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Discussions

Interactive comment on "A statistical fracture model for Antarctic glaciers" *by* Veronika Emetc et al.

Veronika Emetc et al.

veronika.emetc@anu.edu.au

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We would like to thank the referee for his/her feedback. Please, find our response below.

RC: "This is not serious text - nothing breaks because it is close to mountains or a grounding line. Such parameters may be correlated to fracture only if they correlate indirectly via ice mechanics. This is like correlating drowning accidents to ice cream eating."

We do not claim that fracturing is directly influenced by grounding lines or mountains. However, statistically, the occurrence of those events correlate and there is a physical basis that explains this correlation. We explain this in greater detail in the revised ver-

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sion of the manuscript. It is absolutely true that correlation does not mean causation, but more crevasses are observed close to the grounding line due to tidal deformation, or close to nunataks because of high lateral drag. These two physical processes are generally not included in ice sheet models and our model provides a simple parameterization for crevasse propagation in these regions based on a comprehensive analysis. Here we are using a statistical approach and so the method is not “directly” based on ice physics. In addition, it is important to note that we do not explain the formation of fractures only by proximity to mountains. We include all the parameters that directly can cause fracture formation such as stresses and viscosity.

RC: “It is rather easy to construct such measures, but there is nothing to be learned from them. The connection are superficial. For this paper to be published a more relevant crevasse formation measure should be constructed. All included parameters should at least be thoroughly motivated”

We observed over 35 glaciers and thousands of fractures, our results are not based on a few occurrences of fracturing being correlated to our selected observation parameters. Our proposed approach is used to parameterize fracture formation processes and not to invent a new physical model of fracturing.

RC: "For this paper to be published a more relevant crevasse formation measure should be constructed. All included parameters should at least be thoroughly motivated"

Based on your comments we change the mentioned sentences to be clearer: Term “mountains” changed to “edges of glaciers/ice shelves”. Here we describe why each parameter that we include in our analysis is indeed known to have an impact on crack propagation (and this is added to the new version of the manuscript):

Back stress: Back stress provides an additional compressive stress resisting forward motion of glacier ice. [1]

Effective strain rate and Principal strain rates: if the strain rate is sufficiently high,

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crevasses can propagate to greater depth [2]. In addition, stresses can trigger brittle fracturing but, to model a gradual vicious process, strains have to be taken into account.

Horizontal strain gradient: Fractures can be formed in zones where strain experience significant variations.

Principal stress axes: We removed this parameter from the revised version. We agree that there was a confusion using the principal axes. However, this does not affect the results due to the fact that this parameter has a low impact on the most of glaciers/ice shelves (smaller than 0.1 correlation).

Principal stress: the sign of the principal stress determines whether it is compressive or tensile.

There are a number of parameters such as velocity, surface slope and a curvature of a glacier channel that are included in the calculation of the stress field, but for our method, we look at each component separately:

Bed and surface slope: On a steeper slope, shear stress increases and can lead to fracturing (e.g. ice fall is an extreme case).

Surface gradient change: If there is a sudden change in a surface elevation the stress can increase causing fracturing.

Curvature: Fractures can be formed when a glacier flows over a horizontal bend.

Friction coefficient: low friction will lead to a higher sensitivity to membrane stresses, which can lead to more crevassing in tensile mode.

Rheology B: Stiffness of ice that can affect fracturing.

Thickness: Is included due to its physical relation to fracture mechanics

Proximity to the ice front: Included into the analysis due to observations of satellite images where a lot of fracturing occurs near ice shelf terminus.

Proximity to the grounding line: This parameter is included because tidal deformation at the grounding line can cause fracture formation, as observed in satellite images.

Proximity to edges of a glacier: What we meant was the edges cause lateral drag and fracturing. Thus, proximity to mountains (edges) ended up being predictive because lateral friction along the edges of glaciers is not generally considered in ice sheet models when stresses are calculated, therefore the stress field alone does not have the full ability to predict zones of fracture formation. Without the lateral drag only transverse, longitudinal and radial splaying crevasses can be predicted. They are all formed due to opening stress and are normally considered in former methods. However, the prediction of marginal crevasses requires a parameterization of the lateral drag.

Added to P8L14:

Generally, the lateral friction along the edge of a glacier is not considered in ice sheet models when stress is calculated. Therefore, the stress field alone does not have the full ability to predict zones of fracture formation, because without the lateral drag only transverse, longitudinal and radial splaying crevasses can be predicted. They are all formed due to opening stress and are normally considered in existing damage modelling methods. However, the prediction of marginal crevasses requires a parameterization of the lateral drag.

Added:

"The formation of fractures is a complex process that has not been effectively parameterized in ice sheet models to be applied to any glacier in Antarctica. "Previous analysis based on damage accounts for stresses, thickness and viscosity. However, for statistical analysis other factors can be equally important (such as proximity to edges of a glacier and the grounding line as well as the curvature of a channel), which might be crucial for modelling of the fracture formation in Antarctica."

References:

[1] Kenneally, James P., and Terence J. Hughes. "Fracture and back stress along the Byrd Glacier flowband on the Ross Ice Shelf." Antarctic Science16.3 (2004): 345-354.

[2] Benn, Douglas, and David JA Evans. Glaciers and glaciation. Routledge, 2014.

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