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Interactive comment on "Sea ice and the ocean mixed layer over the Antarctic shelf seas" *by* A. A. Petty et al.

Anonymous Referee #2

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In "Sea ice and the ocean mixed layer over the Antarctic shelf seas" Petty, Holland, and Feltham combine the sea ice model CICE with a mixed layer ocean model to study the influence of surface forcing (atmosphere and sea ice) on the formation of deep mixed layers in the Antarctic shelf. The lack of a complex, 3-dimensional ocean model is compensated by restoring ocean grid cells below the current mixed layer to observed (reconstructed) temperature and salinity fields. The study has two objectives, a technical and a scientific. First, the new model is validated for its capability of simulating sea ice coverage, formation as well as export, and mixed layer depth against observations and previous model results. Second, the scientific focus is on the annual cycle of mixed layer depth and its forcing thereby comparing processes in two contrasting shelf sea types, the Amundsen and Bellinghausen seas vs. the Weddell and Ross seas.

The authors nicely demonstrate the dominance of surface salt fluxes (from sea ice growth) over, for instance, wind forcing on the formation of a deep mixed layer using power as the central quantity. Further, it is an interesting point of view to sort the four largest shelf seas into two categories based on their different deep water masses' properties.

Although I like the idea of using a simplified model in order to get a clear understanding of certain processes, the lack of a 3-dim. ocean model and advection in the ocean (the mixed layer (ML) model does not account for horizontal interaction [p.4327/l.6]) are the greatest shortcomings of this study. The uncertainties introduced by neglecting exchange from the ML to the deep ocean and advection must be better discussed.

Using a simplified, computationally less expansive model enables to run the model with high spatial resolution. I am thus disappointed that the authors decided to run with $\sim$55km, a resolution commonly used for global 3-dim ocean models these days. It seems that the development of a sea-ice/mixed-layer model should enable the explicit simulation of coastal polynyas on a, say 5km grid. In this case it would not be necessary to use an arbitrary ice growth threshold (p.4342/l.23) to identify likely positions of polynyas.

The authors provide detailed background information on water masses (temperature and salinity) and their formation in the Southern Ocean from the literature, which I appreciated much. However, they do not compare modeled mixed layer temperature nor salinity to observations. Instead, it is inferred that, for instance, when the mixed layer exceeds 90% of the total water column depth that high saline shelf water (HSSW) is/would be formed. The authors need to compare their shelf water from deep mixed layers with observed properties. Being able to simulate a deep mixed layer is great but only if the bottom water produced has realistic properties.

Although I think the study is interesting and makes a convincing point in sea ice formation being the dominant driver of deep mixed layer formation, I need answers to the

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addressed caveats before I can recommend publication.

I apologize for submitting my review late.

Additional general comments:

1) The introduction provides a comprehensive overview of the water masses and processes in the Antarctic shelf seas. I'd like to suggest to add a sketch, either in the style of a T-S diagram where water masses are labeled, or two idealized cross-sections (depth vs. latitude) showing the layering of water masses, one for each shelf sea type (i.e. WR and AB)âĂŤas in Petty et al. (2013, JPO, Fig. 2).

2) In section 3.1 the authors present a realistic assessment of their models ability to match the observed sea ice distribution. However, the model produces much thicker ice than observed near the coast which likely affects ice growth rates and hence mixed layer formation. The actual difference cannot be estimated from Fig. 6 because modeled ice thickness exceeds the color scale maximum.

3) I doubt that reasonably well simulated mixed layer depth guarantees realistic shelf water properties. Please do present T and S of modeled dense shelf water. Bottom salinity is shown in Fig. 8 with the result that in many grid cells with very deep mixed layers (cells with 'x') the bottom salinity is not much different from the background forcing. Why does a deep mixed layer sometimes yield much higher salinities and sometimes not?

4) It's tricky to neglect ocean circulation on the shelves. You account for the deep large-scale circulation to some extent by restoring to the deep ocean forcing, but your simulation lacks dynamic processes such as Ekman convergence/divergence and horizontal transport within the mixed layer.

5) I probably missed it in the text somewhere, but does the deep ocean forcing have interannual variability or is it a climatology?

Detailed comments (page/line):

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4322/7 abbreviation HSSW needs to be introduced

4323/22 please add the temperature and salinity properties of HSSW

4324/10 split sentence: "...form Antarctic Bottom Water (AABW). AABW drives the bottom ..."

4324/19ff This is exactly what your model could proof if you were using a higher spatial resolution that would enable the simulation of coastal polynyas (assuming that the wind forcing includes the necessary off-shore winds).

4324/24 This should refer to Fig. 2f (winds) and add a reference to the temperature map Fig. 2a in the next line. Consider to rearrange the panels in Figure 2 so that wind becomes panel a.

4325/14 "... have been presented (e.g. Klinck et al., 2004)."

4325/20ff Just recently, Assmann et al. (2013) have found that the background flow is setting the availability of heat on the shelf in form of the CDW. Please comment on this. Assmann, K.M., A. Jenkins, D.R. Shoosmith, D.P. Walker, S.S. Jacobs, and K.W. Nicholls, (2013), Variability of Circumpolar Deep Water Transport onto the Amundsen Sea continental shelf through a shelf break trough , J. Geophys. Res., accepted article, doi:10.1002/2013JC008871.

4328/14 the heat flux is positive for "from surface layer to mixed layer"

4330/5f does 50m or 100m prevent formation of a Weddell polynya? Please rewrite the sentence for clarity.

