

## **Author responses to comments by the editor and three referees**

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

### **Summary of major changes**

Most of the comments that we received were regarding our interpretation of the results. Consequently, most of the changes were made in the discussion section. Specifically, Sections 5.1, 5.2, 5.4, and 5.5 received major updates. Due to changed interpretations, we also modified the conclusions, which is also reflected in the abstract. Technical corrections were made throughout the manuscript.

In the following document you can find the response to the comments received by three reviewers and by the editor. Comments are coloured blue, our answers black, and manuscript changes brown.

## 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

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. Similarly 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 further 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.

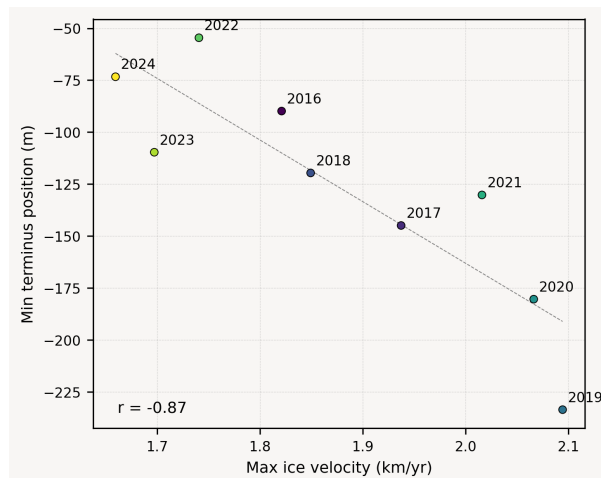


Figure 1: Yearly minimum ice front position and maximum ice flow velocity at Qooqqup Sermia (2016–2024). Note that for 2022 a velocity peak at the beginning of the year corresponding to the retreat of 2021 was excluded.

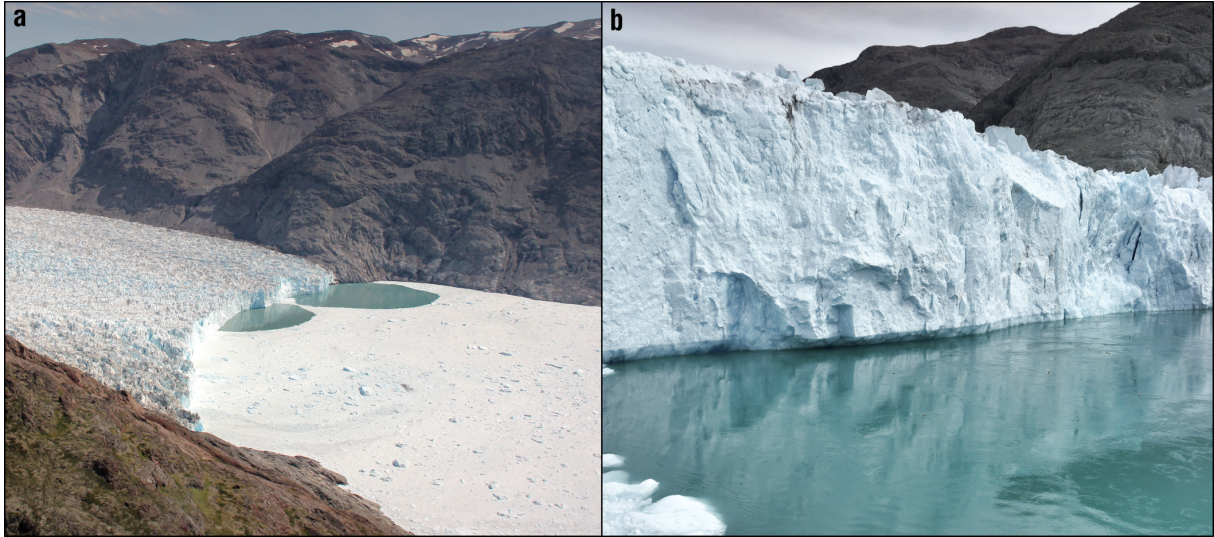


Figure 2: Melt water plume at Qooqqup Sermia (a) two plumes observed at Qooqqup Sermia on 26 July 2025 (b) close up drone image showing the plume and distinct undercutting at the glacier front.

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 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  $< 0.7^{\circ}\text{C}$  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 Bartholomäus (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 Bartholomäus, 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.

## Author Response to comments by referee 2

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

Dear Referee,

Thank you for taking the time to provide us with a detailed review. We believe that your comments challenging some of our interpretations have strengthened our discussion section and made our findings clearer. We provide our response in the following with your comments coloured blue, our responses black, and manuscript changes brown.

Florian Vacek,

on behalf of all authors

## Summary

### Reviewer Comment:

Vacek et al. present a clever natural lab study of the Qooqqup Sermia system in South Greenland, which splits into two branches, one terminating in fjord water and the other in lake water. The authors use the two different terminus environments to investigate changes in glacier behavior that may be caused by the type of water into which a glacier terminates, while the glacier system experiences the same climate forcing. The authors use an impressive combination of remote sensing, field observations, and model outputs to compare the two termini, with the main conclusion being that subaqueous melt rates are the main driver for the different glacier behavior. This manuscript is novel in concept, well written, presents clear and professional figures, and is perfectly within the scope of The Cryosphere. However, the author's analysis supporting their main conclusions is not convincing enough to recommend immediate acceptance. I therefore recommend this manuscript be reconsidered after major revisions. I will happily recommend acceptance once the authors clarify or modify their claim that subaqueous melt rates drive the differences between the two glaciers.

### Author Response:

Thank you for your generally positive summary. We addressed your concerns, specifically about our main conclusion and have changed our manuscript accordingly. See our specific answers below.

