

Interactive comment on “Diagnosing ice sheet grounding line stability from landform morphology” by Lauren M. Simkins et al.

Anonymous Referee #1

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Overview

This paper presents a detailed analysis of the morphology of a large number of grounding line landforms from the western Ross Sea. It is well-illustrated and offers original insights into grounding line processes and controls on GZW and moraine formation. These results will be of broad interest to researchers in the fields of glacial geomorphology and palaeo-glaciology. The main limitation of the paper in its current form is the length of sections 4 and 5, which should be reduced in order to emphasise the key findings. I recommend that the manuscript undergoes revision prior to publication.

Main comments

1) The length of sections 4 and 5 detracts from the key findings of the work. There is

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some repetition both within and between sub-chapters, and some interpretations are better-supported than others. Some examples are highlighted below.

2) The paper is generally well-written but there are some confusing sentences and repetition. In particular, the abstract includes several grammatical errors and unclear sentences.

3) Some discussion of flow velocity (ice stream vs. inter-ice stream flow) would be useful in the context of sediment flux. GZWs have been noted to have a strong association with cross-shelf troughs/ former regions of fast ice flow (e.g. Batchelor and Dowdeswell, 2015). Could GZWs be produced preferentially by faster-flowing ice? This could relate to the point about sediment flux, and could help to explain the existence of large terminal moraines that are produced by low sediment flux and long still-stand duration. It is interesting to note that the landforms in the study area tend to group into clusters (corridors?) of related landforms. Is it possible that these mark the former locations of fast and slow-flowing regions of ice, perhaps transient corridors that developed during regional deglaciation?

4) There should be further discussion of recessional moraines in other locations. Symmetry doesn't appear to be a defining characteristic of all recessional moraines, with some reported to display asymmetry with steeper ice-proximal sides. E.g. some of the larger moraines in Todd et al., 2007; Fig. 2 of Lindén and Möller, 2005 shows an asymmetric De Geer moraine. Flink et al. (2016 in Atlas of submarine glacial landforms) suggest that the asymmetry of recessional moraines in Svalbard may indicate their formation by ice-marginal push. It is also interesting to note that recessional moraines of similar dimensions and geometry have been recorded from the terrestrial environment, whereas GZWs appear to only be produced at the margins of marine-terminating ice. Does this lend support to the ice shelf/ ice cliff theory and/or relate to your ideas about grounding line stability?

Additional comments

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Abstract

- The first sentence of the abstract is confusing. Surely the grounding line is the point where the ice sheet meets the ocean, not the ice sheet flux? Also remove the comma after 'environments.'
- Line 11. Change to 'the grounding line.'
- Line 13. Change to 'The population is divided into two distinct morphotypes by their morphological properties', or similar.
- Line 19. 'time for which a grounding line is occupied.' This is rather convoluted, perhaps rephrase to 'duration of grounding line occupation'.
- Lines 20 – 23. This sentence is a bit confusing. Isn't the main argument that moraines are associated with 'stable' retreat and GZWs are associated with 'unstable' retreat? Please clarify.
- Lines 24 and 25. 'Short-lived grounding line positions manifest as recessional moraine back-step with small magnitude retreat events'. Please clarify and rephrase.

Introduction

- Page 1, Line 29. The word 'grounded' isn't needed in this sentence.
- Page 2, Line 33; Page 3, Line 2. You mention 'terminal' moraines here and 'recessional' moraines later, without explaining why you switch terminology.
- Page 3, Line 6. 'low profile' of GZWs. Be clearer about this. They are referred to as 'higher amplitude' in the abstract and elsewhere. Would considering the length: height ratios of the landforms help to describe the more wedge-like appearance of GZWs?
- Page 3, Line 22. Change 'whose production is' to 'the production of which is'.
- Page 3, Lines 14 – 33. This section details some theories of the controls on GZW vs. moraine formation. You should also mention the global distribution of GZWs, which

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appears to be strongly associated with the sites of formerly fast-flowing sections of ice (i.e. cross-shelf troughs and fjords, e.g. Batchelor and Dowdeswell, 2015). GZW are also only formed in the marine environment.

3. Grounding line landform morphology

- Page 4, Line 28. Change to 'are occasionally.'
- Page 4, Line 31. Add some references for crevasse squeeze ridges (e.g. Ottesen and Dowdeswell, 2006 and references within). - Page 5, Line 13. Change to 'grounding zone wedges in general are found to be more variable in size, sinuosity and asymmetry compared to the... ' to avoid repetition.

