Comments on "Triggers of the 2022 Larsen B multi-year landfast sea ice break-out and initial glacier response"

by N.E. Ochwat et al.

This paper reports on the break-up of land-fast sea ice in the Larsen B embayment and the initial response of glaciers after the buttressing sea ice had drifted away. Furthermore, the authors studied various potential triggers leading to this process, including changes in atmospheric and circulation and sea ice cover during preceding and concurrent periods, checking numerical meteorological re-analysis data and changes in satellite-based sea ice concentration over an extended area. Patterns of fast ice break-up and the retreat of glacier fronts are documented, using optical satellite imagery. The analysis of glacier response is based on satellite observations, focusing on several Antarctic Peninsula outlet glaciers draining into the Larsen B embayment. Repeat observations of surface elevation on specific points and flow velocities along central flowlines are shown for a period spanning the break-up event.

By and large, this is a well written article, presenting interesting material on the land-fast sea ice break-up event, its potential causes and the response of glaciers. The work confirms the influence of land-fast sea ice on glacier flow dynamics, reflecting - with opposite sign - the slowdown, reduced downwasting and frontal advance of Larsen B glaciers during the previous period when fast ice was built-up. Still, there is need for major checks and improvement, as there are various issues lacking traceability or being inconsistent with previously published data.

Main issues:

This section includes a short summary on main issues to be clarified and improved. Details on the concerns and suggestions for improvements are put forth in the next section.

Location of grounding zone: The grounding zone positions are outdated. The 2016 grounding zone position of Hektoria Glacier was 12 km inland of the position shown in Fig. 9, and of Crane Glacier 5 km inland. This mismatch has major implications on various issues such as the interpretation of glacier flow dynamics, the estimation of the thickness of floating ice and the assessment of driving mechanisms for frontal retreat.

Extent and thickness of floating sections of glacier tongues: The floating section of the HGE terminus, extending between the glacier fronts of 2011 and of 21 November 2021 (shown in Fig. 8), covers more than 200 km^2 in area. In the manuscript ice thicknesses of the floating terminus up to some hundred metres are mentioned. This is not an agreement with mass continuity, as it would exceed the ice volume delivered across the flux gate close the 2011 ice front.

Processes of fast ice break-up and drift: The discussion on these processes refers to changes in the backstress of the fast sea ice as main factor, but estimates on the stress magnitude are not provided. It is questionable if changes in the backstress due to depletion of fast ice in a widening bay (as in front of HGE glacier) can be the main trigger or if other factors play an important role as well.

Processes of glacier flow acceleration and frontal retreat: Similarity of the glacier response in the wake of fast ice removal to the response after the 2002 ice shelf disintegration is claimed. However, the prerequisites and course of the events are quite different. The 2022/2023 case refers to recently formed, thin floating glacier tongues of structural weakness, in contrast to the compact, grounded ice bodies of the pre-2002 period. The patterns of frontal retreat and the ice fracture processes are also rather different.

Details:

L53-L56: It would be of interest mentioning in this context also the 10-fold ice speed increase in 2009 at the Hektoria Glacier front compared to the years before 2002 (Wuite et al., 2015) and the declining mass losses during the period when fast ice was present. The total HGE losses of grounded ice amounted to 4.26 Gt/yr in 2011 to 2013 and 1.75 Gt/yr in 2013 to 2016 (Rott et al., 2018).

L59-L60: Taking into account the ice volume discharged from grounded ice to floating sections of the glacier termini and assuming mass continuity, an ice thickness of hundreds of metres can refer only to a very small portion of the floating glacier tongue at its full extent. Rott et al. (2018) derived the mass fluxes across gates close to the 2011 glacier fronts of Larsen B glaciers for the period 2011 to 2016. Based on this number and accounting for further slowdown after 2016, the estimate of the total ice volume supplied to the newly formed section of the HGE tongue amounts to 39 km^3 between 2011 and 2021.

L93-L98; Fig 1: The scale of the figures is too small for providing clear information on features of interest in the glacier bays and Larsen B embayment (e.g. structural properties, deformation patterns, rifts, glacier fronts). The displayed ICESat freeboard map shows blocks and streaks, with discontinuities along straight lines. Furthermore, the grounding zone positions (though not well traceable at that scale) seem to be outdated (see comment on L343ff).