The referee provided a detailed comment (comment 1) questioning our interpretation of subaqueous melt rates at both the marine and lake termini of Qooqqup Sermia, as well as the conclusions we derive from this interpretation. Before giving specific answers to each of the paragraphs of the comment, we wanted to clarify that we are not arguing for exceptionally high melt rates at the marine terminus compared to other marine termini. However, we argue that the melt rates in the fjord must be significantly higher than those in the lake and that these differences contribute to the different dynamics that we observe. For this we have several arguments and observations outlined in the revised section 5.5:

## Manuscript Changes:

1. Freezing point depression: In the marine environment, the freezing point of ocean water is lowered due to the salt content. With a salinity of 32 PSU the freezing point drops to about  $-1.8^{\circ}\text{C}$ . A lower freezing point increases the thermal driving (or thermal excess), consequently increasing submarine melt rates. Even in a cold ocean environment this freezing point depression leads to higher melt rates compared to a freshwater environment. For example, assuming an ocean temperature of  $0.6^{\circ}\text{C}$  (average temperature of the top 100 m measured by Hansen et al. (2025) in Tunulliarfik Fjord, close to Qooroq Fjord ) and a lake temperature of  $0.7^{\circ}\text{C}$  (measured in lake Motzfeldt) results in a thermal driving that is 3 to 4 times higher in the ocean compared to the lake ( $2.4^{\circ}\text{C}$  vs  $0.7^{\circ}\text{C}$  above the freezing point).
2. No subglacial plume formation: The formation of subglacial plumes can significantly enhance submarine melt rates (Jenkins, 2011), promote undercutting, and consequently calving (Slater et al., 2017). However, lakes generally consist of freshwater and therefore lack vertical circulation at the ice front, driven by the density differences of fresh and salt water (Truffer and Motyka, 2016). Consequently, we observe the formation of subglacial plumes at MT but not at LT, arguably leading to even higher melt rates at MT compared to LT. Furthermore, this implies that additional runoff at MT would enhance melt rates by generating stronger plumes, whereas in the lake, additional runoff would not affect melt rates and could even cause the lake to cool. This could possibly explain why seasonality in front positions is observed at MT but not at LT.
3. Heat transport: A lake is a semi-closed system where no transport of large quantities of warm water masses toward the glacier front from distant sources takes place. The energy input to the lake is limited to long and short wave radiation, heat exchange with the atmosphere, and advected heat (e.g., rainwater, streams, and groundwater) (Wetzel and Likens, 2000). In the fjord, on the other hand, water masses can be transported to and from the glacier front through ocean circulation and exchange with more distant water masses. Even in fjords with a prominent sill, exchange with shelf water is not completely blocked, and cold water can be transported away and exchanged with warmer waters (e.g. Mortensen et al., 2018).

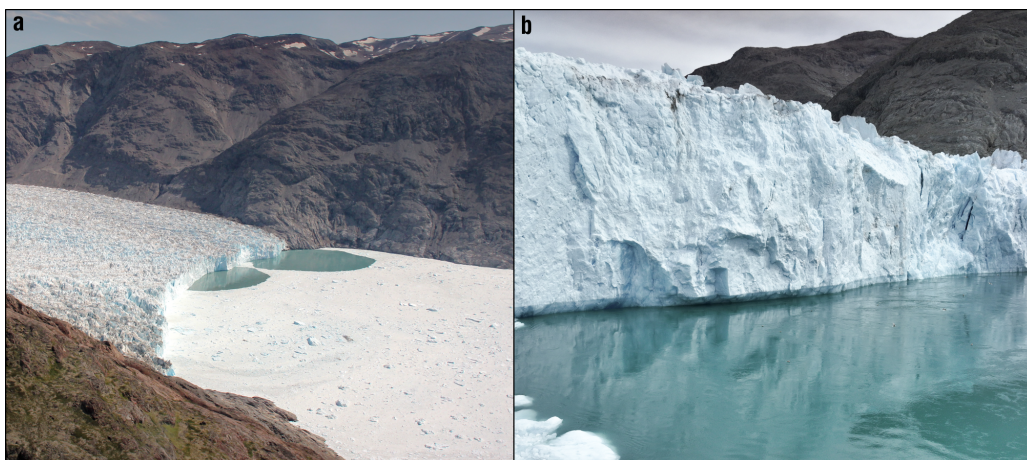


Figure 3: Melt water plume at Qooqqup Sermia (a) two plumes observed at Qooqqup Sermia on 26 July 2025 (b) close up drone image showing the plume and distinct undercutting at the glacier front.

## **Comment 1: Low subaqueous melt rates in the lake are the main driver of these differences**

### **Reviewer Comment:**

The authors provide clear evidence from their CTDs (Fig. A2) that the lake water temperature is very cold, presumably causing a low subaqueous melt rate. They do not provide strong evidence to support that melt rates are the reason why the MT glacier behaves differently.

### **Author Response:**

First, in order to strengthen our argument that subaqueous melt rates must be very low at LT compared to MT, we have extended Section 5.5 and elaborate in more detail about the physical properties of the lake compared to the ocean. The main arguments for that are provided in the list above.

Second, we have revised Section 5.4 about the dynamics of MT. We switched from a narrative of "runoff-dominated" and "runoff-driven" to elaborating more on the indications that we have that the seasonal front variations are influenced by submarine melt through plume formation. 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 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 in the manuscript show that the ice front position seems to at least be influenced by runoff. This is further supported by Figure 1 (in this document) clearly showing a meltwater plume as well as undercutting of the ice front at MT. (we intend to include this figure in the appendix of the new manuscript). In the revised manuscript we state that the seasonality of glacier front positions is influenced by subglacial runoff, however, with other processes likely also playing a role.

### **Manuscript Changes:**

#### **Revised paragraphs in Section 5.4:**

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; Wehrle 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.

#### **Reviewer Comment:**

The authors suggest on lines 374 - 377 that “the intrusion of warm Atlantic waters deep into fjords is a commonly observed phenomenon 375 for tidewater glaciers in all regions of Greenland”. They also comment earlier that this intrusion of warm Atlantic water is unlikely for the MT glacier in lines 335 - 339 because of the presence of a large moraine. This back-and-forth makes it unclear what the authors are trying to say about their study site.

#### **Author Response:**

We agree that these contradicting thoughts make our intended message unclear. We have therefore revised both mentioned sections. The first mentioned paragraph now clarifies that even in a fjord with a distinct moraine, exchange with shelf water is not completely blocked. While sills may keep the warmest and saltiest bottom water out of the fjord, there will always be some transport of water and mixing with other water masses, which is a clear difference to lacustrine environments. In addition to that, in Section 5.5, we elaborate that even with cold ocean conditions subaqueous melt rates must be higher at MT compared to LT for the arguments listed at the beginning of this document.

In the second mentioned paragraph about the historical evolution of the marine terminus, we acknowledge that we lack oceanographic data to assess the influence of ocean warming on the long-term evolution of the glacier.

#### **Manuscript Changes:**

Section 5.5 see list at beginning of this document.

Section 5.3, second paragraph: After reaching its most advanced position in 1994 the glacier recedes about 1.3 km until 2004, where it remains stable until today. Although the cause of the retreat of other

marine terminal glaciers in Greenland during that period is often induced by warming ocean temperatures (Wood et al., 2021), we lack oceanographic data in the inner fjord to confirm or deny this at Qooqqup Sermia.

