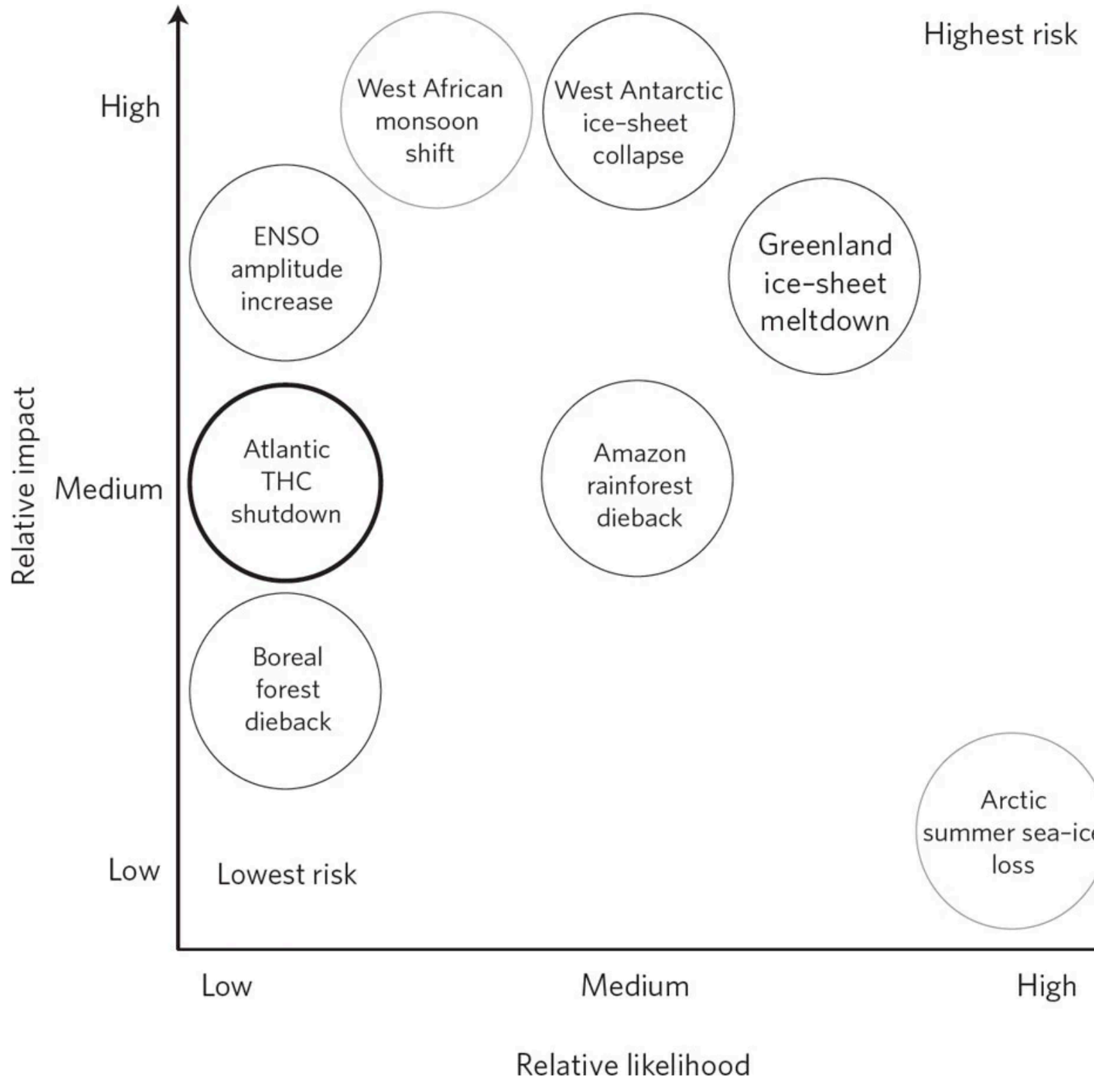
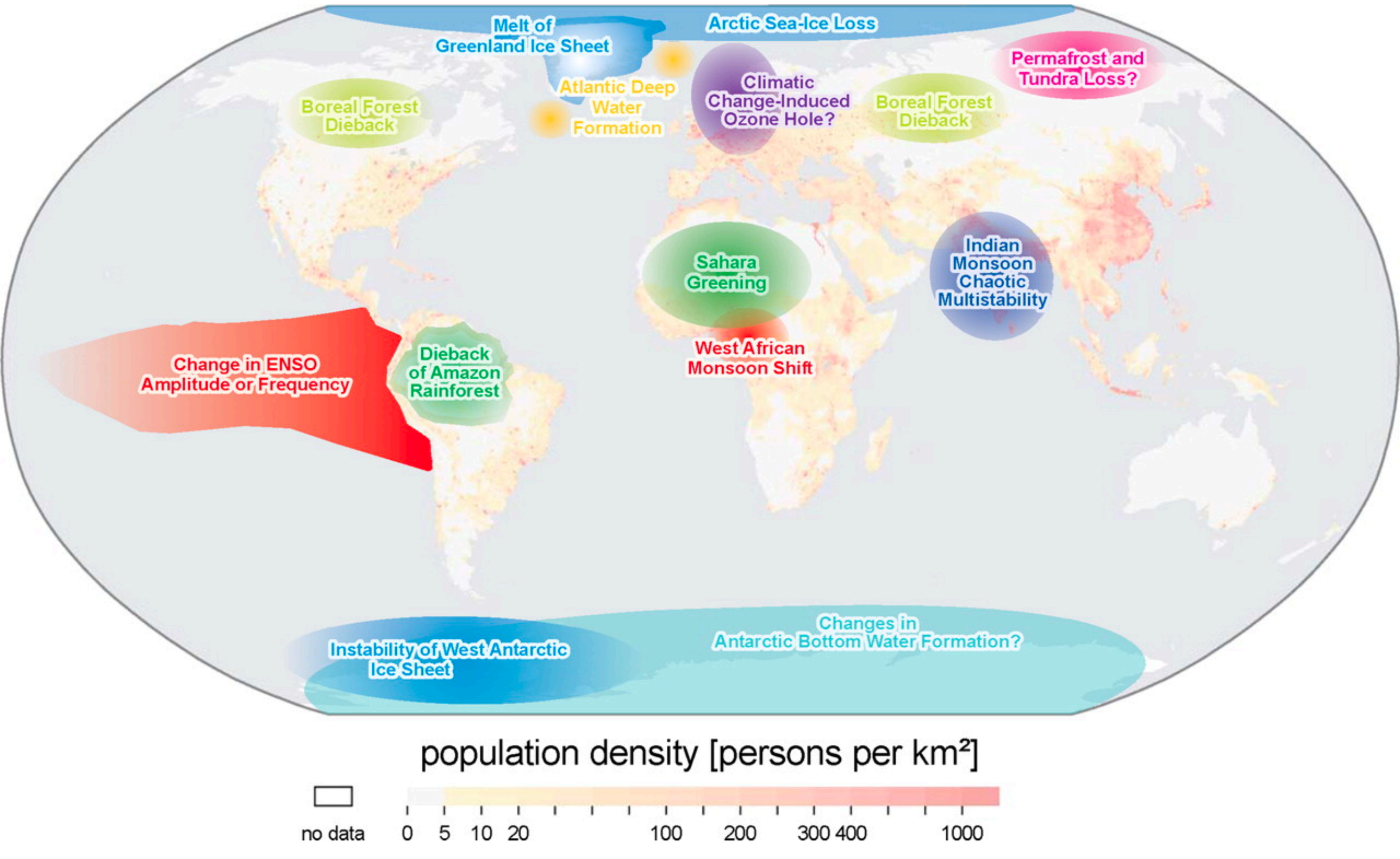
Anticipating Climate Tipping Points

