Author Response to comments by referee 1, Enze Zhang

Manuscript tc-2025-5733: Contrasting dynamics of lake- and marine-terminating glaciers under same climatic conditions

March 31, 2026

Dear Enze Zhang,

Thank you for your constructive and thoughtful review. We appreciate your careful reading of our manuscript. The ideas and references you provided improved our understanding of the glacier system and the quality of our manuscript. We provide responses to your three comments on our discussion in the following. We addressed your specific comment on Figure 5 by adding the correct legend. Reviewer comments are coloured blue, our responses black, and manuscript changes brown.

Florian Vacek,

on behalf of all authors

Summary

Reviewer Comment:

This study presents a well-designed comparison between two branches of the same glacier system—one marine-terminating and the other lake-terminating—to investigate how glaciers with different terminus types respond dynamically under identical climatic conditions. The choice of study site is particularly thoughtful: because both branches originate from a common ice divide, they naturally experience the same regional climate, allowing for a robust controlled comparison. The authors support their analysis with comprehensive datasets, including multi-source remote sensing observations and valuable field measurements from two campaigns. The manuscript is clearly written, and the figures are well-designed and effectively illustrate the key findings. Overall, I recommend this paper for publication after minor revisions.

However, I note three specific points where my interpretation differs from the authors'. These points are offered to refine the discussion and enhance the manuscript's analytical precision:

Author Response:

Thank you for your overall positive summary. See our specific responses below.

Referee Comment 1: Terminus-driven dynamics of the marine-terminating branch

The velocity variations of the marine-terminating branch appear to be primarily terminus-driven rather than runoff-driven. Specifically, the annual onset of acceleration aligns more closely with the start of terminus retreat, typically preceding the melt season, and the deceleration coincides with the end of retreat, often extending beyond the runoff period (as noted by the authors in Line 363). These patterns strongly suggest that terminus position and calving dynamics, not surface runoff, dominate the glacier's flow variability. Such behavior is well-documented for many Greenlandic outlet glaciers (e.g., Moon et al., 2014; Vijay et al., 2019, 2021) and should not be considered "anomalous" (Line 361). That said, short-term velocity pulses during the melt season (e.g., in 2019–2021) may indeed reflect runoff-related processes. Recent work on Eqip Sermia (Zhang et al., 2025), we observed similar characteristics: seasonal acceleration extending beyond the melt period, tight coupling between retreat and speed-up timing, and velocity pulses during melt seasons. This observation may provide useful context for interpreting this system.

Author Response:

We are grateful for the interpretation and supporting references provided by the referee, which are very useful for understanding the flow velocity variations of the marine terminating glacier system. After carefully reviewing Moon et al. (2014) and Vijay et al. (2019), we find that the flow pattern of Qooqqup Sermia certainly is not anomalous. Moon et al. (2014) describe a category of glaciers (termed *type 1*) that experience an increase in flow velocity in spring/early summer and continued acceleration even beyond the runoff season. Similarily at Qooqqup Sermia we observe flow velocity increase after peak runoff and in some years even slightly beyond the runoff season (most visibly in 2017, 2019, 2021) (Fig. 7). Moon et al. (2014) link this flow pattern to changes in the ice front position of the glacier. We also clearly observe this pattern at Qooqqup Sermia (Fig. 7), where the highest velocities coincide with the most retreated ice front positions. This is futher confirmed with the plot below. Therefore we conclude that the ice flow velocity of Qooqqup Sermia seems to be closely connected to its ice-front position (with short-term influences by meltwater pulses) and include this in our revised manuscript.

Additionally, however, we have to differentiate between what drives velocity changes and what drives ice-front position changes. We observe that the majority of Qooqqup Sermia's frontal retreat takes place during the runoff season, whereas most of its advance occurs outside of the runoff season. Front advance appears to begin as soon as the runoff season ends. Slightly less consistently, front retreat starts approximately with the beginning of the runoff season (or slightly earlier). This seasonality of glacier front positions is widely observed in Greenland (Schild and Hamilton, 2013; Moon et al., 2015; Black and Joughin, 2023; Greene et al., 2024) and has been suggested to be mainly driven by meltwater runoff (Black and Joughin, 2023; Fried et al., 2018) and the presence or absence of an

