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

## Author answer to the comment of Mauri Pelto

Thank you fort your comments that will improve our manuscript. We will take them into account in the revised version of the manuscript.

4499-4: I do not see that the stabilization of mass balance can be easily defended as a statement of fact, if it emerges in the conclusion after detailed assessment, fine.

Here we agree that we may seem to have taken a shortcut and put a part of our conclusion into the introduction. We will thus reformulate this sentence as:

*Svalbard seems to be the ice cap the least sensitive to the recent Arctic warming in summer (Serreze et al., 2009) and while melt records have been broken several times in Greenland in the second half of the 2000's, the SMB of Svalbard has been closer to balance after 2004 (Moholdt et al., 2010). Fettweis et al. (2013a) attributed it to atmospheric circulation changes in summer damping the climate change as we will discuss in Section 4. However, this recent stabilisation of the Svalbard mass balance needs to be put on a larger perspective, which has been missed until now*.

The results from Sobota (2007) on Waldemarbreen do not support this. James et al (2012) found increased thinning after 1990. The six glaciers with mass balance results submitted to WGMS displayed in the Norway3 chart of the WGMS mass balance bulletin also does not support this stabilization. Nuth et al (2013) point out area loss was smaller and retreat rate larger during the post 1990 period. This conclusion is supported by Blaszczyk et al (2013). Nuth et al (2012) point out greater surface elevation changes after 1990. This collection of data all based on field observations do not indicate stabilization.

A stable SMB over the whole Svalbard on average over the last 35 years is not in contradiction with a recent increased thinning measured on individual glaciers.

First, a non significant SMB temporal trend over the last 35 years does not necessarily mean that shorter periods, recent or not, could not have had larger SMB decrease, whether it be an integrated value for the entire Svalbard or the SMB of a specific glacier (as we will illustrate later with Kongsvegen).

In addition, the integrated SMB of Svalbard (stable over the last 35 years in our case) does not reflect the variability of some glaciers. Figure 1 shows the correlation ($R^2$, coefficient of determination) between the annual values of the SMB for each pixel and the Svalbard total SMB for the period 1979-2013.

