

*Subglacial hydrology indicates a major shift in dynamics of the West Antarctic Ross Ice Streams within the next two centuries*, S. Goeller, V. Helm, M. Thoma, and K. Grosfeld

## Response to Anonymous Reviewer #1

Dear reviewer,

thank you for your review of the manuscript. We understand that thorough reviewing is a time consuming process, so we appreciate the effort you put into completing the reviews. We found your comments very helpful and modified our manuscript according to them.

Please find all of your comments elaborated in detail below.

Best regards,  
Sebastian Goeller.

### General comments

The paper presents results of subglacial hydrological modelling of water beneath the Ross Sea ice streams, and shows that hydrological flow paths may reorganise in the future due to elevation change in the ice streams. The paper is of interest, but the findings are not presently set in the context of underlying assumptions adequately enough. The main issue is that there is no consideration of how the ice surface may evolve due to deformational flow due to a changing surface/stress gradient. This may be a small effect, but must be discussed more explicitly in the paper.

We agree, that an arising ice bulge, like the observed one at the upper Kamb Ice Stream, would change the ice surface stress gradient. Thus, it would lead to a deformational flow respectively to a dispersion of the initial bulge. However, this effect is already included in the observational data, because the observed elevation change rate includes all influences on the local ice thickness: accumulation, basal melting and ice flow due to basal sliding and deformation. Applying this observational data as an extrapolation for a limited time span is thus highly suitable to gain meaningful statements about the ice geometry of the close future and the associated basal hydraulic potential. To investigate time scales beyond, this extrapolation becomes more and more error-prone and complex interactions between ice dynamic and basal hydraulic system should be considered instead.

We added this paragraph: *Our approach to assess future ice sheet geometries by the extrapolation of observed surface change rates allows robust statements for the next decades and could be used to validate and tune complex ice–water flow models. However, the uncertainties of this projection increase with extrapolation time. Beyond time spans, which typically describe the stagnation*

*or development of an ice stream (e.g., ~150 years for the stagnation of the Kamb Ice Stream; Rose, 1979; Retzlaff and Bentley, 1993), the complex interactions between ice dynamic and basal hydraulic system should be considered. This requires the application of state-of-the-art models, which are also capable to describe observed on-off behavior of ice streams (e.g., Carter et al., 2013; van der Wel et al., 2013).*

The application of the current trend to the next 200 years is not a prediction – it is simply an extrapolation, and as such the title especially is misleading. Without a coupled model of ice & water flow, this cannot be considered a future prediction. I suggest the title is reworded to reflect the content of the paper more appropriately.

*We reworded the abstract to make clear, that we use the satellite data for an extrapolation of the ice thickness into the close future: The future development of the subglacial hydraulic environment is estimated by applying ice surface elevation change rates observed by ICESat and CryoSat-2 to the present-day ice sheet geometry. This extrapolation of the recent ice thickness evaluation allows us to assess prognostic basal pressure conditions.*

Furthermore, we intentionally chose the verb *indicate* for the title of our manuscript to make clear, that our simulation results are not a strict prediction but an indication of a likely future scenario based on observations.

Our focus on observational data (like measured ice thicknesses, ice surface velocities and surface elevation change rates) in combination with well known hydrological water routing principles for large scales is the strength of this study. Our approach bases on measurements and thus on observable data, representing a useful complementary strategy (compared to coupled modeling) to gain meaningful results about the close future of hydraulic pathways beneath an ice sheet. It does not fully cover the complexity of (yet not completely understood) ice–water interactions, but instead avoids the large uncertainties of highly complex coupled ice & water flow models, resulting from free parameters, poorly known forcing parameters (e.g., geothermal heat flux) and uncheckable results (e.g., basal melt rates and water pressure).

Also, on p4005, line 24 the term ”computed future pathways” should be reworded.

*We replaced *computed* by *simulated*.*

Further, the paper mentions the ”assumption” (e.g. in the abstract) that the subglacial hydrology is controlling the location of the ice streams. This is likely, but not completely proven, it could be that the water is just flowing down the hydropotential lows and not interacting with the ice flow. Nothing in the paper ”significantly supports the assumption” (e.g. p4003, line 15), there is no process based understanding in the paper that provides anymore evidence of this link than already exists. A sentence should be added that clarifies this.

*There are numerous papers about the assumption, that subglacial water flow in combination with deformable sediment (widely prevalent at the Siple Coast) is the key component leading to enhanced ice flow respectively the appearance of ice streams, discussed and cited in the introduction.*

In order to show, that we are aware of the fact, that there is always a two-way coupling between water and ice flow we reworded and added this short paragraph: *The existence of subglacial till gives the precondition for the development of ice streams at the Siple Coast. However, their exact locations correlate with the pathways of melt water flow: Basal water lubricates the substrate and enables higher ice sliding velocities. The resulting ice stream draws down the ice surface and thus attracts water from adjacent areas with a higher basal hydraulic potential.*

In addition, we also discuss the fact, that the Kamb Ice Stream has stagnated although observations (and simulations) show water at its bed. See section 3.1 *Present-day subglacial water pathways.*

There is very little detail of the model formulation, there needs to be a short description of the exact nature of the routing algorithm, for example whether it considers 4 vs 8 flow directions. The nature of the algorithm will have an impact on the final results, see for example Le Brocq et al. (2006).

