Ice sheet runoff and Dansgaard-Oeschger Cycles

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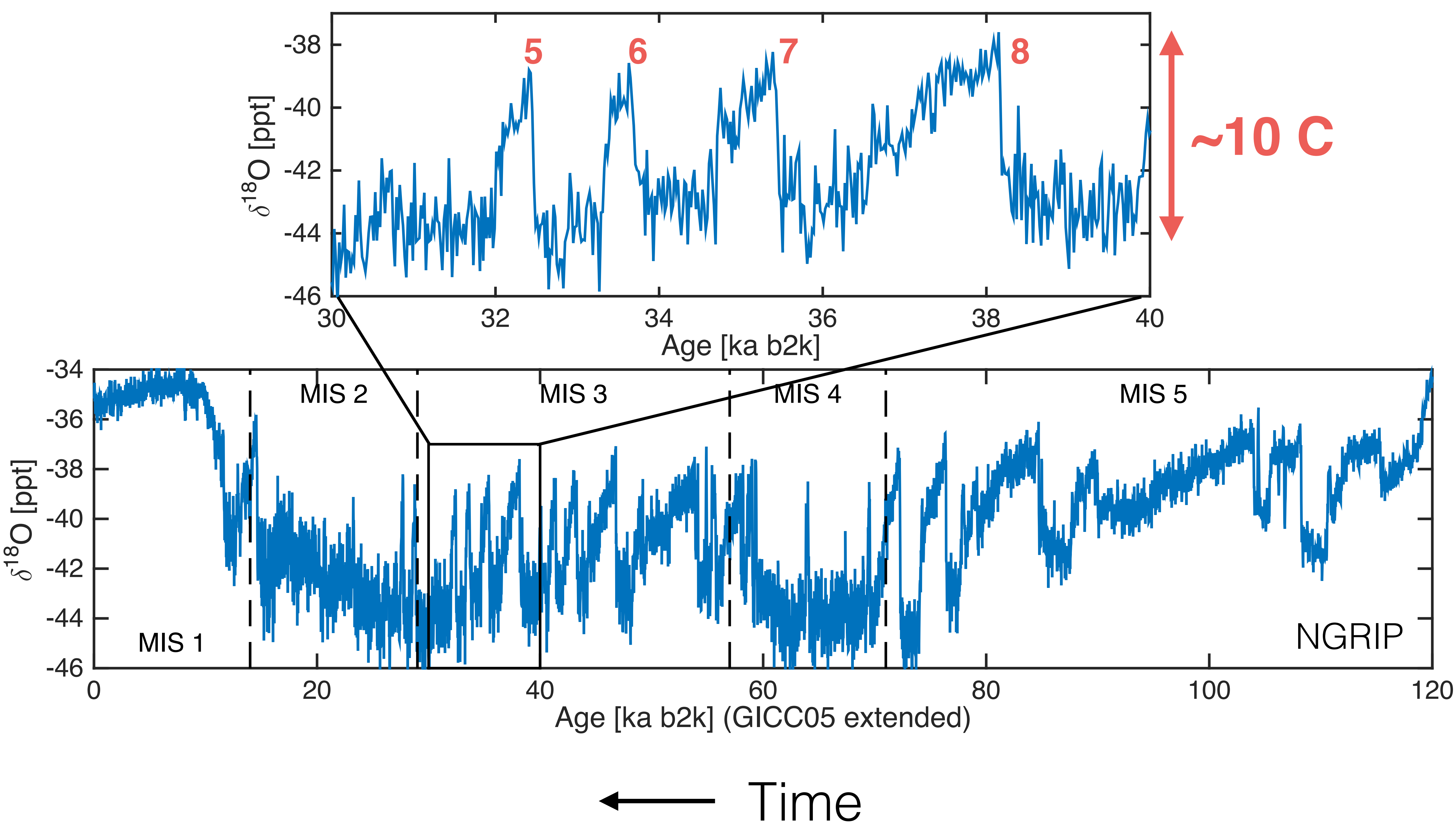
Can feedbacks associated with **meltwater runoff from ice sheets** help explain D-O cycles?

by appealing to available evidence and simple models

Dansgaard-Oeschger cycles



Distinctive features

Rapid warming at onset (‘D-O event’)

→ non-linear feedbacks

Global temperature change obeys bipolar see-saw

→ AMOC important

Quasi-periodic - cycles repeat without obvious trigger

No D-O cycles during interglacials, nor during coldest glacial periods (LGM, MIS4)

Heinrich events occur when climate already cold

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→ Heinrich events not important ?