AOS 801 - Lecture 14

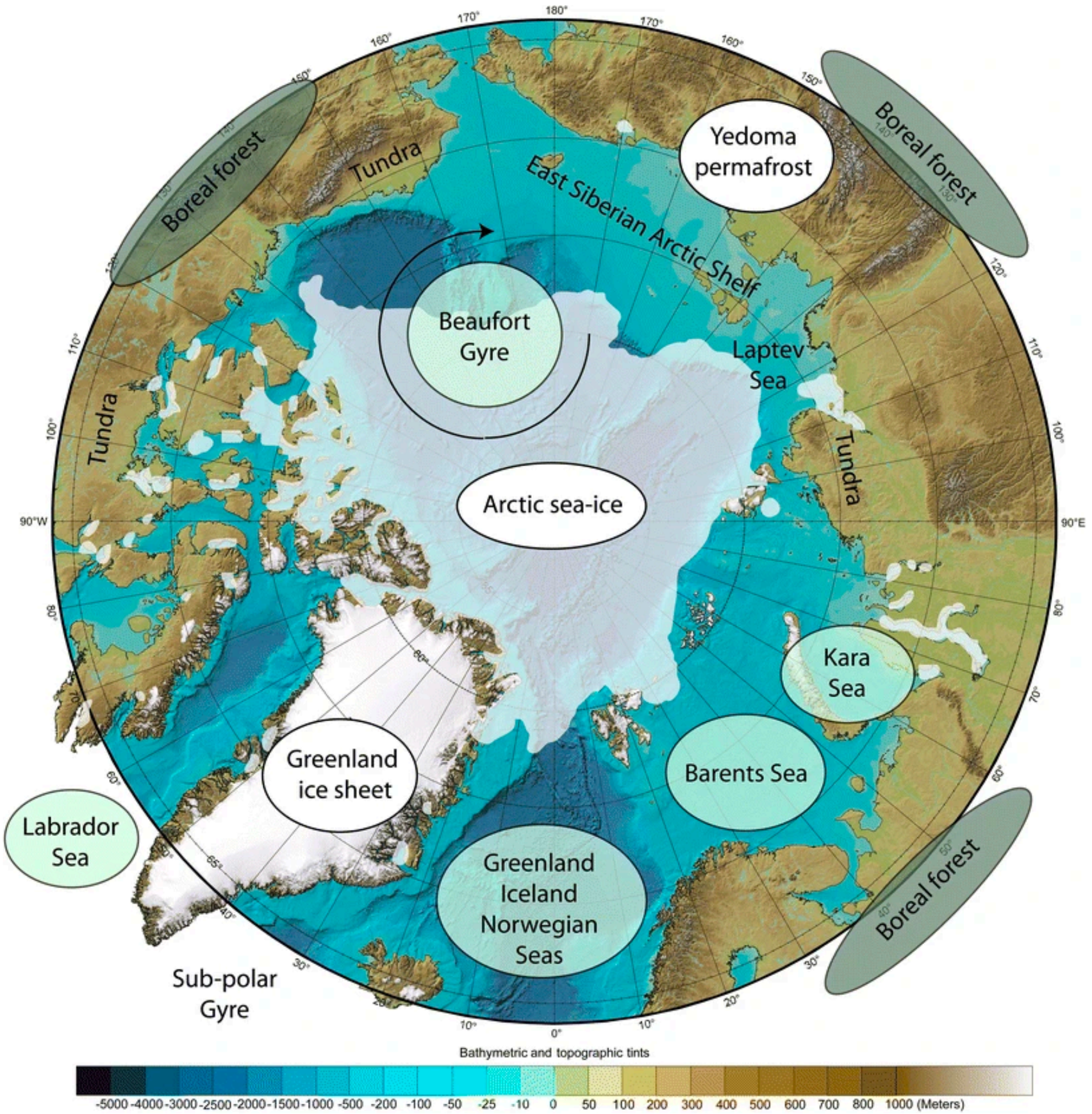
Till Wagner, 24 Oct 2022


Highest risk
High
West African monsoon shift
West Antarctic ice-sheet collapse
ENSO amplitude increase
Greenland ice-sheet meltdown
Relative impact
Medium
Atlantic THC shutdown
Amazon rainforest dieback
Boreal forest dieback
Arctic summer sea-ice loss
Low
Lowest risk
Low
Medium
High
Relative likelihood

