Modeling ice flow variability of the Kangerlussuaq Glacier, southeast Greenland, during 1900-2021

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Observations show significant ice loss associated with the speed-up of the Kangerlussuaq Glacier (KG) in Greenland since the 2000s. Short-term perturbations significantly impact its mass balance on decadal scales. Utilising a long-term data record going back to 1900 together with the Ice-sheet and Sea-level System Model (ISSM) we reconstruct KG since 1900. The final model state is in excellent agreement with today's observed velocity and ice thickness. We estimate at least 250 Gt ice mass loss over the past century. Experiments with various external forcings reveal that the retreat of the ice front alone explains most of the glacier's dynamic variability and mass change.

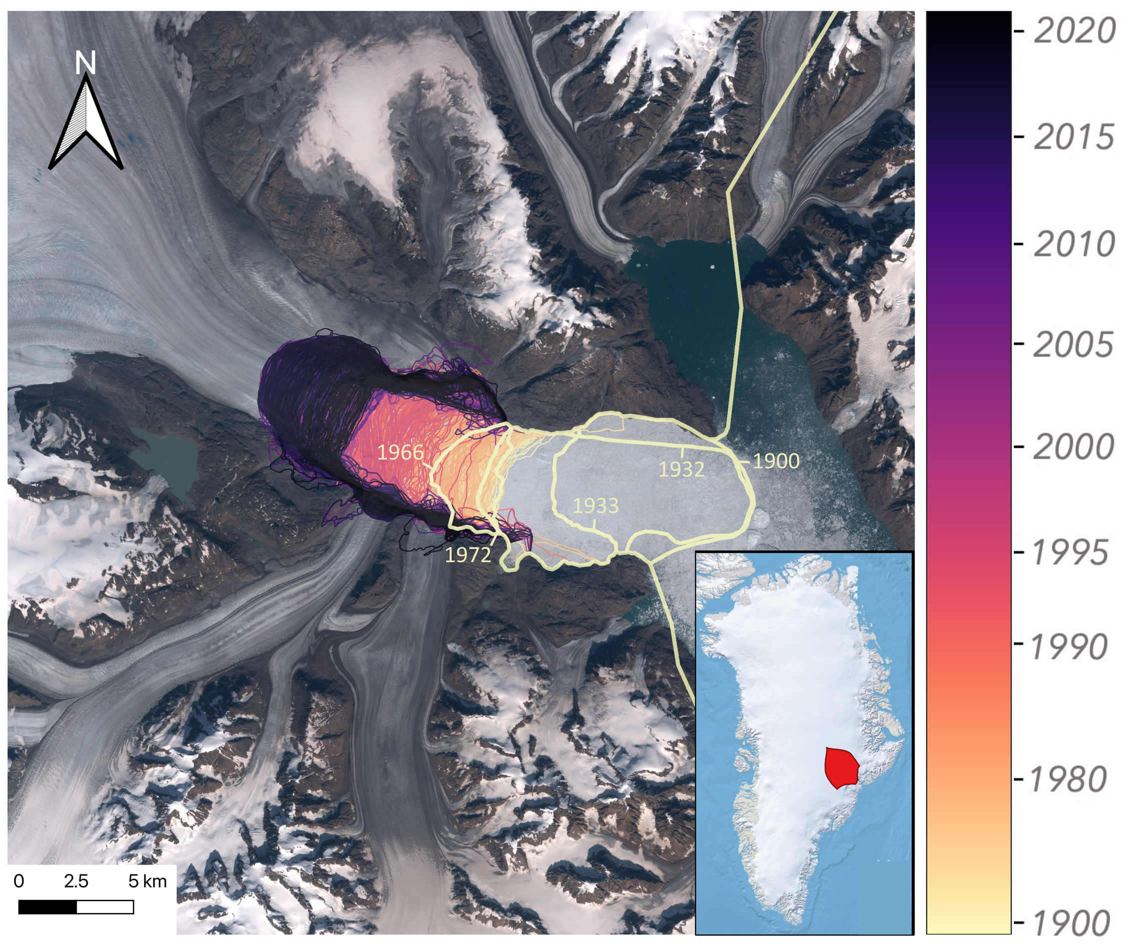

Figure 1: Front observations. Consists of historical data (Khan et al., 2014, Kjeldsen et al., 2015,

Method:
To investigate the behavior of KG over the past century, we employ the Shelfy Stream Approximation (SSA) on a non-uniform mesh, adapted to present-day observed surface velocities, comprising 26,428 elements. We parameterize the basal stress, τ_b, by solving an inverse problem for the friction coefficient C_x based on present-day velocity observations. We find that the models are sensitive to the formulation of τ_b, and method of extrapolating C_x into the fjord. Below are the Budd (1) and Schoof (2) friction laws.