#### **Reviewer Comment:**

More convincingly, the authors point out an observed subglacial plume at the MT glacier, which can enhance submarine melting. However, the presence of this large moraine can complicate melting by “trapping” subglacial discharge between the terminus and the moraine, cooling the water and limiting entrainment from the ambient water (Kajanto et al., 2023).

#### **Author Response:**

We agree that the sill at the fjord entrance complicates circulation in fjord. However, the provided reference (Kajanto et al., 2023) is a comparison of ocean conditions in a high-silled fjord with and without icebergs. The authors of this study describe an inflow of water above the sill in exchange for cold glacially modified water in both cases (Section 4.1 and 4.2 in that paper), therefore strengthening our point that exchange of water masses is not completely blocked by high sills. Furthermore, the authors describe a cooling of deeper basin water throughout the peak season and consequent reduction of submarine melt, in the case where icebergs with a depth of 300 m are present. However, Qooqqup Sermia does not produce these kind of large icebergs, as calving can be described of serac collapse type (see revised paragraphs of Section 5.4 in first comment).

Furthermore, the three bullet points mentioned at the beginning of this document (also part of the new revised Section 5.5), show that even with cold ocean conditions, submarine melt rates must be higher at MT compared to LT.

#### **Reviewer Comment:**

Furthermore, on lines 354-355, the authors claim that the marine terminus is dominated by submarine melt-induced calving events. However, from Fig. 7, there appear to be plenty of calving events outside of the runoff season, judging from the terminus position. If the MT glacier’s calving is dominated by a subglacial plume and the subsequent undercutting, why does the MT glacier calve outside of the melt season, and what mechanism is the cause of this? Maybe winter-time subglacial discharge similar to the neighboring Eqalorutsit Kangilliit Sermiat (Hansen et al., 2025)? Though this would be speculative, and who knows how much discharge is actually happening in the winter at this location.

#### **Author Response:**

We recognise that our formulation about the effect of submarine melt on MT was misleading. In the revised version we try to clarify the calving style of MT and which effect runoff has. We switch away from the narrative of "runoff-dominated" and elaborate more on the indications that we have that the seasonal front variations are influenced by submarine melt through plume formation. The calving of the marine terminus can be described as serac collapse type (Bézu and Bartholomäus, 2024), with very frequent but small size calving events. This type of calving is always the result of a force imbalance at the glacier front and can also occur during winter time. However, in summer due to increased undercutting, calving occurs more frequently and results in the seasonal front variations that we observe. Furthermore,

we want to clarify that the recorded ice front positions at MT represent the cumulative front change between two satellite images as the result of many small calving events and ice flow and do not represent single calving events.

See revised paragraphs of Section 5.4 in first comment

**Reviewer Comment:**

Also, if the MT front position is controlled by runoff, why isn't this the case for the LT glacier too?

**Author Response:**

Due to the lack of salinity differences, runoff does not lead to the formation of plumes in the lake (see Section 5.5 second bullet point at the beginning of the document). Therefore, any additional runoff does not increase melt rates at LT. Furthermore, the catchment of LT is an order of magnitude smaller than that of MT, reducing any possible effects at LT. Nonetheless, and due to other points raised by the referee we have changed our description from "controlled by runoff", to explaining that the seasonal front position is influenced by enhanced submarine melt through subglacial plumes. See revised paragraphs of Section 5.4 in first comment

**Reviewer Comment:**

I believe the presence of this large moraine complicates the melt-rate differences for this conclusion and makes it too difficult to claim, with confidence, that it must be the melt rates. I am also not sure how representative the ORAS5 data are of the MT retreat and MT dynamics, especially given the moraine. I also strongly encourage the authors to review Hansen et al. (2025). A CTD profile from June 2023 shows a temperature of 1 °C in the upper 100 m of Tunulliarfik Fjord (Fig. 4A; Hansen et al., 2025), whereas the June monthly average from the ORAS5 data is about 3 °C (Fig. 4A).

**Author Response:**

We agree with the referee that the ORAS5 data is likely not representative of the ocean conditions close to the glacier front. The issue regarding ORAS5 data was also raised by other reviewers. Therefore, we have removed our analysis and interpretation that relied on ORAS5 data.

We are grateful for the suggestion of reviewing (Hansen et al., 2025) and now include the reference in the discussion about melt rates in Section 5.5, which nicely illustrates that with the mentioned ocean conditions (0.6 °C average temperature of the top 100 m), the thermal driving is 3 to 4 times larger than that of the lake.

**Manuscript Changes:**

Removed all ORAS5 analysis and included the provided reference in Section 5.5.

**Reviewer Comment:**

What I find more convincing than melt-rate differences is the presence of a pinning point and substantial thinning on the LT glacier described in lines 300 - 307. If the LT thinned, lost contact with a pinning point, and then changed calving styles and a different terminus advance and retreat cycle, why exactly

is this due to the melt rates? In other words, if the bed geometries are different between the LT and MT glaciers and not the melt rates, would this not also be a possible reason for the different behaviors? The authors also claim that the pinning points can exert enough backstress to stabilize the glacier on lines 302-303, which does not depend on the melt rate from the lake. Additionally, the authors suggest that there are no visible pinning points below the MT glacier on lines 337-340. So I am very confused as to why the possible and arguably harder to justify melt rate differences are the reason for the different glacier behaviors, and not the different bed geometries? Or likely some combination of both bed geometry and melt rate, though it appears the bed plays a more important role for the LT glacier from the discussion at the end of section 5.1.

### **Author Response:**

We recognise that our manuscript did not elaborate on the important role of geometry. In the manuscript we describe that the reduced contact with the pinning point likely contributed to the disintegration of the floating ice tongue. However, we don't mention that the disintegration was connected to subaqueous melt rates. Rather we try to express that low melt rates contributed to the stability of the ice tongue which allowed it to survive for at least 25 years (earliest observation until break up in 2012). Very likely the ice tongue would not have survived in a saline setting with warmer temperatures, the formation of meltwater plumes, overall higher subaqueous melt rates and frontal ablation by calving. Furthermore, we believe that the low melt rates create favourable conditions for the glacier to form a floating ice tongue each time during the advance phase (described in Section 5.1), unrelated to the pinning point. We try to elaborate this more clearly in the revised Section 5.1. There 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:**

**Revised Section 5.1:** The flat morphology of the glacier surface, the production of large tabular icebergs, as well as the buoyancy compensated thinning rates of LT suggest that prior to 2012, a floating ice tongue was present at the lake terminus (Fig. 2 and 3). Although we are unaware of other descriptions of floating ice tongues in Greenlandic lakes, they are a common phenomenon in other regions like Patagonia (Warren et al., 2001), Alaska (Boyce et al., 2007; Trüssel et al., 2013), and Iceland (Benn et al., 2007). In Greenland, fully floating ice tongues are found at marine-terminating glaciers, but only in the very north (Hill et al., 2018; Millan et al., 2023; Wekerle et al., 2024) following the disintegration of several ice tongues further south (Millan et al., 2023; Mouginot et al., 2015; Johnson et al., 2004).

