in the northern North Atlantic, which is studied here, in multi-centennial to millennial integrations. Finally, the null-hypothesis that the iceberg size distribution might have a greater influence on the climate over Greenland than strong (70 vs 1120 ppm CO_2) changes in radiative forcing is provoca- tive at best. Considering the model has been presented already in earlier publications and the weakness in scientific merit of the sensitivity simulations presented here, I cannot recommend publication of the manuscript.

Nevertheless, I do think that iLOVECLIM is a valid model and one can make valuable contributions to the current scientific discussion with it. Including interactive ice sheets as well as icebergs in AOGCM is an important step forward. I thus would like to en- courage the authors to rethink their experimental set up and research questions posed. Hoping that the authors submit a revised version later I add some detailed comments below.

We would like to thank reviewer #2 for carefully evaluating our manuscript and for providing valuable suggestions for improvement.

Before answering the comments point by point, we would like to address the two main concerns of the reviewer regarding the lack of novelty and the experimental set-up of the presented study.

Concerning the novelty of this study, we would like to emphasize that the paper of Roche et al. (2014) describes the coupling of the ice-sheet model to the atmosphere – ocean – vegetation model, without the iceberg module included. In their study, the coupling methods, e.g. downscaling procedures, are described as well as the effect of the coupling on the different model components such as the ice sheet, the oceanic or atmospheric model component. The coupling of the iceberg module to the ice-sheet – atmosphere – ocean – vegetation model is presented in the paper of Bügelmayer et al. (2014) where the skill of the coupled model to represent observations is tested as well as the validity of parameterizing icebergs by using freshwater fluxes. In Bügelmayer et al. (2014) we thus presented the model developments and performance. In the latter study, we found an indirect effect of the icebergs on the Greenland ice sheet's development. The next step is *to perform sensitivity studies to further test this behavior, which was done in the present study. The iceberg module has been used in previous studies, as correctly stated by the reviewer. Yet, the iLOVECLIM set-up is the only one, that we are aware of, where it is included in an ice-sheet – atmosphere – ocean – vegetation model. The novelty of this study is therefore that for the first time such a coupled model is used to evaluate the impact of icebergs and their sizes on the Greenland ice sheet itself, and also the effect of different forcings (wind and ocean currents) on the iceberg distribution and melt.*

Therefore, we have designed two different types of experiments. First, our aim was to better understand the different effects of the atmosphere and the ocean on the movement of the icebergs. Of course, this is a hypothetical approach as there will always be a combination of winds and ocean currents acting on the icebergs. Nevertheless, we think it is of interest to investigate how the general pattern of iceberg melt flux depends on the wind or ocean current forcing and how this pattern influences its own forcing fields. We explicitly state that we do not aim on reproducing single iceberg tracks because of the coarse resolution, but the model allows us to investigate the interactions between all the different model components over a longer timeframe, which is what we are interested in. Second, we want to use the model to perform experiments to understand climate changes happening in the past and maybe happening again in the future. As correctly stated by the reviewer, we do not model icebergs explicitly in the southern hemisphere yet. But by testing the impact of the initial iceberg size, and even if this is only done for the Greenland ice sheet, we can quantify the error we might introduce by using the respective iceberg size. All the model output has to be interpreted by keeping in mind the shortcomings of the used model, such as its coarse resolution. Yet, we do think that the results and conclusions drawn here are of general interest and validity because the model captures the main properties of icebergs. Further, the results that can be compared are consistent with previous studies as we discussed in the present manuscript and in Bügelmayer et al. (2014). But as also mentioned by the reviewer, the model has a coarse resolution and it would be of great interest to us if the experiments were repeated using a higher resolved model, such as the one currently presented by Marsh et al. (2014) in GMDD.

Further, we submitted the presented study to the GMD manuscript type **"Technical, Development and Evaluation papers"** *and in this type of manuscript it is explicitly stated that* **"in-depth evaluations of already published models"** *are welcomed.*

http://www.geoscientific-model-development.net/submission/manuscript_types.html

Detailed comments: page/line(s)

4354/3 these examples of icebergs effects are not self-explanatory. Please think of a generally more agreeable opening.

As suggested by the reviewer, we changed to opening to (Lines 12-13):

Recent modelling studies have indicated that icebergs play an active role in the climate system as they interact with the ocean and the atmosphere.

4354/6 rewrite to ". . . atmospheric and oceanic forces acting . . ."

