Understanding retreat rate of glacier using flowline model

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Flowline model

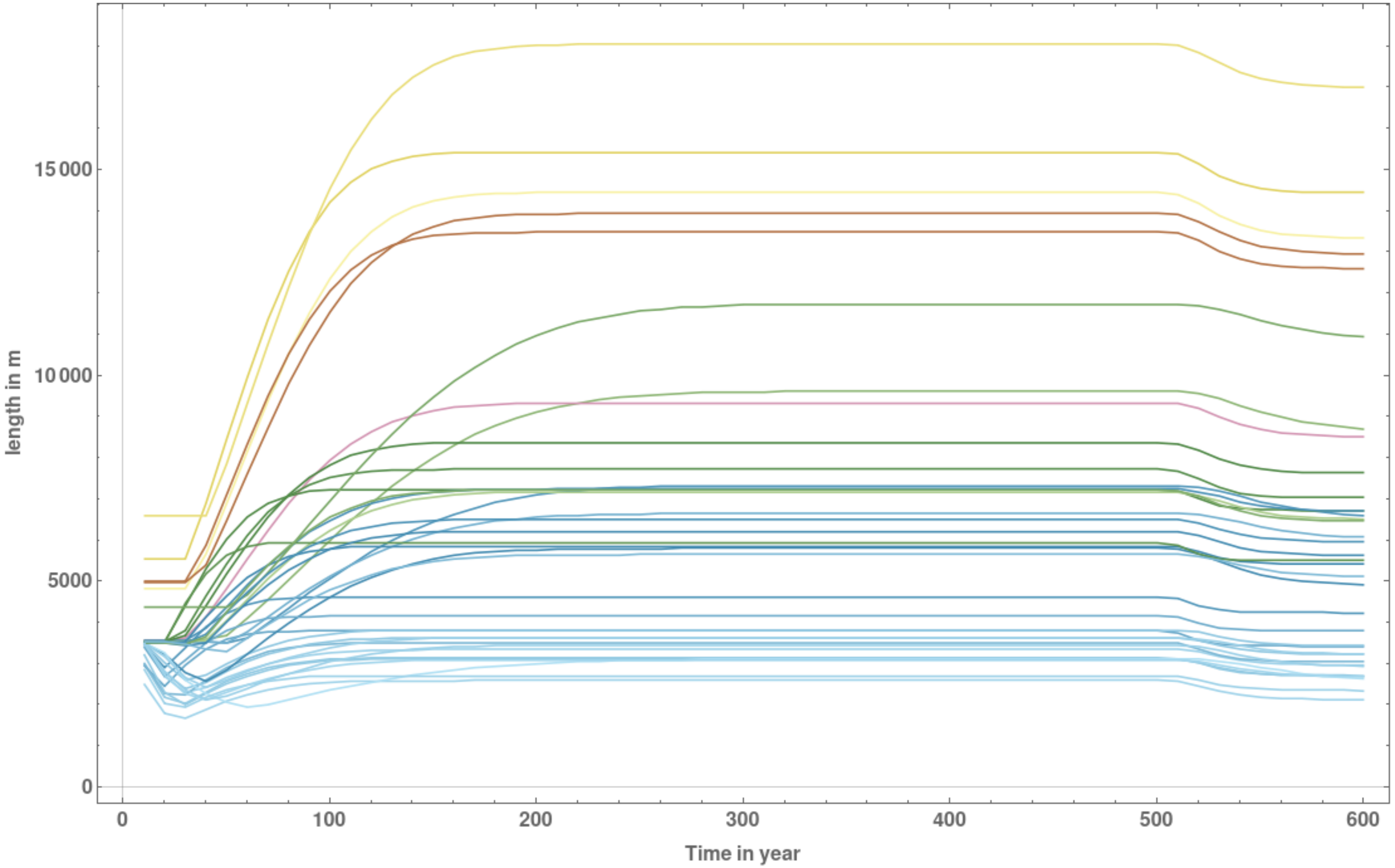
Conservation of Mass

$$\frac{\partial h}{\partial t} = \frac{\partial q}{\partial x} + \beta(z_{ice}\text{-}ela)$$

