Helheim Glacier's terminus position controls its seasonal and inter-annual ice flow variability

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Abstract

At least half of today's mass loss of the Greenland ice sheet is due to the retreat of tidewater glaciers. For example, over the past decade Helheim Glacier in southeast Greenland has been one of the largest contributors to total ice discharge across the Greenland ice sheet. There is broad agreement that the acceleration and retreat of these marine terminating glaciers has been triggered by the intrusion of warmer currents in the fjords, however, other processes such as changes in basal conditions, ice rheology, surface mass balance or calving dynamics may have also played important roles in controlling the retreat of these glaciers. Without quantifying the individual contributions of these processes, it is difficult to determine which of these processes should be included in ice sheet models to correctly capture the present and future retreat and associated mass loss of the ice sheet. In this study, we simulate the dynamics of Helheim Glacier, from 2007 to 2020, using the Ice-sheet and Sea-level System Model (ISSM) to investigate the model response to changes in external forcing and boundary conditions. By switching off each of these external forcing components and comparing the numerical solution with observations, we identify that the seasonal to inter-annual variability of Helheim Glacier is relatively insensitive to the choice of friction law or the ice rheology, but that the position of the calving front has a direct and large impact on ice velocity.We then apply automatic differentiation to quantify the transient sensitivity of the ice flux near the terminus to changes in ocean-induced melting rates, basal frictions, ice rheology, calving dynamics and surface mass balance. These sensitivities highlight the regions where each parameter may contribute the most to changes in ice flux and which process should be properly captured by numerical models in order to accurately project the future response of Helheim Glacier. This study, as a result, can be used as a guide for model development of similar glaciers.

C35A-0866 Helheim Glacier's terminus position controls its seasonal and inter-annual ice flow variability

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Method and Data

Which processes are responsible for the seasonal and inter-annual variability of Helheim Glacier's surface velocity?

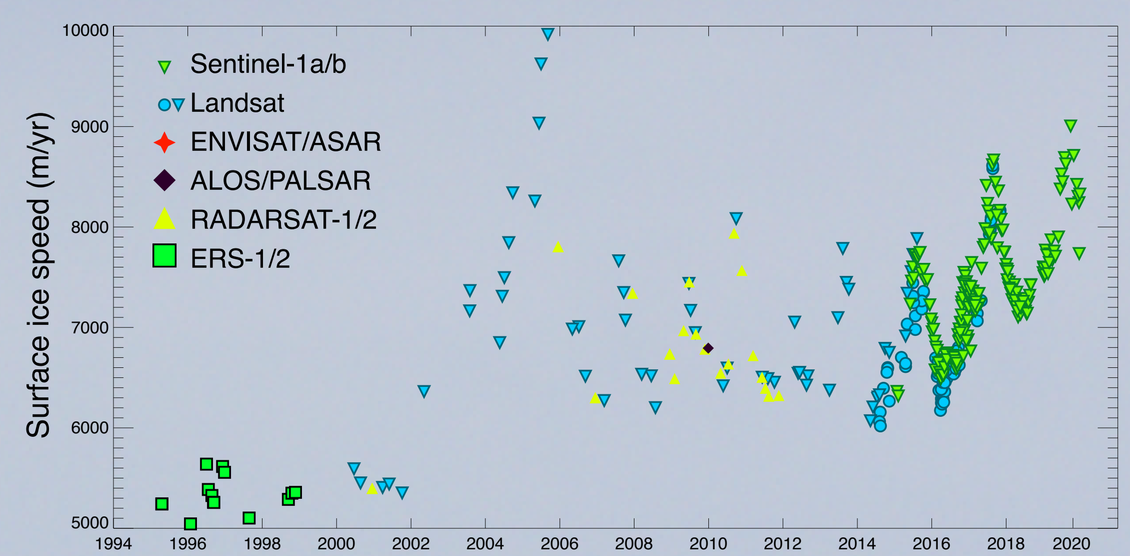

Figure 1: Mean surface velocity of the Helheim Glacier (Mouginot et al., 2017, 2019).

