Potsdam Institute for Climate Impact Research

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FROM HEINRICH EVENTS TO CYCLIC ICE STREAMING: THE GROW-AND-SURGE INSTABILITY IN PISM

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INTRODUCTION

- Glacial surging is characterized by rapid speed-up of ice flow and abrupt increase in ice discharge
- Examples are the repeated activation and stagnation of ice streams which drain the Siple Coast region West Antarctica and the quasi-periodic, large-scale surging of the Laurentide Ice Sheet (Heinrich Events, being connected to abrupt climate changes on a global scale)
- **Here we report on a cyclic, physical ice-discharge instability in the Parallel Ice Sheet Model (PISM), simulating the flow of a three-dimensional, inherently buttressed ice-sheet-shelf system which periodically surges on a millennial timescale**

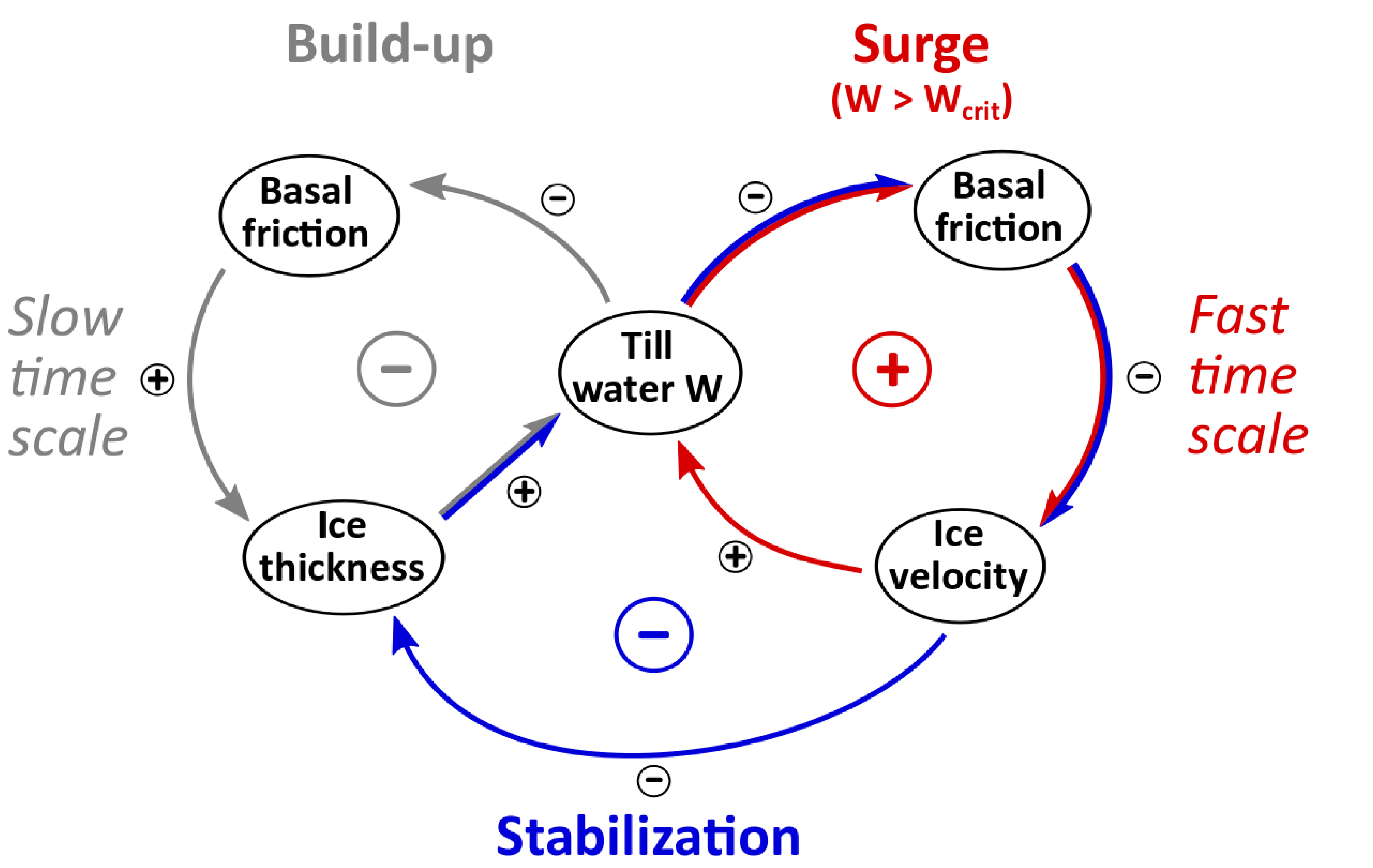

Fig. 1: Schematic visualizing the three main feedback mechanisms, each of them dominating one of the three sub-sequent phases of slow ice build up (gray), abrupt surging (red) and stabilization (blue), forming a full surge cycle. The sign next to an arrow pointing from variable A to B indicates whether a small increase in variable A leads to an increase (+) or decrease (-) in variable B. According to this convention one can deduce from counting the negative links of a full loop whether this loop describes an amplifying (positive) or stabilizing (negative) feedback. An even number of negative links indicates a positive feedback loop (large +) whereas an odd number of negative links indicates a negative feedback loop (large -).