Lenton (2011)

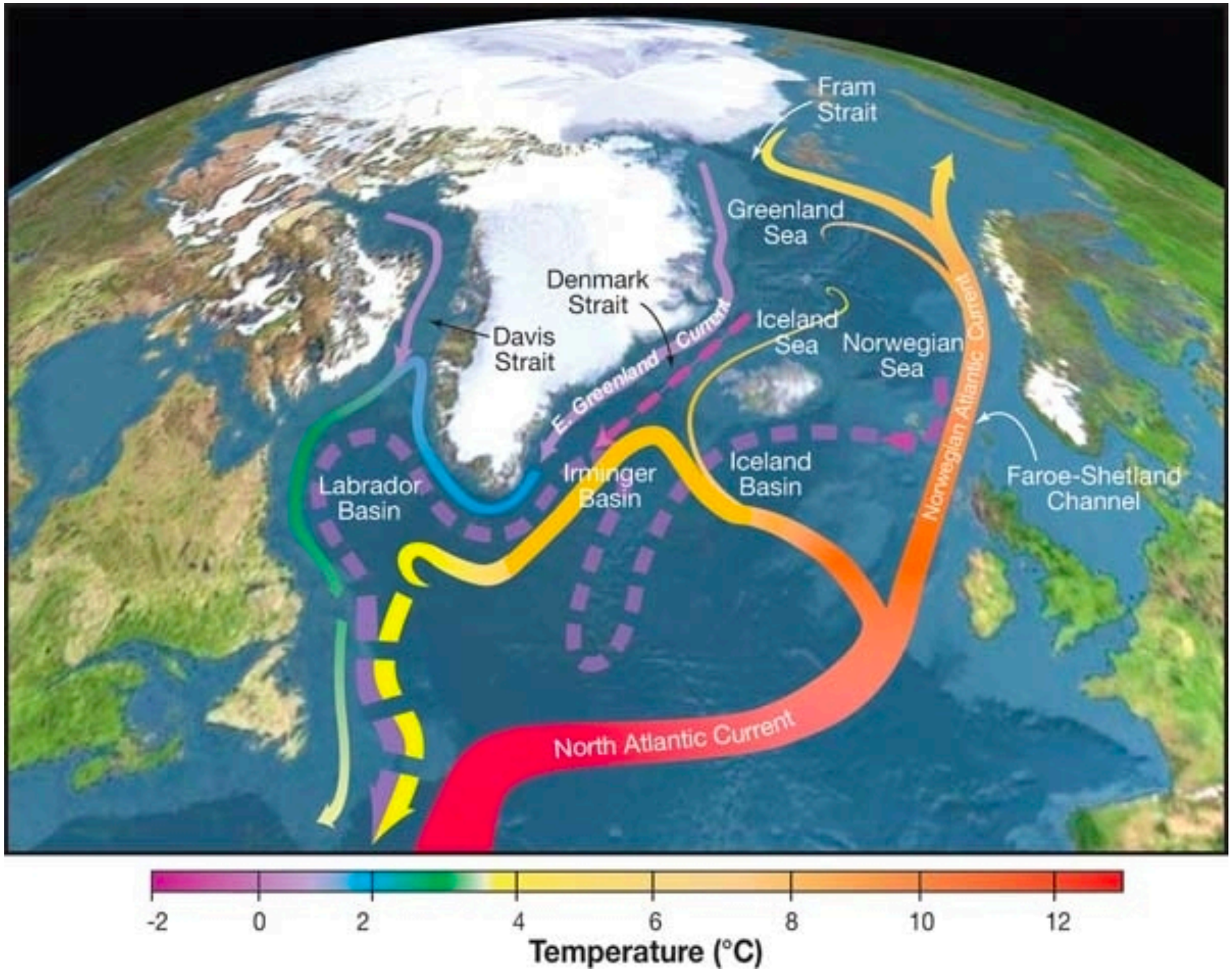


Lenton et al (2008)


Boreal forest
Tundra
Yedoma permafrost
East Siberian Arctic Shelf
Boreal forest
Beaufort Gyre
Laptev Sea
Tundra
Tundra
Arctic sea-ice
Kara Sea
Greenland ice sheet
Barents Sea
Labrador Sea
Greenland Iceland Norwegian Seas
Boreal forest
Sub-polar Gyre
Bathymetric and topographic tints
-5000 -4000 -3000 -2500 -2000 -1500 -1000 -500 -200 -100 -50 -25 -10 0 50 100 200 300 400 500 600 700 800 1000 (Meters)

Lenton (2012)

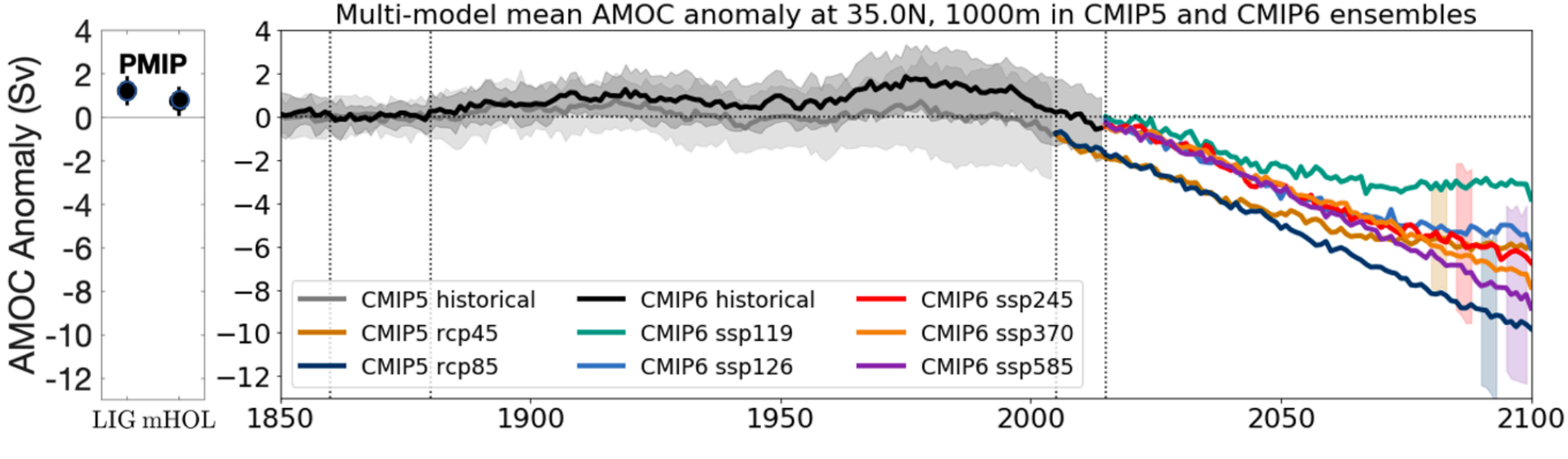
Atlantic Meridional Overturning Circulation

