Stable climate and surface mass balance in Svalbard over 1979–2013 despite the Arctic warming

Authors response to the review of Jan Lenaerts

First, we would like to thank Jan Lenaerts for his very useful and relevant review which will improve our manuscript a lot. The textual comments will be included in the revised version of our paper.

Major comment

I strongly advise to remove the part concerning the MIROC model. I believe this is a rather distracting part of the paper, and it does not add anything relevant to its content. I would recommend moving this part to a follow-up paper that discusses the climate projections. For this review, I have therefore chosen to focus only on the ERA-Interim part.

Concerning the sections about the evaluation of MIROC5 and MAR_{MIROC5}, we are writing a companion paper about future projections performed by MAR forced by MIROC5. This paper will be submitted to TCD in the next few weeks. It makes more sense to us to write a first paper with all the present results and all the evaluation (the reader that is only interested in the MAR_{ERA} results can skip the last sections) and get directly to the heart of the subject in the future projections companion paper. If we move the MIROC and MAR_{MIROC} sections to the future projections paper, the reader that want detailed information about the validation will still have to read the MAR_{ERA} validation in the first paper as we compare MAR_{MIROC} to MAR_{ERA} in the MIROC5 sections.
Anyway, we will wait for the opinion of the other reviewers and the editor and will go along with the editor's opinion.

Minor comments

1. Sea-ice forcings in fjords

I would like to see more discussion of the limitations of this study with respect to the forcing of sea-ice fields. In fact, many of the stations used for model evaluation are located next to fjords that are – at least partly – sea-ice covered. Because these fjords are so narrow, this sea-ice cover is not included in the ERA-Interim re-analysis; however, it largely determines the climate of the neighbouring land and glacier areas.

The sea-ice cover (SIC) is extrapolated from the ERA-Interim reanalysis (resolution: 0.75°) at a resolution of 10km and the SIC in the fjords is extrapolated from the SIC of the closest ERA pixels. The SIC of the closest pixels may not be representative of the SIC in the fjords but this approximation is better than no SIC at all and is the best we can do from the ERA-Interim reanalysis (the same goes for SST).

2. SMB vs calving

If the SMB has been negative for the past 30 years, this would imply that Svalbard glaciers lost mass. How important is calving in comparison with SMB? Is mass loss also observed (IceSAT, GRACE, etc.)? Does this approximately meet your SMB estimate minus the amount of calving?

According to Hagen et al. (2003), the surface mass balance integrated over Svalbard is estimated to be -14 ± 3 mm w.e. yr^{-1} (based on measurements made in the 60s-90s). Our mean value of -48 mm yr^{-1} over 1979-2013 therefore aligns with the values of Hagen et al., considering the large interannual variability of our SMB (210 mm yr^{-1}) and the fact that the time period over which the simulations were performed are not the same (e.g. our mean value would have been -32 mm yr^{-1} over 1979-2012 instead of -48 over 1979-2013). Values are given in mm w.e. yr^{-1} instead of Gt yr^{-1} as the integrated permanent ice area is not the same in the different studies.

Calving has been estimated by Hagen et al. to be 4.5 Gt yr^{-1} (~110 mm yr^{-1}) and therefore is a very important component of the mass balance compared to their estimation of the SMB (-0.5 Gt/yr) . However, it is small compared to the contribution of surface runoff to the total loss (680 mm yr^{-1} in Hagen et al. and 620 mm yr^{-1} with MAR_{ERA}).

ICESat data have been used by Moholdt et al. (2010) to study elevation changes over 2003-2008. Over that period, their mass balance over the whole Svalbard, excluding calving front fluctuations, is estimated to be -0.12 ± 0.4 m yr^{-1} whereas MAR_{ERA} SMB estimation for that period is -0.088 m yr^{-1}, which is included in their error interval. Also, the elevation has decreased on average over the whole Svalbard but has increased over the Austfonna ice cap and northeastern Spitsbergen. The pattern is the same with MAR_{ERA} but it is difficult to compare elevation changes directly as only the first ~10 m of ice and snow are modelled and the compaction of the ice layer is therefore not accurately represented in MAR.

Błaszczyk et al. (2009) estimated a calving flux of 6.75 ± 1.75 km^3 yr^{-1} w.e. over 2000-2006 from ASTER imagery and we used this value to estimate the SMB from the different MB estimates.

Study	**Period**	**MB estimate (km^3 yr^{-1})**	**SMB estimate (mm w.e.)***	**MAR_{ERA} estimate (mm w.e.)**
Mémin et al. (2011)	2003-2008	-9.1 ± 4.2	-65	-88
Mémin et al. (2011)	2003-2008	-15.5 ± 2.4	-243	-88
Mémin et al. (2011)	1998-2007	-25	-508	-79
Wouters et al. (2008)	2003-2007	-8.8 ± 3	-49	-106
Nuth et al. (2010)	03/07-65/90	-9.71 ± 0.53	-106	-48

* **SMB estimate** = mass balance (MB) estimate – calving flux from Błaszczyk et al. 2009, then converted in mm w. e.

