cryospheric tipping point

a tipping point exists if the ice does not recover from loss caused by climatic warming even if the climatic forcing returns to the colder conditions that existed before the loss

the response of a cryospheric element must show significant hysteresis

Dirk Notz, PNAS 2009

ODE model for temperature evolution

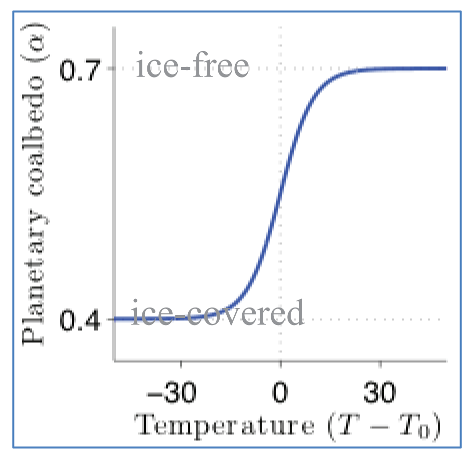
nonlinearity from planetary coalbedo

• Simple 0-D model of sea ice and climate: Temperature evolution from outgoing longwave radiation, incoming shortwave radiation, and specified climate forcing.

$$c\dot{T} = \underbrace{-A - B(T - T_0)}_{\text{Linearized Stefan-Boltzmann}} + \underbrace{\alpha(T)}_{\text{Planetary coalbedo}}\underbrace{S}_{\text{Solar forcing}} + \underbrace{\mathcal{F}}_{\text{Climate forcing}}$$

• Planetary coalbedo (absorbed/incident radiation) depends on temperature, transitioning from ice-covered to ice-free values as temperature warms.

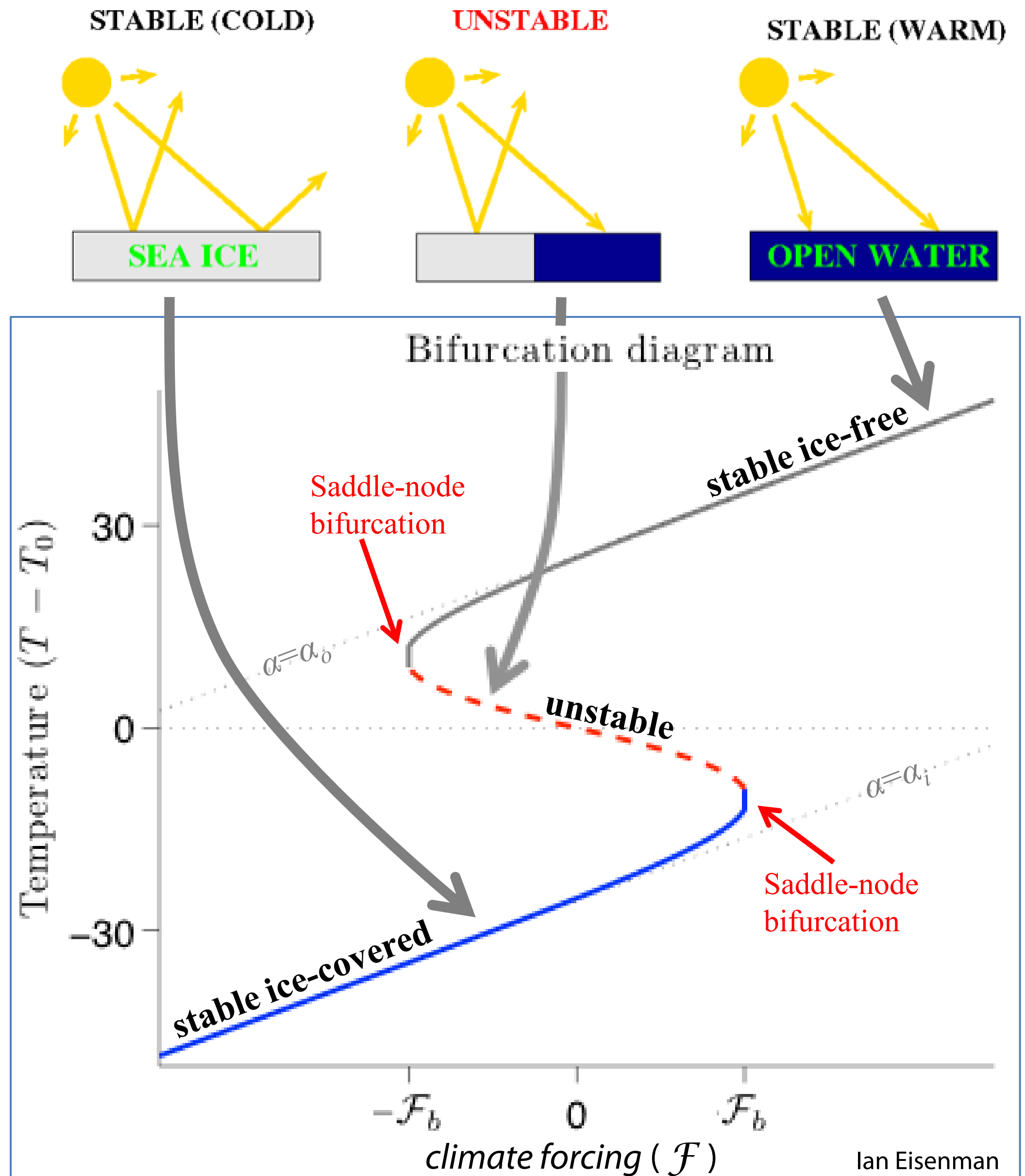
$$\alpha(T) = \alpha_i + (\alpha_o - \alpha_i)\,\frac{1}{2}\,\mathrm{Tanh}\left(\frac{T - T_0}{\Delta T}\right)$$