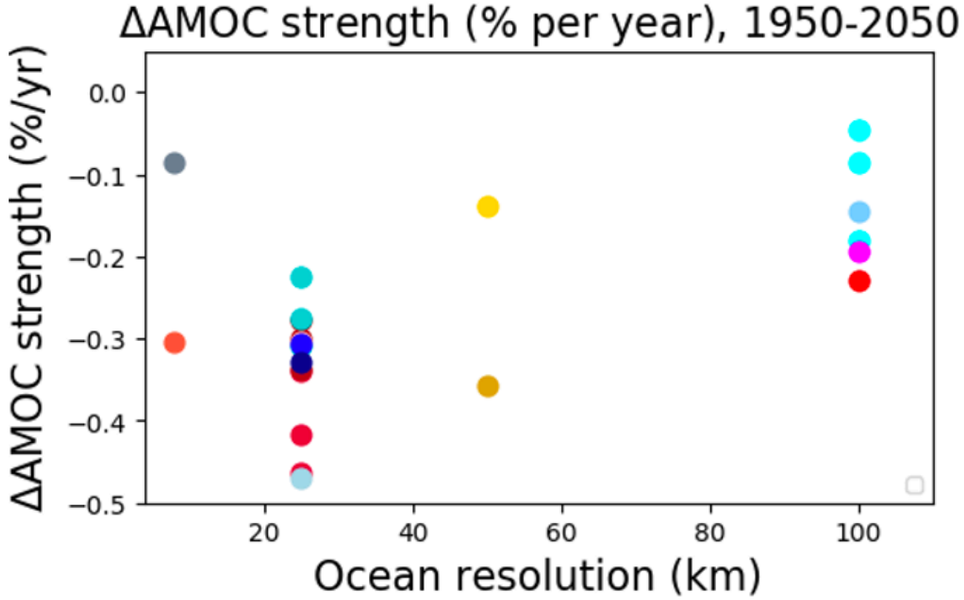


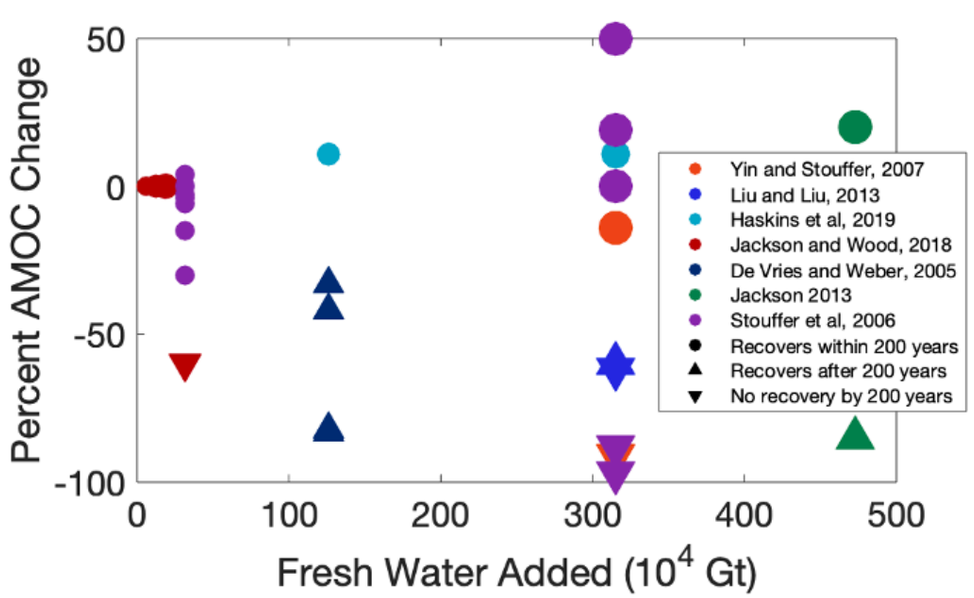
AMOC in the IPCC

HISTORICAL Runs:
Medium confidence of weakening (SROCC) ->
Low confidence of weakening (AR6)

Recent observations:
Medium confidence of weakening (AR6)