Numerical Model

- Shelfy-Stream Approximation (SSA, MacAyeal, 1989)
- Mesh resolution: between 100 m and 1.5 km (∼28,000 elements)
- Bed from BedMachine v4 (Morlighem et al., 2017)
- Ice-sheet and Sea-level System Model (ISSM, Larour et al., 2012)
- Transient simulation from 2007 to 2020 (time step: 1.8 days)

Observations (2007-2020)

- A time series of surface velocities at 150 m resolution, derived from the data acquired by Landsat-8 or Sentinel-1 (Mouginot et al., 2017, 2019)
- A time series of calving front positions, extracted from satellite images by the Calving Front Machine (CALFIN, Cheng et al., 2021)

Experiments

1. Constrain the calving front position using observations, and run the model with different friction laws and ice temperatures. For comparison, we also show the observed surface velocity and a control run whose ice front is kept fixed during the whole simulation
2. Remove the constraints on the terminus positions and apply smoothed ablation rates using moving average filters with different time span

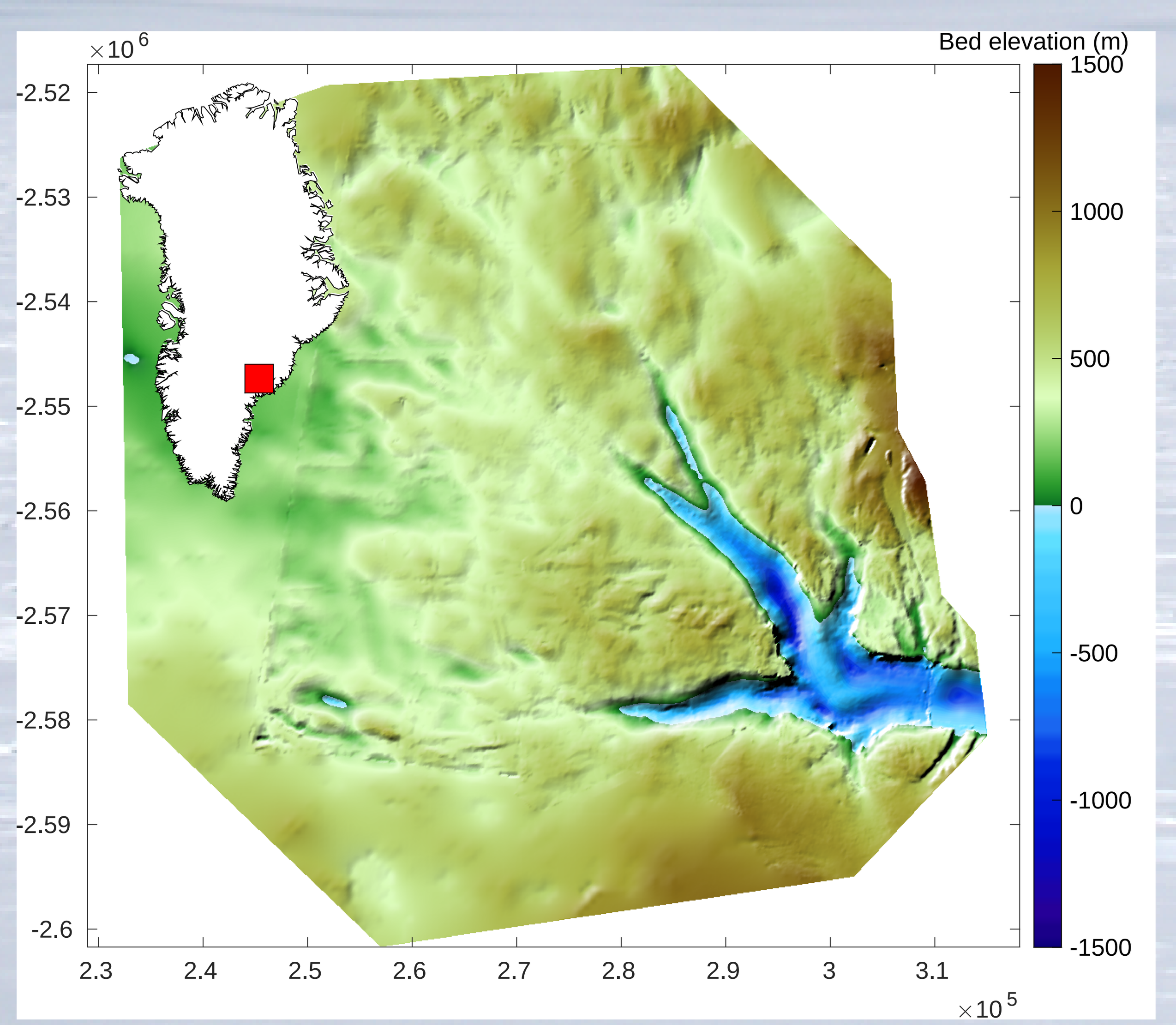

Figure 2: Bed topography (Morlighem et al., 2017) of the model domain.