As suggested, we added a sentence, stating that we consider four flow directions, and added a citation to Le Brocq et al. (2006). The routing algorithm itself is described by Budd and Warner (1996), who is cited as well.

Secondly, some of the findings of this paper cover material discussed in Le Brocq et al. (2009) which should therefore be referred to in the paper.

We added a citation to give Le Brocq et al. (2009) credit for earlier, similar findings.

## Specific comments

p3997, line 6 & Fig. 1: Add labels to the ice streams you talk about the ice streams, but dont provide a location map to describe which is which.

We regenerated all figures with labels (they were missing due to an conversion mistake).

p3997, line 26: The sentence starting "But also the currently existing ..." is not a very well written sentence, please revise.

Sentence reworded to: *However, the currently existing Whillans Ice Stream was also detected to decelerate.*

p3998, line 26, clarify what you mean by "latter" in this case.

We replaced *latter* by *last-named*, to make the reference to the onsets of the Kamb and Bindschadler Ice Streams (previous sentence) more clear: *Peters et al. (2006) also observed sedimentary basins in seismic reflections upstream of the Kamb and Bindschadler Ice Streams, which are considered to control the onsets of these ice streams. The inland termination of these sediments suggests that a possible future migration of the last-named onsets is unlikely (Siegert et al., 2004).*

p3999, line 5: "their exact locations seem to be defined by" is not very scientific language.

Reworded to: *However, their exact locations are defined by the pathways of melt water flow.*

p4000, line 6: The sentence starting "However, the precise ..." needs to finish with some references as it is currently structured. You then go on to describe the contradicting results, but it doesn't flow. Maybe a semi-colon could help, or restructure the sentences so they flow better.

We inserted a double dot at the end of this sentence, in order to point out that the mentioned contradiction is elaborated in the next sentences including the related citations.

p4000, line 13: Should be "... inland ice account for about 87% of the total melting ..."

Changed like suggested.

p4000, line 16: Sentence "... this melt water transports latent heat from beneath inland ice to the base of the ice streams, while temperatures at the bottom of the ice streams itself and accordingly the melt rates are low ..." needs tidying.

We split this long sentence to make it easier to read: *Following Parizek et al. (2003), this melt water transports latent heat from beneath inland ice to the base of the ice streams. The temperatures at the bottom of the ice streams itself and accordingly the melt rates are low, caused by the scarce internal ice deformation and the consequently lacking internal frictional heating.*

p4002, line 1: As above, more details of the routing scheme are needed.

Please see above.

p4003, line 18: 1) Be consistent as to whether you use the name and/or the letter for the ice streams. 2) Do you mean Whillans (B) or Bindschadler (D)?

1) We consistently use the names of the ice streams in the text. In figure 1, we show both the names of all Ross Ice Streams and the letters to make the assignment clear (both labels were missing due to a graphic conversion mistake in the manuscript, see above). In the following figures, we use the letters only due to the lack of space. Discussing these figures, we use names and letters to make the reference for the reader crystal clear.

2) Typos corrected to: ... *Whillans Ice Stream (B)*.

p4003, line 21: The sentence "This does not necessarily mean the model results are wrong" is not a very good way of putting this, consider re-wording to something along the lines of "The routing of some meltwater beneath Kamb ice stream is supported by evidence from airborne radio echo sounding ..."

As suggested, we discarded the odd sentence and reworded the following one to: *The routing of some meltwater beneath Kamb Ice Stream is supported by evidence from airborne radio echo sounding field campaigns, which detected a wet bed derived from strong reflections for the main trunk of the Whillans and the stagnated Kamb Ice Stream (e.g., Bentley et al., 1998).*

p4004, line 22: change the words "overspreads" and "heaviest" to something more appropriate.

We changed the sentence to: *The Whillans Ice Stream (B) covers the largest flow of water which is draining  $31.3\pm 4.6\%$  of the upstream catchments.*

p4005, line 23: It would be good to have a figure that demonstrates the fact that there is no difference at varying resolutions.

We decided to show only the calculated future water pathways for 5 km resolution for both satellite campaigns and to omit the two more figures for 10 and 20 km resolution, because we don't want to overcrowd the paper with figures. In addition, the exact changes of catchment areas are shown in Fig. 4 for all resolutions. It shows, that the mentioned redirection is most distinct at the 5 km resolution, which we interpret as a resolution convergence.

p4006, line 1: This is a very long sentence without any punctuation.

We shortened this sentence to: *The basal water fluxes beneath the main trunks of the Ross Ice Streams are estimated for the next 200 years by using ICESat and CryoSat-2 surface change rates.*

p4006, line 14: Consider "similarity" rather than "analogy".

Replaced like suggested.

p4006, line 17: "watersheds"

Corrected.

## References

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