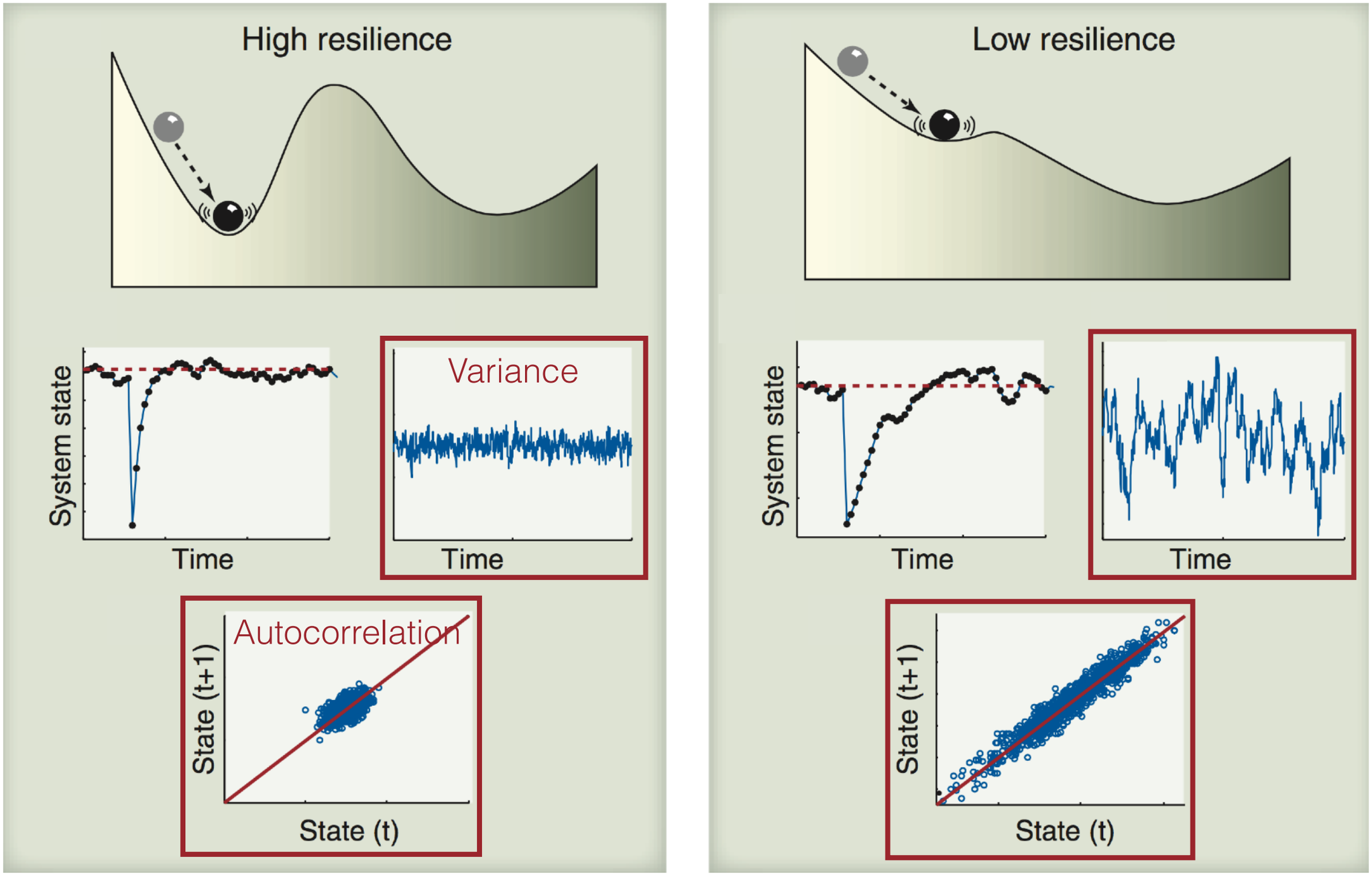


Collapse very unlikely (SROCC, AR5)
->
Medium confidence no collapse by 21000 (AR6)

AMOC on Wikipedia

An August 2021 study in *Nature Climate Change* analysed eight independent AMOC indices and concluded that the system is approaching collapse.[3]

Critical Slow Down as Early Warning Sign for Abrupt Change



Scheffer et al, *Science* (2012)

- Autocorrelation is the leading candidate to act as an early warning indicator.

PNAS
Proceedings of the
National Academy of Sciences
of the United States of America

RESEARCH ARTICLE

Critical slowing down suggests that the western Greenland Ice Sheet is close to a tipping point

Niklas Boers and Martin Rypdal
+ See all authors and affiliations

PNAS May 25, 2021 118 (21) e2024192118; https://doi.org/10.1073/pnas.2024192118

Edited by Stephen R. Carpenter, University of Wisconsin–Madison, Madison, WI, and approved April 5, 2021 (received for review November 22, 2020)

Geophysical Re

RESEARCH LETTER
10.1002/2015GL066297

Key Points:
• Rising autocorrelation, a common

ARTICLES
https://doi.org/10.1038/s41558-021-01097-4

nature climate change

Observation-based early-warning signals for a collapse of the Atlantic Meridional Overturning Circulation

Niklas Boers [1,2,3] ✉

What's a Tipping Point?

discontinuous jump in state variable x at a critical parameter value $\mu = \mu_0$