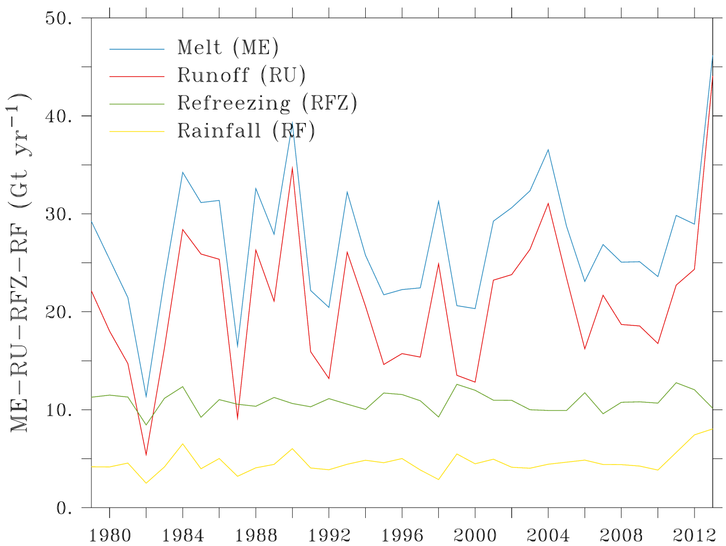
Our MAR_{ERA} estimates are close to the low value of Mémin et al. (2011), obtained from GRACE measurements (-9.1 Gt yr^{-1}) and compares quite well with Wouters et al. (2008) and Nuth et al. (2010), knowing that the estimate of Nuth et al. (2010) does not include Austfonna and the time period is different from ours. The high value of Mémin et al. (2011), obtained from GRACE (-15.5 Gt) and the value obtained by ground gravity observations (-25 Gt yr^{-1}) give a surface loss much larger than ours but those values are also quite large compared to the other studies.

In short, MAR_{ERA} compares well with studies for which the SMB has been estimated and also gives satisfying results compared to other studies for which we had to estimate the SMB contribution using a calving flux value estimated over the same period mostly.

This extended comparison will be added in the revised version of our paper.

3. Refreezing

How important is refreezing in Svalbard? Although MAR contains a sophisticated snow model, there is little to no discussion on the partitioning of melt into runoff vs. refreezing.



	Mean (Gt yr^{-1})	SD (Gt yr^{-1})
ME	27.1	6.6
RU	20.9	7.3
RFZ	10.8	1.0
RF	4.6	1.1

Mean = 1979-2013 mean value

SD = standard deviation

The figure shows the evolution of melt (ME), runoff (RF), refreezing (RFZ) and rainfall (RF) integrated over the permanent ice area from 1979 to 2013 and the table gives the integrated 1979-2013 mean values and the standard deviation.

About 64 ± 9% of the total liquid water (melt plus liquid precipitation) runs off and the remaining 36% refreezes.

The melt, runoff and refreezing linear trends are not significant. The melt and runoff have a large interannual variability (standard deviation of 6.6 and 7.3 Gt yr^{-1}) whereas the amount of water that refreezes is much more constant from year to year (SD = 0.95 Gt yr^{-1}).