4330/9 I think, if your model cannot produce the polynya this is an indication for it being related to the deep ocean and deep ocean heat and circulation that your forcing does not resolve. If you find a polynya in your simulation then this is an indication for it being a product of atmospheric forcing (sea ice formation and surface circulation). Either way, it is a difficult decision to artificially suppress its evolution.

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Interactive Comment

4330/21 Which one is the mixed layer depth you diagnose and plot (that of T or that of S, which is a 10m difference if I understand correctly)?

4332/Equ.14&15 typo: “w” is supposed to be Greek letter omega referring to Equ. 12, I guess

4334/1 “(ocean currents are neglected here)” Does this mean U_w=0 in Equ. 12? If so, please state this clearly: “U_w=0”. In fact, this is an item of major concern (see general comments above).

4336/25f nice conclusion!

4337/4 Please properly introduce abbreviations/labels used in map plots, e.g. “Berkner Bank (BB)”.

4337/21 What is the salinity of LSSW in your simulation? By the way, this is a good example of where you present observed salinity but actually only compare “(de)stratification” with the model. (see general comment above)

4341/6 reading about ice export I am again worried about the neglect of advection in the mixed layer, i.e. export of fresh melt water in summer or salty water in winter. Please elaborate more why you can neglect this (either in Introduction or Model [4327/6] section)

4342/23 You estimate the presence of polynyas based on an ice growth threshold, which is a nice, valid approach, I think. However, I would be interested how this compares to an ice concentration or ice thickness or thinnest ice category area fraction threshold. Your model must show some loose or thin ice in these grid cells to grow more ice than average.

4343/10ff This sentence tipped me off: You run a simple model. Why do you not run it with 5 km resolution to actually simulate polynyas?

4343/19 - 4344/12 This paragraph is messy. I can’t find the respective numbers of

Weddell polynya, Weddell shelf, Ross polynya, and Ross shelf ice production form your model. It seems to me that a Weddell polynya production of 258 kmˆ3 is already 25% of the total (Weddell + Ross?) shelf production of 1020 kmˆ3. Also, this part adds to my confusion about when you validate your model against observations and when you actually aim to provide new scientific insight.

4344/22 Please provide boundary lines defining your regions of all Weddell (Ross) sea incl. deep ocean, shelf only, and polynya area. Do you use the white line in Fig. 7 and 11 to limit the shelf area? What does the line show?

4345/19f remove sentence "To our knowledge . . ." I assume that if there were any, you would compare your results to them.

4345/20f Fig. 10c shows net export form the Bellinghausen Sea in most years. So, there's great import and melt but still net export? Is ice just passing through Bellinghausen Sea?

4346/19f Again, increased spatial resolution would help fix this shortcoming.

4348/1 please rewrite this to stress the difference between Table 3 and Figure 12 even more: spatial correlation using time mean vs. temporal correlation using spatial mean. See 4353/20.

4348/22 – 4349/10 and 4350/5-24 pick highlights, don't discuss every correlation.

4351/12f remove sentence "Figure 13 shows . . ."

4351/18 – 4352/5 This paragraph uses a lot of language that expresses speculation, such as "are thought to", "will result", potentially increases", "probably plays". You are running a relatively simple model, i.e. you should be able to completely understand the processes or consider removing this speculative paragraph.

4352/13 Does your model produce HSSW (T and S properties) where the water column is destratified, i.e. where there is a deep mixed layer?

4352/19ff This is the major contribution of your study to new scientific understanding. I strongly recommend to stress this more and shorten everything else.

Table 1 Please use a separate column for the values of the constants.

Table 3 “P” could easily be misunderstood as power. Maybe using “F_rain+F_snow” would be more clear (see Fig. 3)

Figure 1 I really like this figure as a starter. Nevertheless, I’d like to suggest splitting it in two, i.e. make panels b and c a separate figure, and move the inlays in a outside the plot.

Figure 2 Mention what “(JAS)” means, i.e. “(July-September, JAS)”

Figure 3 Please add much more information to the caption: A=ice concentration, F=fluxes, S=salinity, T=temperature, . . .; what are black and red arrows, red=heat flux? What is Fˆo; add h_s=10m and h_mix on the right side of the panel with a bracket spanning the respective part of the water column.

Figure 6 The color scale ends at 2m; it is not clear by how much your model actually overestimates ice thickness since maximum color is reached in many places along the coast.

Figure 7 Please add explanation for black crosses and white outline to caption.

Figure 8 List all abbreviations used in the maps in the caption. There are many grid cells where mixed layer depth exceeds 90% of the water column (black cross) but salinity didn’t change from deep ocean salinity boundary condition. This needs to be better discussed in main text.

Figure 9 Panels a-d should be climatology just like panel e. You focus on seasonal variations not inter-annual ones – which is fine but I think a showing a climatology would be a better match. You can mention in main text that you don’t find any trends. Consider making panel f a separate figure , it’s hard too read. You could also add a panel in which P_net is scaled to 1 so one can see the partitioning for the Bellinghausen and Amundsen seas better.

Fig. 10 Again, the time series is not discussed, focus on climatology. You could indicate interannual variability by adding a shading around climatological curves, e.g. 1 standard deviation.

Figure 11 What does the white outline indicate?

Figure 13 I didn't understand the discussion associated with this figure very well. It seemed pretty speculative to me. I suggest removing this part for conciseness and focus on your main story (Fig. 9).

Interactive comment on The Cryosphere Discuss., 7, 4321, 2013.