Drivers of Helheim's Variability

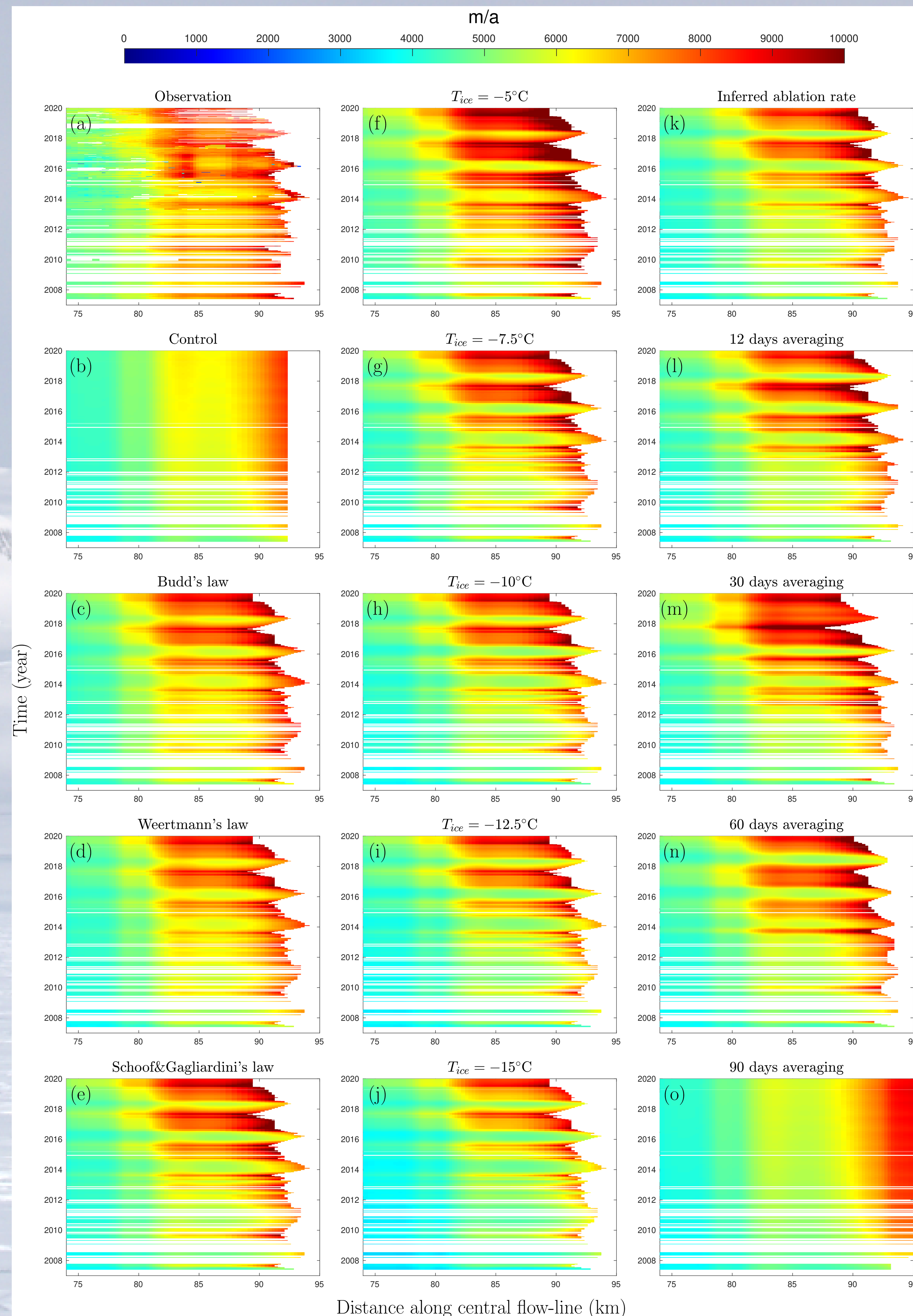

Figure 3: Hovmöller diagram of ice velocity along the central flowline of the (a) observation, (b) control run with fixed calving front position, (c)-(e) different friction laws, (f)-(j) different ice temperatures, (k)-(o) use inferred ablation rate. The x-axis indicates the distance along the flowline and the y-axis is time.