4.1 Topographic setting

This section is long and contains some repetition, which serves to hide the interesting main points that are being made.

For example, Page 6, Line 22: 'suggesting water depth alone does not dictate the formation of a particular landform' and Page 6, Line 26: 'again implies that water depth has little direction influence on the type of grounding line landform.' This point is made yet again in Page 6, Lines 26-27: 'we question, therefore, whether water depth has an influence on landform-building processes.'

Another example is Page 7, Lines 2-3: 'grounding zone wedges more commonly follow slope contours' and Page 7, Lines 6-7: 'grounding zone wedges more commonly adjust orientation to slope contours.'

This level of repetition is not necessary considering that these points are summed up concisely in Section 4.4.

- Page 6, Line 19. Add 'which is' before 'not conducive to.'

4.2.1. Sedimentation mechanism

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- This section should refer to the fact that some other recessional moraines have been reported to have asymmetry. Perhaps this has something to do with the amount of forward motion of the ice/ ice push?

- Page 8, Lines 19-21. Consider adding a caveat to this statement. Could the lack of these meltwater-related features relate to the climatic regime, which is colder in Antarctica compared with other locations in which these features have been reported? Could this also be an issue of resolution?

4.2.2 Sediment flux and duration

- Some discussion of ice velocity (ice stream vs. inter ice stream locations) should be included in this section. Could a difference in ice velocity explain why the sediment flux at the grounding line position is higher for grounding zone wedges than for recessional moraines?

- This section is an example of where an interesting point, e.g. that there is a difference in sediment flux between the landforms, is made multiple times within a sub-chapter. E.g. Lines 24-26, Line 27, Line 23, Lines 29-30.

- Page 9, Line 6. Remove comma.

- Page 9, Lines 10-11. This sentence is unclear. Perhaps rephrase to 'GZWs are characterised by...'

- Page 9, Lines 16-17. Change to 'A paired group of grounding zone wedges and recessional moraines, where grounding zone wedges transition to recessional moraines (Fig. 6), allows us to isolate the time factor of sediment accumulation.'

- Page 10, Lines 9-11. Are proximal fans more likely to develop in more meltwater-dominated environments?

- Page 10, Line 25. Is asymmetric atypical of moraines beyond those in the study area?

- Page 10, Lines 25 – 28. This is an important point which should be addressed

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further. Include an example of a large moraine in the marine environment, e.g. the Skjoldryggen moraine ridge on the mid-Norwegian shelf (Rise et al., 2005; Ottesen et al., 2005). It has been suggested that large moraines are typically found in inter-ice stream locations that are characterised by relatively low full-glacial sedimentation rates.

4.3 Presence or absence of an ice shelf

- From Fig. 5, it seems as though those GZWs that reach higher amplitudes than moraines are particularly wide in the ice-flow direction. Vertical accommodation space below an ice shelf increases away from the grounding line. As a caveat, could a GZW therefore 'grow' higher at its ice-distal point compared with its most ice-proximal point?

- Page 11, Line 9. Does this contradict Lines 25-26? Please clarify.

- Page 11, Lines 15 – 22. Consider removing this section as it is inconclusive and doesn't add to the argument.

4.4 Discussion of controls on landform morphology

- Consider shortening the paragraph from Page 11, Line 24 to Page 12, Line 11, which essentially summarises the points made in the preceding sub-chapters.

5. Implications for grounding line (in)stability

- This chapter should be shortened in order to emphasise the most interesting and conclusive arguments. E.g. Page 13, Lines 28-29 isn't needed as this is already stated in Lines 25-26.

- Page 12, Lines 22 – 29. Shorten or remove this section, focusing on the definition of stability that is used in this paper.

- Page 13, Lines 11 - 13. This is an interesting point. Could it relate to ice velocity? I.e. do ice streams tend to have a more 'unstable'/ episodic style of retreat compared with slower-flowing areas?

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Figures

- The landforms in several of the figures need to be labelled or arrowed. E.g. the moraines in Fig. 1B; moraines in Fig. 3A and B, crevasse squeeze ridges in 3H and I; moraines/ GZWs in Fig. 12C and D; moraines/ GZWs in Fig. 13A-C.
- Figure 2 needs to more clearly show the depth of the seafloor, either by using a different colour scheme or by showing some depth contours. The seafloor depth and locations of the troughs/ banks are not clear at present.

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