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  $< 0.7^{\circ}\text{C}$  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.

**Reviewer Comment:**

Lastly, there is also a reference to “rapid, melt-driven calving” in the Conclusions on lines 396 - 397 to support this claim. What is “rapid, melt-driven calving”? Do you observe a top-down toppling over of a calving iceberg?

**Author Response:**

We have rephrased this bullet point due to a change of interpretation. For clarification, with melt-driven calving we referred to the undercutting of the glacier front through subglacial plumes and the consequent calving. The calving style can be described as serac collapse as for example in (Bézu and Bartholomaus, 2024).

**Manuscript Changes:**

New conclusion bullet point, also as response to reviewer 1 (coupling of front position and flow velocities):

- The marine terminus of the Qooqqup Sermia system is fast flowing, grounded, characterised by frequent serac collapse type calving and experiences seasonal front advance and retreat. Ice flow velocities appear to be coupled to the ice front position.

## Comment 2: The floating ice tongue of the lake-terminating glacier

### Reviewer Comment:

I am not sure what the authors mean in lines 292-294: “Therefore, the presence of the floating ice tongue in Lake Motzfeldt for an extended period (at least 1987–2012), despite being located in the very south of Greenland, can only be explained by the different environment at the terminus”. I am not sure whether differences in water temperature or salinity cause the LT to begin floating while the MT does not. Again, we don’t know the temperature at the MT, so it is very difficult to suggest this. However, could differences in water depth between the two glaciers be the cause?

### Author Response:

We recognise that our elaboration on the floating ice tongue was not clear enough and have therefore revised the whole section. We try to more clearly express that a certain geometry must be given to allow the formation of a floating ice tongue. Furthermore we explain that low subaqueous melt rates create favourable conditions and promote the stability of the floating ice tongue. 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.

### Reviewer Comment:

The calving style post 2012 retreat also reminds me of Helheim Glacier’s terminus position and calving style (Bézu and Bartholomaus 2024). Although Helheim Glacier is a marine-terminating glacier, it has recently formed a long floating tongue and has calving events that do not affect velocity, similar to LT calving events (Shahin et al., 2025). That said, similar calving styles and terminus advance/retreat cycles can occur in environments with presumably higher subaqueous melt rates, or at least in environments with warmer water (e.g., Helheim; Straneo et al., 2010).

### 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 fully floating ice tongues such as Petermann (e.g. Johannessen et al., 2013) and Ryder Glacier (e.g. Holmes et al., 2021) which are only found in North Greenland. We have added to the section "Dynamics of the lake terminus" to more clearly explain the type of calving that we see.

#### **Manuscript Changes:**

We observe a distinct calving pattern at the lake terminus that can be described as follows: The glacier experiences long advance phases that can persist 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 larger than 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 Bartholomäus, 2024) and resembles that of large fully floating ice tongues in North Greenland, like Peterman (e.g. Johannessen et al., 2013) and Ryder Glacier (e.g. Holmes et al., 2021).

#### **Reviewer Comment:**

Also, do the authors observe any changes in the LT glacier's grounding line? Could this also have a significant impact on the LT dynamics?

#### **Author Response:**

Unfortunately, we don't have a record of grounding line position.

### Comment 3: Lake ice analogy to an ice mélange

#### Reviewer Comment:

This is more of a minor point, but I am confused as to why the authors claim that lake ice is the reason for the absence of calving activity outside the runoff season, rather than simply that runoff is the reason. Or at least a combination of lake ice and runoff. Since this is stated in the abstract, it requires clarification. I am also not sure how much buttressing force lake ice can provide when considering mélange thickness, as mélange can be an order of magnitude(s?) thicker than lake ice (Meng et al., 2025).

#### Author Response:

We agree with reviewer and are grateful for the provided literature. We have removed our interpretation that lake ice acts in a similar way as an ice mélange, as evidence for that is lacking. In the revised manuscript we mention that lake ice possibly prevents icebergs from drifting away and helps to keep the glacier front together in winter, but not that it provides a buttressing effect similar to an ice mélange.

#### Manuscript Changes:

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.

## Comment 4: on Section 5.5

### Reviewer Comment:

Both of the bullets in this section describe a “general” lake and fjord system in Greenland, but since the Qooqqup Sermia system is so unique, I don’t believe these general statements apply here. Below are my confusions with this section.

1. The authors state that warm Atlantic Water likely doesn’t reach the MT glacier because of the moraine, but in point 1 they describe a general tidewater glacier system in Greenland that does? This does not appear relevant for its own list element for this manuscript
2. Since the MT glacier calves quite often outside of the runoff season, I’m not sure how much this point applies here, other than possible but speculative winter-time discharge (Hansen et al., 2025).

The authors also indicate that direct observations are missing in lines 385-386, so I am confused as to why inferring melt rates for the MT glacier is necessary. I would consider removing this section, or perhaps making it about how the Qooqqup Sermia system is unique and not like a “traditional” tidewater glacier system in Greenland.

### Author Response:

We have revised the section 5.5 in order to elaborate in more detail as to why subaqueous melt rates are lower at LT compared to MT. The arguments we provide hold true for our case but also for a comparison of lakes and fjords in general. We think that it is a very valuable comparison for readers working with these environments as it also applies to other regions.

### Manuscript Changes:

#### 5.5 Key differences between the lake and marine terminus and potential causes

In previous sections, we illustrated that the lake- and marine-terminating glacier exhibit contrasting dynamics, despite being subject to the same climatic conditions. The key differences can be summarised as the following: We observe the marine terminus to be a fast flowing, grounded glacier with frequent small-size calving events, mainly in the form of serac failure type. The lake terminating glacier, on the other hand, has a floating extension and experiences rare, but very large calving events, producing large tabular icebergs. Furthermore, MT shows a clear seasonality with glacier front retreat in summer and advance in winter as well as a coupling of ice flow velocities to the glacier front position. In contrast, LT does not have seasonal ice front fluctuations, and ice flow velocities do not seem to be coupled to the front position.