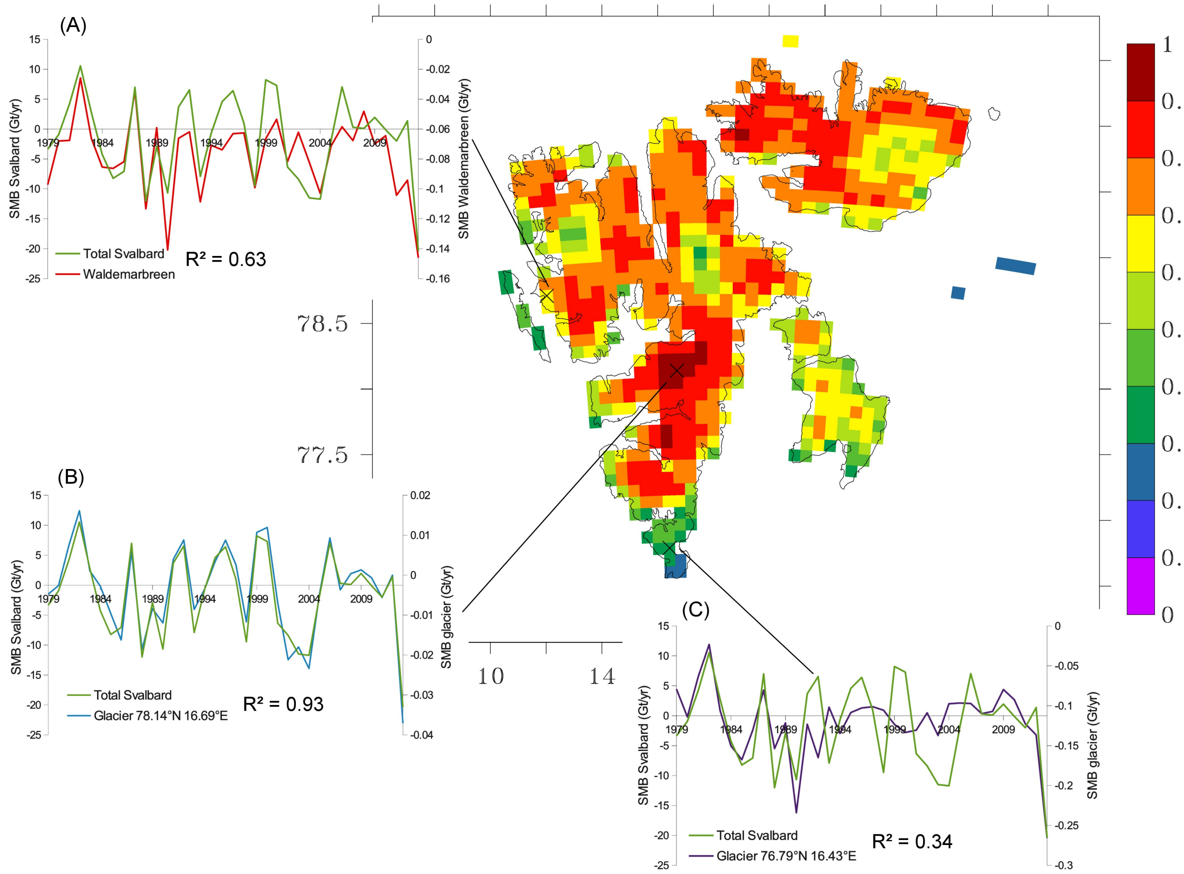


***Figure 1:*** *Correlation ($R^2$) between the annual SMB time series and the SMB time series integrated over the entire Svalbard. The A, B and C panels give the annual SMB time series (Gt $yr^{-1}$)for 3 different pixels with the SMB time series integrated over Svalbard (green curves) as comparison.*

Some regions (inland of Spitsbergen and Nordaustlandet, except the central regions of NW and NE Spitsbergen and Austfonna) have a SMB highly correlated to the Svalbard total (e.g. figure 1B with $R^2 = 0.93$) while some other (along the coastlines of Spitsbergen, on Barentsøya and Edgeøya and in the centre of NW and NE Spitsbergen as well as Austfonna) are poorly correlated to the total (e.g. figure 1C with $R^2 = 0.34$). Figure 2, showing the 1979-2013 SMB linear trend for each pixel (in mm $yr^{-2}$ with the significant trends in dotted pattern), also illustrates the difference in SMB variability over the last 35 years at local scale versus global Svalbard case (-3.4 mm $yr^{-1}$).

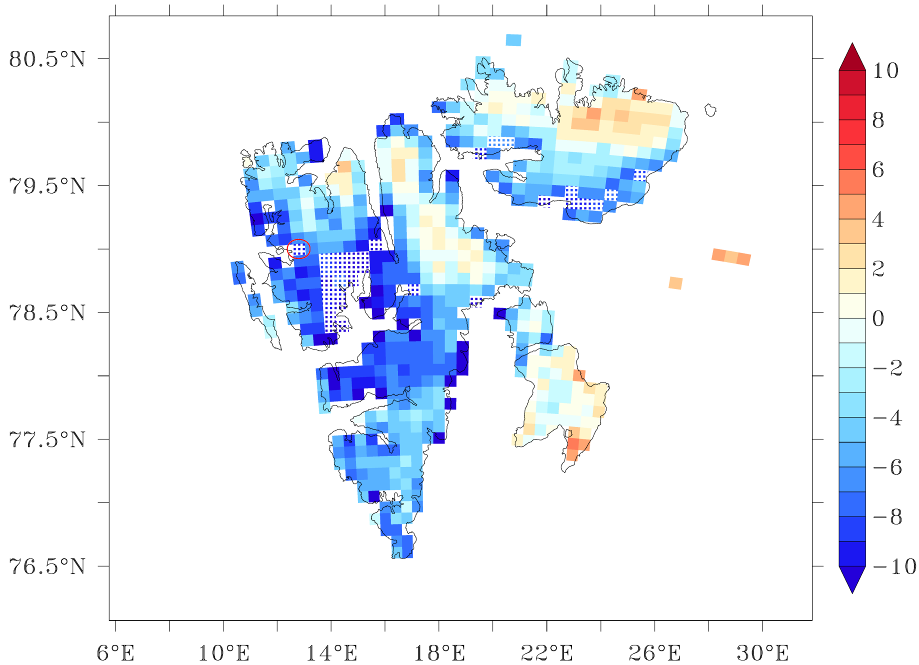


***Figure 2:*** *1979-2013 SMB linear trend (mm yr$^{-2}$). The dotted areas correspond to the regions for which the trend is significant.*

Sobota et al. (2007) used SMB measurements made on Waldemarbreen between 1996 and 2004 and meteorological data from Ny-Ålesund to reconstruct the SMB from 1970 using 3 different methods (climatological and geodetic). Two of their reconstructions (methods 1 and 2) display a significant linear trend whereas nor the third nor the observations do (the linear trends have been calculated by us using their values).