L108-109: Relative humidity less than 79% is not a suitable criterion for determining surface melt conditions. If the vapor pressure on the snow surface is higher than in the atmosphere sublimation may take place also at air temperatures above 0°C, depending on the net incoming energy.

L167-L171: Please provide information on the procedure for deriving flow velocities (matching window size, sampling steps, cross-correlation threshold) and on the uncertainty of the velocity products for the different sensors and time spans.

L215- L216: Considering the ice export across the 2011 glacier front, ice with thickness on the order of 300 m can stretch out only over rather small areas. Please provide details on the ice thickness information (dates, extent of area with freeboard > 40 m). Due to the coarse resolution the Fig.1 is not a suitable source for this information.

L217-L218: The maps of surface elevation change (SEC) 2013 to 2016 by Rott et al. (2018) show increase in surface elevation on the lower 10 km of Crane Glacier and frontal advance, coinciding with major surface lowering in the upper reaches of the main glacier trunk. This contradicts the statement on dominating ice input from tributary glaciers in the paper of Needell and Holschuh (2022) who do not cite the observations of Rott et al.

L218-L219: Referring to the glacier fronts on 25 June 2011 (TanDEM-X image, shown in Fig. 2 in Supplement of Rott et al., 2020) and on 21 November 2021 (shown in Fig. 8 of Ochwat et al.) the Hektoria Glacier front advanced during this period by about 20 km and the new floating area covered more than 200 km^2.

L232: Fig. 1b and 1c show MODIS images of 16 and 21 January 2002, not 18, 19 and 20 January.

L261-L264: Please explain the decision rule for identifying and for shutting on and off foehn events. According to Fig. S1 a threshold of 3 m/sec is used for Foehn detection. This number corresponds to a light breeze, not suitable for facilitating the breakthrough of the flow at the leeside of a mountain range.

L274, Fig. 4: The label of Fig 4a abscissa is date (not time).

L295: The surfaces may have been frozen on the date of the Landsat image (16 January 2022), but the temperature record (Fig. S2) shows several days of high temperature in January 2022, an indication for with surface melt that is also apparent in SAR images.

L343ff, Section 4.3.1: In the context of various issues addressed in this section, an outdated version of the grounding zone positions is used. Estimates for grounding line locations of Larsen A and Larsen B glaciers in 2013 and 2016 were obtained by Rott et al. (2018), based on changes in surface elevation of TanDEM-X data. The transition from grounded to floating ice is associated with a strong drop in surface elevation change (dh/dt). The 2016 grounding lines of Hektoria Glacier and Crane Glacier (see zoom images in Rott et al., 2020) are about 12 km (Hektoria) and 5 km (Crane) inland of the position shown in Fig. 9 of Ochwat et al. The 2016 Crane location refers to the centre of the canyon. Further retreat during recent years has to be expected.

L346-L350: Please provide evidence on the iceberg properties and calving features described, as well as on the dates of the images to which the described features refer. Checking the pre-frontal embayment area in the Sentinel-1 time series of 2022 and 2023, there are no features that can be uniquely allocated to a toppled iceberg. In the SAR images of January and February 2022 and December 2023 to February 2023 icebergs in the pre-frontal areas show low reflectivity, evidence for the presence of melting firn. In subsequent colder periods the firn freezes, causing a transition to high backscatter intensity.

L373: An extended thick (>300 m) floating tongue in front of HGE glaciers does not match the mass continuity for input across the 2011 glacier front (see related comments above).

L389-L428, Section 4.3.2: Also for this section an update on the grounding zone positions is needed (see comment L343ff). The main parts of the velocity profiles shown in Fig. 9 are located either on floating ice and or on pre-frontal ice mélange. This questions the argumentation of issues referring to the grounding zone and to velocities on grounded ice.

L420, Figure 9: Please mark the updated location of the grounding line and the location of the ice front on different dates. The profiles of Hektoria and Green glacier deviate from the course of the central flowline. The Landsat-based Hektoria Glacier velocities of Nov. 2022 to Jan. 2023 deviate significantly from the Sentinel-1 based velocities of June to Oct. 2022. How reliable are the Landsat velocities?