Differences in bedrock geometry and ice thickness certainly partly determine the dynamics at the two termini. However, in addition, we identified the following physical differences between the two environments, which potentially influence the morphology and dynamics at the glacier termini. The following considerations apply to this study and, in general, to the comparison of marine- and lake-terminating glaciers.

1. Freezing point depression: In the marine environment, the freezing point of ocean water is lowered due to the salt content. With a salinity of 32 PSU the freezing point drops to about -1.8 °C. A lower freezing point increases the thermal driving (or thermal excess), consequently increasing

submarine melt rates. Even in a cold ocean environment this freezing point depression leads to higher melt rates compared to a freshwater environment. For example, assuming an ocean temperature of 0.6 °C (average temperature of the top 100 m measured by Hansen et al. (2025) in Tunulliarfik Fjord, close to Qooroq Fjord ) and a lake temperature of 0.7 °C (measured in lake Motzfeldt) results in a thermal driving that is 3 to 4 times higher in the ocean compared to the lake (2.4 °C vs 0.7 °C above the freezing point).

2. No subglacial plume formation: The formation of subglacial plumes can significantly enhance submarine melt rates (Jenkins, 2011), promote undercutting, and consequently calving (Slater et al., 2017). However, lakes generally consist of freshwater and therefore lack circulation, driven by the density differences of fresh and salt water (Truffer and Motyka, 2016). Consequently, we observe the formation of subglacial plumes at MT but not at LT, arguably leading to even higher melt rates at MT compared to LT. Furthermore, this implies that additional runoff at MT would enhance melt rates by generating stronger plumes, whereas in the lake, additional runoff would not affect melt rates and could even cause the lake to cool. This could possibly explain why seasonality in front positions is observed at MT but not at LT.
3. Heat transport: A lake is a semi-closed system where no transport of large quantities of warm water masses toward the glacier front from distant sources takes place. The energy input to the lake is limited to long and short wave radiation, heat exchange with the atmosphere, and advected heat (e.g., rainwater, streams, and groundwater) (Wetzel and Likens, 2000). In the fjord, on the other hand, water masses can be transported to and from the glacier front through ocean circulation and exchange with more distant water masses. Even in fjords with a prominent sill, exchange with shelf water is not completely blocked, and cold water can be transported away and exchanged with warmer waters (e.g. Mortensen et al., 2018).

The differences outlined above clearly demonstrate that subaqueous melt rates must be higher at MT than at LT, even with cold ocean conditions. The presence of a meltwater plume, the undercutting of the ice front, and the correlation between surface runoff and glacier front position all suggest that submarine melting affects the dynamics of the marine-terminating glacier. At LT on the other hand, low melt rates create favourable conditions for a floating extension of the glacier through limited thinning and calving rates. This comparison indicates that the difference in subaqueous melt rate contributes to the contrasting dynamics that we observe.

## Comment 5: on the conclusion

### Reviewer Comment:

On line 401, what parameterizations are you referring to? Calving, sliding, melt rates? When making a general call for modelers, consider what specifics a modeler might need to take your advice.

### Author Response:

Because this sentence was too unspecific we have removed it.

### Reviewer Comment:

For the third bullet (lines 402 - 405). The pinning points and water depth appear to have a much more considerable effect than the melt rates. Would this statement imply that the lake melt rates changed, and hence why the LT glacier responded to a potential change in melt rates? I think the bed geometry and pinning points should be emphasized more in the conclusions.

### Author Response:

We have emphasized the role of the pinning point for the disintegration of the ice tongue.

### Manuscript Changes:

- The massive retreat of more than 3 km of the lake terminus in one year highlights the possibility of rapid mass loss at lake-terminating glaciers in Greenland, stressing their importance for the future evolution of the Greenland ice sheet. The retreat was likely connected to the separation from a pinning point.

### Reviewer Comment:

4th bullet (lines 406-407). Is it lake ice, or runoff, or both?

### Author Response:

We have removed this bullet point, as we have also revised our interpretation of the effect of lake ice.

## Technical corrections:

### Reviewer Comment:

L13: The authors mention “require different parameterisations” several times, but it is unclear what parameterisations they are referring to. Consider being more specific here. Calving parameterisations? Sliding?

### Author Response:

Changed to "Our results stress that lake- and marine-terminating glaciers require separate estimates of frontal ablation through subaqueous melt when included in model simulations of the Greenland Ice Sheet."

### Reviewer Comment:

L31: What regions are you referring to?

### Author Response:

North East. (Carrivick et al., 2022)

### Reviewer Comment:

L53: Similar to the L13 comment. How would the authors suggest handling this unique situation at their study site? Consider removing or rephrasing this.

### Author Response:

Changed to "Our results stress that lake- and marine-terminating glaciers require separate estimates of frontal ablation through subaqueous melt when included in model simulations of the Greenland Ice Sheet."

### Reviewer Comment:

L54: Consider changing the section title to “Qooqqup Sermia system: A unique study site in South Greenland”. This provides the reader with easier access to the name of the study site and does not have to go searching through the text as much.

### Author Response:

Changed as suggested.

### Reviewer Comment:

L94-96: Where the calving events not cataloged for the MT glacier, too?

### Author Response:

No. We want to clarify that the recorded ice front positions at MT represent the cumulative front change between two satellite images as the result of many small calving events and ice flow, therefore not representing single calving events.

**Reviewer Comment:**

L146: I would reorder to conductivity, temperature, and depth.

**Author Response:**

Changed as suggested

**Reviewer Comment:**

L148: What is a RBR Duet3?

**Author Response:**

It is the name of the temperature and depth sensor. We added "temperature and depth sensor" to clarify.

**Reviewer Comment:**

L348: No need for parentheses around the citation.

**Author Response:**

The citation was removed, while the section was revised to reply to other comments.

**Reviewer Comment:**

L367: Very minor, but I'd consider these "sections" and not chapters.

**Author Response:**

Changed to "sections".

## Figures:

### Reviewer Comment:

Figure 1: Adding both the OMG bathymetry and the lake bathymetry to the map would greatly improve the interpretation of this environment. Please consider adding this, especially since the moraine is quite important for the ocean dynamics.

### Author Response:

Here we would like to refer the reader to our descriptions of the study site as well as of the bathymetry measurements. The essential locations are indicated in Figure 1 and the lake bathymetry is shown in Figure 4. We believe adding the two bathymetry datasets, would decrease the overall readability of the map.

### Reviewer Comment:

Figures 2-3: These are beautiful figures.