The SMB of the pixel corresponding to the location of Waldemaarbreen (figure 1A) is moderately well correlated to the Svalbard SMB ($R^2 = 0.63$). The correlation between the MAR Waldemarbreen ($MAR_{WB}$) SMB time series and the Svalbard series is also better before 1995 than after ($R^2 = 0.77$ vs 0.55). This suggests that $MAR_{WB}$ recent behaviour is distinct from the average Svalbard behaviour and a first piece of evidence that a recent acceleration of the melt of some glaciers is not in contradiction with our message. Moreover, SMB has been very negative in 2004 but the following years had less negative or even positive SMB values in MAR, except in 2013 (reported by Moholdt et al. (2010b) for 2005-2008). On Waldemarbreen on the other hand, the SMB modelled by MAR decreases steadily between 2008 and 2013, displaying a different behaviour than the Svalbard average and being closer to the Greenland situation.

Furthermore, whereas nor our Svalbard SMB trend nor the $MAR_{WB}$ trend is significant over 1979-2013, the $MAR_{WB}$ linear SMB trend after 2005 is significant but the Svalbard trend is not.

Nuth et al. (2012) modelled the SMB of 2 glaciers, Kongsvegen and Kronebreen over 1966-2007 in order to estimate the long-term calving flux of the latter. Their results showed that the SMB of Kongvegen was close to zero up to the late 1990s but then became more negative (see their table 4 and figure 7, also shown here as figure 3). However, it is not mentioned that the trend is significant.

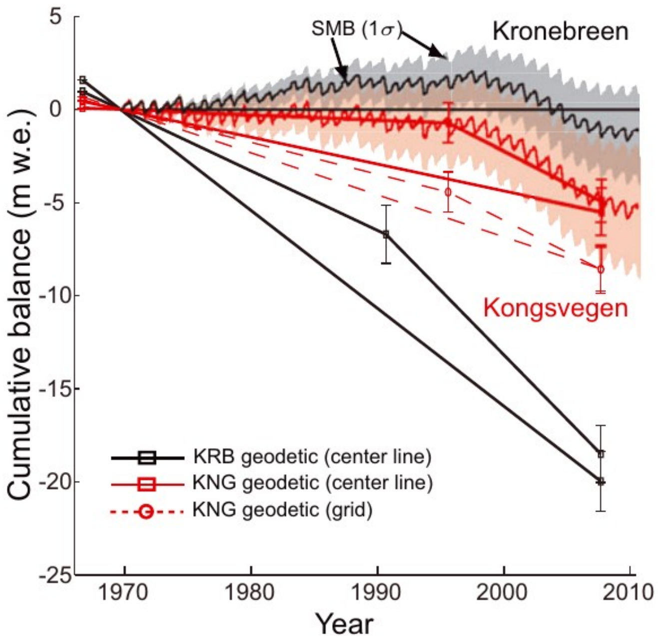


***Figure 3:*** *Figure 7 of Nuth et al. (2012). The cumulative SMB curve of Kongsvegen is the red curve.*

Figure 4 shows the cumulative SMB over 1979-2013 for the MAR pixel corresponding to Kongsvegen. The SMB is also close to zero until the late 1990s (-21 mm $yr^{-1}$ for the period 1999-2013) but then becomes more negative (-225 mm $yr^{-1}$ for the period 2000-2013). However, given the large interannual variability of the SMB (standard deviation of 303 mm for 1979-2013), neither the 1979-2013 nor the 2000-2013 linear trends are significant.