Results

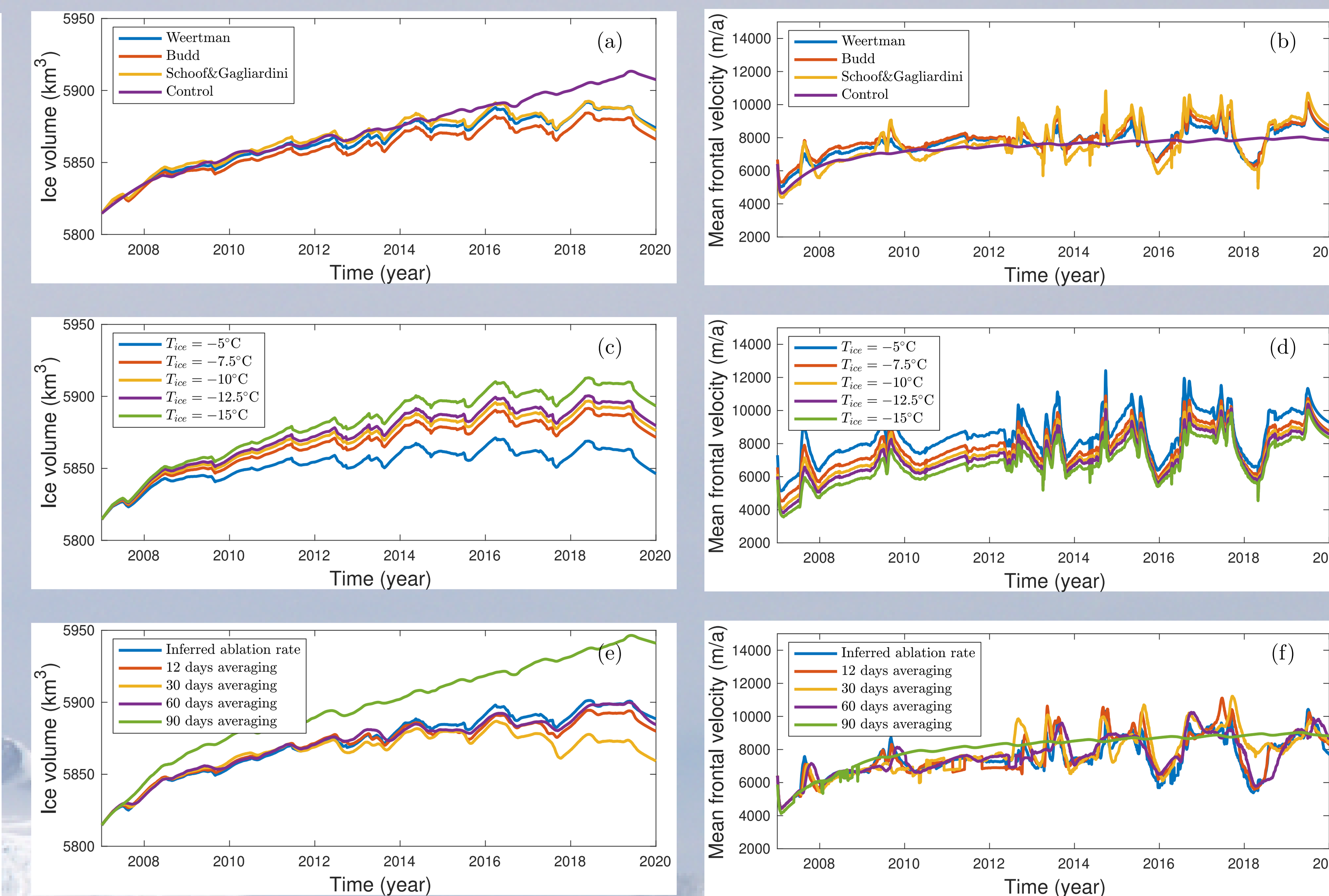

Figure 4: Total ice volume and mean frontal velocity at the calving front. (a)-(b) Friction law experiments. (c)-(d) Ice rheology experiments. (e)-(f) Inferred ablation rate experiments.

Discussion

- Weertman, Budd, and Schoof&Gagliardini's laws work equally well
- Higher ice temperature makes the ice softer and flows faster, but has no influence on the variability
- We are able to reproduce the ice speed variability with an ablation rate smoothed over 60 days (i.e., without the need to capture individual calving event)

Conclusion

- Calving dynamics controls Helheim's variability, irrespective of basal friction or ice rigidity
- Averaging the ablation rate over 60 days does not change the glacier behavior significantly
- Constraining a more realistic calving law is critical to model the future of Helheim Glacier

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References

Cheng, D., Hayes, W., Larour, E., Mohajerani, Y., Wood, M., Velicogna, I., and Rignot, E. (2021). Calving Front Machine (CALFIN): glacial termini dataset and automated deep learning extraction method for Greenland, 1972-2019. *The Cryosphere*, 15(3):1663–1675.

Larour, E., Seroussi, H., Morlighem, M., and Rignot, E. (2012). Continental scale, high order, high spatial resolution, ice sheet modeling using the Ice Sheet System Model (ISSM). *Journal of Geophysical Research: Earth Surface*, 117(F1):n/a–n/a.