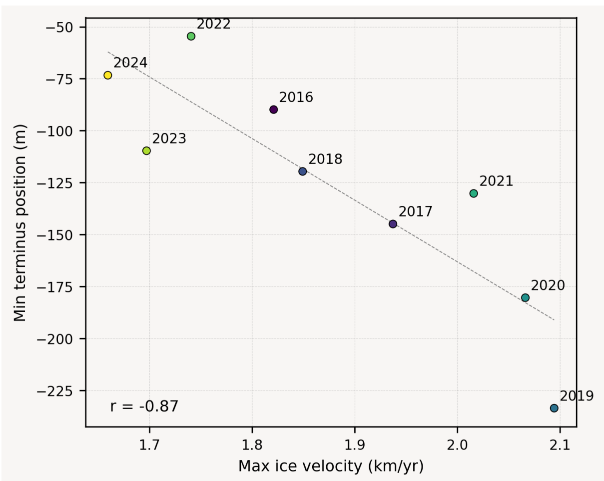

Figure 1: Yearly minimum ice front position and maximum ice flow velocity at Qooqqup Sermia (2016–2024). Note that for 2022 a velocity peak at the beginning of the year corresponding to the retreat of 2021 was excluded.

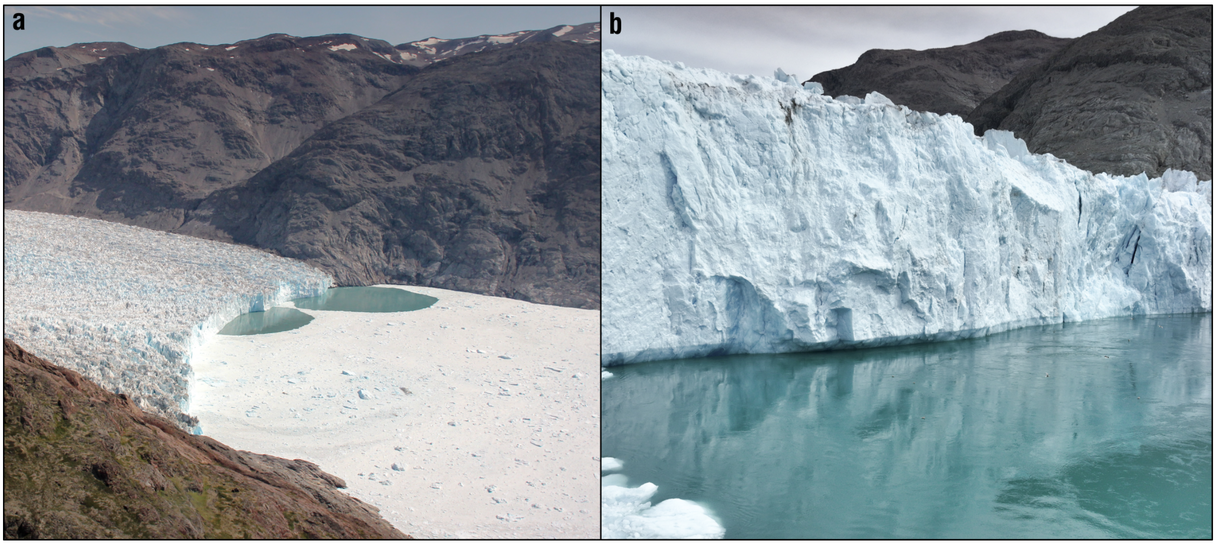

Figure 2: Melt water plume at Qooqqup Sermia (a) two plumes observed at Qooqqup Sermia on 26 July 2025 (b) close up drone image showing the plume and distinct undercutting at the glacier front.

ice mélange (Joughin et al., 2008; Todd and Christoffersen, 2014; Cassotto et al., 2015; Kneib-Walter et al., 2021; Wehrlé et al., 2023), both of which affect the calving rate. While we have no time series record of ice mélange presence or absence, Fig. 7 and 8 show that the ice front position seems to at least be influenced by runoff. This is further supported by the following figure clearly showing a meltwater plume as well as undercutting of the ice front.

Finally, this leads us to the following interpretation: Flow velocity appears to be closely connected to the ice-front position, while the ice-front position seems to be influenced by runoff.

Manuscript Changes:

Revised Section 5.4: Dynamics at the marine terminus

Since 2004, the glacier remained at approximately the same position with seasonal ice-front advance during winter (October–May) and retreat during summer (June–September). The position around which the glacier front oscillates is characterised by a visible narrowing of the fjord through a bedrock protrusion on either side. Seasonal advance and retreat of glacier fronts are common phenomena (Schild and Hamilton, 2013; Moon et al., 2015; Black and Joughin, 2023), observed at more than 80 % of marine-terminating glaciers in Greenland (Greene et al., 2024). This seasonality of glacier front positions has been suggested to be mainly driven by meltwater runoff (Black and Joughin, 2023; Fried et al., 2018) and the presence or absence of an ice mélange (Joughin et al., 2008; Todd and Christoffersen, 2014; Cassotto et al., 2015; Kneib-Walter et al., 2021; Wehrlé et al., 2023), both of which affect the calving rate. In agreement with these findings, we observe that the majority of Qooqqup Sermia's frontal retreat takes place during the runoff season, whereas most of its advance occurs outside of the runoff season (Fig. 7 and 8), indicating that the ice-front position is influenced by submarine melting due to meltwater runoff. This is supported by observations during both field campaigns and on satellite images, where we observed meltwater plumes for extended periods during the melt season (see Fig. A3). These plumes, formed by runoff entering the fjord subglacially, enhance submarine melting and can trigger calving by undercutting the ice-front (Rignot et al., 2015; Fried et al., 2015; Slater et al., 2017; Hewitt, 2020). Fig. A3b also shows strong undercutting of the glacier front at the location of the plume. The calving that we observe at MT can be classified as serac collapse type (Bézu and Bartholomaus, 2024) with frequent calving of small icebergs.

However, in some years, the coupling of ice-front position and runoff is slightly less evident. In the years 2019–2021 the front position starts to retreat before the beginning of the melt season. Similar observations at other glaciers showed that this can be caused by an early clearing of the ice mélange and the accompanied reduction of resistive stresses at the glacier front (Cassotto et al., 2015; Bevan et al., 2019; Wehrlé et al., 2023). However, we have no time series documenting the presence of an ice mélange at Qooqqup Sermia to confirm this. Therefore, we conclude that the seasonality of glacier front positions is influenced by subglacial runoff, however, with other processes likely also playing role.

As is typical for calving glaciers, Qooqqup Sermia's flow velocity also increases towards the terminus, thereby more than doubling its speed from 8 km upstream to the glacier front. The upstream ice-flow velocities remain relatively constant throughout the observation period, with a notable spike at the beginning of the runoff season each year. This short-term increase in flow velocities is also observed in other regions of Greenland (van de Wal et al., 2008) and can be linked to the efficiency of subglacial drainage when meltwater or rainwater enters the system (Bartholomaus et al., 2008; Schoof, 2010). At the glacier front, ice flow velocities begin to accelerate in late spring and continue to accelerate even after peak runoff is reached, indicating a decoupling from runoff after initial acceleration (Fig. 7). This is observed for many glaciers in Greenland as shown by large scale (Moon et al., 2014; Vijay et al., 2019) and case specific studies (e.g. Zhang et al., 2025). Moon et al. (2014) show that for this category of glaciers (called "type-1"), ice flow velocity is closely coupled to changes in ice-front position. Also, at Qooqqup Sermia, we observe that the highest flow velocities coincide with the most retreated glacier front positions. This can be explained by reduced resistive stresses when the ice front retreats behind the pinning point. (Bevan et al., 2012; Howat et al., 2008).

Referee Comment 2: Formation of the floating ice tongue at the lake-terminating branch

I agree with the authors that the relatively flat surface profile of the glacier suggests a floating ice tongue may have been present at the lake terminus prior to 2012. However, I am not fully convinced that "low subaqueous melt rates" were the primary driver of its formation. Instead, I believe the glacier geometry, particularly the exceptional depth of Lake Motzfeldt (Line 220), played the decisive role. A floating terminus arises when ice thins sufficiently to reach buoyancy equilibrium over deep water; subaqueous melt rates may modulate stability and retreat, but it is unclear how subaqueous melt rates alone could induce flotation. To put it another way: if another lake-terminating glacier terminates in a shallow basin, I believe it is unlikely to develop a floating tongue even under equally low subaqueous melt rates.

Author Response:

We agree with the referee and think that the geometry of the lake certainly plays a crucial role in the formation, stability and the breakup (L301–305) of the floating ice tongue in Lake Motzfeldt. Certainly, a floating ice tongue would not have formed, if the lake wasn't deep enough to allow floatation. We recognise that our manuscript did not elaborate on this important detail. However, we also believe that low subaqueous melt rates played a role in the fact that the ice tongue sustained for at least 25 years (earliest observation until break up in 2012). We believe that the ice tongue would not have survived in a saline setting with warmer temperatures, the formation of meltwater plumes, and overall higher subaqueous melt rates. In our new manuscript we include the geometry as a major factor and emphasise that the low melt rates contributed to the stability of the ice tongue.