We have changed Lines 15-16 as suggested by the reviewer.

The spatial distribution of the icebergs and their melt water depends on the atmospheric and oceanic forces acting on them as well as on the icebergs' size.

4354/10 replace "To address these shortcomings, . . ." with "To study the sensitivity of the modeled iceberg distribution to initial and boundary conditions, . . .". Your previous sentence does not necessarily list shortcomings.

Thank you for pointing this out, we have changed the sentence accordingly (Lines 19-21):

To study the sensitivity of the modeled iceberg distribution to initial and boundary conditions, we performed 15 sensitivity experiments using the climate model iLOVECLIM that includes actively coupled ice-sheet and iceberg modules, …

4354/12 rewrite to ". . . atmospheric and oceanic forcing fields . . ."

We have changed Line 21 as suggested by the reviewer.

… 1) the impact of the atmospheric and oceanic forces on the icebergs' distribution and melt flux, …

4354/22 At this point it is unclear how icebergs feedback on the ice sheet they calved from, i.e. why the authors assume that there is a feedback.

To take this valid comment into account, we have changed Lines 23-25 to

… 2) the effect of the used initial iceberg size on the resulting Northern hemisphere climate as well as on the ice sheet, due to feedback mechanisms such as altered atmospheric circulation, under different climate conditions (pre-industrial, high/low radiative forcing).

4355/6 update reference. Rignot et al. 2013 recently showed that in some places ice- ocean melt dominates calving. Rignot, E., S. Jacobs, J. Mouginot, B. Scheuchl, 2013, Ice Shelf Melting Around Antarctica, Science Express, DOI: 10.1126/science.1235798.

Thank you for pointing this out, we have modified the Lines 40-43 accordingly:

Most importantly, icebergs play an important part in the global fresh water cycle since currently up to half of the mass loss of the Antarctic (Rignot et al., 2013) and Greenland ice sheets is due to calving (approx. 0.01 Sv, 1 Sv = $1*10^6$ m^3/s, Hooke et al., 2005).

4355/8 replace "take up" with "uptake"

We have changed Line 44 as suggested by the reviewer.

/11 remove "thereby"

We have changed Line 46 as suggested by the reviewer.

4365/15ff please rephrase (be careful about the advancements made with each study). I suggest: "In the latter study, the icebergs were seeded based on a prescribed constant calving flux based on observational estimates but moved according to the modeled winds and currents and interacted with the model atmosphere and ocean. Martin and Adcroft (2010) then implemented the iceberg model into a coupled global climate model (CGCM) using the model's variable runoff as a calving flux though still lacking an ice sheet component. Most recently, Bügelmayer et al. (2014) took the next step by using an EMIC with both dynamically coupled ice sheet and iceberg model components."

This paragraph has been re-written following the kind suggestion of the reviewer (Lines 77-83):

In the latter study, the icebergs were seeded based on a prescribed constant calving flux based on observational estimates but moved according to the modeled winds and currents and interacted with the model atmosphere and ocean. Martin and Adcroft (2010) then implemented the iceberg model into a coupled global climate model (CGCM) using the model's variable runoff as a calving flux though still lacking an ice sheet component. Most recently, Bügelmayer et al. (2014) took the next step by using an EMIC with both dynamically coupled ice sheet and iceberg model components.

4357/4 ". . . on the atmospheric and oceanic forces acting on the icebergs."

We have changed Line 95 as suggested by the reviewer.

4357/5ff Although I generally agree with the assessment of uncertainties in this para- graph I believe that uncertainties inherent to the empirical relationships contained in the iceberg model of Bigg and Gladstone and others, which is used here, are much greater. However, we lack observations, in particular on iceberg decay, to reliably esti- mate these. Nevertheless, I think this should be noted here.

Thank you for pointing this out, we have modified this paragraph to also state the uncertainties related to the iceberg module (Lines 97-104):

Computing iceberg melting and tracks is linked to various types of uncertainties. First, the iceberg's drift and melting, as computed in the iceberg module, are based on empirical parameters and simplifications (e.g. Jongma et al., 2009) that would need further observations to be improved. Second, uncertainties in the reconstructed and modelled wind fields and ocean currents, used to force the icebergs, directly affect the distribution of the freshwater. Third, the initial size distribution of the icebergs is prescribed and based on present-day observations (Dowdeswell et al., 1992). Yet, this chosen size distribution may not be a valid representation of calving events in past or future climate conditions.

