Answers by authors to anonymous reviewer #2

Black, normal text: reviewer's comments/suggestions.
Blue, italics: author's answers

Interactive comment on "A 14 year dataset of in situ glacier surface velocities for a tidewater and a land-terminating glacier in Livingston Island, Antarctica" by Francisco Machío et al.

Anonymous Referee #2

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The authors present a 14-year dataset of in-situ measured surface velocities from an area in Antarctica that undergone a warming in the last decade(s). The dataset is very valuable for ice flow modelling or calibration of remotely sensed velocity fields (as already done by Otero et al., 2010; Osmanoglu et al., 2014). However, I have some comments that could help to improve the paper. As the other reviewer has already made many suggestions (that I have read, and I agree with most of them), I will try to avoid repeating suggestions.

COMMENTS

Abstract

I think, the abstract could state that velocities are only collected during summer season. So, possible seasonal variations are not covered.

> *The abstract already includes the sentence "**The measurements** cover the period 2000-2013 and **were done at the beginning and end of each austral summer season**." Consequently, from these data summer velocities as "extended winter" velocities can be calculated.*

Introduction

In general, I think the Introduction could better state the provided dataset was already used for tuning an ice flow model (Otero et al., 2010) and calibration of remotely sensed velocities (Osmanoglu et al., 2014)

> *We agree and have mentioned at the end of Section 1 that an earlier (and shorter) version of the presented dataset has already been used with such purposes, including the corresponding references.*

Page1, Line 32: It is correct, that observed velocities could be used as Dirichlet BC, but I would drop this sentence, because no ice sheet modeler apply that (to my knowledge).

> *We agree that **traditionally** glacier/ice sheet modellers have not used the velocities as Dirichlet BC. However, as mentioned later in the text (same paragraph) it is becoming more*

*and more common to solve an inverse Robin problem which involves two direct problems: one using Dirichlet BC at the glacier surface and another using Neumann BC at the glacier surface (and the misfit between both solutions is used to fit the viscosity and basal friction coefficients). Consequently, we have slightly modified the first sentence stating "**In theory**, they (observed surface velocities) could be directly used as Dirichlet boundary conditions … **However, the usual practice is** to set traction-free boundary conditions …" and later the more recent use of both Dirichlet BC is mentioned (as it was in the previous version of the manuscript).*

Page 1, Line 34/37/40: What do you mean with viscosity coefficient? In the viscosity relationships the ice hardness, effective strain hardness, a power coefficient, the effective strain rate and the enhancement factor appear. To my knowledge, the enhancement factor or the ice hardness is tuned.

In our opinion, saying "viscosity coefficient" should be clear enough (at least for glacier (ice sheet modellers), in the sense that "coefficient" gives the idea of a multiplying factor (so powers are discarded) and also gives the idea of a constant (and the effective strain rate is a function of position). Of course it could be both ice hardness and/or enhancement factor (in fact, these can be joined together into a single coefficient or kept as two separate coefficients). The possible use of this coefficient as a function of position (as suggested in the procedure by Arthern and Gudmundsson (2010)) makes the interpretation of the term "viscosity coefficient" even more unclear. Consequently, we have added in brackets "ice hardness" to clarify the term.

Page 1, Line 34/37/40: I prefer basal friction coefficient instead of basal drag coefficient.

We agree and have changed it accordingly (3 occurrences).

Geographical Setting

In **Fig 2**, I cannot identify the stake ID EJ14 (the one, that is plotted in Fig. 3). Also, a few more locations in Fig 2 are missing, if I compare the upper right inset in Fig. 3. The same holds for Fig. 5, it seems that some velocities at the marine terminating outlet of JG are not plotted (or not available?). I prefer to show every location in Fig. 2 and the following Figures. If in the result plots velocities are not available (for whatever reason), just show it with a black.

Throughout the years some of the stakes have been lost (e.g. by iceberg calving at Johnsons Glacier front, or fallen down because of intensive melting, or buried by heavy snowfalls) and new ones have also been added (either as replacement, or to enlarge the available network of stakes). This is why stake EJ14 does not appear in Figure 2, as happens with some stakes appearing in later figures. In fact, what the figures show are snapshots in time which only include part of the stakes of the complete dataset in the PANGAEA database. To clarify this, we have added at the beginning of Section 3-Methods some clarifying sentences. In the particular case of stake EJ14, we have also noted in the caption of Figure 3 the fact that it was lost: "The stake fell down to a newly opened frontal crevasse during 2010-2011 and was subsequently lost by iceberg calving, so it does not *appear in Figure 2". With these clarifications, the suggestion by the reviewer of marking a black dot with the location of the missing stakes becomes unnecessary. Furthermore, this could be confusing. Note that the plots are snapshots in time and, for lost stakes, it would make no sense either to include its last recorded position (because it would correspond to an earlier time) or its "expected position" assuming that it had not been lost. The latter would be awkward in most cases, as many stakes have been lost by iceberg calving as they reach Johnsons front, so their "expected position" at the time of the snapshot would be at sea (at the proglacial bay).*

Methods

I think, the equations could be shortened by presenting only one component in each equation (similar as Eq. 6, 7, 8).

