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Interactive comment on "Decadal trends in the Antarctic sea ice extent ultimately controlled by ice-ocean feedback" *by* et al.

Anonymous Referee #1

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General comments:

This paper sheds more light on the reasons for the observed upward trend in Antarctic (AA) sea ice during the last 30 years. The study is based on 1000-year simulations with a coarse-resolution coupled climate model of intermediate complexity extracting 30-year periods that show AA sea ice increase. These have been compared to historical simulations using the same model but constraining AA sea ice. A simple 1-d model has been employed to understand the mechanism of the ice-ocean feedbacks indicated in the climate model simulations. The results have also been compared to historical CMIP5 simulations. The main conclusions are that at interannual time scales the ice-ocean feedbacks are governed by the stratification of the water column, which in turn is controlled by inflow of sea ice and by a net "downward salt transport" due to seasonal brine and freshwater release associated with freezing and melting. Both contribute to a stronger stratification with less oceanic heat flux and thus more sea ice. There is no particular spatial pattern as demonstrated by investigating the 11 periods of AA sea ice increase out of the 1000-year simulation individually. The main message seems to be that where sea ice is getting involved in the seasonal cycle of mixed layer deepening and retreat, downward salt transport eventually leads to a stable stratification which in turn leads to a positive feedback with sea ice increasing locally.

The paper is quite suitable for publication in TCD, but there are some points the authors should consider to discuss or change before final publication. These are listed in the following.

Main comments:

-> The claim that the net downward salt transport due to the presence of sea ice eventually leads to a stabilization of the water column (also illustrated in Fig.4) seems new and somewhat controversial. I would assume that brine release initially weakens the stability of the water column thus leading to a larger oceanic heat flux. This would reduce sea ice formation. Furthermore, the rate of brine release would need to change over longer time scales to cause a long-term change in stratification. Zhang (2007) argues that reduced ice formation due to surface warming leads to less brine release, less oceanic heat flux, and thus overall thicker ice. On the other hand, based on 1000-year numerical experiments with a comprehensive coupled climate model, Martin et al. (2013) argue that a gradual involvement of the seasonal freezing/melting cycle will eventually lead to a switch from a mode of strong open-ocean convection to a mode of no open-ocean convection. Perhaps the authors could relate their findings to those of Zhang (2007) and those of Martin et al. (2013).

-> The paper should be shortened avoiding redundancy. The number of figures could also be reduced. I don't think that Figs.1 and 6 are necessary.

-> An English language overhaul is necessary. This should also lead to a clearer presentation of the main points the authors want to make.

Details:

Page 4588, lines 18-21: Even though their experiments were multi-centennial, Stössel and Kim (2001) proposed a mechanism for decadal variability, not "multi-centennial variability". That reference would better be suited for the last sentence of this paragraph.

Fig.3 is very confusing as the color scales do not consistently indicate red for positive trends and blue for negative trends. Furthermore, the choice of the color ranges seems arbitrary. Why do some variables cover the whole range from deep blue to deep red, while others, e.g. (c), (h), and (k), do not? It is also confusing to not have all subfigures on one page. What does the "vertical oceanic heat flux at the ocean surface" mean? Is it the heat flux into the uppermost model layer? The units for (i), (j), and (k) are hard to compare (cm/year for precipitation, m/year for snow precipitation, and m/day for net sea ice production). It might be better to convert all of them into water or ice equivalent units. Concerning the signs of the trends and color scale ranges, the same applies for Fig.7 and 12.

Page 4591, line 26: "...is associated with..." sounds like the increase in ice concentration is due to a "cooling of the air". In a coupled model, this may also be the result of a higher ice concentration.

Page 4592, line 12: "0.72"; shouldn't the spatial correlation between trend in ice concentration and that in oceanic heat flux be negative? See Fig.3a vs. 3f. Is "Heat flux at the ocean surface" in Table 1 the same variable as that shown in Fig.3f? Lines 19-21: what do you mean by "shallower at higher latitudes"? Fig.3g shows wide regions south of 65S that have apparently no trend (the same holds for Fig.3c and 3f), and locations north of that latitude with large negative trends. Also, the increase of heat content at depth does not reduce the vertical oceanic heat flux, but is rather a result of its reduction. Line 24: should read "...other surface variables...".

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Page 4593, lines 8-13: Is the snow precipitation (Fig.3j) a fraction of the "precipitation" (Fig.3i)? In other words, is the latter the total precipitation or just the water portion of it? There are regions where the precipitation trend is -0.02 m/year that simultaneously show some +10 m/year snow precipitation trend. There is either something wrong with the numbers or units, or all precipitation must have been converted from water to snow in those regions. Even converting to water equivalent (about + 3 m/year) seems vastly overestimated. Concerning "bringing additional mass to the snow/sea-ice system" and the resulting "weak positive feedback" do you mean snow-ice formation, or just addition of freshwater from snow melt? Both would lead to thicker ice.

Page 4594, lines 20-29: This mechanism of downward salt transport explains the seasonal increase in stratification. How is this mechanism going to lead to a long-term upward trend in sea ice extent/thickness (see also main comment)? With less brine release due to gradual warming there would accordingly be less downward salt transport thus leading to a weaker stratification, and thus less ice because of enhanced oceanic heat flux.

Page 4596, lines 3-11: I cannot follow the logic here. Why is it "surprising" to have a lower ice concentration go along with a warmer upper ocean? Irrespective of the fact that the deeper heat content and the surface salinity are not everywhere spatially correlated with ice concentration and the upper-ocean heat content, there should be no reason for why a "lower heat content at depth" (actually only between 200 and 500 m) "would favor an increase in ice extent".

Page 4597, lines 20-21: the described mixing process is due to static instability not "diffusion". Line 23: change "identical if sea ice is present or not" to "independent of sea ice".

Table 2: "level" should read "layer". The latent heat of fusion of water is normally around 3.3x105 J/kg (e.g., Washington and Parkinson, 1986).

Page 4599, lines 4-5: “the top layer is always stable” doesn’t make sense in this context.

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Fig.9a, caption: K should be in 0C.

Page 4601, lines 21-24: referring to the trend in ice extent and its value being much higher. I guess what is meant here is that the rate is much lower in the assimilated than in the non-assimilated simulations.

Page 4602, lines 19-21: it is hard to compare Fig.12b with Fig.3c since different scales are being used. Lines 21-22: I cannot reconcile from Fig.12d that "the depth of the mixed layer is decreasing at high latitudes". Lines 24-25: I can also not see how the decrease in surface salinity is supposed to be "associated with an increase in the oceanic heat content at depth". The corresponding trends seem spatially uncorrelated. Lines 27-28: What is "those results" referring to? Assuming these are referring to Fig.12, how are these results "compatible with the combination of a general temperature increase and freshening at high latitudes"? Both are not shown. Only the decrease in surface salinity indicates a freshening.

Page 4603, line12: “except the salinity increase in the Bellingshausen Sea” referring to observations: a few lines before it says that the salinity increase is what is being observed. There is a similar contradiction with the sentence at the bottom of this page and the last sentence of that paragraph.

Page 4604, line 8: it seems better to write “Each 30-yr period member of a ...”, and line 11 “that differ among members.”. Lines 21-22: the “downward transport of salt” due to brine release would need to change in order for a long-term change in stratification to occur. How do you suggest more brine release to occur with warmer surface conditions (see main comment)?

Interactive comment on The Cryosphere Discuss., 7, 4585, 2013.