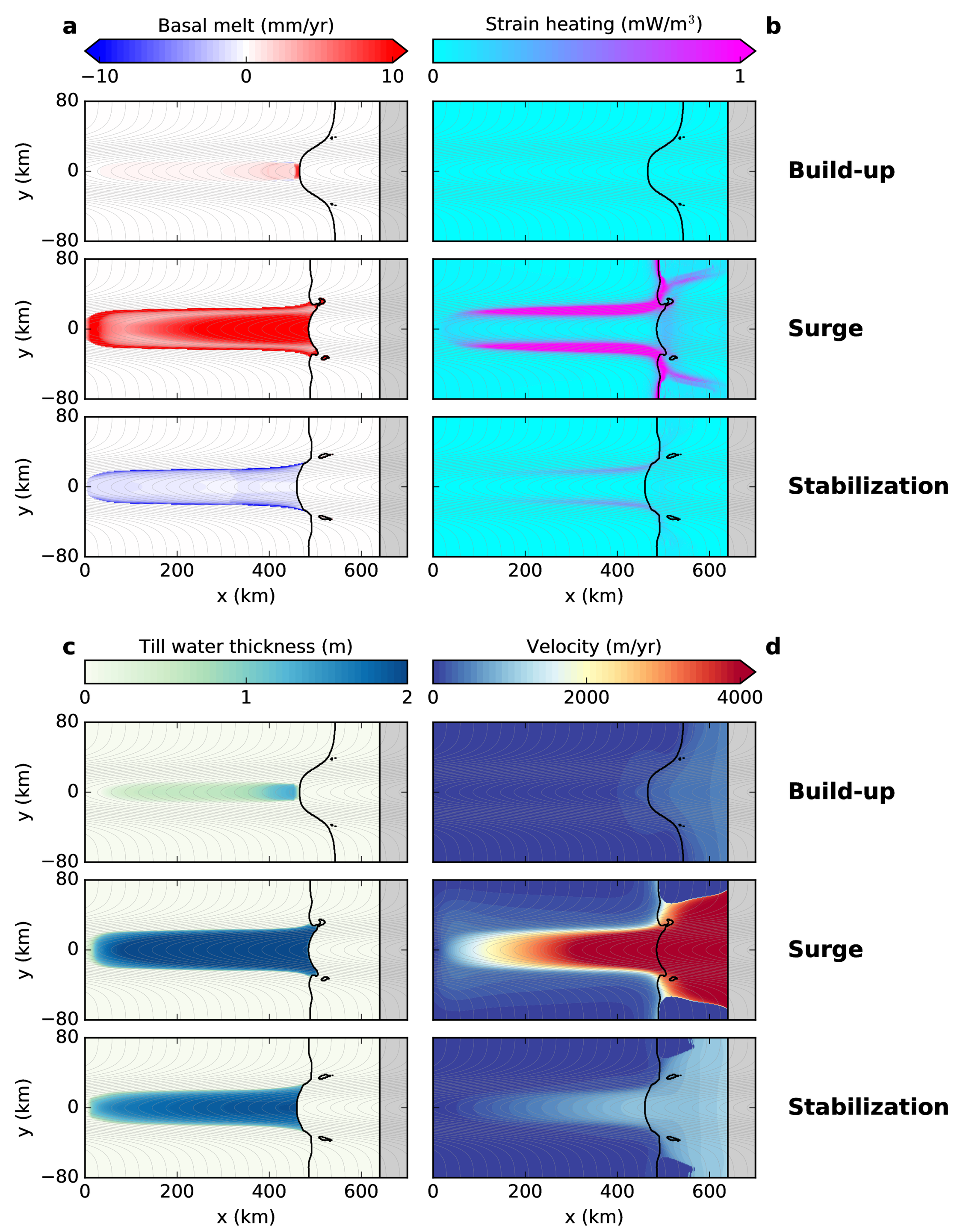

Fig. 2:. Fields of **(a)** basal melt rate m, **(b)** strain heating, **(c)** till water thickness and **(d)** velocity for a representative snapshot for each of the three phases of build-up, surge and stabilization (as denoted by the colored circles in Fig. 1). Thick black contours mark the grounding line and calving front. Bed topography shown by thin gray contours.