### Author Response:

Many thanks!

### Reviewer Comment:

Figure 4: What numeric values do the floatation index represent? Try expanding the color bar and add the numeric values.

### Author Response:

Numeric values added. A value of zero means that the ice thickness below water is exactly the same as the water depth. A value of negative 100 means that the ice thickness is 100 less than the water depth at that location. A value of positive 100 means that the theoretical ice thickness exceeds the water depth by 100 m. Hence, the glacier must be grounded at that location.

### Reviewer Comment:

Figure 5: The calving event label is missing in the legend.

### Author Response:

Label added.

## Author Response to comments by referee 3

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

Dear Referee,

Thank you for reviewing our manuscript and for providing us with constructive and structured feedback, which we believe strengthened our work. We provide our response in the following with your comments coloured blue, our responses black, and manuscript changes brown.

Florian Vacek,

on behalf of all authors

## Summary

### Reviewer Comment:

Overall, this is a very nice study. It presents a well-designed examination of a glacier system that has both a marine-terminating branch and a lake terminating branch. Overall, lake-terminating glaciers in Greenland are understudied, and also the literature on marine and lacustrine termini are somewhat disconnected. Thus, this paper addresses an important knowledge gap and helps bridge these two fields. In particular, the results highlighting the contrasting front dynamics of the two branches are very interesting, including the different styles of seasonal variability, the episodic large calving events at the lake terminus, and the role of geometry and potential pinning points in modulating stability. The manuscript is clear and very well written.

My comments primarily surround the transition from the results section — which is largely clear, careful, and well supported by the data — to the discussion & conclusions, which at times feel somewhat speculative or more strongly framed than the evidence allows. Some interpretations would be better presented as discussion points or potential implications rather than firm conclusions. In particular, the sections involving ocean conditions inferred from the offshore reanalysis product appear to be a weak point. Nevertheless, I am confident that, with some revision and clarification, this manuscript will make a valuable contribution to the field.

### Author Response:

Thank you for your overall positive summary. We have addressed your concerns, specifically about the ocean conditions as well as the effect of lake ice and have changed our manuscript accordingly. See specific answers below.

## Major comment 1: Ocean conditions

### Reviewer Comment:

This paper uses the ORAS5 ocean reanalysis data, at a grid cell outside the fjord mouth and averaged between 20–100 m depth, to infer the ocean conditions at the marine terminus. I have several concerns about this approach. First, there's no discussion if ORAS5 performs well in this general region of coastal Greenland (I would suspect not). Second, I would be skeptical that the ocean conditions from ORAS5 outside the fjord mouth would be representative of conditions in the upper fjord at the terminus, especially given the shallow moraine/sill of less than 50 m that would restrict the deep inflow. The fjord geometry, combined with the inputs of subglacial discharge at the glacier, means there's a strong possibility that the near-glacier conditions are markedly different from those outside the fjord and follow a different seasonal cycle.

I wonder if there are any CTD casts from the fjord, from OMG or other campaigns, that could be used to validate the reanalysis product and/or to compare inside vs. outside fjord conditions.

Further, one of the central results is that retreat rates correlate more strongly with runoff and air temperature than with ocean temperature. However, the uncertainty in the ocean temperature estimate is likely much larger than that of the atmospheric and runoff variables, because the ocean temperature is derived from a low-resolution reanalysis product outside the fjord, whereas runoff and air temperature are better constrained. A weaker correlation with ocean temperature could reflect higher uncertainty/spatial mismatch, rather than weaker physical influence.

For these reasons, I think the manuscript currently overstates the ability to rule out ocean forcing as a driver of marine terminus variability. Unless the reanalysis product can be validated for this setting or a better data set is available, the results related to the ocean conditions should be framed more cautiously.

### Author Response:

We agree with the referee that the ORAS5 data is likely not representative of the ocean conditions close to the glacier front. The issue regarding ORAS5 data was also raised by another reviewer. Therefore, we have removed our analysis and interpretation that relied on ORAS5 data.

In our revised manuscript, we rely on a comparison of the physical properties of the ocean and the lake (see revised Section 5.5 below). This comparison illustrates that even under cold ocean conditions subaqueous melt rates must be much higher at MT compared to LT. Following the suggestion of referee 2, we included a CTD measurement from Hansen et al. (2025) just outside of the moraine. The CTD measurement shows an average temperature in the top 100 m of about 0.6 °C in June 2023. Assuming this temperature and a lake temperature of 0.7 °C (measured), results in a thermal driving which is 3 to 4 times larger in the ocean due to the freezing point depression in salt water.

Therefore, in the revised manuscript we focus on elaborating that melt rates must be much lower in the lacustrine environment, even under cold ocean conditions and that these low melt rates contributed to the formation and stability of the floating ice tongue in the lake. Nonetheless, we have good indication that MT is at least influenced by submarine melting through subglacial plumes (please see response to referee 1, first comment where we also include images showing undercutting and plume formation at MT).

## Manuscript Changes:

1. Freezing point depression: In the marine environment, the freezing point of ocean water is lowered due to the salt content. With a salinity of 32 PSU the freezing point drops to about  $-1.8^{\circ}\text{C}$ . A lower freezing point increases the thermal driving (or thermal excess), consequently increasing submarine melt rates. Even in a cold ocean environment this freezing point depression leads to higher melt rates compared to a freshwater environment. For example, assuming an ocean temperature of  $0.6^{\circ}\text{C}$  (average temperature of the top 100 m measured by Hansen et al. (2025) in Tunulliarfik Fjord, close to Qooroq Fjord ) and a lake temperature of  $0.7^{\circ}\text{C}$  (measured in lake Motzfeldt) results in a thermal driving that is 3 to 4 times higher in the ocean compared to the lake ( $2.4^{\circ}\text{C}$  vs  $0.7^{\circ}\text{C}$  above the freezing point).
2. No subglacial plume formation: The formation of subglacial plumes can significantly enhance submarine melt rates (Jenkins, 2011), promote undercutting, and consequently calving (Slater et al., 2017). However, lakes generally consist of freshwater and therefore lack vertical circulation at the ice front, driven by the density differences of fresh and salt water (Truffer and Motyka, 2016). Consequently, we observe the formation of subglacial plumes at MT but not at LT, arguably leading to even higher melt rates at MT compared to LT. Furthermore, this implies that additional runoff at MT would enhance melt rates by generating stronger plumes, whereas in the lake, additional runoff would not affect melt rates and could even cause the lake to cool. This could possibly explain why seasonality in front positions is observed at MT but not at LT.
3. Heat transport: A lake is a semi-closed system where no transport of large quantities of warm water masses toward the glacier front from distant sources takes place. The energy input to the lake is limited to long and short wave radiation, heat exchange with the atmosphere, and advected heat (e.g., rainwater, streams, and groundwater) (Wetzel and Likens, 2000). In the fjord, on the other hand, water masses can be transported to and from the glacier front through ocean circulation and exchange with more distant water masses. Even in fjords with a prominent sill, exchange with shelf water is not completely blocked, and cold water can be transported away and exchanged with warmer waters (e.g. Mortensen et al., 2018).