Glen's Flow Law

Force balance

Length variation with time

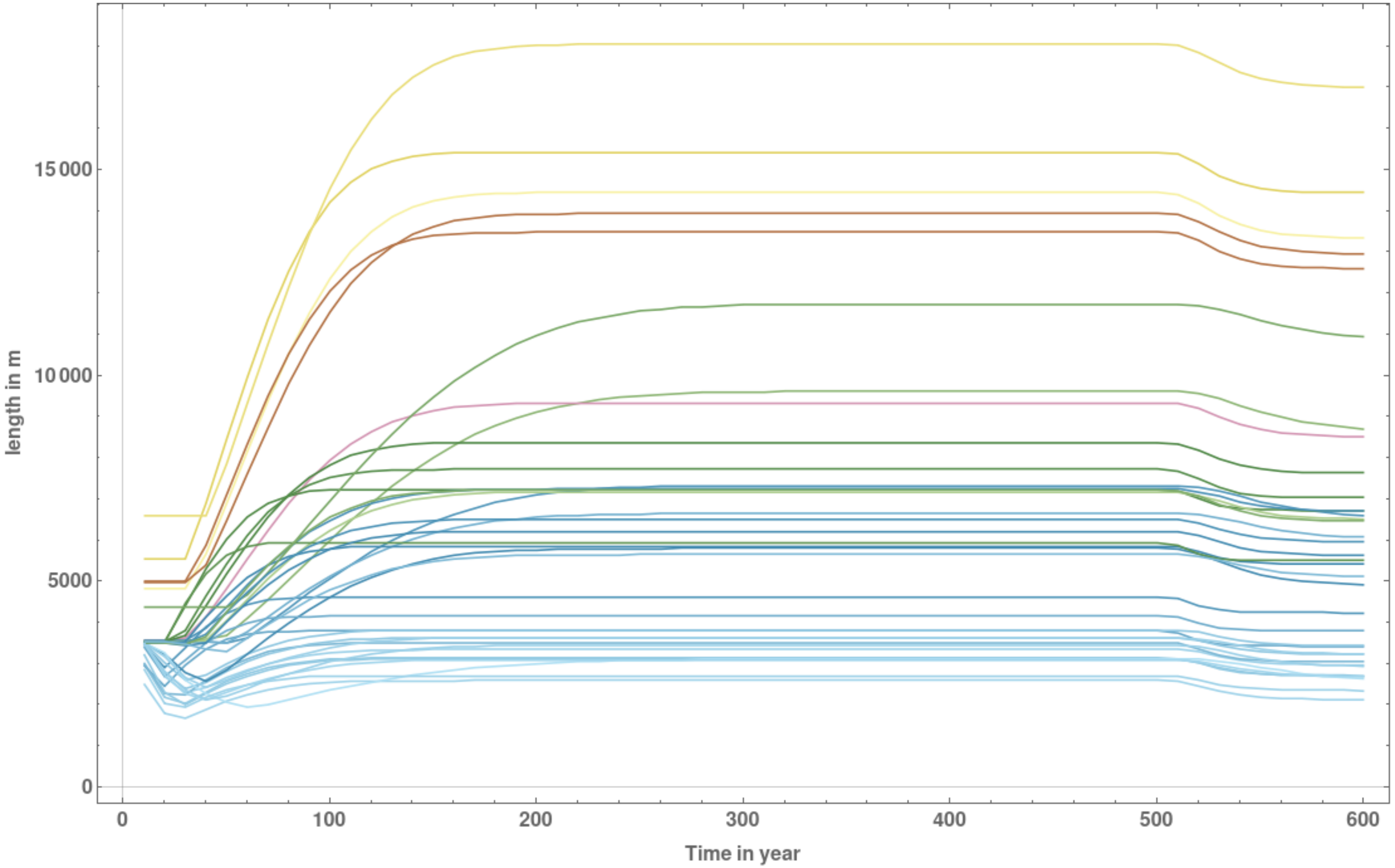


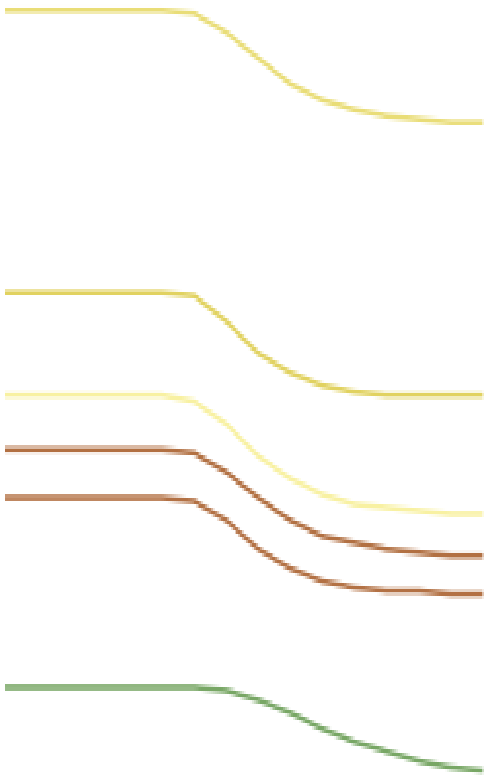
$$\frac{-\partial q}{\partial x} + \beta(z_{ice}\text{-}ela)$$ → Glacier advances

$$\frac{-\partial q}{\partial x} + \beta(z_{ice}\text{-}ela)$$ → Glacier retreats

$$\frac{-\partial q}{\partial x} + \beta(z_{ice}\text{-}ela)$$ → Steady state

Length variation with time