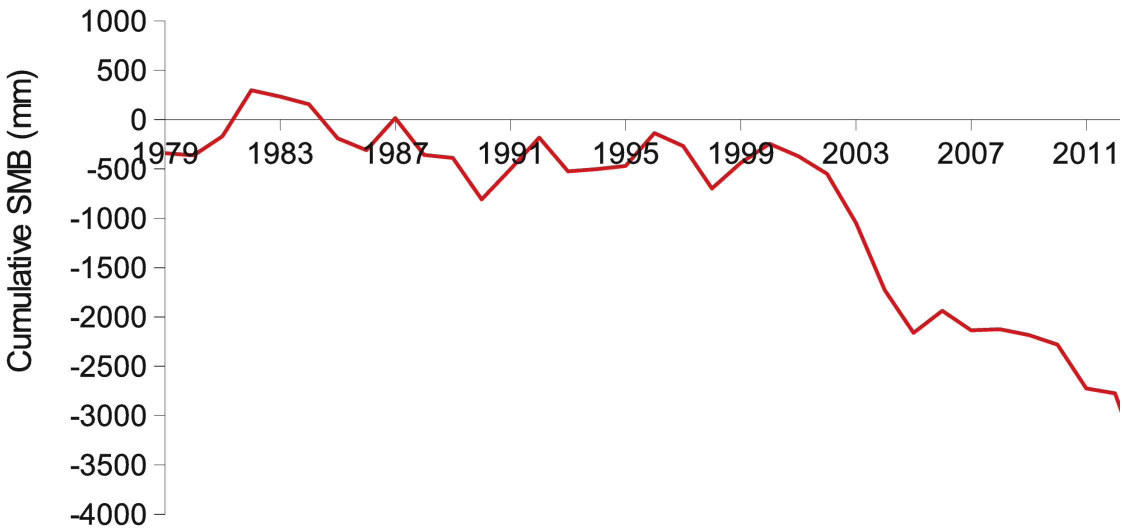


***Figure 4:*** *Cumulative SMB (mm) of the MAR pixel corresponding to Kongsvegen over 1979-2013.*

Moreover, Nuth et al. (2012) also suggests that the mass balance of Kongsvegen and Kronebreen stabilised after 2007.

Therefore, this is still not contradicting the fact that our integrated SMB is stable over 1979-2013.

Finally, as shown in figure 2, some glaciers do have a significant trend over the last 35 years (therefore not only a recent enhanced surface melt), in particular an area including part of Kongsbreen (circled in red in figure 2), located right next to Kongsvegen and Kronebreen.

This proves that (i) the SMB of the entire Svalbard can be stable while the surface melt of a particular glacier can accelerate and (ii) MAR shows a recent acceleration of the melt for some glaciers and even over the last 35 years.

In conclusion, the thinning of the glaciers studied by Sabota (2007) and James et al. (2012) could definitely be accelerating without contradicting a stabilisation of the total SMB. Neither is the recent enhanced elevation of Kongsvegen and Kronebreen pointed out by Nuth et al. (2012) opposite to a 35-years stable (but yet negative) integrated SMB.

Finally, we can unfortunately not use the inventories in Nuth et al. (2013) to validate MAR as it does not only involve SMB but also glaciers dynamics. Whereas different glacier have different dynamical responses to climate change (depending on their size but not only), the SMB of two different glaciers will react the same way to the same climate perturbation. There is also a certain response time in the dynamic of a glacier while the response of the SMB to climate is immediate.

In the revised version of the manuscript, we will insist on the fact that this stabilisation concerns the integrated surface mass balance of the entire Svalbard but that it does not exclude that some glaciers may experience a recent enhanced thinning.

4505-20: This is a weak temporal data set for validation.

Although it is true that the data are not recent, we do not think it is a weak temporal data set, especially because we were able to select the same years for our comparison. The only really short time period is for Kon K stake but we do not attribute the disagreement between the measured and modelled SMB to a too short time period but to the complex precipitation pattern that can not be correctly modelled at our resolution, as we explained P 4506, L9-15. The 2 studies have been cited in a number of recent studies: Moholdt et al. (2010a; 2010b), Nuth et al. (2010), Day et al. (2012), Dunse et al. (2012) and other papers published earlier in the 2000s.

Moreover, Pinglot et al. (1999; 2001) provided data distributed over most of the archipelago, included on Austfonna and far from the coast, where we do not have climate data to compare to our outputs.

They also give SMB values in m w.e. rather than elevation changes, which is more convenient for MAR, as we explained in our answer to Jan Lenaerts's review. We also provided a more detailed comparison with other studies in the same document that we will add to the validation in the revised version of the manuscript.

Why is the Waldemarbreen SMB data not used it has been submitted to WGMS since 1995. This would be an ideal data set since the glacier is not calving or surging and has summer and winter balance values. Sobota (2007) discusses it at length. In terms of validation how do the results compare to James et al (2012), who provide changes with elevation?

We are not able to use the Waldemarbreen data in the validation as this small glacier (2.5 $km^2$, representing only 2.5% of the area of one pixel) is not represented in our topography, nor is the complex topography surrounding it.

For the same reason we are not able to use the results of James et al. in our validation. The glaciers used in this study only cover a small part of a MAR pixel and the topography in their area is constant as it is also included in only one pixel (the topography is anyway smoothed even if the surrounding pixels are considered).