4358/5 The methods section lacks detail and relies heavily on Bügelmeyer et al. (2014) instead, which is a paper still under review. I suggest to either add considerable detail to the present paper to make it independent or wait until the former has been accepted.

The paper of Bügelmayer et al. (2014) will likely be accepted before this one, but if this is not the case, we will be happy to add the needed information in the methods section.

/12 I must say that I have considerable trouble with the idea of estimating the uncertainty of iceberg distribution due to the atmospheric forcing using a model with such very coarse resolution of 5.6 deg and only 3 layers.

/24 same holds for the coarse ocean grid.

As correctly stated by the reviewer, our model has a coarse resolution, in both, the atmosphere and ocean model components. This is exactly why we think it is important to perform these sensitivity studies because in the manuscript submitted to TC, we show that we capture the main characteristics of iceberg drift and more importantly, we find that including icebergs has an impact on climate and, through feedback mechanisms, on the ice sheet. So in the current study we want to investigate, if and to what extent the interactions of the icebergs with the ocean-atmosphere-ice-sheet are dependent on the exact location of the iceberg melt flux because we do not expect to model this as accurately as a higher resolution model.

4359/15 When running millennial control simulations one should take the Southern Hemisphere into account. Icebergs in the Southern Ocean affect the stratification and thus bottom water formation, which may impact on the AMOC. AMOC variability forced in the South can emerge in the North Atlantic within a century.

In the current model set-up, the Greenland ice sheet is actively coupled and its freshwater fluxes (calving and runoff) are computed explicitly. The Southern Hemisphere ice sheet however, is fixed. It is thus correct, that changes in the Antarctic's topography due to the applied high/low radiative forcing are not considered. Yet, altered ice shelf melting is taken into account because ice shelf melting is parameterized depending on the ocean's temperature. Iceberg calving is parameterized as homogenous uptake of latent heat around Antarctica whose amount depends on the total accumulation. Jongma et al (2009) investigated the impact of explicitly modelling icebergs in the Southern Hemisphere, without an ice-sheet model coupled, and found that including active icebergs increases the Antarctic Bottom Water (AABW) by up to 10%. It is correct that we *neglect this effect, but since we do not expect that the initial iceberg size has an impact on the Southern Ocean, this effect is comparable in all the radiative forcing experiments and thus does not influence the difference between the experiments. Having both the Greenland and the Antarctic ice sheet interactively coupled in iLOVECLIM is a goal that, unfortunately, lies beyond this study.*

We have included a short paragraph concerning the Southern Hemisphere in the methods (Lines 149-153):

The Antarctic ice sheet is prescribed according to present-day conditions following the ETOPO1 topography (http://www.ngdc.noaa.gov/mgg/global/global.html). Icebergs are parameterized in the form of homogenous uptake of latent heat around Antarctica and ice shelf melting is computed according to the prevailing ocean conditions. The Greenland ice sheet is coupled actively and computed using the GRISLI ice-sheet model.

and discussion (Lines 398-406) :

Second, we repeated the experiments under a strongly increased and decreased radiative forcing for 1000 years. During this time scale, changes the Southern Ocean can interact with the Northern Hemisphere. Jongma et al. (2009) showed that including active icebergs increases the net production of Antarctic Bottom Water by 10% under pre-industrial conditions. We do neglect this direct effect of icebergs here since icebergs and Antarctic ice-sheet runoff are computed using parameterizations that depend on the prevailing climate conditions. However, we do not expect that the size of the icebergs released from Greenland has an impact on the Southern Hemisphere, thus, the uncertainty introduced by not actively coupling the Antarctic ice sheet is comparable in all the radiative forcing experiments.

/17 This statement is inconsistent with Table 2, where you list iceberg thicknesses of up to 300m. Please check that this is not an inconsistency in the model code.

*The 150m threshold, as stated in Line 17, is applied in GRISLI to provoke calving. As soon as one grid cell is calved, the volume (thickness of ice * grid cell size) is stored as calving mass at the corresponding location. The sum over one GRISLI model year at each calving location is then used in the iceberg module to generate icebergs according to the size distribution based on observations in Greenland (Dowdeswell et al., 1992) where the calved icebergs measure up to 300m. In our method, the thickness of the calving front does not directly determine the icebergs size but the amount of icebergs.*

We have clarified this information in Lines 184-187:

Therefore, the thickness and width of the calving front as defined in GRISLI affects the amount of ice mass available to generate icebergs, but not the icebergs' dimensions.