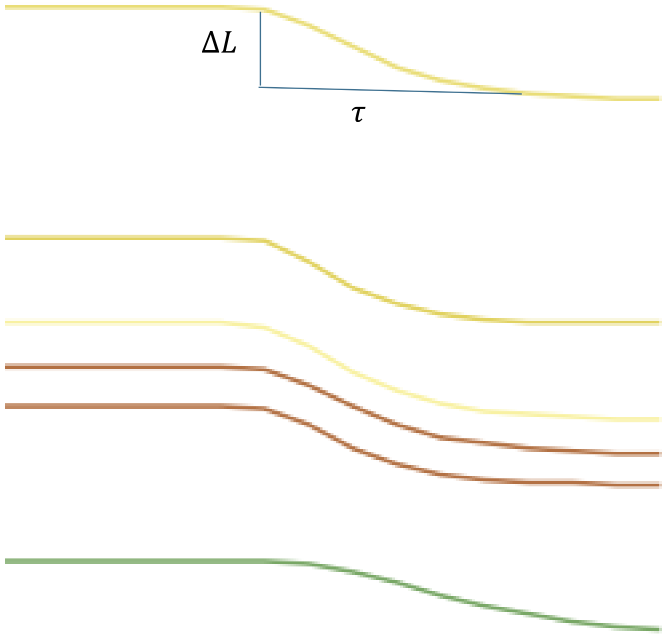


$$\frac{-\partial q}{\partial x} + \beta(z_{ice}\text{-}ela)$$

$$\frac{-\partial q}{\partial x} + \boldsymbol{\beta(z_{ice}\text{-}ela)}$$

$$\frac{-\partial q}{\partial x} + \beta(z_{ice}\text{-}ela)$$

Sensitivity and Response time



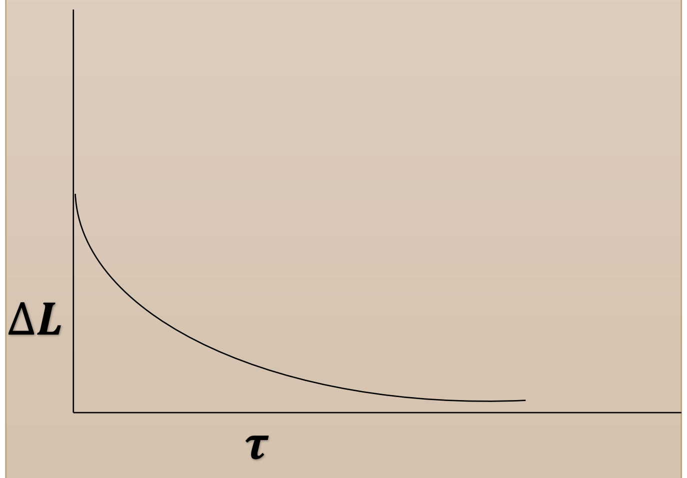
After ela is raised up the length decreases and the glacier again tries to attain the steady state

How much??