At a pinch, we could maybe use the data from Albrechtbreen as it is a bit larger than the other glaciers, even though we consider only the pixels covered with at least 50% of ice (corresponding to at least 50 $km^2$ of the pixel covered with ice) in our analysis. However, the results would most probably show a large SMB bias and support what we already stated about modelling the SMB over a very complex topography with a 10 km resolution.

Moholdt et al (2010) found a varied SMB with elevation with interior thickening of up to 0.5 m a$^{-1}$, at the same time as the margins are thinning at a rate of 1–3 m a$^{-1}$ on Austfonna, this would be a key result that the SMB model should also generate.

We have compared our results to Moholdt et al. 2010b rather than 2010a (see ref. below), as the paper includes the whole Svalbard instead of only Austfonna. Figure 5 shows the mean elevation change rate (dh/dt in m yr$^{-1}$) over 2003-2008 with a zoom on the Austfonna/Vestfonna region, to be compared to fig. 1 of Moholdt et al. (2010b) (also shown here as figure 6).

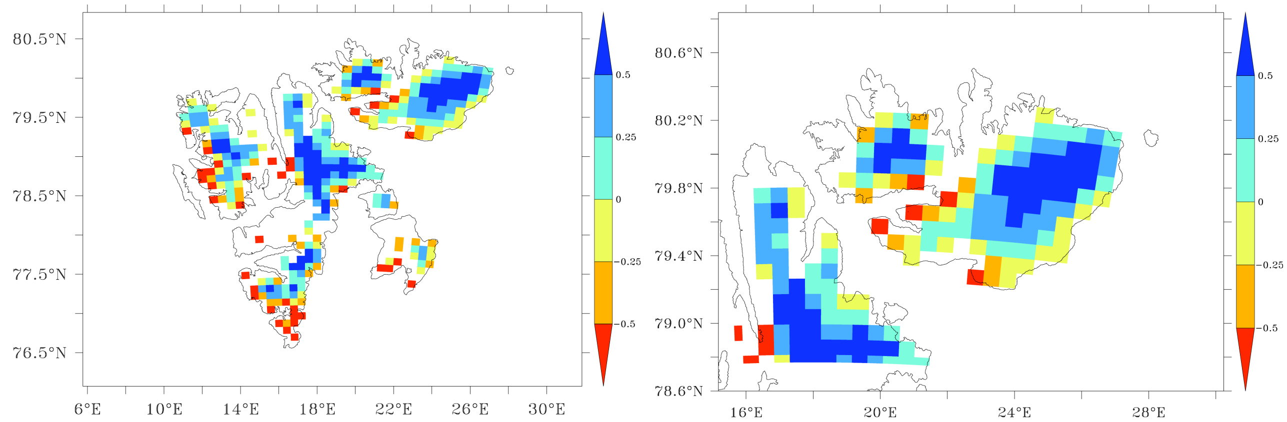


***Figure 5:*** *(a) Mean elevation change rate (dh/dt in m yr$^{-1}$) over 2003-2008. (b) Same with a zoom on Austfonna and Vestfonna.*