MODEL & EXPERIMENTAL SETUP

- Thermo-mechanically coupled simulations on 1 km resolution in hybrid SIA-SSA mode using a simple sub-glacial hydrology
- Idealized geometric setup designed to model a marine ice sheet, which drains through a bed trough, feeding a bay-shaped ice shelf which calves into the ocean
- Non-linear Weertman-type sliding law (basal shear stress τ_b entering the SSA is proportional to basal velocity u_b to the power of $m\in[0,1]$):

$$\tau_b = -\tau_c \frac{u_b}{u_0^m \, |u_b|^{1-m}}.$$

- Simulations: variation of basal friction exponent (ranging from purely plastic to linear sliding), bed roughness and surface accumulation

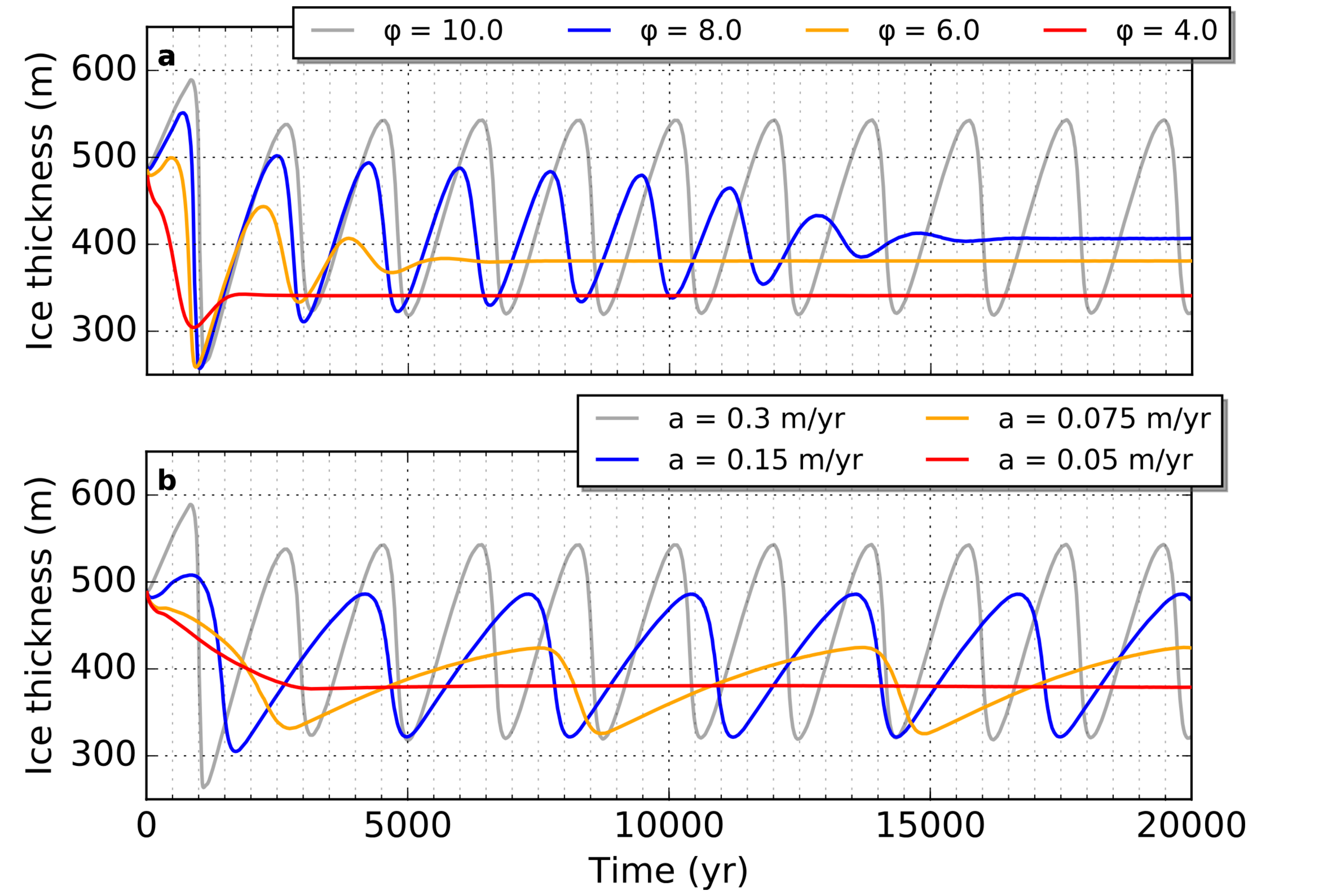

Fig. 3: Ice thickness evolution for a decrease of **(a)** the till friction angle (decrease in basal roughness) and **(b)** the surface accumulation rate. For both parameters surging ceases if a critical threshold is crossed.