$\boldsymbol{\Delta L}$

Till what time??

$\boldsymbol{\tau}$



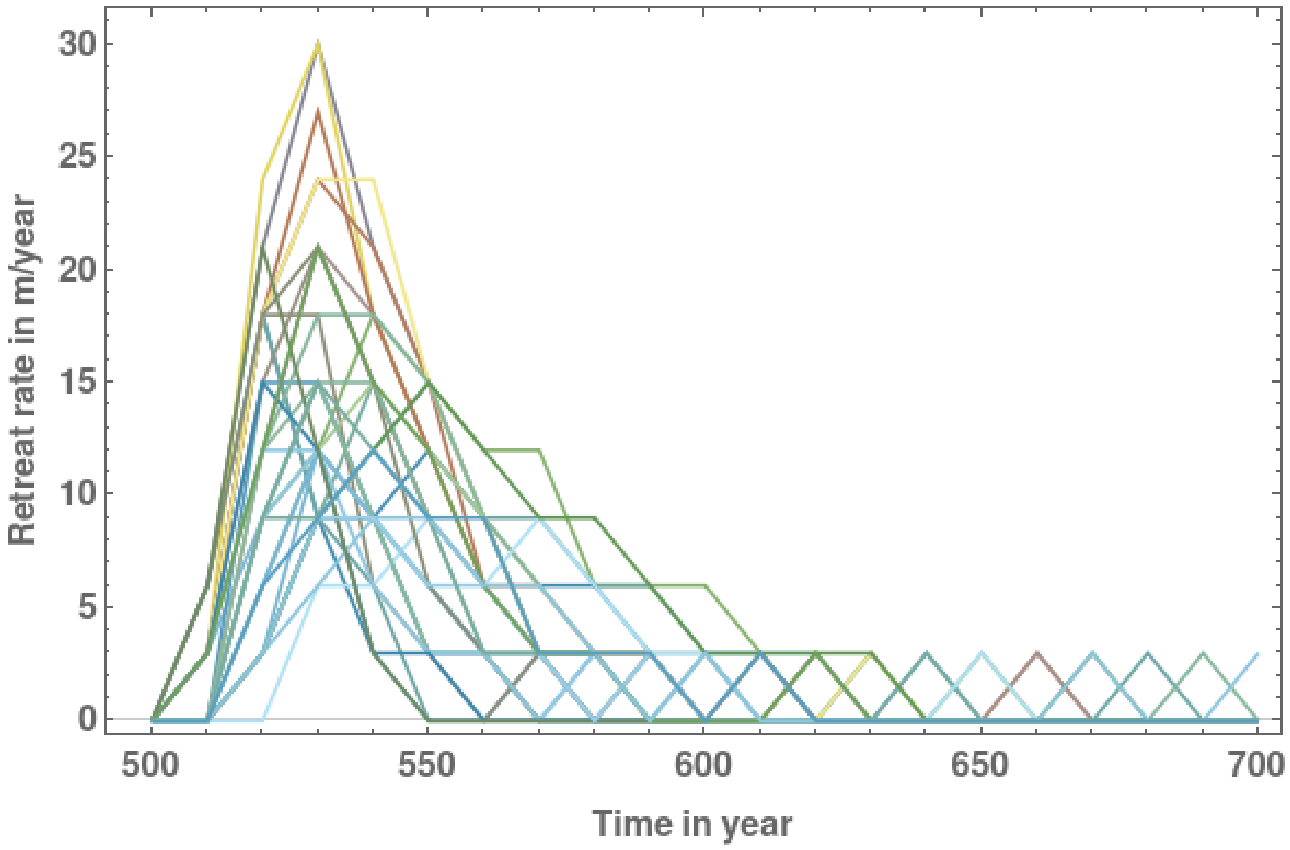
$$L = L_0 - \Delta L(1 - e^{-\frac{t}{\tau}})$$

Sensitivity and Response time

Sensitivity: The rate of change length of the glacier from one steady-state to another, with respect to the ELA is defined as the climate sensitivity, $\frac{dL}{dE}$. For this model we can take it to be $\frac{L_0 - L_f}{50}$.