Indeed most equations could be shortened. In fact, at the request of the other reviewer, we have removed former equation (1), which was unnecessary, and rewritten former Eq. (2) (now Eq. (1)) in a simpler way. Also the subscript notation has been simplified/modified and in our opinion is now clearer. However, we believe that keeping the equations (1), (2) and (4) (with the new numbering; one unit more with the former numbering) for both X and Y coordinates makes the text more easily readable. Only equation (3) (formerly 4) could benefit of some shortening, but its location before Eq. (4) (which we believe should be kept in all space dimensions) would make awkward the use of a single space dimension, so we have preferred to maintain it as it was. We additionally note that Eq. (5) (formerly (6)) has also been simplified (some unneeded expressions removed) so the total "load" of equations is now lower (even if, at the request of the other reviewer, the equations regarding estimates for velocity errors -Eqs. (6) and following- have been modified and expanded).

Page 4, Line 1-4: Can you explain the choice for the locations? Were you able to maintain the stakes for 14 years? So, none of the stakes was covered with snow or fallen down due to melting? However, I am a bit confused, as I count more than 60 stake locations in the provided shape file.

All of these aspects have been addressed in the first paragraph of the methods section of the modified manuscript:

"The location of the stakes was chosen to provide a coverage as wide as possible of the entire glacier basins and their accumulation and ablation zones. Moreover, several sets of stakes were installed following glacier flowlines, thinking of possible glacier dynamics modelling studies. Ease of access for stake measurements and maintenance was also a consideration (e.g. some heavily crevassed areas had to be avoided, for safety reasons)."

Regarding the number of stakes, we agree that the earlier writing of the manuscript was not clear enough, so we have clarified this aspect, again in the first paragraph of the new methods section (as well as other locations in the text, including some figure captions):

"We note that, over time, some of the stakes have been lost (e.g. by iceberg calving at Johnsons Glacier front, or fallen down because of intensive melting, or buried by heavy

snowfalls) and new ones have also been added as replacement or to enlarge the original network. Because of this, there are differences in the set of stakes shown in the various figures in this paper, as they correspond to different snapshots in time. Also, the set of stakes included in the PANGAEA database (see Section 4) is larger than that in any of the figures, because it includes all of the stakes that have existed at any time within the complete measurement period."

Page 4, Line 5: Could you explain, why you take the measurements several times in each season?

At least one measurement at the beginning and another at the end of each summer season are performed. In this way, we are able to compute not only annual-averaged velocities but also summer velocities an "extended winter" (all year excluding the summer) velocities. In some cases a third measurement is done upon stake maintenance. Some years a further measurement was done in the middle of the summer to get a rough idea of the velocity evolution along the summer. Currently, just two measurements (at the start and end of the summer season are usually carried out). An important point that was not mentioned in the previous version of the manuscript is that Juan Carlos I station (which provides the logistic support for the measurements) is operated only during the austral summer, and this is why the measurements are limited to the summer period. These aspects have been clarified in the second paragraph of the new methods section.

Page 4, Line 6-13: Could you give a few more details about the positioning accuracy? How have you determined the tilt at each stake? And how do you get an error estimate from the tilt?

We have added some further info on the positioning accuracy (and in fact corrected some typos in the previous version). Over the years, the tilt of the stakes has been determined either using a clinometer (together with a compass, to measure the azimuth of the tilt) or by measuring by differential GNSS the coordinates of two points on the stake, to calculate from them the tilt and azimuth. The estimate of the error in tilt is a cumbersome process, depending on the particular measurement technique, not worth –in our opinion– to be described in the paper.

As far as I understood, the positioning error does not enter the calculation of the velocity error (Eq. 7 and 8). The velocity error only depends on the polynomial interpolation. Is that right? The positioning error should also be provided in the data repository for each stake. Please use same units (m or cm) when specifying the accuracy.