Background

Many models exist - most invoke changes in ocean circulation to help explain global pattern

Sudden freshwater sources to North Atlantic - e.g. Clark et al 2001, Ganapolski & Rahmstorf 2001

Ice shelf growth and sea ice - Petersen et al 2013

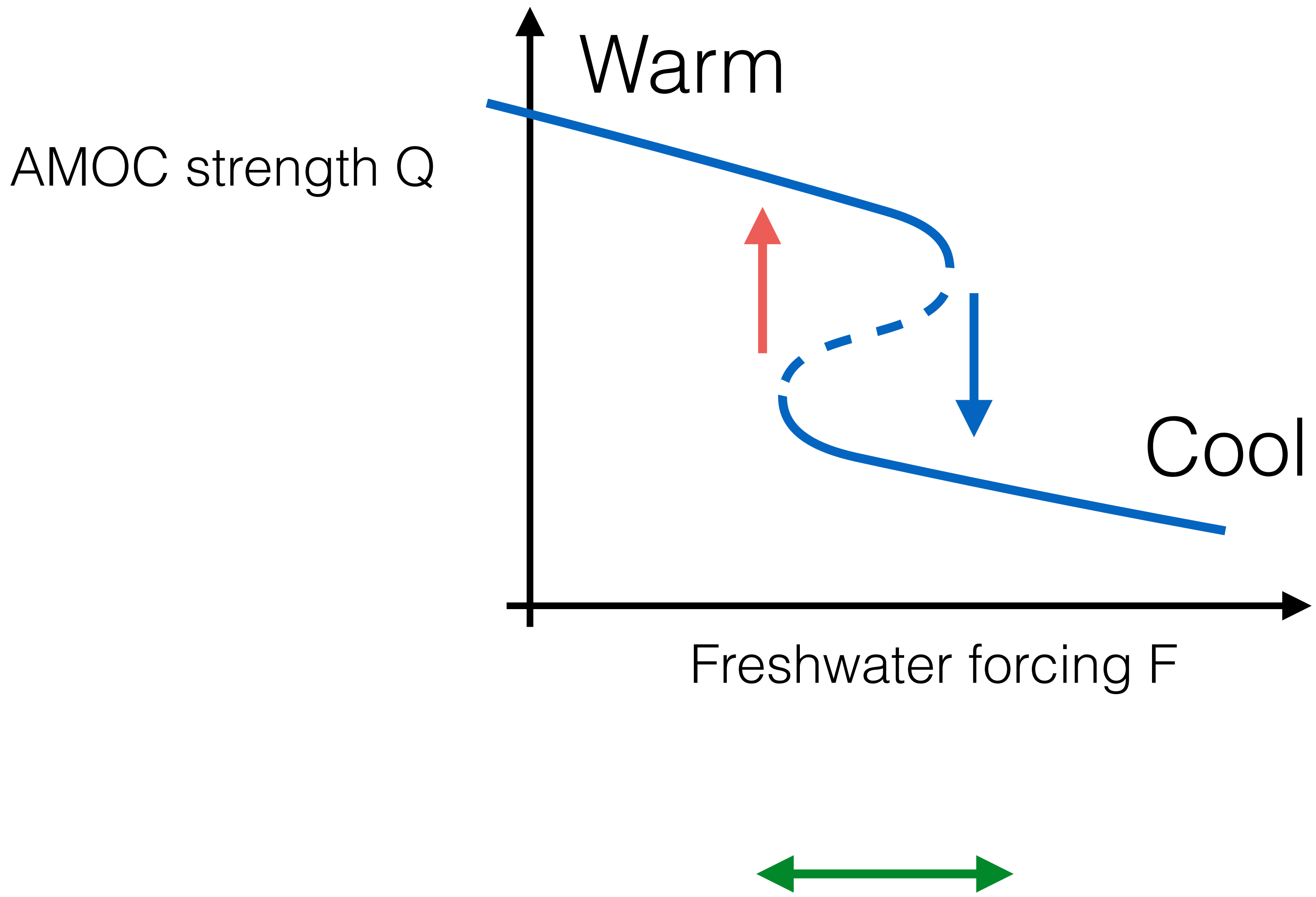
Sea ice and North Atlantic stratification - Dokken et al 2013, Jensen et al 2016

Atmospheric-sea ice-ocean feedbacks caused by changing height of Northern hemisphere ice sheets - e.g. Zhang et al 2014

Salt oscillators - Broecker et al 1990, Birchfield & Broecker 1990, Peltier & Vettoretti 2014

Meltwater routing through the Arctic has most effect on AMOC Condron & Winsor 2012