The differences outlined above clearly demonstrate that subaqueous melt rates must be higher at MT than at LT, even with cold ocean conditions. The presence of a meltwater plume, the undercutting of the ice front, and the correlation between surface runoff and glacier front position all suggest that submarine melting affects the dynamics of the marine-terminating glacier. At LT on the other hand, low melt rates create favourable conditions for a floating extension of the glacier through limited thinning and calving rates. This comparison indicates that the difference in subaqueous melt rate contributes to the contrasting dynamics that we observe.

## Major comment 2: Lake ice

### Reviewer Comment:

The paper attributes reduced winter calving to the buttressing effect of lake ice cover. However, calving also coincides strongly with the runoff season, so couldn't reduced winter calving just reflect the absence of subglacial discharge? Given that lake ice cover and runoff seasonality are closely aligned, it seems difficult to disentangle their relative roles, and the discussion should acknowledge this ambiguity (or provide further reasoning for how you separate their effects).

### Author Response:

A similar point was also raised by referee 2. We have removed our interpretation that lake ice acts in a similar way as an ice mélange, as evidence for that is lacking. In the revised manuscript we mention that lake ice possibly prevents icebergs from drifting away and helps to keep the glacier front together in winter, but not that it provides a buttressing effect similar to an ice mélange. We also discuss that 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. We are now more careful with our formulation and phrase it as a possibility that runoff and or lake ice has an influence on calving.

### Manuscript Changes:

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.

## Minor comments:

### Reviewer Comment:

1. Figure 4: why is the colorbar not quantitative? It's just labeled as floating vs. grounded but why not show the numeric value of the flotation index, especially since the text mentions specific values (e.g. "on the ridge, the flotation index reaches up to 200 m")

### Author Response:

Changed to numerical values.

### Reviewer Comment:

2. I would consider putting A1 and A2 figures in the main text (perhaps combined into one figure). It

seems a little arbitrary why those two in the appendix relative to the rest of the figures.

**Author Response:**

We would prefer to keep the figures in the appendix, as the manuscript already has 8 figures in the main text. We chose to put those two figures in the appendix, as it can easily be described with words what is seen in the plots (e.g. CTDs show a depth averaged temperature of 0.7 at the glacier front).

**Reviewer Comment:**

3. Section 5.5 feels somewhat misaligned with the results presented for this glacier system. For example, point (1) appears to summarize mechanisms (e.g., the influence of warm Atlantic water reaching the glacier) that might not apply to this fjord due to the shallow sill. In point (2), the discussion draws on studies of plume-driven melting in marine settings when interpreting subaqueous melt in the lake, but the physical processes in lacustrine environments might not be entirely analogous

**Author Response:**

We have revised the Section 5.5 "Key differences between the lake and marine terminus and potential causes" in order to elaborate in more detail as to why subaqueous melt rates are lower at LT compared to MT. The arguments we provide hold true for our case but also for a comparison of lakes and fjords in general. We think that it is a very valuable comparison for readers working with these environments as it also applies to other regions. See list of arguments provided in reply to comment 1.

**Reviewer Comment:**

4. It would be helpful to clarify whether there is any information on the relative magnitude of subglacial discharge routed to the marine versus the lake terminus. Even a qualitative estimate or catchment-based comparison could strengthen the interpretation of differences between the two branches.

**Author Response:**

The catchment is about an order of magnitude larger at MT compared to LT. However, due to the lack of salinity differences, runoff does not lead to the formation of plumes in the lake (second point in the list in the reply to comment 1). Therefore, any additional runoff does not increase subaqueous melt rates and calving through undercutting at LT.

**Reviewer Comment:**

5. At several places through the text, it refers to the two termini as experiencing the same "climatic conditions" or same "climatic forcing." I guess this is not wrong, but perhaps a little confusing because one might think that the climate that the glacier experiences is based on water and air temperature - but water temps are not similar in these two places. (As an analogy, two locations that are nearby geographically but at very different elevations would have different air temperatures and not the same climate forcing.) Perhaps a bit subjective, but I would suggest rewording to something about how they exist in the same regional climate but experience different water boundary conditions, or something.

**Author Response:**

We changed this as suggested on several occasion.

## Line by line comments:

### Reviewer Comment:

Fig 1 caption: “CTD profiles” instead of “CTD measurements”, especially to make clear between the moored temp-depth sensor

### Author Response:

Changed as suggested.

### Reviewer Comment:

L146: would mention that CTD profiles were collect from surface to bottom, or surface to XX m depth, or whatnot

### Author Response:

Changed as suggested.

### Reviewer Comment:

L 178; is there a typo here? Should second “before” be “after” instead?

### Author Response:

Changed as suggested.

### Reviewer Comment:

L223: says no distinct moraine where the glacier was stagnant until 2012, but isn’t this the location of the front, not the grounding line?

### Author Response:

Yes, indeed. We removed the part about the moraine.

### Reviewer Comment:

L232, should be “depth average temperature” not just “depth average”

### Author Response:

Changed as suggested.

### Reviewer Comment:

Figure 6 caption: should this say “full lake ice cover” instead of just “lake ice cover”?

### Author Response:

Yes. Changed as suggested.

**Reviewer Comment:**

L376: “sections” instead of “chapters”

**Author Response:**

Changed to section.

## Comments by the editor

### Reviewer Comment:

Sect. 5.4: If runoff is proposed as a primary control on the MT front position, it would be helpful to clarify why a similar effect is not observed for the LT glacier. Consider being more precise in the language, for example, stating that the effect is due to “runoff-induced buoyant plumes.”

### Author Response:

In the revised manuscript we changed our tone from "runoff-controlled" to explaining that runoff likely has an influence on the seasonality of front positions that we observe (see Section 5.4). Furthermore, in Section 5.5 we explain in more detail that runoff does not lead to the formation of plumes in the lake and therefore does not enhance frontal ablation. Please also see our response to referee 2, who had a similar comment.