You are partly right. Partly, because indeed it depends only on the polynomial approximation (current Eq. 4), but note that this one is derived from the polynomial approximation for positions (current Eq. 2), which is affected by the errors in position of the original stakes.

The new writing of current equations (6) and (7), and their associated text, clarifies the distinction between the errors in the observed velocities and their associated values in the polynomial function derived from the polynomial fit to the observed positions.

Just curious: In the user manual of the Trimble 5700 receiver (https://www.ngs.noaa.gov/corbin/class_description/5700-5800V2UserGuide.pdf; Page 92), I found accuracies for both modes (RTK and faststatic) that are depending on the baseline length. Have you used these formulas?

> *No, we did not explicitly use such equation. In fact, what appears in page 92 is the minimum initialization time, and what we mention in the text is the occupation time (the initialization time was in fact larger, and dependent on measurement settings such as number of available (visible) satellites. Moreover, we note that there was a typo in this part of the text: the occupation time of 10 seconds actually corresponded to RTK measurements, while for fast-static measurements it was of 3-5 minutes:*
>
> *"The measurements were performed either in real-time kinematics (RTK) or in fast-static (post-processed) mode; for the former, an occupation time of 10 seconds was set, and for the latter it was of 3-5 minutes depending on the number of satellites available."*

Page 4, Line 14: Please rewrite. The procedure described here does not create the surface velocity map (-> nearest neighbor interpolation, Page 10, Line 1), it describes the time interpolation. You should also somewhere motivate the polynomial interpolation. I think, it is a nice method, but I don't really see the benefit by using the interpolated velocities compared to the direct measured velocities (just extrapolate the measured displacements to meter per year).

> *You are right. This has been modified. It now reads: "From the collected positions of the stakes at different epochs, the stake positions at any time can be estimated by applying the procedure described below." This, in fact, gives the main motivation, in the sense of providing a means for estimating the stake positions at any time from the polynomial interpolation of the observed positions. This is better than using interpolated/extrapolated displacements because it provides smoother particle trajectories.*

Page 4, Eq. 3 and Table 1: Can you specify the units of the coefficients a_x, b_x and c_x?

> *Done in the Table caption* ($\mathrm{m\ y^{-2}}$*,* $\mathrm{m\ y^{-1}}$ *and* m)*. It is now Table B.1 in Appendix B.*

Page 5, Eq. 6: Sigma_x0^2 is not explained. In the legend the vector of residuals R is missing the subscript x.

> *Thanks for pointing this out. In the new version of the manuscript, the notation has been slightly changed, former eq. (6) (now Eq. 5) has been simplified and all terms are now explained.*

Description of datasets

In the shape file I found 26 fields instead of the 22 fields described here. I also suggest uploading the data for non-GIS users as a simple ascii file to the PANGAEA database. I think, the chapter could be moved to the Appendix.

> *The information has been added both in the description made in the text and in the files available in PANGAEA.*

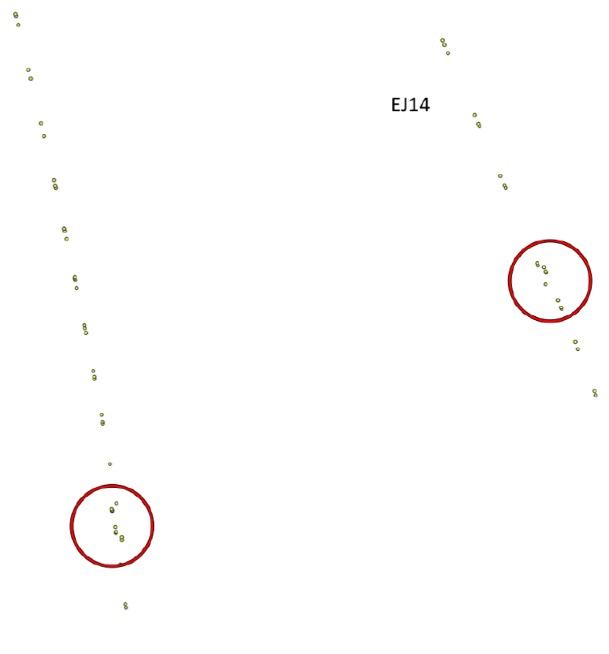
We have added a folder with the same information but in non-GIS users format (.xls and .txt).
We have also followed your suggestion regarding moving this section to an Appendix.