MacAyeal, D. R. (1989). Large-scale ice flow over a viscous basal sediment: Theory and application to ice stream B, Antarctica. *Journal of Geophysical Research: Solid Earth*, 94(B4):4071–4087.

Morlighem, M., Williams, C. N., Rignot, E., An, L., Arndt, J. E., Bamber, J. L., Catania, G., ChauchÃ©, N., Dowdeswell, J. A., Dorschel, B., Fenty, I., Hogan, K., Howat, I., Hubbard, A., Jakobsson, M., Jordan, T. M., Kjeldsen, K. K., Millan, R., Mayer, L., Mouginot, J., Noel, B. P. Y., O'Cofaigh, C., Palmer, S., Rysgaard, S., Seroussi, H., Siegert, M. J., Slabon, P., Straneo, F., Broeke, M. R. v. d., Weinrebe, W., Wood, M., and Zinglersen, K. B. (2017). BedMachine v3: Complete Bed Topography and Ocean Bathymetry Mapping of Greenland From Multibeam Echo Sounding Combined With Mass Conservation. *Geophysical research letters*, 44(21):11051–11061.

Mouginot, J., Rignot, E., BjÃ¸rk, A. A., Broeke, M. v. d., Millan, R., Morlighem, M., Noël, B., Scheuchl, B., and Wood, M. (2019). Forty-six years of Greenland Ice Sheet mass balance from 1972 to 2018. *Proceedings of the National Academy of Sciences*, 116(19):201904242.

Mouginot, J., Rignot, E., Scheuchl, B., and Millan, R. (2017). Comprehensive annual ice sheet velocity mapping using landsat-8, sentinel-1, and radarsat-2 data. *Remote Sensing*, 9(4):364.

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