Response to Anonymous Referee #1:

We thank the anonymous referee for his/her comments on the manuscript. Especially the clean listing of input data sources in tables will improve the manuscript greatly. Our responses are marked in blue.

Major remarks

My **first** major remark concerns the dataset and the fact that all the DEMs and velocity fields are not synchronous. For sure, we have to deal with the available datasets, but my concern is how much the results are influenced by using asynchronous datasets. In the present paper, for each inversion (for each date) one need a surface DEM, a surface velocity field and a contour of the glacier.

Which contours are used for each date is not clearly explained in the paper: it seems from the figure that the glacier contour, and especially the front of the glacier, is always the same. Is that correct? As discussed in the introduction, changes in the ice-shelf buttressing may partly explain the increase of velocity, so that the inverted basal shear stress might be strongly influenced by a change of the glacier front position. Sensitivity of the result to this geometry uncertainty might be inferred by inverting τ_b for different front contours.

To clarify that we use changing frontal positions according to the DEM for each year, we will add the following text to the method: "PISM treats the SSA as if it applies to the entire grid domain, even in ice-free locations. No additional boundary conditions are applied to the terminus of the glacier, instead the ice thickness simply decreases to zero from one grid point to the next. In this way the glacier outline is determined by the ice thickness given in the DEM for each year." And the following to the discussion: "We solely concentrate on snapshots of ice geometry and do not investigate causes of the change in geometry, such as increased melt or decreased buttressing at the ice front. In other words, the inversion examines an instantaneous stress state given a certain geometry and surface velocity, but it can, by itself, not attribute any causes."

Only the 1985 and 2007 DEMs are available over this period, and it seems that the DEM at each date are constructed using dh/dt maps. Because velocity fields are obtained as the difference between two successive measurements, which date was used to produce the surface DEM? How sensitive are the results to small changes (in the order of error measurements) in surface elevation?

To conclude on that point, I would suggest to add a tabular containing for each inverted date, i) the period covered by the velocity field (and reference), ii) the precise date(s) of the surface DEM and how it was obtained, iii) the date of the contour of the glacier and reference.

Table 1 will show the requested information for each inverted date. The outline of the glacier is given by the ice thickness from the DEM for each year. The misfit area is the same for all years, so surface velocity data is used to infer the basal yield stress only up to the 2008 grounding line for all years.

My **second** major remark is about the choice of the inverted parameter (τ_c). I guess that in fact what is inverted is the β parameter of a linear friction law $\tau_b = \beta u$. Is that correct? (if not, forgot about what is proposed hereafter, but then which parameter is really inverted and how should be

clearly explained in the paper).

We used an approximation to a plastic sliding law, not the commonly used linear friction law. And are inverting directly for the basal yield stress tau_c. We will adjust the methods section to clarify this.

It is well know that we don't expect a linear friction law, and that in fact β encompasses the complexity of the basal friction processes (non linearity, water pressure dependency, threshold velocity, . . .). Because the inversion can give access to only one parameter, the reconstruction of a more complex friction law is only speculative and is based on assumptions that have to be discussed. In Jay-Allemand et al (TC, 2011), almost the same approach is proposed to invert for the evolution of the basal shear stress at the base of Variegated glacier over a 10-year period. In a first step, only the evolution of β is presented and then using a more complex friction law, these changes in β are explained in term of changes of basal water pressure. I would suggest that a similar approach is adopted here, explaining clearly that the first key parameter inverted is β and then that this β encompasses more complexity, and that, assuming a till friction law, changes in β can be explained by changes in τ_c.

In the case of Jakobshavn Isbrae, the water pressure is largely determined by the ocean in areas where the bed is below sea level. We compare our inferred changes in tau_c to the observed changes in effective pressure under the assumption that the water pressure stays constant. Other types of analysis would be interesting and worthwhile, but go beyond the scope of this study.

Other minor remarks

page 2155, lines 9-20: At the list of the potential processes, you might also add an increase in basal water pressure by a change of the hydrological system (in- crease of runoff) and a decrease of the lateral resistance by again an increase of runoff (and increase in water in the crevasses of the lateral shear bands of the glacier).

Will add the following: "Other possible processes include weakening of the ice in the lateral shear margins and increase in basal water pressure through changes in the hydrological system (Van der Veen, 2011)." While these are indeed possible mechanism, the observations clearly point to changes originating near the terminus and propagating inland.

Equation (1): the choice $u_{threshold} = 100$ m a^{-1} and $q = 0.25$ should be dis- cussed (give some references here).

Will add: "The chosen values for q and u_threshold used here were found to provide the best representation of observed ice motion (Bueler, personal communication, 2012). As mentioned before, the results derived in this paper are basal yield stress fields that are consistent with our model choices and surface observations, and might not reflect actual physical till properties. The main conclusions of this paper, namely a weakening of the till near the terminus, remain valid for different choices of q and u_threshold."

page 2157, line 23: is it really τ_c that is inverted? (see second major remark)

yes, see answer to major remark

page 2159, line 8: as stated in my first major remark, the error induced by the ice geometry should be discussed more deeply.