L446: The statement “Hektoria Glacier lacks long-term elevation change data points” is not valid, at least for TanDEM-X data 2011 to 2016 (Rott et al., 2018), but also regarding further data from this mission and from other satellite sensors (e.g. CryoSat).

L523-L525: Quantitative estimates on the fast ice backstress magnitude and its spatial pattern are needed for affirming this conclusion, as well as considerations regarding possible changes of other driving factors, such as winds and ocean currents.

L531-L554: The argumentation, referring to proposed governing processes for glacier response and claiming similarity to the 2002 break-up event, are not well founded. There are various clues indicating major differences regarding the calving regimes and dynamic response of the Larsen B tributary glaciers in 2002 versus 2022/2023. Up to the 2002 event the glaciers were close to a balanced state, the tongues were several hundred metres thick and grounded. In 2022 the newly formed sections of the glacier tongues were composed of comparatively thin floating ice. Furthermore, there is evidence of structural weakness. On the floating sections high resolution elevation data show rugged surface structure and wave-like surface features of different wavelengths. There are also indications for major strain-rate weakening, as velocity data show. For example, on the central flowline of Hektoria Glacier a threefold increase of velocity between the grounding line and the glacier front is evident in 2017 data, and on Crane Glacier a twofold increase (Rott et al., 2020).

L537-L538: On Crane Glacier close to the calving front a velocity of 9.6 m/day was observed in June 2007 data (Wuite et al., 2015), 2.3 times the 2003 value cited in L538.

L542: Based on the updated grounding line position, the number for retreat of grounded ice should be corrected.

L543-L544: The floating ice of 15 km length in front of Hektoria Glacier was in fact a remnant section of the Larsen B ice shelf that remained in the pro-glacial bay for several month after disintegration of the main ice shelf. The boundary of the ice shelf is clearly evident in the tidal deformation pattern of ERS-tandem (1-day repeat) interferometric data. The retreat of grounded ice started in March 2003. The changes between February 2002 and April 2003 are documented by Rack et al. (2004) by means of several SAR images.

L555ff, Conclusions: Major revisions are needed, taking into account the comments above.

References cited in the manuscript, but not included in the list:

Crawford et al., 2022 (cited in L159)

Hersbach et al., 2020 (cited in L104)

Kwon et al., 2020; (cited in L473)

Ochwat et al., 2022 (cited in L159)

Robel et al., 2017 (cited in L527)

Smith et al., 2020 (cited in L38 and L 501)

References

Needell, C., and Holschuh, N.: Evaluating the retreat, arrest, and regrowth of Crane Glacier against marine ice cliff process models. Geophys. Res. Lett., 50, e2022GL102400. https://doi.org/10.1029/2022GL102400, 2023.

Rack, W., and Rott, H.: Pattern of retreat and disintegration of Larsen B ice shelf, Antarctic Peninsula, Ann. Glaciol., 39, 505-510, 2004.

Rott, H. Abdel Jaber, W., Wuite, J., Scheiblauer, S., Floricioiu, D., van Wessem, J.M., Nagler, T., Miranda, N., and van den Broeke, M.R.: Changing pattern of ice flow and mass balance for glaciers discharging into the Larsen A and B embayments, Antarctic Peninsula, 2011 to 2016, Cryosphere, 12, 1273–1291, https://doi.org/10.5194/tc-12-1273-2018, 2018.

Rott, H., Waite, J., De Rydt, J., Gudmundsson, G.H., Floricioiu, D., and Rack, W.; Impact of marine processes on flow dynamics of northern Antarctic Peninsula outlet glaciers, Nature Communications, 11:2969,| https://doi.org/10.1038/s41467-020-16658-y, 2020.

Wuite, J., Rott, H., Hetzenecker, M., Floricioiu, D., De Rydt, J., Gudmundsson, G. H., Nagler, T., and Kern, M.: Evolution of surface velocities and ice discharge of Larsen B outlet glaciers from 1995 to 2013, Cryosphere, 9, 957–969, https://doi.org/10.5194/tc-9-957-2015, 2015.