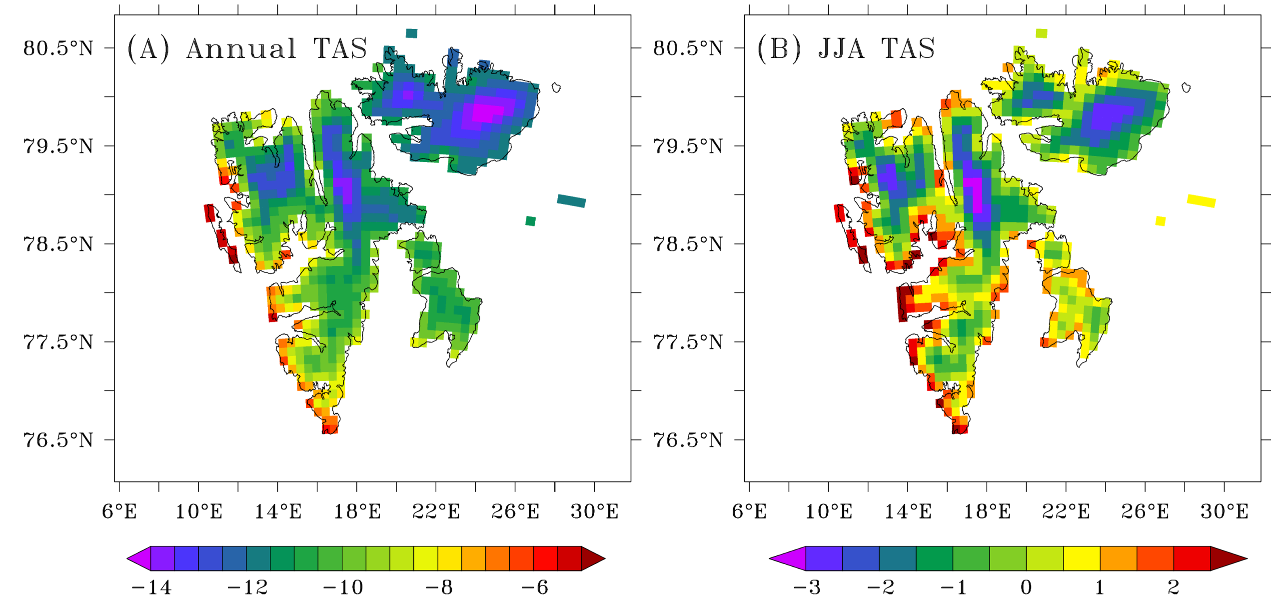
4. Climate

I really miss a figure and discussion, just showing temperature, wind speed, precipitation, etc. Since this is a paper describing the Svalbard climate, and the authors have all the data available, this is a necessity.

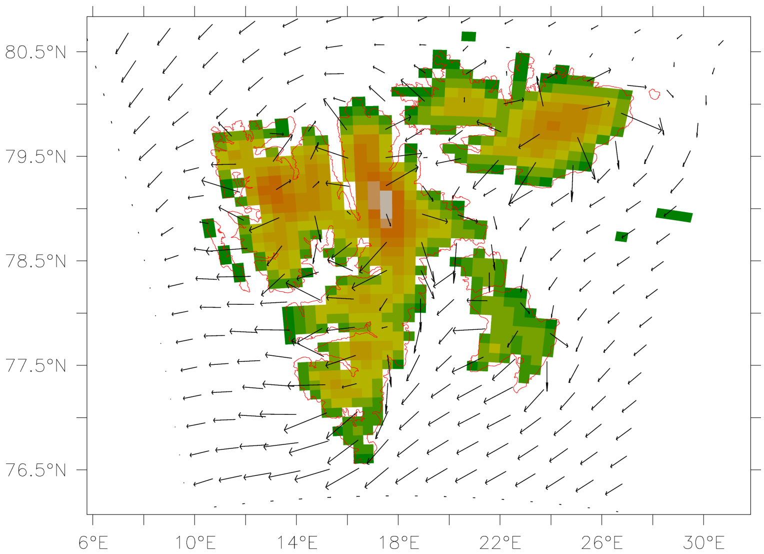
Figure 8 already discusses the 1979-2013 mean annual temperature and precipitation (together with a surface mass balance figure, see your comment about figure 15).

we could add a summer (JJA) temperature to this figure as shown below. In summer, the West-to-east temperature gradient associated with the presence of the North Atlantic Drift is less pronounced than on the annual time scale, as there is less sea ice on the east coast of Spitsbergen to further cool it and increase the temperature contrast with the east coast.

The sea-ice cover should also have a cooling effect on the immediate vicinity of the coastline, which should be a little bit colder than a few kilometres inland. Unfortunately, this effect is not visible at our 10-kilometre resolution.



A wind speed figure (here corresponding to the ~10m level) would not add much relevant information to the paper. With our smoothed topography, the pattern of katabatic winds is barely visible, apart from Austfonna and the east coast of northern Spitsbergen.



Additional references (not used in the TCD manuscript)

[1] Błaszczyk, M., Jania, J. A., and Hagen J. O.: Tidewater glaciers of Svalbard: Recent changes and estimates of calving fluxes, Pol. Polar Res., 30(2), 85–142, 2009

[2] Mémin, A., Rogister, Y., Hinderer, J., Omang, O.C., and Luck B.: Secular gravity variation at Svalbard (Norway) from ground observations and GRACE satellite data, Geophys. J. Int., 184, 1119–1130, 2011

[3] Nuth, C., Moholdt, G., Kohler, J., Hagen J.O., and Kääb, A.: Svalbard glacier elevation changes and contribution to sea level rise, J. Geophys. Res., 115, F01008, doi:10.1029/2008JF001223, 2010

[4] Wouters, B., Chambers, D., and Schrama, E. J. O.: GRACE observes small-scale mass loss in Greenland, Geophys. Res. Lett., 35, L20501, doi:10.1029/2008GL034816, 2008