Hysteresis in ocean circulation



Stommel 1961, Ganapolski & Rahmstorf 2001, Rahmstorf et al 2005

Oscillation mechanism

Strong AMOC produces warmer Northern hemisphere

warming accentuated by sea ice - albedo feedback

→ Leads to more runoff from ice sheets

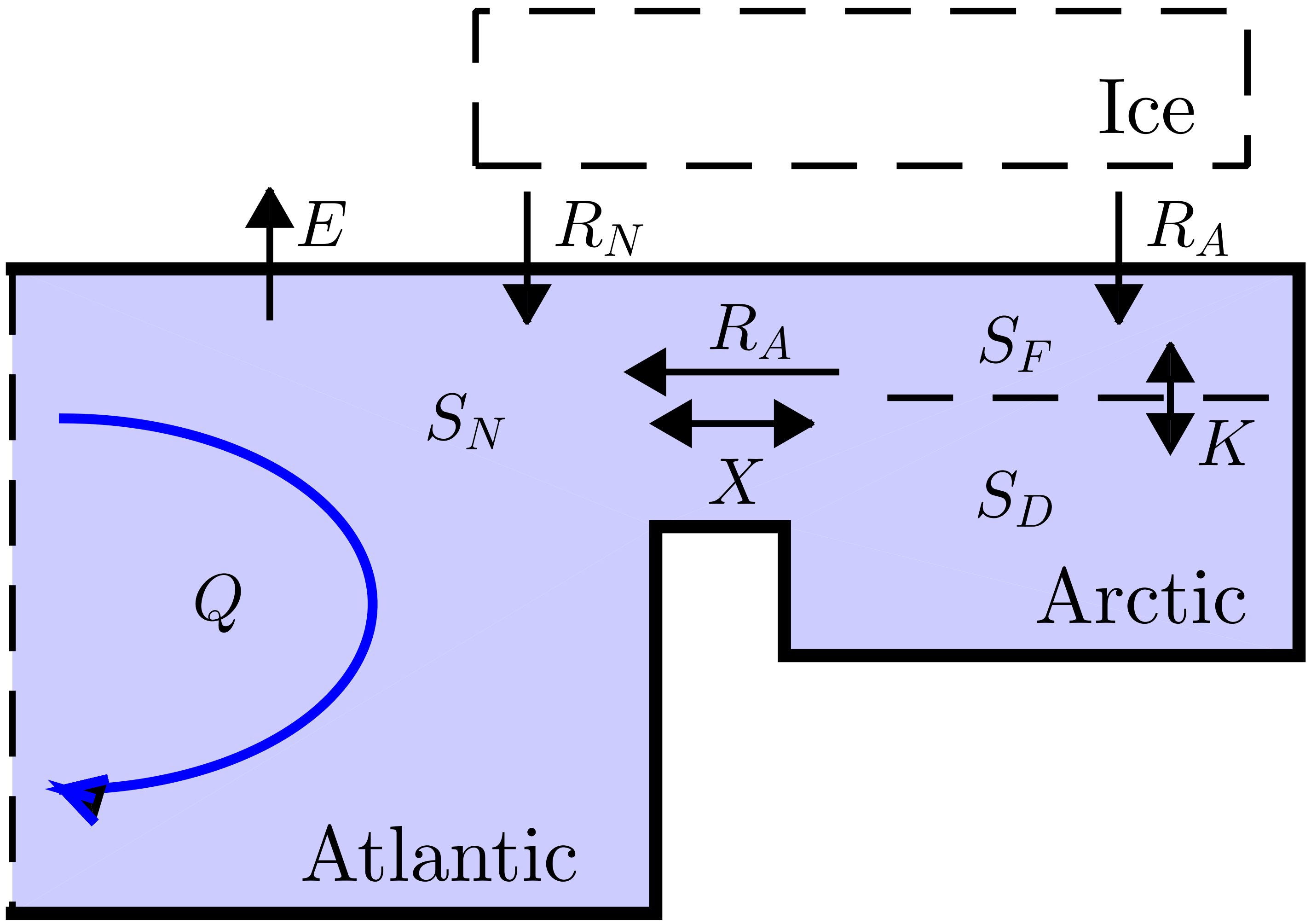
→ This freshwater sends AMOC onto weaker branch