$\longrightarrow$

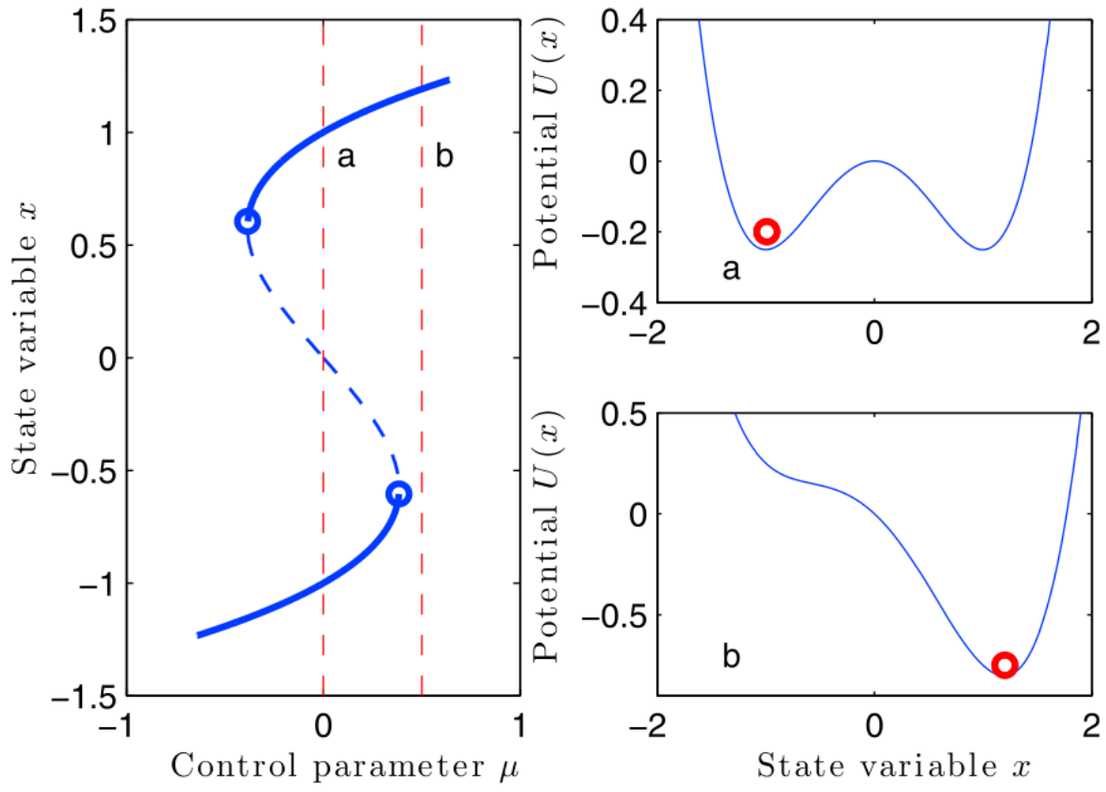
x

e.g.,

1. meridional overturning circulation
2. ice volume in glacial ice sheet
3. global mean surface temp.
4. sea ice area

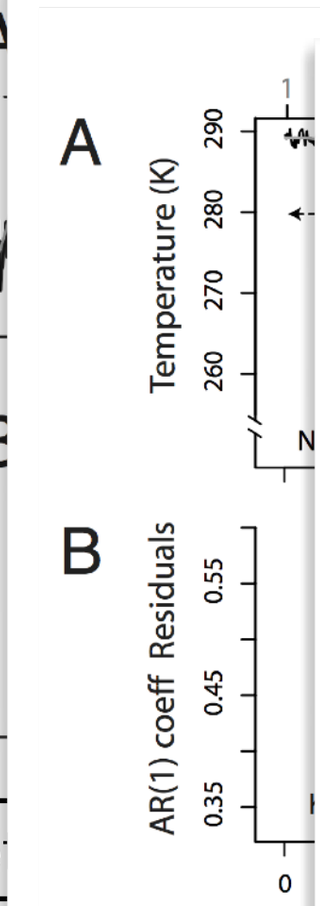
μ

1. freshwater added at 50-60 N lat
2. summer solstice insolation at 65 N
3. atmospheric CO_2 concentration
4. outgoing longwave/CO_2/insolation (?)

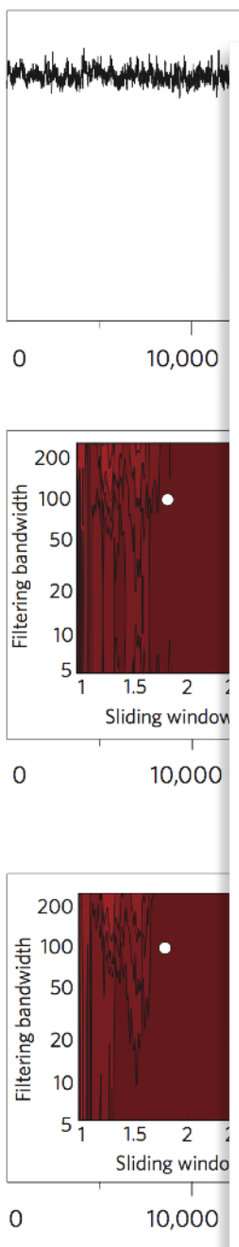


Ditlevsen (2010)