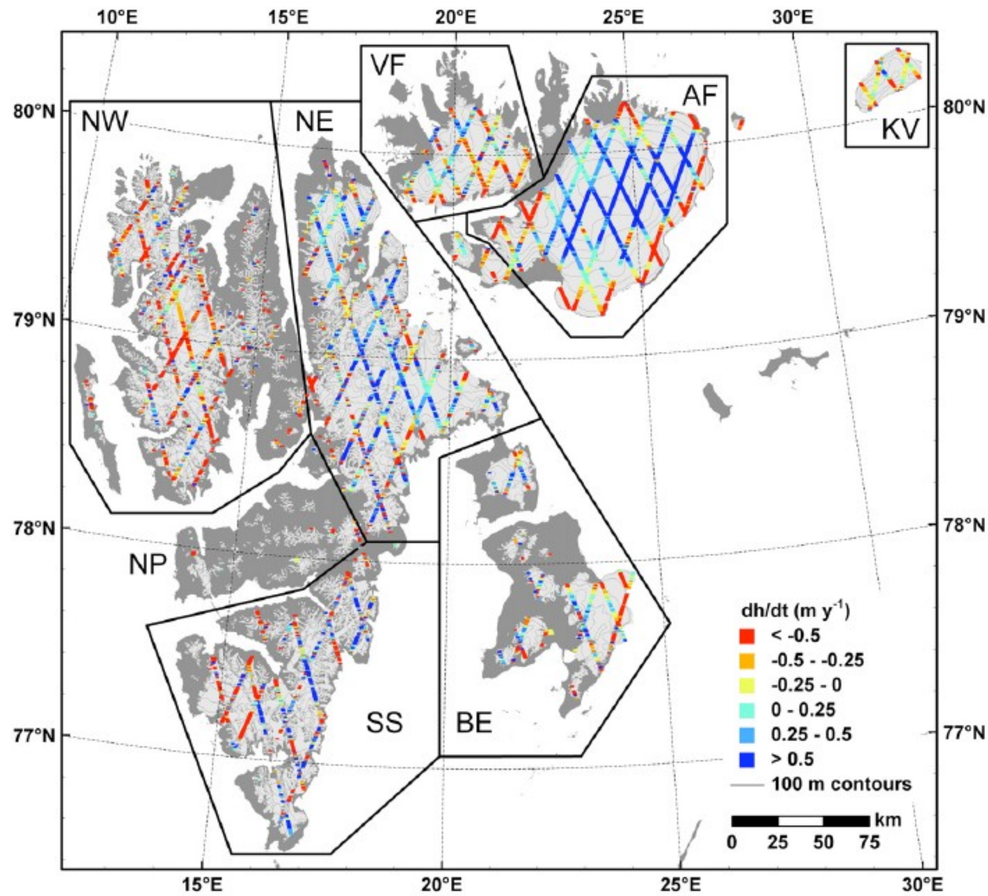


***Figure 6:*** *Figure 1 of Moholdt et al. (2010b). 2003-2008 mean elevation change.*

As already mentioned, apart from the northwest of Spitsbergen, the pattern corresponds well to Moholdt et al. (2010b). But, because we only model the first ~10 metres of snow and ice, there could be another bias, in addition to the biases we already mentioned (due to the used resolution). MAR represents well the thickening of the interior of Austfonna and Northeastern Spitsbergen but underestimates the thinning at the margins (lower than 0.25 m $yr^{-1}$ over most of the Austfonna margins).
Averaged over the different regions, MAR gives results comparable to Moholdt et al. (2010b) (see table), except again in Northwestern Spitsbergen, where the thinning is underestimated because MAR shows a thickening of the interior whereas in Moholdt et al. (2010b), there is thinning over the whole Northwestern Svalbard.

| | **dh/dt (m $yr^{-1}$)** | |
|---|---|---|
| **Region** | **MAR** | **Moholdt et al.** |
| **Austfonna** | 0.04 | 0.11 ± 0.04 |
| **Vestfonna** | -0.10 | -0.16 ± 0.08 |
| **West** | -0.14 | -0.54 ± 0.10 |
| **East** | 0.15 | 0.06 ± 0.06 |
| **South** | -0.31 | -0.15 ± 0.16 |
| **BE** | -0.30 | -0.17 ± 0.11 |
| **Total** | **-0.13** | **-0.12 ± 0.04** |

Our values for Vestfonna and South Spistsbergen are included in Moholdt et al. (2010b) interval and the only region for which we have a large difference is Northwestern Spitsbergen (Austfonna, East Spitsbergen and Barentsøya/Edgeøya (BE) are only slightly outside the interval).
On BE, we overestimate the thinning a bit whereas in South Spitsbergen our value is closer to the lower limit of the interval, suggesting that we either slightly overestimate the melt or underestimate precipitation in this region.

The value for the entire Svalbard is also the same as the value of Moholdt et al. (2010b).

In conclusion, our results compare well with Moholdt et al. (2010b) both regionally and globally and this comparison will be added to the revised version of the manuscript.

**Additional references (not used in the TCD manuscript)**


[1] Dunse, T., Schuler, T. V., Hagen, J. O., and Reijmer, C.H.: Seasonal speed-up of two outlet glaciers of Austfonna, Svalbard, inferred from continuous GPS measurements, The Cryosphere, 6, 453–466, doi:10.5194/tc-6-453-2012, 2012

[2] Moholdt, G., Hagen, J. O., Eiken, T., and Schuler T. V.: Geometric changes and mass balance of the Austfonna ice cap, Svalbard, The Cryosphere, 4, 21–34, 2010a

[3] Moholdt, G., Nuth, C., Hagen, J.O., and Kohler J.: Recent elevation changes of Svalbard glaciers derived from ICESat laser altimetry, Remote Sens. Environ., 14, 2756–2767, 2010b

[4] 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