→ Cooling reduces runoff and starves ocean of fresh water

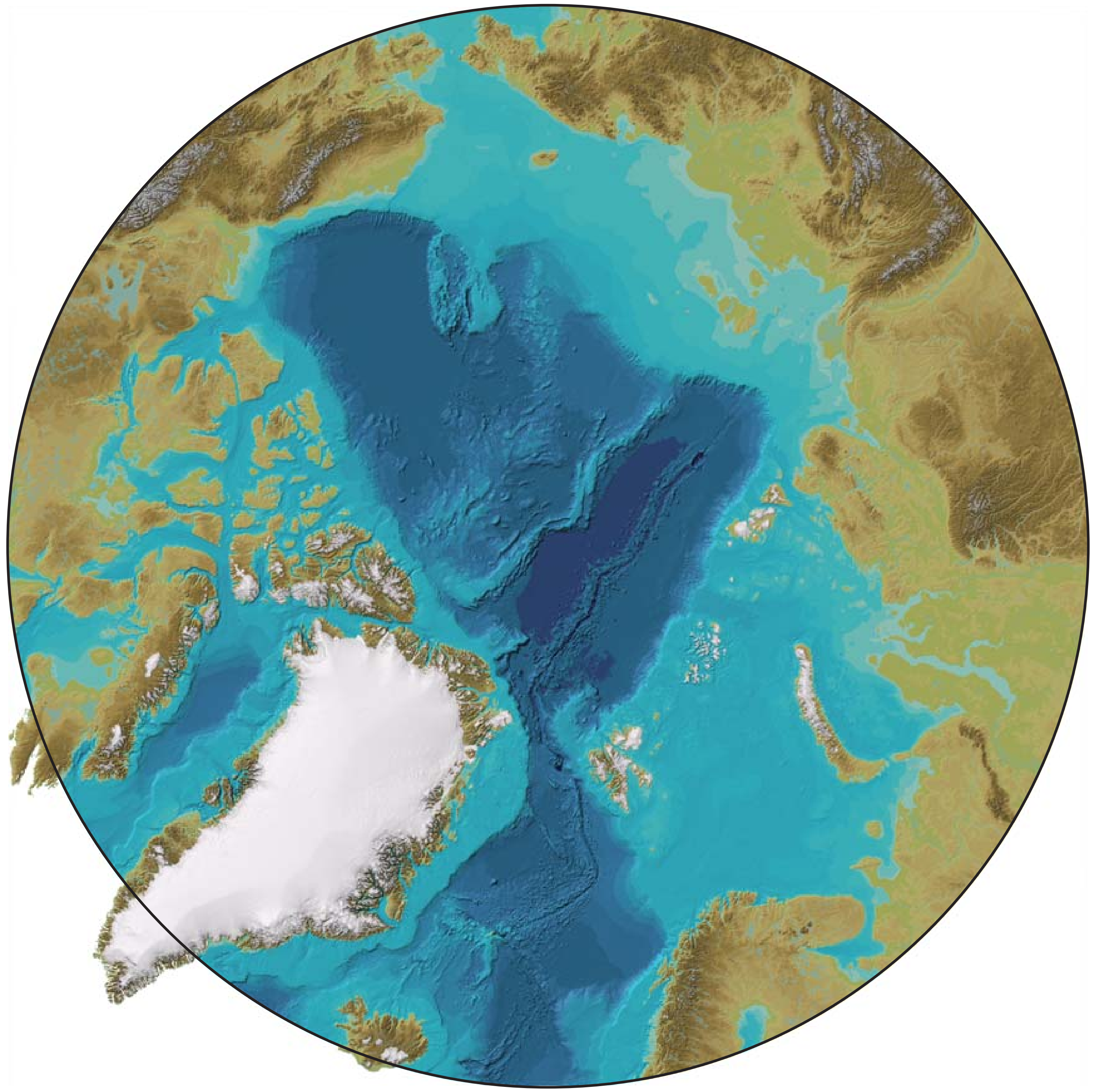
↰ Sends AMOC back to strong branch

Effect of runoff on ‘freshwater’ delivery is buffered by changes in Arctic Ocean salinity

