

Interactive comment on “In-situ GPS records of surface mass balance and ocean-induced basal melt for Pine Island Glacier, Antarctica” by David E. Shean et al.

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SUMMARY

This paper describes a GPS-based technique to make estimates of basal mass balance (BMB) and surface mass balance estimates for Pine Island Glacier ice shelf (PIGIS). The inclusion of GPS-derived snow surface height relative to the GPS antenna is a particularly interesting addition to standard ice-shelf GPS analyses, and the results are tied in well to other utilized datasets including the stereo-imagery of the DEM and the surface snow/firn state from a RACMO-based firn density model (FDM).

I have the advantage of being late in my review, so I don't need to make the detailed

C1

review comments in RC1. However, I agree with all of these. In particular:

(a) It took me a long time to get the actual vertical coordinate system sorted out in my head. The “surface relative to the receiver” is a great addition, but it means finding clearer symbols, and explaining the coordinate system more carefully, early. (e.g., Already by line 15 in the Abstract, I was confused by the statement that “The antenna height time series shows a surface elevation *increase*” on an ice shelf that is thinning rapidly.) RC1 suggested fewer symbols. I agree with this, and suggest using relative height values as close to fundamental measurements as possible (the ‘h’ variables in Fig. 4), rather than derived difference quantities (‘z’ variables) even if it means adding text volume. Then also use longer but more descriptive subscripts. So, e.g., instead of z_a , use $(h_{\text{antenna}} - h_{\text{snow_sfc}})$.

(b) The issue of whether the hydrostatic assumption is really appropriate in the presence of small-scale ice thickness variability needs to be better addressed. Maybe this has something to do with the obscure (to me) “diffusion of local topography”? But somehow convince us that hydrostatic is okay.

(c) I agree with RC1 on the general layout of the revised paper. Revisions responding to RC1 cautionary comments about data analyses (e.g., maybe other poles also lean?) run the risk of weakening your conclusions specifically about BMB. However, I don't think that matters too much, as your paper will still describe an interesting approach to GPS analysis that will likely lead to much improved GPS installation practices and data value from future GPS sites.

Specific comments are divided into “Major”, where I'd like to know what you did in response, and “Minor”, which don't require documentation in revision. Numbers refer to original page.line.

– Laurie Padman

MAJOR COMMENTS

C2

Title is not right. First, what “*not* in-situ” method is available for GPS? Second, there are other important data sets and model output sets used here.

1.15: This is when it first became clear I didn’t understand the vertical coordinate system; see SUMMARY comments and RC1.

3.7-8: The Jacobs et al. (2011) paper compares just one cruise in 1994 with another in 2009. This doesn’t seem like robust evidence for a causal link between the “increased ocean heat content” and accelerated mass loss. It probably is, although glacier dynamics must figure into this, so maybe put an “attributed to” in there.

3.9-10: The 40-50 GT/a is *net* mass loss *from the grounded glacier*, right? Otherwise these numbers don’t make sense given 130 Gt/yr discharge. Need to be specific.

6.13-25: What does a bias in the atmospheric model do to the results from a firn density model? And is the bias even taken into account when the FDM is run? Since RACMO2.3 is run from ERA-Interim (I think), then presumably RACMO2.3 has similar biases that need to be corrected for before running the FDM.

9.8: What is “diffusion of local topography”?

9.34: “reflector height” is a confusing term. See extended discussion of coordinate and naming issues in RC1.

10.35: Identify, on Fig. 10, the “flow” and “transverse” directions.

MINOR COMMENTS

3.9: either “with annual discharge of ~130 Gt” or “with discharge of ~130 Gt/year”.

5.2-3: I agree with RC1 that it doesn’t make sense to detide with a tide model when you have tide-resolving GPS. It’s nice to see that CATS works well, so keep the comparison, but detiding with a tide model only makes sense for short or gappy GPS records. A better approach would be using T-Tide (in matlab) or the equivalent Foreman (1977) FORTRAN code.

C3

5.25: Does “firn” include “snow”? Fig. 4 suggests that snow and firn are regarded distinctly. If so, the interface you are getting the relative surface elevation from is not necessarily “firn-air”

6.21: 917 kg/m³ is solid ice, right? So it’s a bad criterion for the firn-ice transition.

page 7 and elsewhere. Once the vertical coordinate symbol set is finalized, make sure all occurrences are formatted the same, e.g., $\{H\}$, not H.

7.25: 5 kg/m³ seems like a high error for water density, and probably also high for solid ice, although there is might be used as a fudge factor for firn density profile.

8.14: “30-40 m/yr” doesn’t seem “subtle” to me.

8.17: velocity units on Fig. 5 are m/y, so don’t use cm/day in text.

9.22: (a) first call to Figure 9 is to Fig. 9C. Organize panels in the order that they come up. (b) Figure 9 called out before Figure 8?

10.5: either “from May to August” or “for the period May–August”

10.18 and 16.12: What is “NMAD” ?

10.25-27: Not sure what you mean by “aggregated” here.

10.34: delete “(Figure 10)”; sentence already starts “Figure 10 shows”

11.5: In text you quote mwe/month but in the figure you send us to (9F), SMB is given as mwe/day, so I can’t directly compare them.

12.2: delete “the” in “The results in the Section 3”

14.33: repeat “bottom” in “bottom altimeter” here. I lost the thread of what altimetry you were talking about. Alternatively, reorganize this to tell us all about the altimeter then compare its results with your estimates.

15.11-14: This text could be tightened up.

C4

FIGURES

See RC1 for some other figure comments.

F.1: Add a bold “North” (N) arrow since occasionally you refer to directions and it is hard to get oriented with this map.

F.2A: again, north arrow would be good, and a flow-direction arrow would help. (Better than just having it in the caption.)

F.4: As in RC1, recommend that you minimize the number of different vertical variables, even if you end up writing (h_i-h_j) in text rather than derived ‘z’ quantities. The fundamental measured values are antenna height above ellipsoid/geoid, and antenna height above snow/firn surface, right? This figure would also be a good place to define distinctions between snow and firn, and between firn and ice.

F.5: Minor point, but commit to all caps everywhere, including figure legends, for site names etc. (e.g., “pig1”=>”PIG1” etc)

F.8 and F.9: switched order?

F.9: stack panels according to order of introduction in text. (Or modify text, if you think the figure panel order is more logical.)

F.10: mark “along-flow” and “transverse” directions on at least one panel.

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