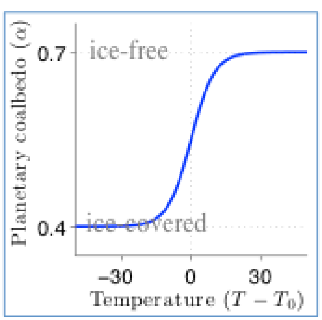


Ian Eisenman

Sea ice bifurcations

• Stable ice-covered and ice-free stable states, separated by an unstable state, are possible in a range of climates ($-\mathcal{F}_b < \mathcal{F} < \mathcal{F}_b$) that is bracketed on both sides by saddle-node bifurcations.

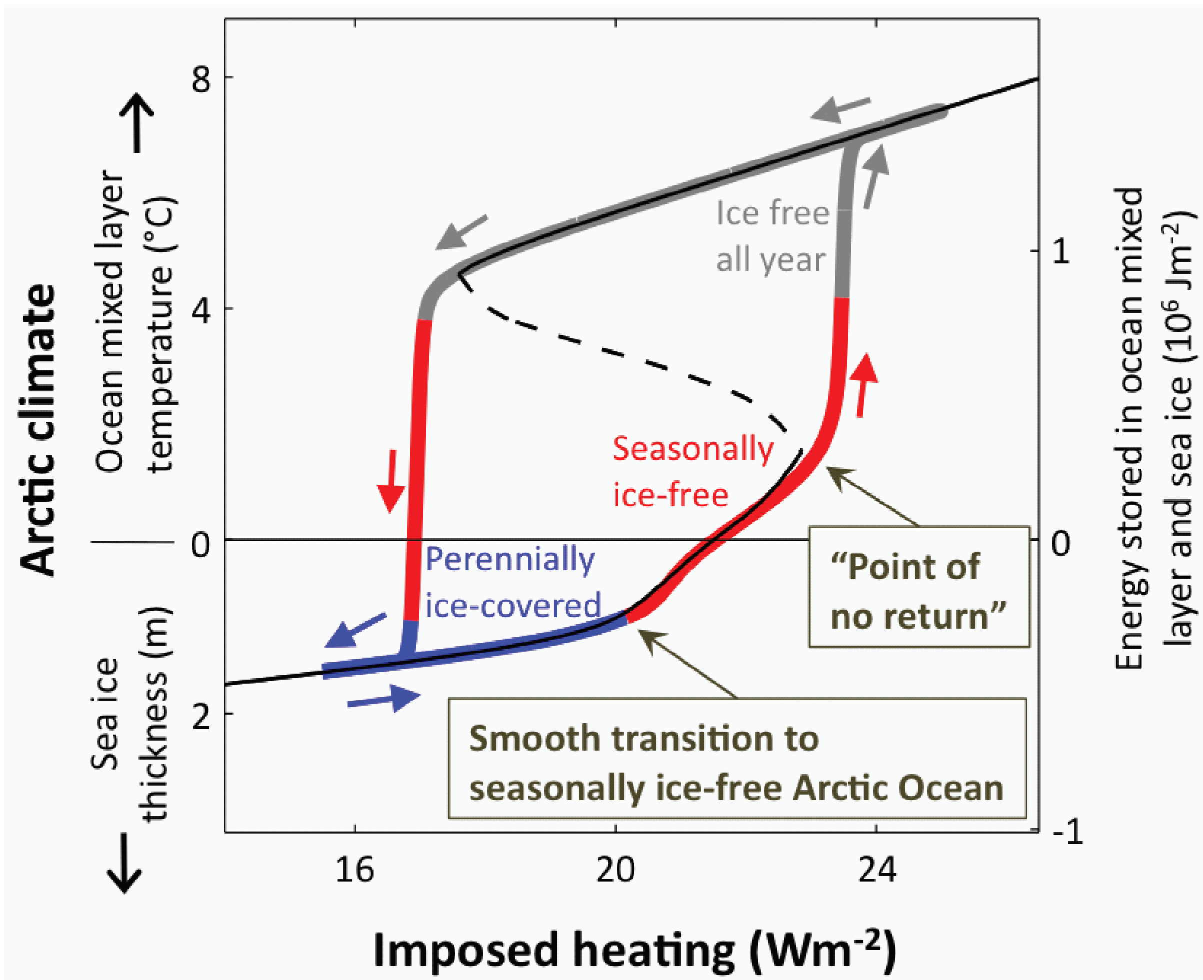




loss of summer Arctic sea ice ***smooth transition***

loss of winter Arctic sea ice ***critical threshold***

tipping point



Ice-albedo is a ***destabilizing*** feedback.

Nonlinear thickness--growth is a ***stabilizing*** feedback.
(thinner ice grows faster)

Ian Eisenman