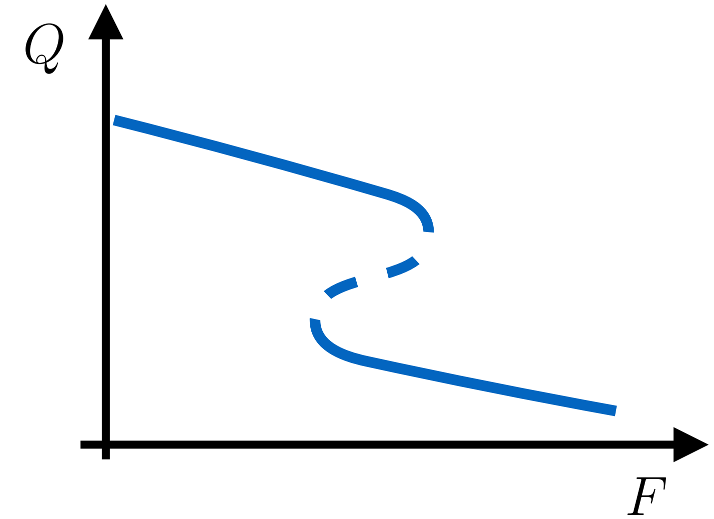
Model schematic



Arctic Ocean



Model equations

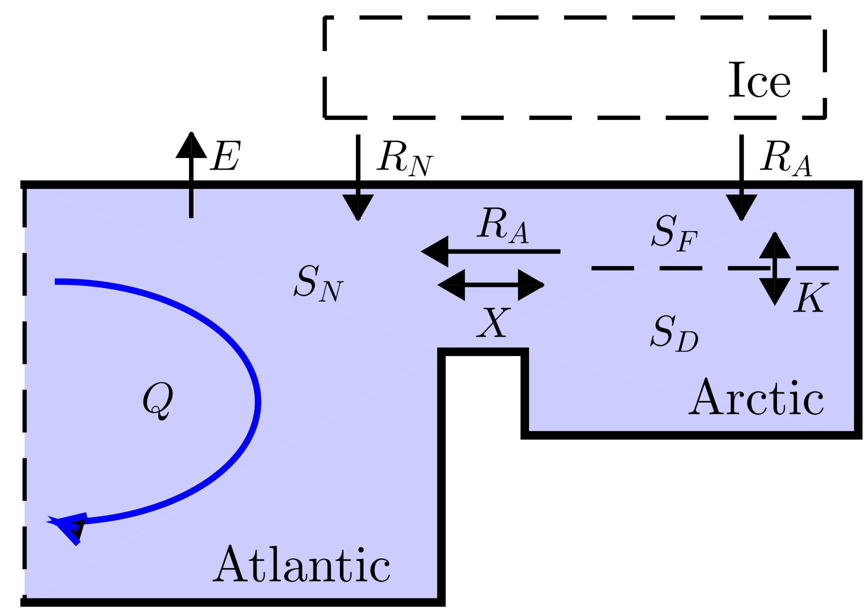


AMOC $$b\tau \frac{dQ}{dt} = f(Q) - F.$$

phenomenological model of hysteresis in ocean models

Runoff $$R_A = R_0 + \lambda (Q - Q_0)$$

amplification by ocean and sea ice rolled into λ



Freshwater $$F \approx F_* + (X + R_A)\left(1 - \frac{S_D}{S_N}\right)$$

effective freshwater flux through Fram Strait

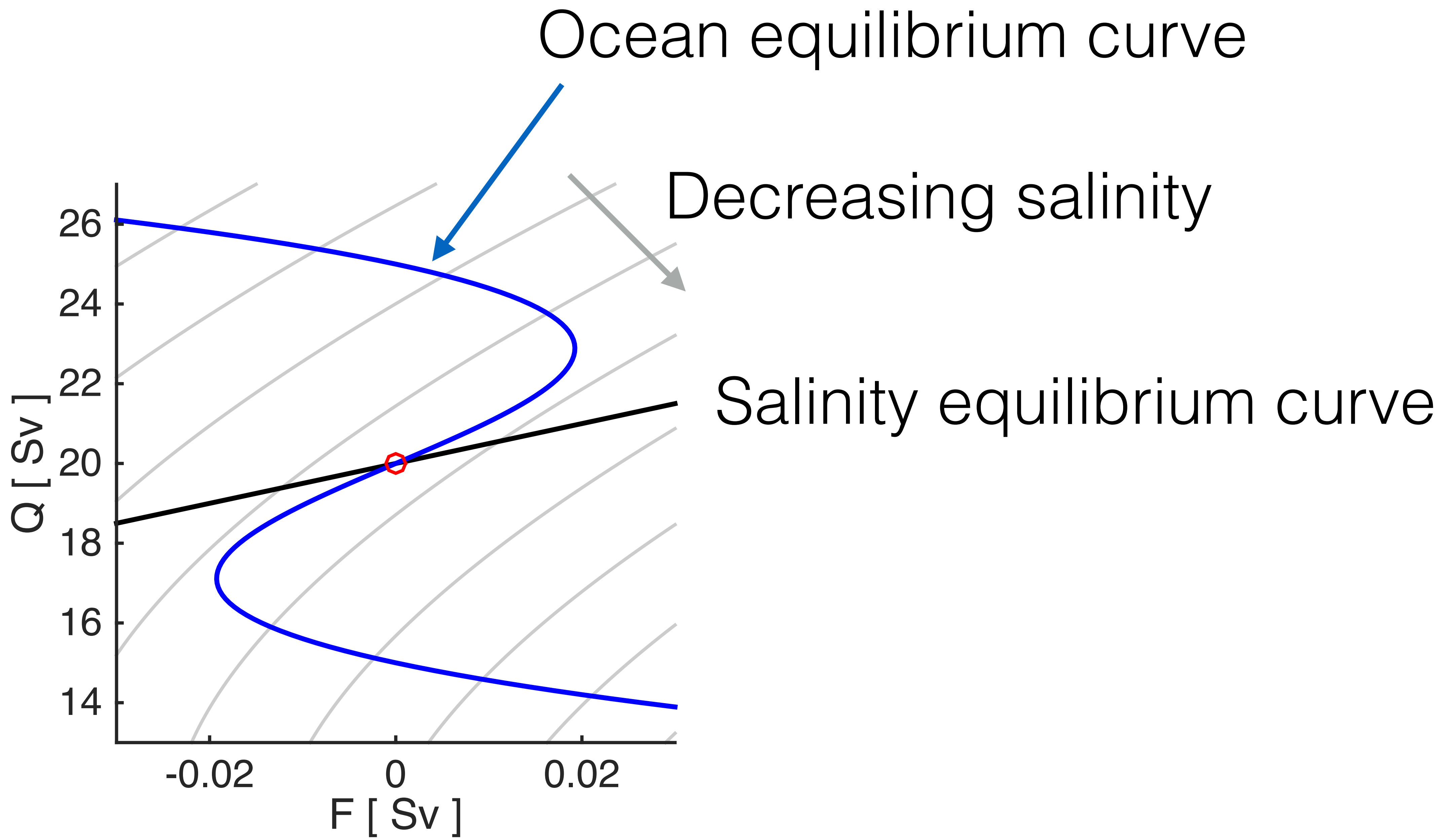
Salinity $$V_D \frac{dS_D}{dt} \approx X(S_N - S_D) - R_A S_D$$

salt balance for deep Arctic (fresher surface layer evolves more rapidly)