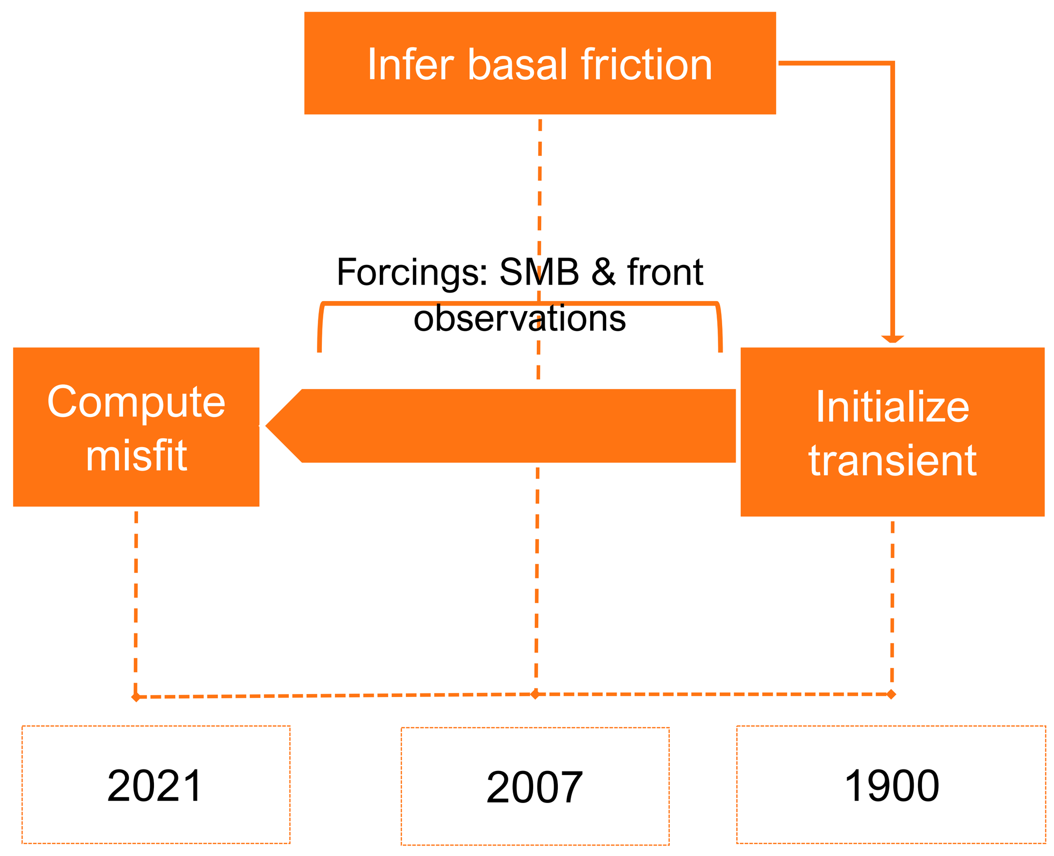

Figure 2: Flowchart outlining method for modeling KG since the maximum extend of the little ice age (1900)

$$\boldsymbol{\tau}_b = -C_B N^q |\mathbf{v}_b|^{m-1} \mathbf{v}_b, \quad (1)$$

$$\boldsymbol{\tau}_b = -\frac{C_S |\mathbf{v}_b|^{m-1} \mathbf{v}_b}{\left[1 + \left(\frac{C_S}{C_{max} N}\right)^{1/m}\right]^m}, \quad (2)$$