### Reviewer Comment:

L117–121: If 0.001 m is the median and 0.51 m is the deviation, it is unclear how changes below 0.1 m/yr are detectable, as they appear to be within the uncertainty range. Please clarify this point.

### Author Response:

We agree that the old description was confusing. We tried to express that we are confident in detecting changes for the 11 year period (2012–2023) larger than 0.51 m. In the old version of the manuscript, we simply divided the NMAD by the amount of years, meaning that if we have a total change of  $11 \pm 0.51$  m, expressed as yearly change would be  $1 \pm 0.046$  m. We notice that this approach is misleading. Therefore, we now only refer to the total NMAD.

### Manuscript Changes:

... With the co-registration, we were able to reduce the median elevation change above stable terrain from -3.12 to 0.001 m for the ArcticDEM and from -3.17 to 0.002 m for the historical DEM. The normalised median absolute deviation (NMAD), which gives an indication of dispersion, was reduced from 0.92 to 0.51 m and from 3.89 to 3.55 m for the ArcticDEM and historical DEM, respectively. Thus, for the 2012–2023 period we can reliably detect changes greater than 0.51 m, and for the 1987–2012 period we can reliably detect changes greater than 3.55 m. To avoid point sampling of local features such as crevasses, we resampled the co-registered ArcticDEMs to 25 m resolution using bilinear interpolation. Furthermore, we extracted width-averaged values of a 400 m wide band following the glacier centre lines (Fig. 1).

### Reviewer Comment:

L262: The assertion that calving has no effect on flow velocity may be too strong. Figure 5 shows instances (e.g., 2016, 2019, 2021, 2022, 2024) where velocity increases coincide with calving events. It may be useful to more carefully analyze or contextualize these velocity changes, particularly with respect to spatial gradients.

**Author Response:**

Indeed, in some years velocity increases coincide with calving events. However, these increases are tiny ( $<25$  m/yr) and their origin is difficult to entangle, as many of them also coincide with increased runoff input. Nonetheless, we now phrase it more carefully:

**Manuscript Changes:**

In some cases, calving events coincide with small flow velocity increases (Fig. 5).

**Reviewer Comment:**

Section 5.4: If basal hydrology drives short-term velocity changes in MT, it is unclear why this effect is absent in LT. The difference in terminus configuration, particularly the presence of an ice tongue in LT, may be a key factor. The MT glacier appears to be more front-controlled, whereas the LT glacier's seasonal velocity pattern suggests less frontal influence. A brief discussion of this from a glacier dynamics perspective could strengthen the manuscript. Moreover, the second conclusion regarding differing calving parameterizations may actually reflect a fundamental contrast between grounded and floating calving styles.

**Author Response:**

Please see our response to referee one about the coupling of front positions and flow velocities.

**Reviewer Comment:**

Sect. 4.1: Consider adding a panel to Figure 3 showing thinning rates or elevation differences to better convey spatial changes in thickness.

**Author Response:**

Below a figure version including thinning rates. We personally prefer the figure without the thinning rates due to simplicity. However, we happily change it if required.

**Reviewer Comment:**

Figures 4b and 4c: Please confirm whether the color scales are the same. Including the color bars would improve clarity.

**Author Response:**

The color scales are the same. We have added the numerical values of the colorbars.

**Reviewer Comment:**

Figures 5 and 7: Since these are directly comparable, using consistent axes and color scales for ice velocity and runoff would aid interpretation

**Author Response:**

We believe that aligning the scales would make it unreadable, since the velocity changes at LT are very

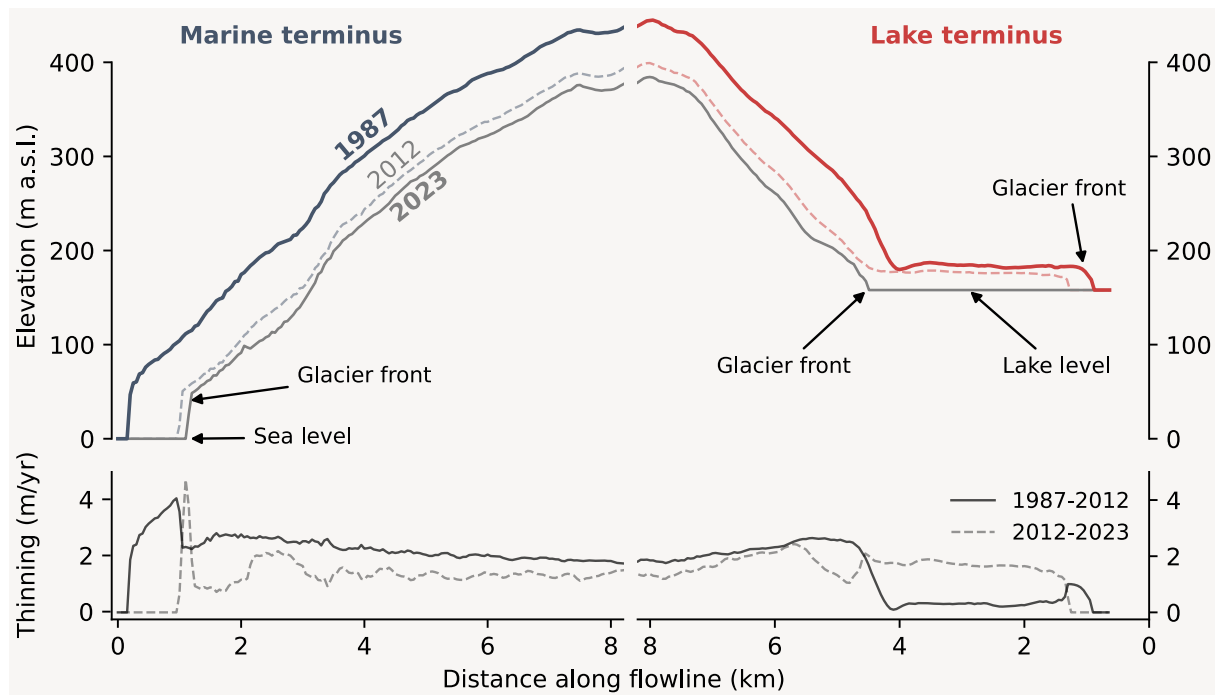


Figure 4: Revised Fig. 3 with thinning rates

small compared to those of MT, while front changes are much larger at LT than MT. We now note the different scales in the figure caption to make the reader more aware of this.

**Reviewer Comment:**

l213, remove 'to'

**Author Response:**

Removed.

**Reviewer Comment:**

l229, 'of 80 m'

**Author Response:**

Changed.

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