➡ Non-linear dynamical system - relaxation oscillation

Parameters estimated using current day values

Oscillations



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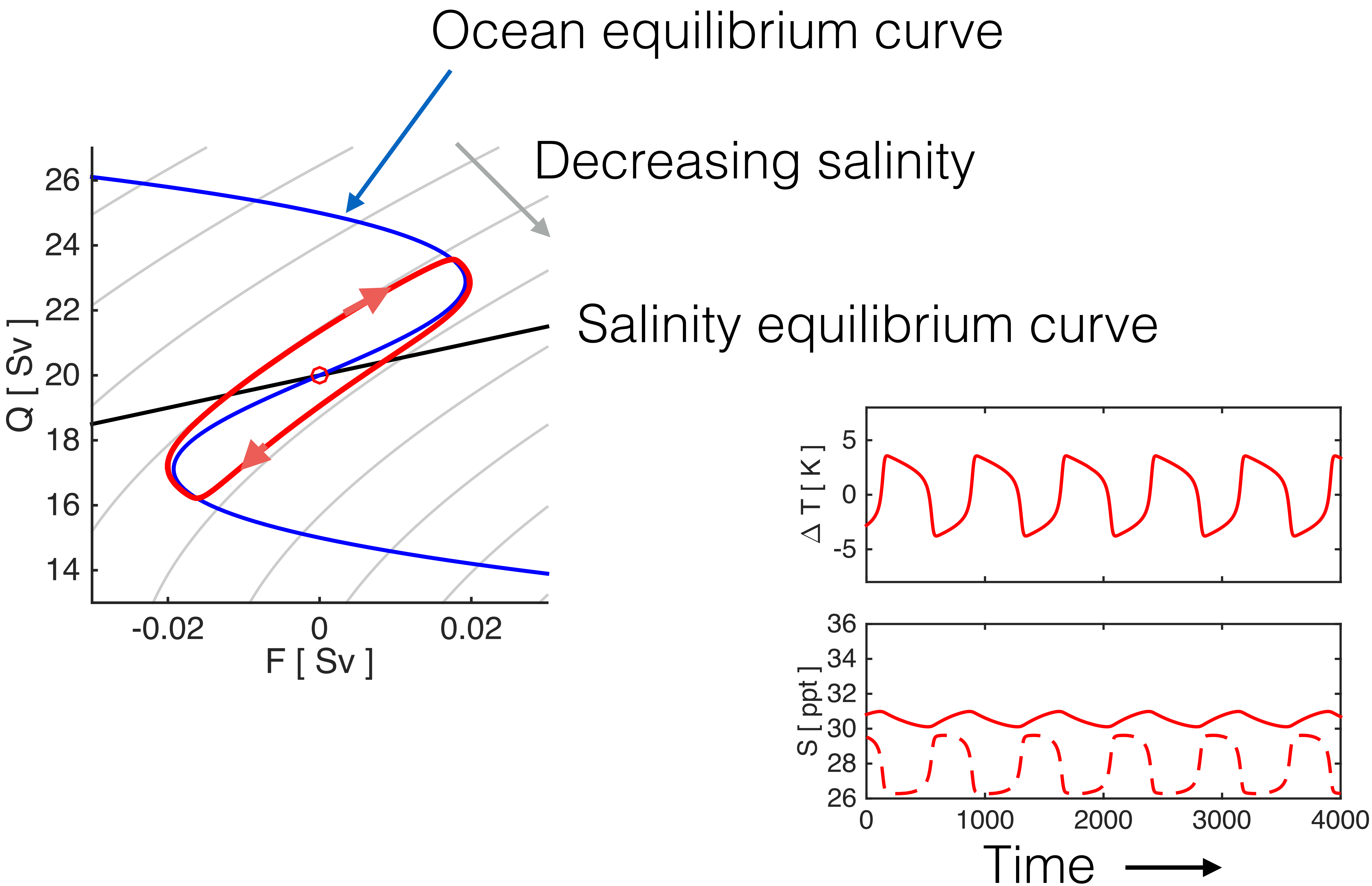