RESULTS

- Simulated cyclic build-up, surge and stabilization (Fig. 1) emerge from interactions between ice-flow dynamics (velocity, stresses, thickness), thermodynamics (heat conduction, frictional heating, melting/refreezing) and the sub-glacial hydrology (melt-water storage + drainage) (Fig. 2)
- Surge-cycle frequency increases with increasing bed roughness, decreasing accumulation and towards a more linear basal sliding law (Figs. 3+4)
- Cyclic surging is damped and ceases when crossing critical parameter thresholds (Figs. 3+4)
- Ice sheets of medium thickness are most susceptible to surging (Fig. 4)

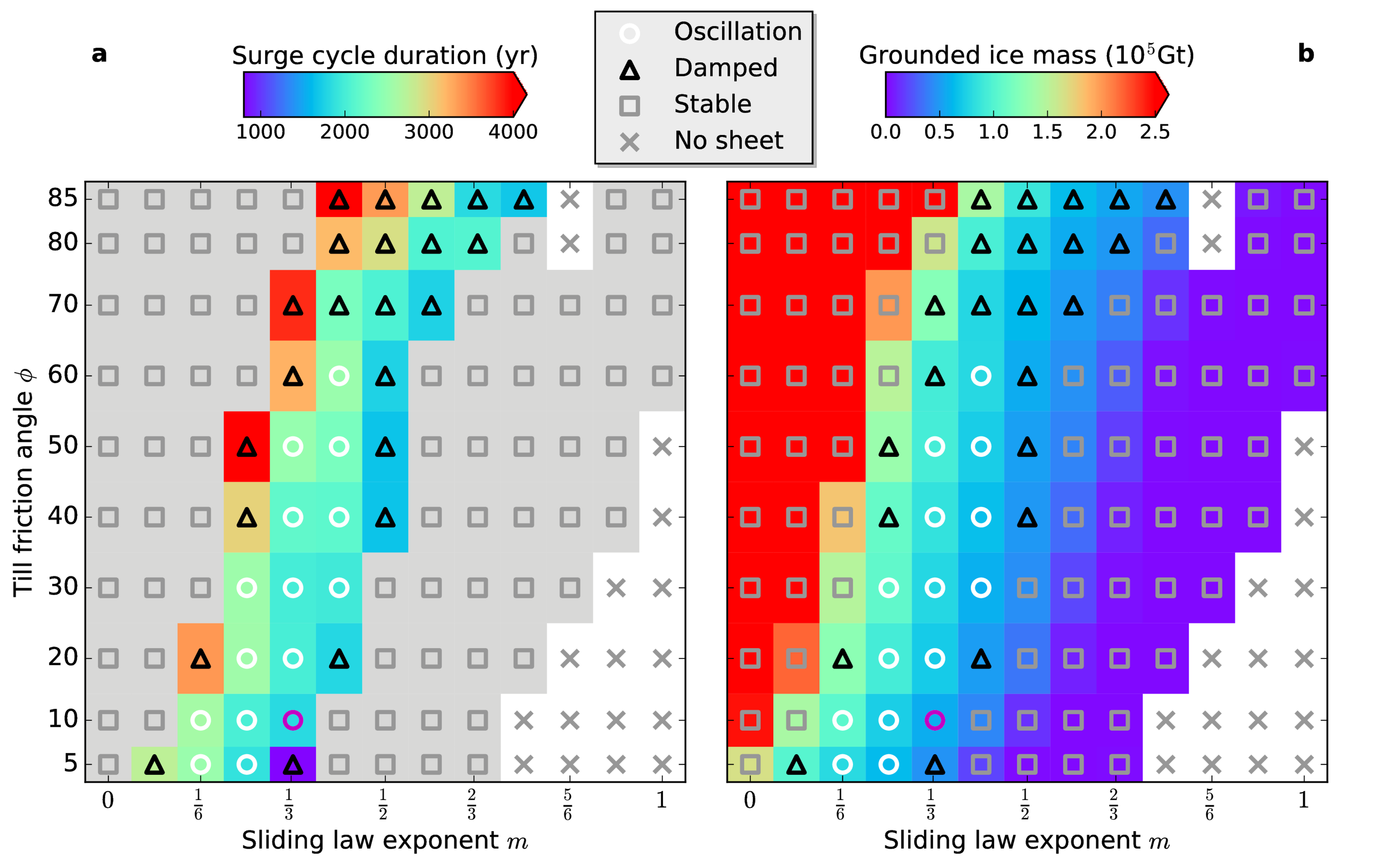

Fig. 4: **(a)** Surge-cycle duration and **(b)** mean grounded ice mass for the m – ϕ parameter space. Each colored rectangle represents a simulation characterized by either oscillatory surging (white circles), damped surging (triangles) or stable equilibrium (squares). White rectangles with an "x" denote parameter combinations for which no grounded ice forms inside the bed trough. The default simulation with parameters of m = 1/3 and ϕ = 10 (see Figs. 2 and 3) is highlighted by a purple circle.