/19 Why does the ice sheet model exchange fluxes with the iceberg model only once per year?

The coupling time step of one year is chosen on the one hand to fit the ice sheet's response time that is much slower than the one of the atmosphere (4hours) or of the ocean (1 day) and on the other hand to save computation time. But in the climate and the iceberg model, the freshwater fluxes are incorporated according to the respective time step, thus the iceberg model receives a daily amount of ice discharge to generate icebergs.

We have modified lines 167-168:

The runoff is then given to ECBilt where it is re-computed to fit its time-step (4 hours) and incorporated into the land routing system.

As well as lines 162-164:

After one model year, the total yearly amount of calving is given to the iceberg module where icebergs are generated daily, as described in detail in Section 2.3.

And lines 179-182:

The provided ice mass is re-computed to fit the daily time-step of the iceberg module and taking into account the seasonal calving cycle, with the maximum calving occurring from April to June and the minimum occurring in late summer (Martin and Adcroft, 2010).

4360/8 I think Martin and Adcroft presented two opposing seasonal cycles, one for ice- berg calving and one for iceberg melt. I believe observations rather support enhanced calving in summer (melt water lubricates and lets ice move faster; lack of stabilizing sea ice cover) and fall (refreezing of melt water in cravasses). Add a note about the shape of the seasonal cycle you applied.

As correctly stated by the reviewer, Martin and Adcroft (2010) displayed both the melting rate and calving rates. In the presented study, we followed the calving rate for Greenland, with the maximum occurring in April to June and the minimum in late summer (August, September). This seasonal cycle fits relatively well to observed iceberg numbers on the Grand Banks (Reid, E. J.: NRC Publications Archive (NPArC) Archives des publications du CNRC (NPArC) Iceberg Distribution on the Grand Banks : Past and Present).

We have added some information on the shape of the seasonal cycle, as stated above.

/17 Why don't you put the melt water at the respective depth in the ocean?

We add the melt water to the surface layer because we have to simplify the complex process of upwelling of the iceberg's basal meltwater.

/27 But doesn't an offset in ice sheet thickness potentially bias the feedback to variations in iceberg distribution that you do study? An error of 1/3 seems a lot to me. I think you need to argue why this does not affect your results.

It is correct that the overestimation of the ice sheet has implications for the iceberg distribution because the fact that the ice sheet is too extensive and in combination with the pre-industrial boundary conditions causes higher calving rates than observed. Further, the too extensive central Greenland ice sheet results in a negative temperature bias (Roche et al., 2014). Yet, this does not affect the conclusions we draw here because all the experiments are started from the same ice sheet and climate conditions and thus changes at the end of the model runs are only due to the different forcing or iceberg size distribution. To clarify this point, we have modified lines 202-205:

The fact that the initial ice sheet thickness is about $^1/_3$ bigger than the observed one does not impact our results because all the experiments are started from the same ice sheet and climate conditions and thus changes at the end of the model runs are only due to the different forcing fields or iceberg size distribution.

4361/19 please add at end of paragraph an introduction of experiment COM, e.g.: "In experiments called COM the combined atmosphere and ocean forcing is applied, i.e. all terms of (1) are used."

We have added this information as suggested by the reviewer (lines 216-217):

In the so-called "COM" experiments, the icebergs are moved according to Equation 1, thus by the combined atmospheric and oceanic forcing.

Question: In order to truly assess the impact of atmospheric vs. oceanic forcing wouldn't you need to split the melt functions as well? For instance bottom melt is ocean forcing but erosion due to waves is a function of wind speed, i.e. atmospheric forcing.

It is correct that the melt function has not been changed for the OCE and ATM experiments and that this causes the icebergs to melt faster than when only be melted by either ocean forcing or wind forcing. But we were specifically interested in the movement of the icebergs, on their drift pattern and how this is dependent on the forcing fields. By changing also the melt function, we would have prolonged their lifetime and thus additionally altered their melt flux distribution.

We have added lines 222-224 to state clearly that only the equation of motion was changed:

The differentiation between atmospheric and oceanic forces was only made in the equation of motion of an iceberg. The melting of icebergs, which depends on bottom- and lateral melt (oceanic forcing) and the wave erosion (atmospheric forcing), was not altered.

