Reply to the Short comment posted by Prof. Jonathan L. Bamber

We thank Prof. Jonathan Bamber for his insightful comments on the manuscript. He has pointed out some important issues that we address below and further discuss in the reply to reviewer #2, who raised some of the same issues.

General comments:

The most important concern by J. Bamber is related to the conversion of volume change to mass change. It is important to stress that the effect of ice dynamics is included in our mass balance estimate, and that our method of converting volume change to mass change is general and similar to a other published works (Zwally et al. 2011, Journal of Glaciology). We can see, however, that the text may be misleading. We explain the method below, and in the reply to referee #2, who also raised this issue.

We believe that the mass balance estimate is appropriate. The suggestion of a new title to emphasize the importance of interpolation and sampling techniques to obtain the volume change is still very good and an improved title could be: " Mass balance of the Greenland Ice Sheet 2003-2008 from ICESat data - the impact of interpolation, sampling and firn density". This title would also resolve the last minor comment regarding the epoch of the observations.

Specific comments

1. On Equation 10

We can see how the text leading to equation 10 may be misleading. We calculate the mass change by first estimating the volume change, dH/dt, then correct dH/dt for changes of the air content in the firn to obtain dH/dt(corrected), and finally to convert the corrected volume change to a mass change by using a density that varies spatially depending climate and whether the location is above or below the ELA. Below the ELA, we use the density of ice, above the ELA, we use the density of snow when the thickness has increased, and the density of ice when the thickness has decreased, this way taking the ice dynamics into account in a simplified way. This may imply an error in the mass estimate, which we consider in the uncertainty estimate, see below.

We have revised the text and equation 10 to clarify this, and we also improved the uncertainty estimate in section 5.5.

2. 5.1 Firn compaction, paragraph 2

It is clear that the chosen refreezing scheme is the simplest possible of these types of studies. As pointed out by Janssens and Huybrechts 2000, this model treatment is equivalent to a maximum retention model, where the top of each summer surface acts as an impermeable layer for the new melt. Therefore the snow pack cannot contain more water than the density difference between snow and ice. This treatment might overestimate the densification, and this has to be added to the error induced by the firn model.

The issue with the use of the HIRHAM5 RCM, is elaborated on in the reply to referee #2, however validation have been done.

3. 5.1 Firn compaction, paragraph 3

The polynomial parameterization is a simplification. We agree with the comment and as seen in the reply to referee #2 the ELA is now determined by HIRHAM5 RCM.

4. 5.1 Firn compaction, paragraph 4

The ice density is now changed to 917 kg m^{-3}.

5. 6 Additional elevation change

At locations above the ELA with elevation increase after corrections, we use a density of surface firn to estimate the mass change. If there is basal melting or if there are changes in the ice dynamics (inflowing ice), the density may be too low. This is contributing to the error.

In the interior of the GrIS a maximum melt rate found at a deep ice core site is 6.1 mm/yr [Buchardt 2007]. This basal melt interpolated to grid point above the ELA and with a positive dH/dt is equivalent to 5.5 Gt/yr. If the 15 mm/yr is assumed [Fahnstock et al. 2001] this error is as high as 13.68 Gt/yr. However, the average melt rate is lower, and if we assume an average melt rate of 1 mm/yr as mentioned by J. Bamber, the error is 0.9 Gt/yr.

If all elevation increase above the ELA is due to ice instead of surface firn (As the most extreme case of changing dynamics), we calculate the error as the density difference between surface firn and ice times the elevation increase and obtain and mass of 38 Gt/yr, this would also include the special case of basal melting. This is the maximum contribution of the conversion from volume to mass.

This explanation should be added to the end of Section 5.5 page 2123.

6. 7 Mass balance of the GrIS, paragraph 1

As proposed in the answer to referee #1 a section will be added in which the errors are summarized.

7. 7 Mass balance of the GrIS, paragraph 2

Surface density is modeled according to the temperature given by HIRHAM5 and applied with the firn correction in mind.

8. 7 Mass balance of the GrIS, paragraph 3

The volume mass conservation is clearly a hot topic, judging from the newly published article from Zwally et al. 2011. The reply to referee #2 gives an extended view of the assumptions given in section 5 and due to the misleading text in the discussion paper a revised text is given.

9. Last comment

The epoch should be added to the title.

References

Buchardt and Dahl-Jensen 2007	S. L. BUCHARDT, D. DAHL-JENSEN (2007): Estimating the basal melt rate at NorthGRIP using a Monte Carlo technique. Annals of Glaciology 45
Fahnestock et al. 2001	Fahnestock, M., W. Abdalati, I. Joughin, J. Brozena, and P. Gogineni (2001), High geothermal heat row, basal melt, and the origin of rapid ice how in central Greenland, *Science*, *294*(5550), 2338-2342.
Jassens 2000	Ives Janssens and Philippe Huybrechts (2000): The treatment of meltwater retention in mass-balance parameterizations of the Greenland ice sheet, Annals of Glaciology,31, 133-140(8)
Zwally et al. 2011	H. Jay ZWALLY, Jun LI, Anita C. BRENNER, Matthew BECKLEY, Helen G. CORNEJO, John DiMARZIO, Mario B. GIOVINETTO, Thomas A. NEUMANN, John ROBBINS, Jack L. SABA, Donghui YI, Weili WANG (2011). Greenland ice sheet mass balance: distribution of increased mass loss with climate warming; 2003–07 versus 1992–2002. J. Glaciolm 201, 88–102