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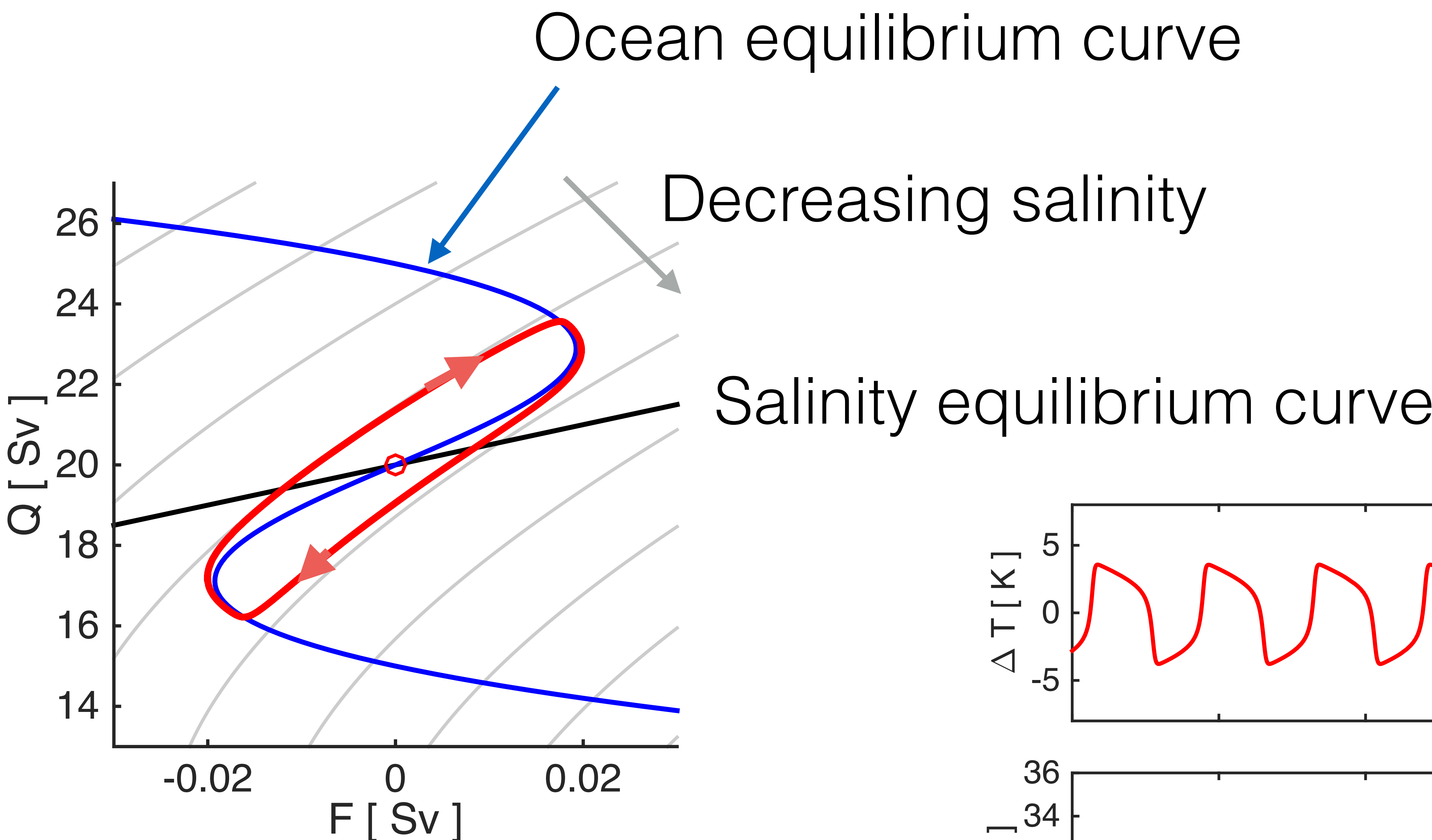
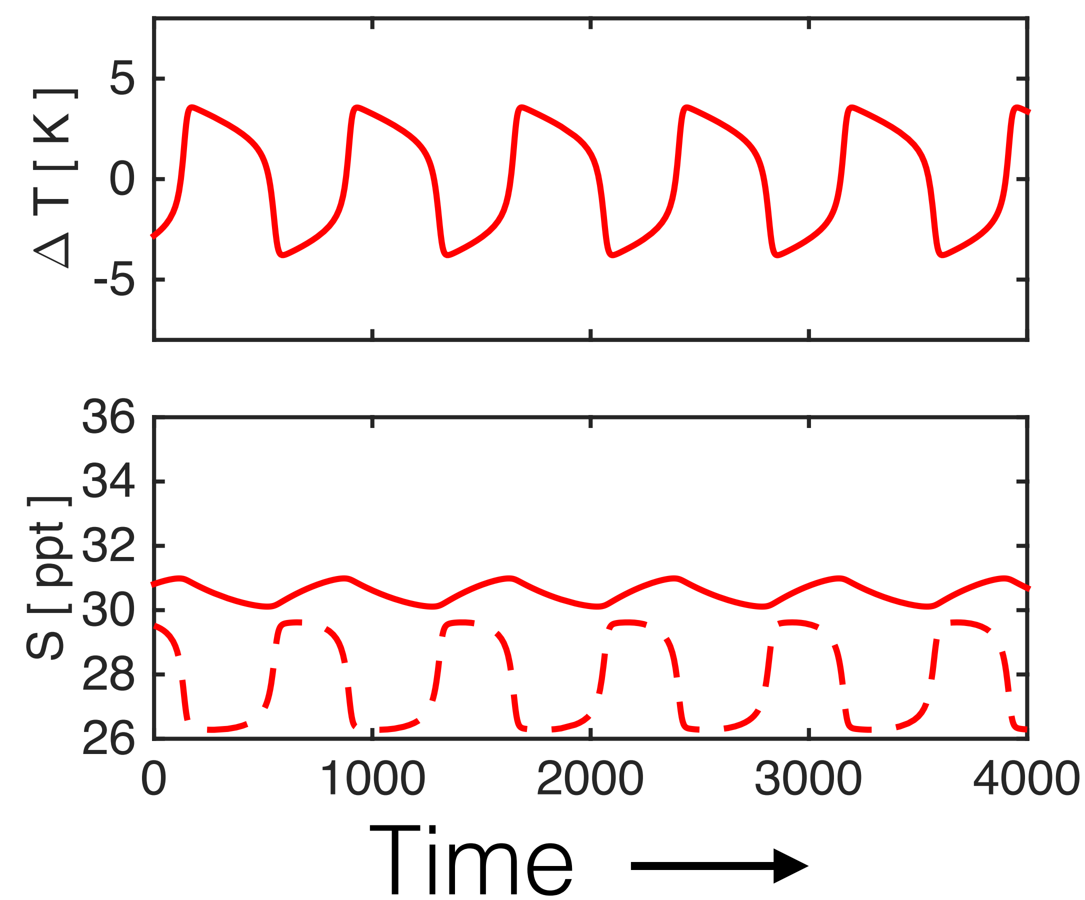