4362/11 I strongly recommend to re-arrange your results section in the sense that you first discuss the control simulation CTRL-COM and then discuss deviations from these results. With respect to Figure 1, start with panel 1g, then discuss 1a and 1d in section

We have changed the result section as suggested by the reviewer. The revised sections are 3.1, 3.2 and 3.3 in the manuscript (lines 239-394).

3.1.1. Introduce new section 3.1.2 that discusses BIG and SMALL runs, again first BIG-COM and SMALL-COM, then the other cases. Rearrange Figure 1 accordingly. (Section 3.1.2 Lifetime of icebergs would become new section 3.1.3.)

We have changed the result section as suggested by the reviewer, please have a look at the manuscript.

/19 remove "(Fig. 3)" in favor of addressing figures in the correct sequence. I think a reference to Fig. 3 is not necessary here. Lifetime of icebergs is discussed in a later section.

Since the whole results section has been modified, this is no longer an issue.

/20 I am confused. I would expect that BIG icebergs provide a greater area and higher freeboard for the wind stress to act on. Then, why is the "atmospheric forcing not strong enough"? Please explain.

We have repeated the experiments to correct for a minor internal error in the model set-up (the orbital parameters were not fixed to pre-industrial conditions) and have redone all the figures and revised the manuscript accordingly. The corrected results did not change in comparison to the previous manuscript, except that the corrected results of the BIG-ATM experiment display that the icebergs are spread as far as the SMALL-, and CTRL-ATM ones, except in the GIN Seas where they follow the strong southward wind without being distributed. This sentence has thus been removed from the manuscript and changed to (lines 278 - 281):

The BIG-COM icebergs are transported further than the BIG-ATM in all the regions considered and especially in the GIN Seas (Fig. 2c). There, the BIG-ATM bergs follow the strong southward component of the wind without being distributed further into the GIN Seas.

4365/12 suggest to revise section titles to "Experiments with high radiative forcing" . . .

4366/8 . . . and "Experiments with low radiative forcing"

We have changed the titles as suggested by the reviewer.

4367/13 While I think that it is worth exploring the impact of atmospheric vs. oceanic forcing in order to understand the spatial distribution of icebergs, a discussion with respect to climate impacts is purely hypothetically since icebergs are driven by both atmospheric as well as oceanic forces. I recommend to limit the climate sensitivity discussion to the BIG and SMALL scenarios.

To take this good advice into account, we have modified the discussion (lines 407-409):

Bigg et al. (1997) showed that about 80% of the small bergs (size class 1 to 3) melt within the first year, which is higher than in our SMALL-COM set-up where about 60% are melted.

4368/14 This is why I think the experiments could have been chosen more carefully. Maybe you also need to consider Antarctic sized tabular icebergs, i.e. bigger than BIG, for the cold climate.

As we also stated in the discussion, we are aware of the fact that the strong forcing probably overrules feedback coming from the iceberg size. But we have chosen this set-up consciously because we wanted to force a strong change in the ice sheets' topography so that we also have a strongly altered calving flux and thus iceberg number.

We have added Lines 236 - 238 at the end of the methods section:

The latter two sets of experiments were done to analyse the effect of the size (CTRL/SMALL/BIG) distribution during periods of a strongly changing ice-sheet under non – equilibrated conditions.

Concerning the iceberg size, as was also noted by reviewer #1, when only modelling Greenland, the chosen distribution is valid, even for glacial periods.

4374/Tab.1 I don't understand this table. My first impression was that since all cells onlycontain "x" all scenarios are the same. Now I suggest, if I interpret this table correctly, to remove line "Experiment name" and column "Name" and instead write the respective full experiment name in each cell, i.e. BIG-ATM, BIG-OCE, BIG-COM, BIG-HIGH, BIG- LOW for the "Big Bergs" row. In fact, "COM" should be in the first column and CTRL the first row. Please provide more information in the caption.

We improved table 1 as suggested by the reviewer.

