Interactive comment on "Investigating future changes in the volume budget of the Arctic sea ice in a coupled climate model" by Ann Keen and Ed Blockley

Anonymous Referee #2
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We thank the reviewer for reading our manuscript, and for his/her comments. Our responses are included below in blue text.

General Comments
In this work the authors decompose in the coupled climate model HadGEM2-ES the global Arctic sea ice volume budget over the late 20th and 21st century into its main components – top melt, basal growth, basal melt, frazil ice formation, advection, snowfall less sublimation.
In many ways this study appears as a follow up study of the earlier Keen et al., 2013 paper - see section 5 on 'modelled heat budget of the Arctic snow and ice' but instead of taking a local (per unit ice area) analysis here the authors present a global perspective that presents the advantage of explaining the mechanisms that control sea ice volume decline at the Arctic basin scale.
The main results of this study are:
- To present a detailed methodology of how to analyse the HadGEM2-ES Arctic sea ice volume budget components at the basin scale - To characterise and rank in order of importance the different terms controlling the seasonal and inter-annual sea ice growth (and melt) - To show that the changes in the volume budget are a function of the sea ice cover and not of the speed at which the sea ice retreats

My overall impression is that there is nothing fundamentally wrong with this paper but that at the same time that it does not contribute to any significant advances in the field.

We feel that the type of study outlined here is now necessary in order to understand inter-model differences in projected future ice decline: we need to consider changes in the underlying processes as well as looking at how the ice state changes. We also feel that there are a number of novel aspects to our study, some of which are summarised below. However we recognise from this review, and from comments from reviewer 1, that we have not been clear enough about the scope and interest of the study so we will be updating the manuscript to improve this.

- Our formulation of the volume budget includes individual components of the melt/freeze terms, so we know whether changes are attributable to atmospheric or oceanic processes.
- We consider the seasonal cycle of these changes, to understand the (sometimes opposing) changes at different times of year.
- We consider different ways of looking at changes in the budget components:
    - Ensuring the (declining) ice area is taken into account in order to construct a budget that balances the changing ice volume, and
    - Considering 'local' changes over the ice itself, which are more easily related to physical processes (eg more surface melting in a warmer climate)

  The combination of these approaches helps to understand the (important) impact of the declining ice cover on the budget.

I encourage the authors to explore one of the following possible extensions of their work in order to give it a wider audience:

- Explore impact of sea ice physics even at a simple level. Comparing results with results from HadGEM1 analyzed in Keen et al., 2013 could be informative. While it would be difficult to separate the impact of the different physics in the two models on the total volume budget it would show how model developments modify our understanding of the drivers of sea ice decline

We have applied the same analysis to HadGEM1, but the sea ice physics in these two models is essentially the same, so this comparison would not show the impact of different sea ice physics. The two

models showed very similar budget change, with the main differences being due to different rates of ice decline. While we *are* interested in the impact of the ice decline in the changing budget, we felt this was better illustrated using one model and a range of different forcing scenarios.

. - Compare the model results with other climate models.
In that sense the reader would get a better sense of inter-model variability. The authors suggest that their methodology is appropriate to analyse other models. Why not do it?

This will be possible using the diagnostics from CMIP6 models, and we plan to do this once the data is available.

- If these options appear too ambitious the authors may at least consider improving the quality of the figures and explain in greater details how the decompositions presented in those figures help explain the future evolution of the sea ice cover and its role in the climate as a whole. For example what can we learn about the changing climate based on seasonal changes in the different terms in the volume budget. Similarly what do the figures 9 and 10 on the changes of effective thickness as a function of sea ice area tells us about climate change in the Arctic and beyond.

We will be widening the discussion to include:

- Drivers of the ocean warming causing extra basal melt
- Relationship between the ice area and global changes
- Changes in the surface fluxes contributing to melt at the ice surface.

Interactive comment on The Cryosphere Discuss., https://doi.org/10.5194/tc-2017-216, 2017.