Results

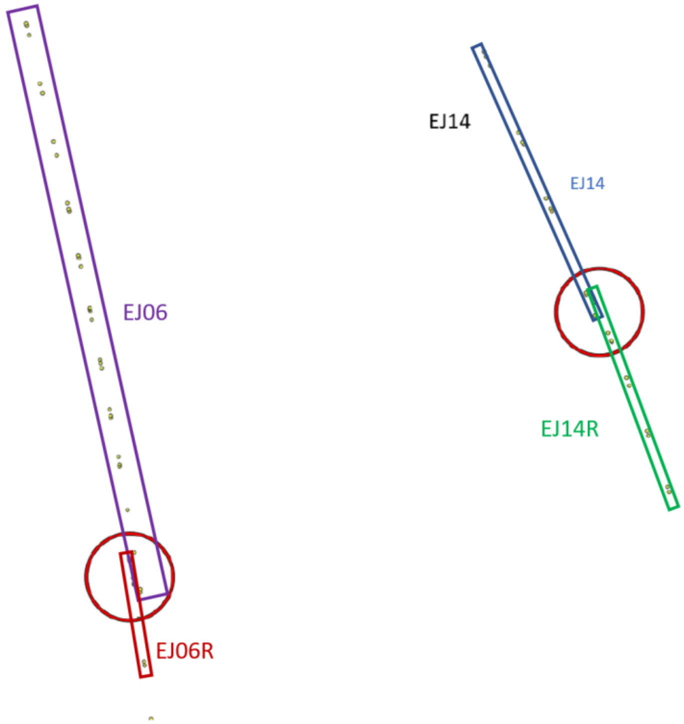
I recommend switching the Tables (Table 1 in the Appendix and the Table A1 in the main text), as the result of velocity calculation is the main task of this paper.

We have followed your suggestion. You are fully right in that the main result to show in the paper is that on velocities, and the coefficients of the polynomial adjustment best fit in the Appendix (in fact, the most significant information in this table is that on the positioning errors).

I plotted the data from the shape file in Qgis and have seen some strange behaviors (see attached figure). Most of the points are located on smooth lines/trajectories, but some outliers are observable. What is the reason for these outliers? Are these outliers considered in the velocity calculation or dropped?



This is a subtle point. In fact, there are no outliers. Your plot induces to think about outliers or estrange behaviour because you are interpreting two different stakes (in each trajectory) as if they were a single one. In particular, it seems that your plot is representing the evolution over time of stakes EJ06 and EJ06r (which are different) and EJ14 and EJ14r (which are also different). At a certain point in history some stakes were installed at exactly the same position that was occupied some years earlier by another stake (if the original stake was named e.g. EJ14, the new stake installed in its former position was named EJ14r). And what you interpreting as strange behaviour is sample that the stake "r" is arriving at positions previously occupied by the stake without the "r" in its name). See figure below.



ADDITIONAL COMMENT: The complete story would be a much longer and complicated one: an earlier network of stakes, with fewer stakes, was deployed in the late 1990s in Johnsons Glacier –none in Hurd Glacier– by glaciologists from the University of Barcelona; they are the ones who did this experiment of installing new stakes in the former positions of another one, and in fact existed e.g. EJ14, EJ14r, EJ14rr, … This was an attempt to do some kind of "Eulerian" measurement of velocities (at fixed locations) versus the "Lagrangian" way of measurement, in which one follows the stakes as they move through the glacier. However, this procedure revealed to be too cumbersome and time- and resource-demanding. When we "inherited" in 2000/01 this network of stakes, we deployed additional stakes on Johnsons Glacier and deployed a new network on Hurd Glaciers, and we discontinued this practice (of r, rr, … stakes) from our colleagues, though kept the "r" stakes until they were lost (this took many years, and some are currently still "alive").

Of course we should not explain this story in the paper text, but we have remarked on the stake list in PANGAEA dataset that stakes such as EJ14 and EJ14r, etc. are actually different stakes.

In order to reduce the number of figures, I think Figure 4,5 could be overlaid on Figure 6,7.

We have followed your suggestion.

Figures and tables

Figure 3: For colorblind people I recommend to use other colors than red and green.

Done.

Figure 4: The upper right inset marks JG instead of HG.

Modified.

Figure 4,5: I suggest enlarging the arrows or plotting the velocity magnitude with different colors.

Done.

Figure 4-7: I cannot read the stake IDs. Please enlarge the stake IDs or provide a better figure quality (pdf version looks fine, but my printout not).

Done.

Table A1: The error provided is derived from Eq. 8?

Yes, but in the current version of the manuscript the corresponding data are given in Table 1 and the velocity errors derived from Eq. (7).

For all tables, please move the caption to the top.

Done.