Response Time: The climatic state is changed stepwise from C1 to C2, here represented as ela change. The corresponding equilibrium lengths are L_0 and L_f. The response time τ, is the time a glacier needs to attain a length $L_0 - \frac{L_0 - L_f}{e}$.

Retreat rate of a glacier

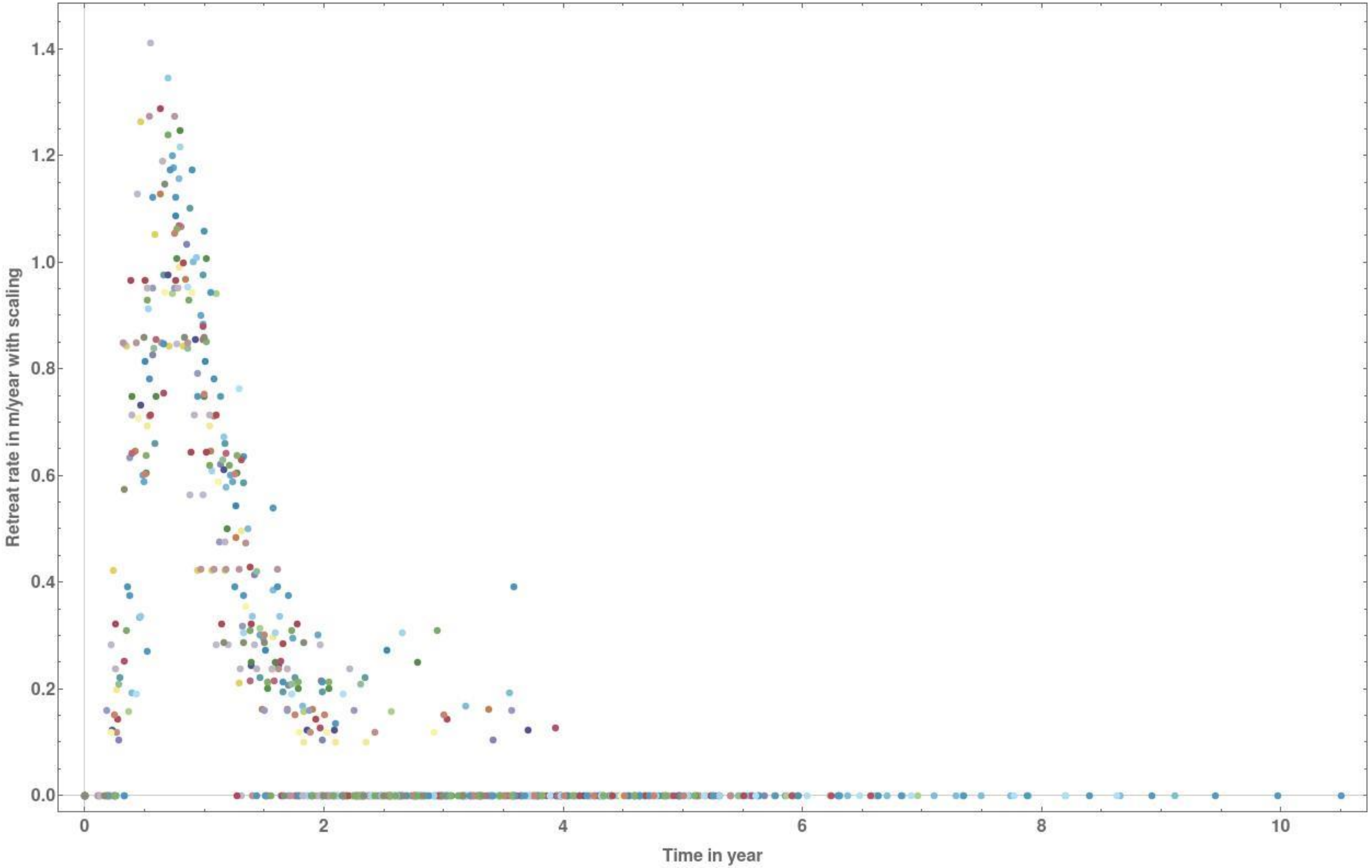


Notice the nature of the retreat rate curves.

Can you find the hidden parameters
$\boldsymbol{\Delta L}$ and $\boldsymbol{\tau}$
in these curves??