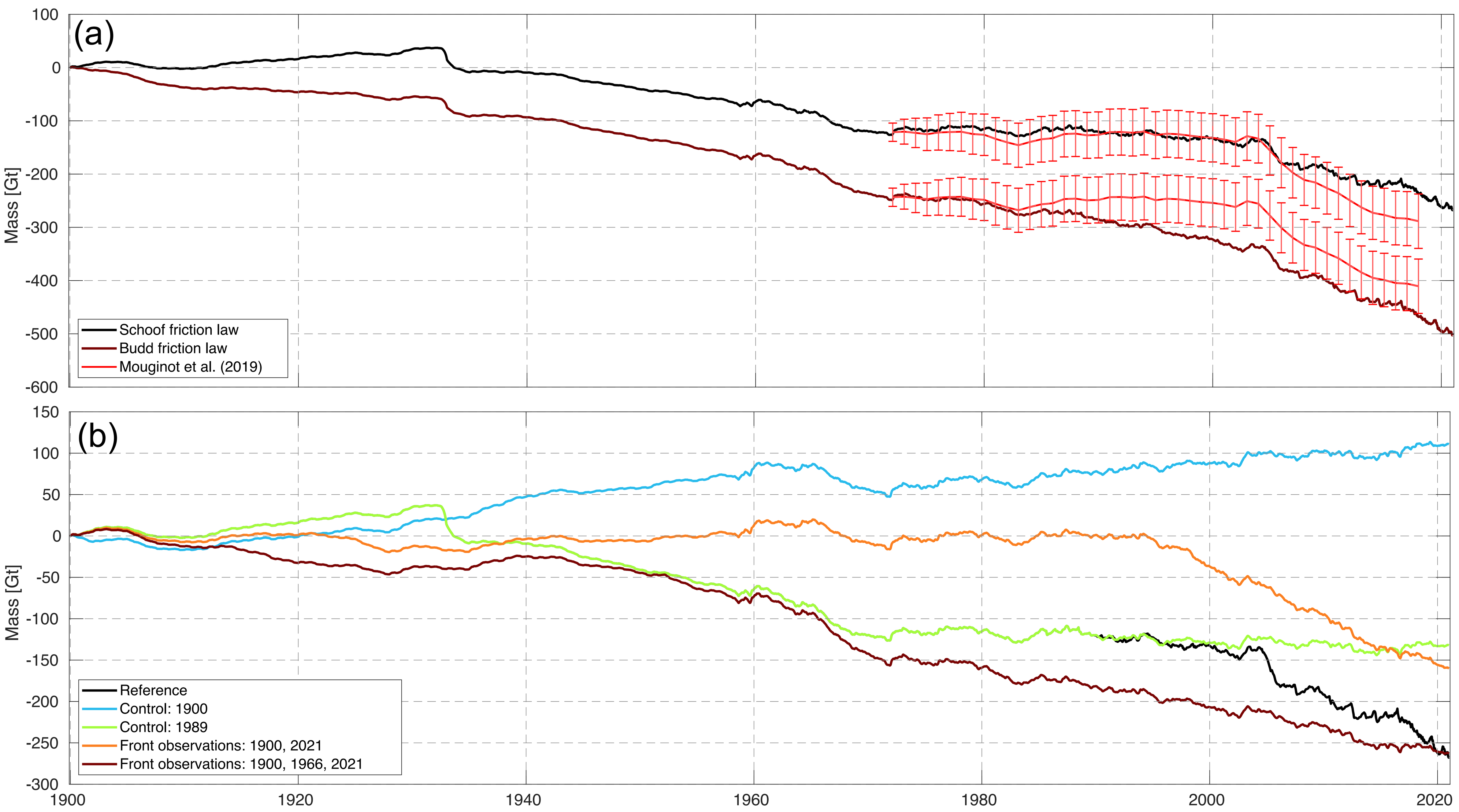

Figure 3. Mass balance curves. Top: shows the centennial mass loss based on two different friction laws. Bottom: shows mass balance curves resulting from various experiments with applying different front forcings

Results:
We show that KG has lost between 250-500 Gt of mass since 1900, depending on the friction law (Fig. 3a). We selected the Shoof-based model as a reference model for the study as the Schoof friction law is more realistic and as the model had a lower misfit. The extrapolation of the inverted friction coefficient into the fjord was revealed to have a great impact on the overall model performance, we found that correlating friction to bed topography provided the best trade-off. We find that the ice front retreat explains 50% of the mass loss since 1989. Decadal front variability is not necessary for reproducing the modeled centennial mass loss, while semi-centennial variability is.

Conclusion:
We were able to reconstruct KG over the past century and show that while basal stress plays a great role on centennial mass loss, short-term variability of the front is less important. Finding a way to make τ_b time-dependent and lowering uncertainty in initial ice thickness are some areas to explore in future work.