	PRE-INDUSTRIAL (ATM & OCE FORCING) **= 280 ppm**	**ONLY ATMOS-PHERIC FORCING**	**ONLY OCEANIC FORCING**	**4xCO_2** (ATM & OCE FORCING) **= 1120ppm**	**¼xCO_2** (ATM & OCE FORCING) **= 70ppm**
ALL SIZES	CTRL-COM	CTRL-ATM	CTRL-OCE	CTRL-HIGH	CTRL-LOW
BIG BERGS	BIG -COM	BIG-ATM	BIG -OCE	BIG-HIGH	BIG-LOW
SMALL BERGS	SMALL -COM	SMALL-ATM	SMALL-OCE	SMALL-HIGH	SMALL-LOW

Table 1: performed experiments

4376/Tab.3 add lines every third row (grouping CTRL, BIG, and SMALL); also replace "0.00" by "-" for all CTRL cases, since it is the respective reference.

We improved Table 3 as suggested by the reviewer.

Experiment	**Mean**	**STDEV**	**% diff**
CTRL-COM	3,90E+15	2,53E+12	-
BIG-COM	3,91E+15	2,61E+12	-0,09
SMALL-COM	3,91E+15	1,96E+12	-0,08
CTRL-ATM	3,91E+15	1,90E+12	-
BIG-ATM	3,91E+15	2,14E+12	0,02
SMALL-ATM	3,91E+15	1,99E+12	-0,06
CTRL-OCE	3,91E+15	2,11E+12	-
BIG-OCE	3,91E+15	1,29E+12	-0,03

SMALL-OC	3,91E+15	2,20E+12	-0,14
CTRL-HIGH	3,50E+15	5,03E+12	-
BIG-HIGH	3,49E+15	4,40E+12	0,32
SMALL-HIGH	3,49E+15	5,69E+12	0,14
CTRL-LOW	4,04E+15	1,90E+12	-
BIG-LOW	4,06E+15	2,74E+12	-0,41
SMALL-LOW	4,04E+15	3,20E+12	-0,05

Table 3: Ice-sheet Volume (m3): Mean and Standard deviation of last 100 years, % diff = difference between the ice sheet volume of the CTRL experiment and the BIG/SMALL experiments in percent

4378/Fig.2 I find this graph confusing.

We agree with the reviewer that there is a lot of information in this figure since all the experiments and all the size classes are shown. But we do think that it is an important figure to compare the behavior of the different experiments (e.g. do the BIG bergs cluster, etc.). If you have a suggestion on how to improve this figure, we are happy to do so!

4379 & 4380 Switch figures 3 and 4 as this would suite the presentation of results better.

We have changed to result section, so now 3 and 4 suit the way they were.

Regarding Fig. 4 Are the differences between COM, ATM, and OCE significant with respect to the internal (inter-annual) variability? Same for CTRL, BIG, and SMALL.

*To analyze whether or not the differences of the last 100 years between CTRL-COM/ATM/OCE and CTRL-COM/BIG/SMALL are 95% significant, we computed for 1000 years of CTRL-COM its 100yr running mean and its standard deviation to determine the internal variability. In the GIN Seas we see the biggest internal variability (2*sd of 1000 year equilibrium experiment is: SST 0.23°C and TAIR 0.32°C). This already indicates that this region is especially variable and sensitive due to the ocean convection site. Variations in the deep ocean circulation directly affect the sea surface and air temperatures. We therefore also find the biggest differences between the different experiments in the GIN Seas because the spatial distribution of the IMF directly impacts the deep ocean circulation, but none of the experiments are significantly different from the internal variability (Table 1).*

	Sea Surface Temperature			**Air Temperature**		
	40-90°N	**GIN**	**NA**	**40-90°N**	**GIN**	**NA**
	2*sd of 100yr running mean (95%)			**2*sd of 100yr running mean (95%)**		
CTRL-COM (1000 yrs)	0,18	0,23	0,17	0,25	0,32	0,21
	mean 100 yr Difference			**mean 100 yr Difference**		
CTRL-COM – CTRL-ATM	-0,09	-0,18	-0,06	-0,06	-0,18	-0,10
CTRL-COM – CTRL-OCE	0,08	0,02	0,07	0,20	0,19	0,06
CTRL-COM – BIG-COM	-0,10	-0,15	-0,08	-0,13	-0,19	-0,12
CTRL-COM – SMALL-COM	0,03	-0,01	0,05	0,05	0,02	0,06

Table 1: The internal variability of the CTRL-COM experiment was calculated by first, computing the 100yr running mean of 1000 years equilibrated conditions and second, to determine the internal variability, its

standard deviation. The 2*standard deviation is used to analyze whether or not the mean difference of the last 100 years of the performed experiments is significant within the 95% interval; the areas correspond to Figure 2.