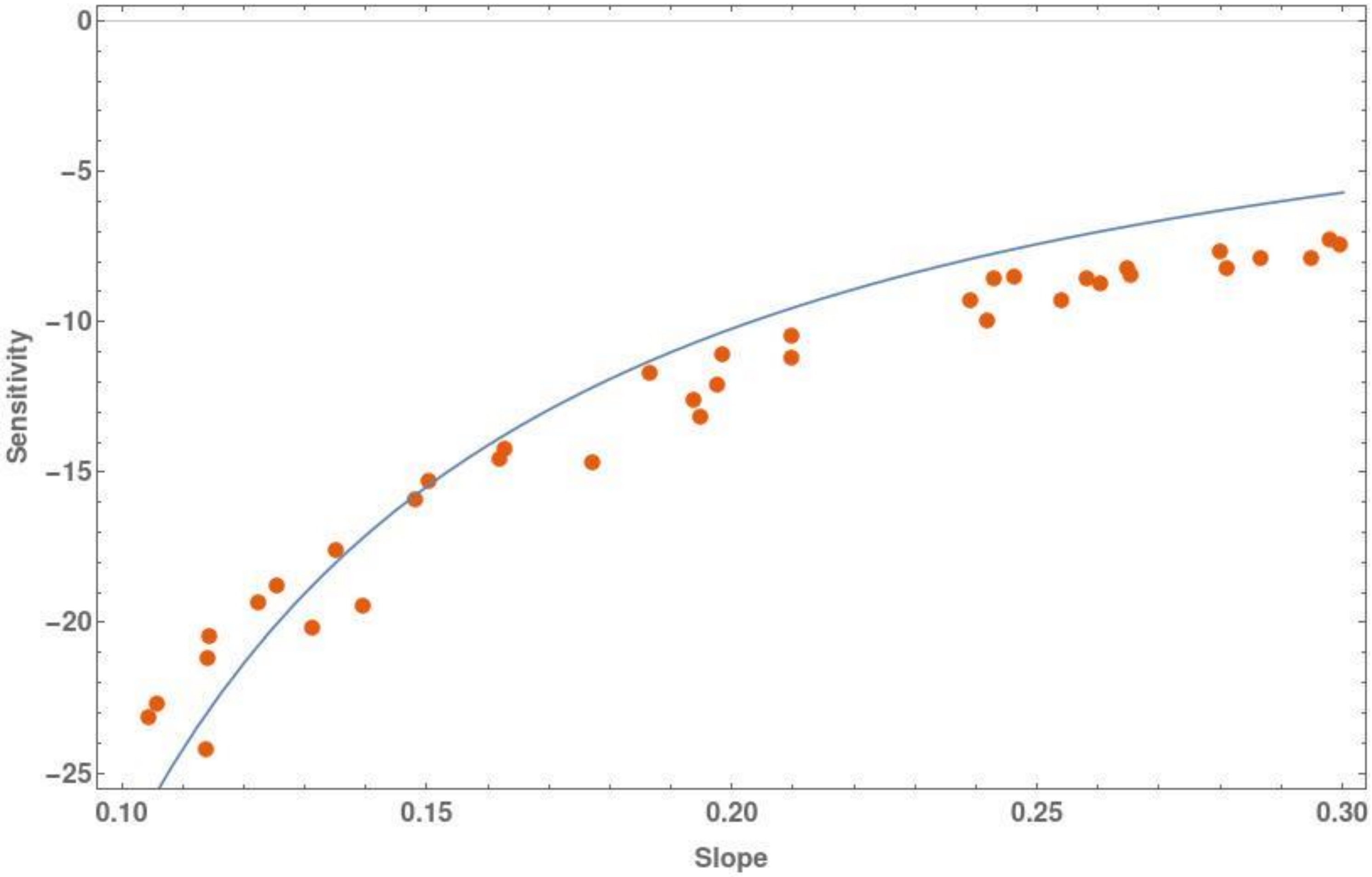
$$\frac{dL}{dt} = \frac{\Delta L}{\tau}\frac{t}{\tau}e^{-\frac{t}{\tau}}$$

Retreat rate of a glacier



Retreat rate depends on sensitivity and response time of the glacier.