Manuscript Changes:

We believe that the formation and sustained presence (at least 1987–2012) of the ice tongue in Lake Motzfeldt in the very south of Greenland was possible for two main reasons. First, lake Motzfeldt is exceptionally deep and therefore provides the necessary geometry. Second, subaqueous melt rates in Lake Motzfeldt are low, therefore limiting thinning rates and promoting stability. This falls in line with Truffer and Motyka (2016) who suggest that floating ice tongues in lakes can occur in more temperate regions further south compared to marine-terminating glaciers due to colder water temperatures and the lack of salinity-driven circulation, which strongly limit subaqueous melt as well as calving as a result of undercutting of the glacier front. And indeed, our CTD and temperature measurements in Lake Motzfeldt show a very cold lake, with a depth averaged temperature at the glacier front of < 0.7 °C in August 2025. The lake can sustain such a cold temperature throughout the year due to meltwater input and the immense amount of icebergs present. Any additional energy input through solar radiation or heat advection is likely transferred into the icebergs, efficiently cooling the lake.

Referee Comment 3: Calving seasonality and floating-glacier behavior

The authors note that the lake-terminating glacier exhibits long advance phases punctuated by abrupt, large calving events. However, this floating-glacier behavior is not unique to northern glaciers in Greenland; similar patterns are observed at several marine-terminating glaciers in central Greenland, such as Helheim, Kangerdlussuaq, and the northern branch of Rink Glacier. What appears distinctive about the lake-terminating glacier in this study is that its major calving events consistently occur during the melt season, whereas the aforementioned marine glaciers experience large calving events throughout the year. This seasonal contrast may be linked to the lake's low background subaqueous melt rates: only during the melt season does subaqueous melt increase sufficiently to destabilize the terminus and trigger large-scale calving. While this interpretation remains speculative, it warrants brief discussion, as it could point to a fundamental mechanistic difference between lacustrine and marine floating termini.

Author Response:

The referee compares the calving style of LT with that of other marine-terminating glaciers like Helheim, Kangerdlussuaq and Rink Glacier. However, we believe that the calving style is distinctively different compared to those glaciers. The difference between the two calving styles is nicely summarised in Bézu and Bartholomaus (2024), differentiating the categories of "slab capsize" and "tabular rift" calving. The former describes glaciers that are "nearly grounded" and experience somewhat frequent calving of icebergs that capsize and are usually < 200 m. Here calving occurs dominantly due to buoyant forces pushing the terminus upward leading to the formation of basal crevasses and icebergs rotating bottom out away from the glacier front. For the second category, however, calving occurs due to rifts forming horizontally across the glacier, discharging large tabular icebergs, usually > 200 m and without capsizing. Although rifting is not always visible from satellite images at LT, the immense size, the fact that icebergs don't capsize and the low frequency of calving indicate that LT falls into this category and is comparable with large floating ice tongues such as Petermann (e.g. Johannessen et al., 2013) and Ryder Glacier (e.g. Holmes et al., 2021) in North Greenland.

We believe that the occurrence of calving events only between mid May and mid October is connected to increased buoyant forces through surface melt and lake level rise during the melt season as well as the absence of lake ice which could help keeping the glacier front together during the winter months. Since buoyant plumes don't form in the lake and because the lake stays cold with only 0.7 degrees above the melting point, we believe that subaqueous melt rates stay low during summer.

Manuscript Changes:

We observe a distinct calving pattern at the lake terminus that can be described as the following: The glacier experiences long advances phases that can sustain throughout the melt seasons and can last longer than a full year. These advance phases are interrupted by the calving of large tabular icebergs (most >200 m). Some calving events follow the formation of clearly visible rifts, while others don't show clear rift formation. Almost all icebergs detach from the glacier front and drift away without capsizing. This calving style is typical for fully floating ice tongues in Greenland (Bézu and Bartholomaus, 2024) and resembles that of large ice tongues in North Greenland, like Peterman (e.g. Johannessen et al., 2013) and Ryder Glacier (e.g. Holmes et al., 2021).

Remarkably, all documented calving events occur between mid May and mid October, coinciding with the runoff period. This could indicate that also buoyant forces play a role in triggering calving events, as it was observed at several other lake terminating glaciers (Howarth and Price, 1969; Holdsworth, 1973; Warren et al., 2001). During the runoff period, buoyant forces are increased through thinning of the glacier from the surface as well as through a rise in lake level due to increased meltwater input (Fig. A1). Furthermore, we observe that all calving events occur outside of the lake ice covered period. Although lake ice could provide some backstress to the glacier, it is unclear as to what magnitude and what effect it would have on calving. However, we believe that lake ice possibly functions as a binder, preventing icebergs from drifting away, helping to keep the glacier front together during winter.

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