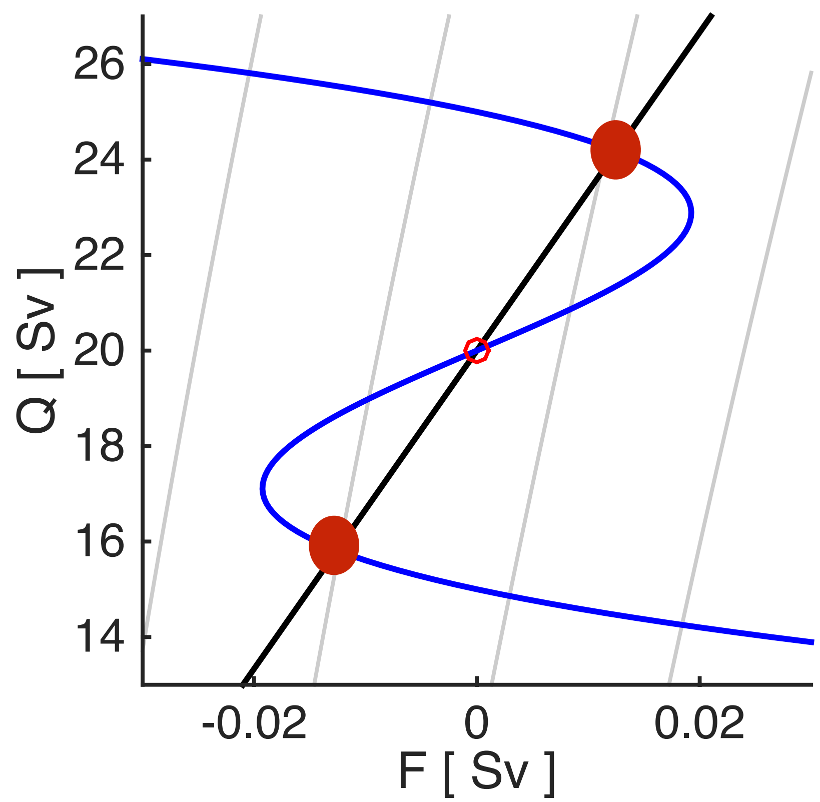
Time scale controlled by Fram Strait exchange

To get ~1000 years, exchange flow around 10 times smaller than present day

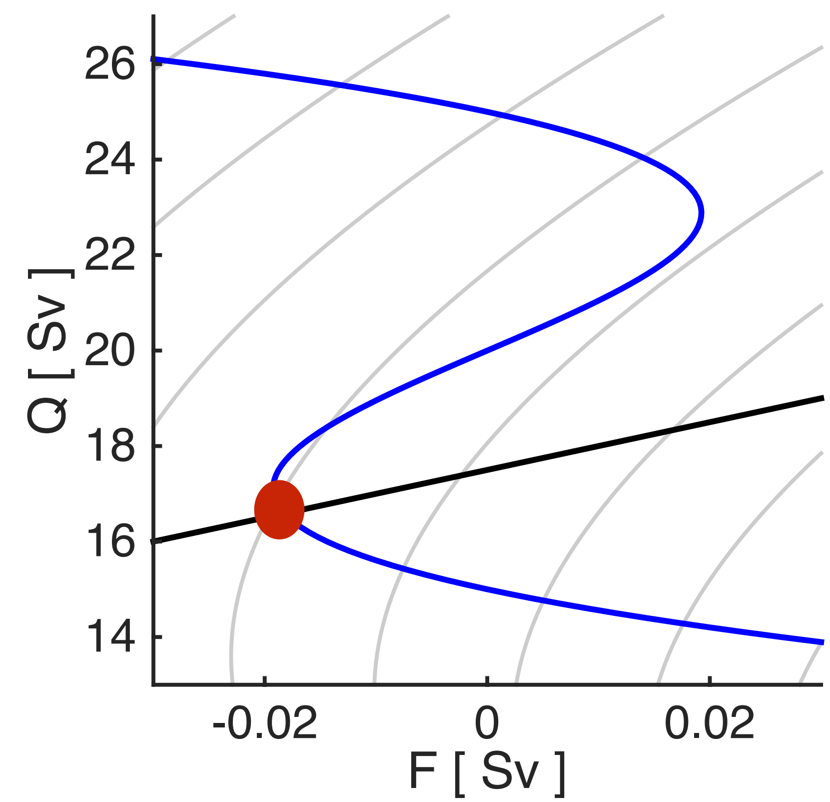
Can we rationalise observed variability?

A slow change of parameters can alter period of cycles, or produce steady (but ‘excitable’) states.

Reduced **sensitivity** of runoff to AMOC



Increased background runoff



Interglacials (no ice)

? LGM (Arctic melt pathway blocked) Clark et al 2001

Summary

Investigated a possible mechanism for D-O cycles, combining AMOC hysteresis and temperature-driven runoff

Successes

Self-sustaining oscillation - gives rise to regular 'shape' of D-O cycles

Variable frequency, and lack of events during interglacials and during LGM, are naturally explained

No sudden source of freshwater required (though could prolong cold stadials)

Potential issues

Relies on lengthy buffering effect of Arctic Ocean - lower exchange flux

Any evidence for lower exchange flux, or lower salinities? Or other relevant data?

Ideas (ice-sheet runoff & routing) need exploring in more comprehensive models to test whether this mechanism important