Sensitivity-slope dependence

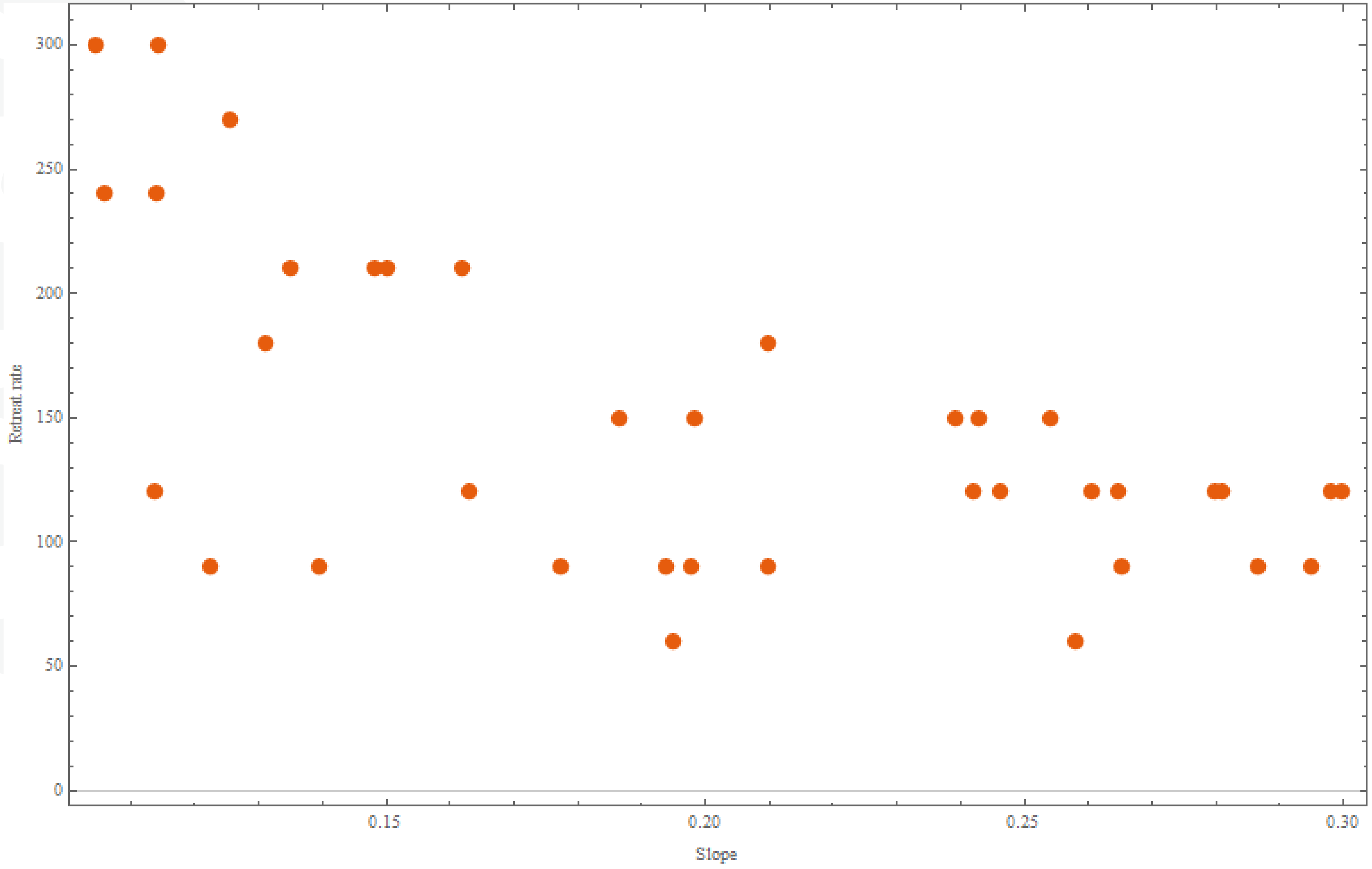


$$\frac{dL}{dE} = \frac{1}{slope^{1.44}}$$

$$\frac{dL}{dE} \approx \frac{1}{slope^{1.5}}$$

(Oerlemans,J., 1950)

Retreat rate slope relation



Retreat rate depends on response time, response time is a strong function of slope but retreat rate and slope are not related! What could be the hidden factor controlling the retreat rate of a glacier