Will add: “We investigate the influence of bed topography on the inversion results in Habermann (in print) and we find that errors in bed topography lead to residuals that are larger than the residuals due to errors in velocity observations. This large expected error is consistent over all inversions performed here and we do not expect a significant influence on the changes in basal yield stress.” Where Habermann (in print) refers to Habermann, M. (in print). *Basal shear strength inversions for ice sheets with an application to Jakobshavn Isbrae, Greenland*. Ph.D. Thesis, University of Alaska, Fairbanks.

page 2159, line 26: the L-curve analysis has been used previously in other glaciology related applications that might be cited here (e.g. Jay-Allemand et al., TC 2011; Gillet-Chaulet et al., TC 2012)

Will add both suggested references.

page 2160, line 13: why the datasets are interpolated to a 500 by 500 m grid should be discussed. What is the grid size of the model itself is also important and should be given (might justify this interpolation?).

Will add: “All data sets are given on or interpolated to a 500 by 500 m grid, which is the grid size chosen for the model.” And clarify earlier on that this grid size is used in the model. Additionally I will add: “We chose a grid resolution of 500 by 500 m. A finer resolution is not warranted by the data and tests with coarser grids show convergence. A finer grid might be desirable in the area of the deep trough, where basal topography changes rapidly.”

page 2161, line 2: what about the boundary of the domain? (see first major remark).

See answer to first major remark.

page 2162, line 8: which dates of the dataset are used for the choice of the model parameters should be specified in the text.

Will add: “For the model norm and the prior estimate of basal yield stress we used the 2006 data set, for all other parameters all inverted years where considered to determine the value.”

page 2162, line 20: I don’t see many other parameters for the forward model?

We were thinking about q and u_threshold, but these parameter choices will already be discussed in more detail in the new Methods section. We will delete “The forward model contains many parameter choices, here we only discuss the ice softness parameter. All other values for the forward model are discussed in the Methods section. Default values, or values that have proven to be good choices in other studies are used whenever possible.”

page 2163, line 10: the spin-up experiments purpose was to compute a temperature field and see how the ice viscosity vary spatially? Correct? You might specify that not only the ice flow but also the temperature field were computed during these spin-up experiments.

Will change the sentence to: “Additionally, we conducted time-dependent numerical experiments (spin-ups), where not only the ice flow but also temperature fields were computed. These experiments show little horizontal variability in the vertically averaged ice softness.”

page 2163, line 12: p.72ff (?)

ff implies ‘and the following pages’

page 2163, line 23: the temperature corresponding to the adopted ice softness should be given and compared to the measured temperature by Lüthi et al. (2002).

Will add: “This ice softness is equivalent to an isothermal ice column with a temperature of ~ 3 C using the

flow law temperature dependence given by (Cuffey, 2010). For comparison, at a site on the ice sheet adjacent to the ice stream (Luthi, 2002) measured borehole temperatures that provide an estimate of ice softness equivalent to ~15 C isothermal ice, indicating our chosen ice softness has some enhancement relative to the borehole."

Equation (5): ice thickness has already been defined page 2157.

Will delete the repeated definition of ice thickness.

page 2170, line 20: and what about the firn density. Are you accounting for firn in the chosen ice density (which value should be given).

Will add the ice density (set to 917 kg/m^3) and the statement: "The area of interest lies entirely in the ablation area, so that density variations due to firn do not need to be considered. Density variations caused by heavy crevassing, however, can occur, but are not considered here."

page 2171, line 4: no b mark in Fig 12.

Will delete mentioning of Fig. 12 "b".

Fig 1: the two bends indicated in Fig 7 should be marked by two points on the flowline.

We will mark the two bends as requested.

Fig 6: this figure is too small to really see the differences between the different dates. Also, it seems that the front position is the same for the 5 dates?

Will add a figure showing a close-up of the basal yield stress results. Will add: "The area past the 2008 grounding line is not included in the misfit area and is blacked out." to the caption of Fig. 6.

Fig 7: why the velocity are decreasing toward zero at the front except for 1985? We don't expect the velocity to be zero at the front.

The text in the methods section will explain that the SSA is solved at every grid point in the domain and that therefor the points where the ice thickness is zero (because the glacier terminates) the calculated velocities go to zero.

Fig 9: I cannot see the red dashed line.

Will delete the mentioning of red dashed line

Fig 10: I cannot see the green thin solid line on this figure.

Will take out the thin green and blue lines that were hard to see and adjusted the caption accordingly.

Fig 12: it is difficult to figure out what is the geometry of the glacier from this figure. May be, the glacier contour should be added.

The color choices and caption text will be improved and the centerline will be added.

Fig 13: labels should be a, b, c and d.

Will correct labels and add a, b, c and d in the caption itself.