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Glacier as a dynamical system

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The macroscopic behavior of a glacier can be described with the two quantities length and volume (e.g. the LV-model of Harrison et al., 2003). Here I derive a dynamical system in the variables length L, typical ice thickness H, and an additional variable G that describes the inflection point of the surface (LGH-model). Mass balance is included in the LGH-model with a constant mass balance gradient. The system is forced by changing the equilibrium line altitude (ELA).

The equilibrium states of the dynamical system closely match the steady states obtained with a full numerical solution (implemented with the Finite Element method). Stability analysis of the equilibrium states gives the reaction time scales. For certain glacier configurations (steepness and balance gradients) the reaction times are complex numbers. Indeed, for these configurations the numerical model also produces oscillatory solutions.

Going from an equilibrium state to a periodically oscillating climate leads to big transients, especially for oscillation periods shorter than 50 years and typical mountain glacier geometries. The trajectories in the L-H phase space spiral wildly until they settle into a limiting cycle after 5 to 10 climate cycles. Similar big transients are observed when going from an oscillating to a steady climate. Such behavior is surprising and leads to serious concerns about the interpretation of glacier length change records in terms of climate.