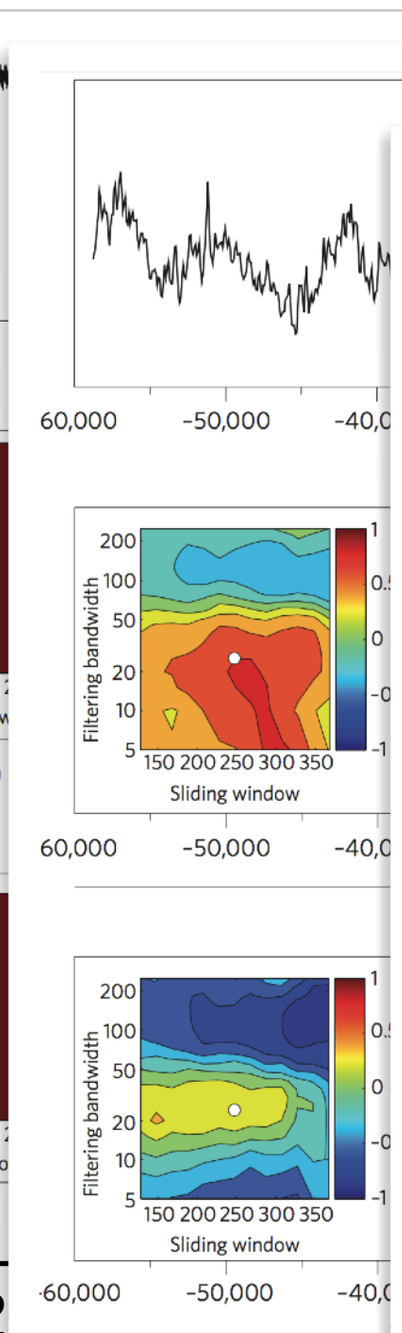
Dakos e



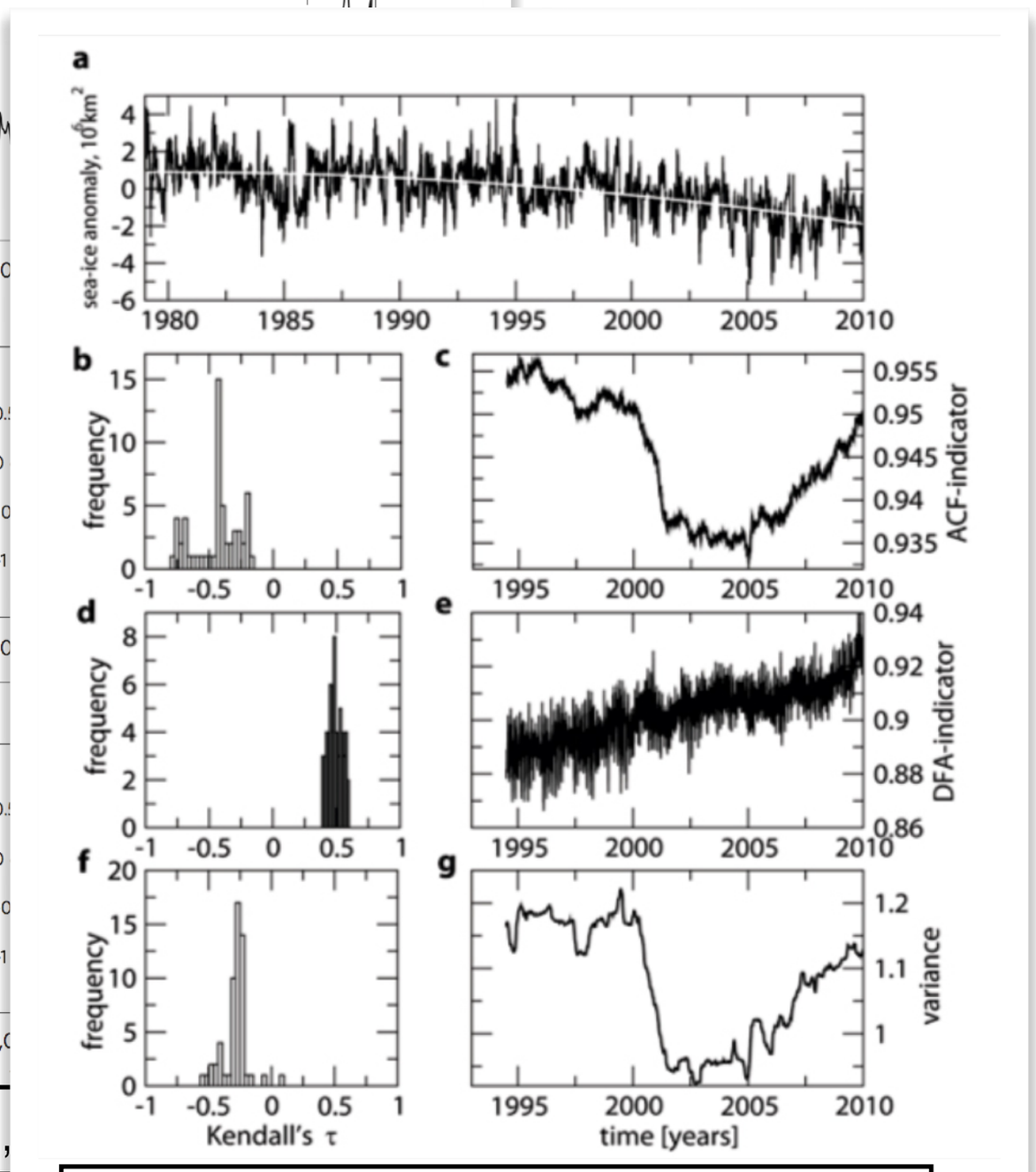
Dakos et a



Lenton 2



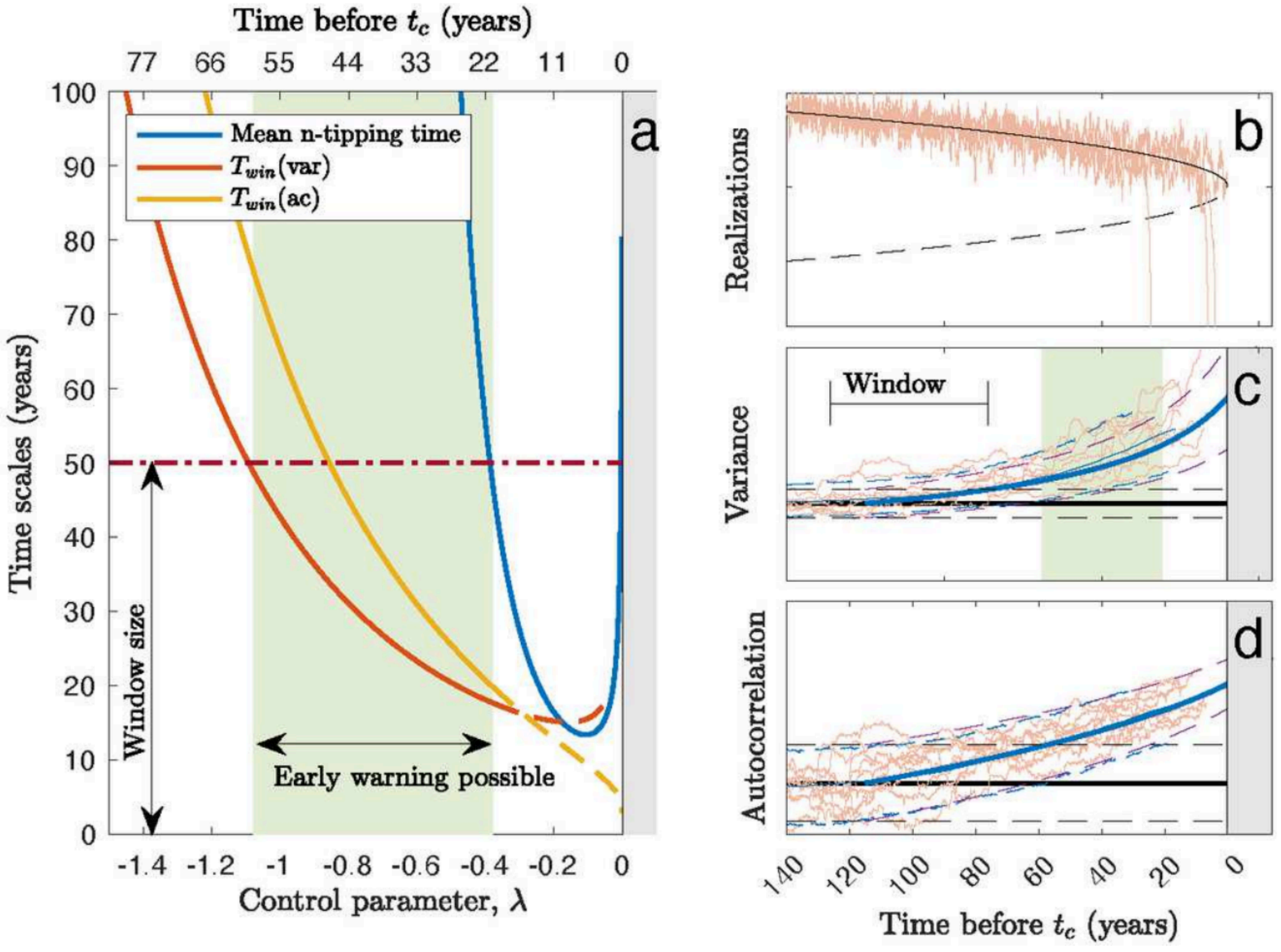
Lenton 2011,



Livina & Lenton 2013, **Observations**

Rising Autocorrelation as Indicator for Climate Tipping Points

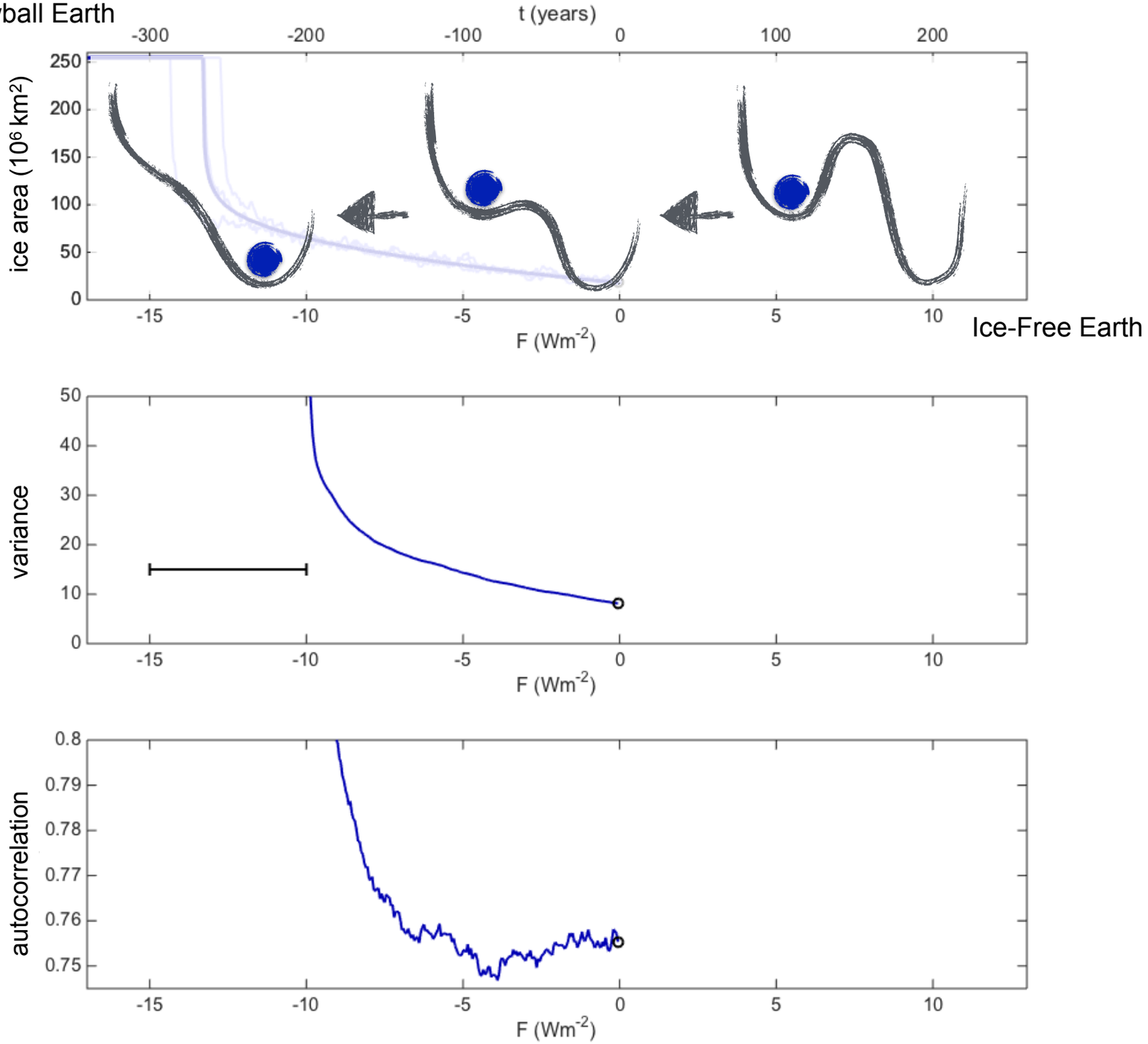
Ditlevsen & Ditlevsen (2022)



How Does Autocorrelation Behave in an idealized model of climate and sea ice ?

$$\frac{\partial E}{\partial t} = \underbrace{aS}_{\text{solar}} - \underbrace{(A + BT)}_{\text{OLR}} + \underbrace{D\nabla_x^2 T}_{\text{transport}} + \underbrace{F_b}_{\text{ocean heating}} + \underbrace{F}_{\text{climate forcing}} + \underbrace{N.}_{\text{noise}}$$

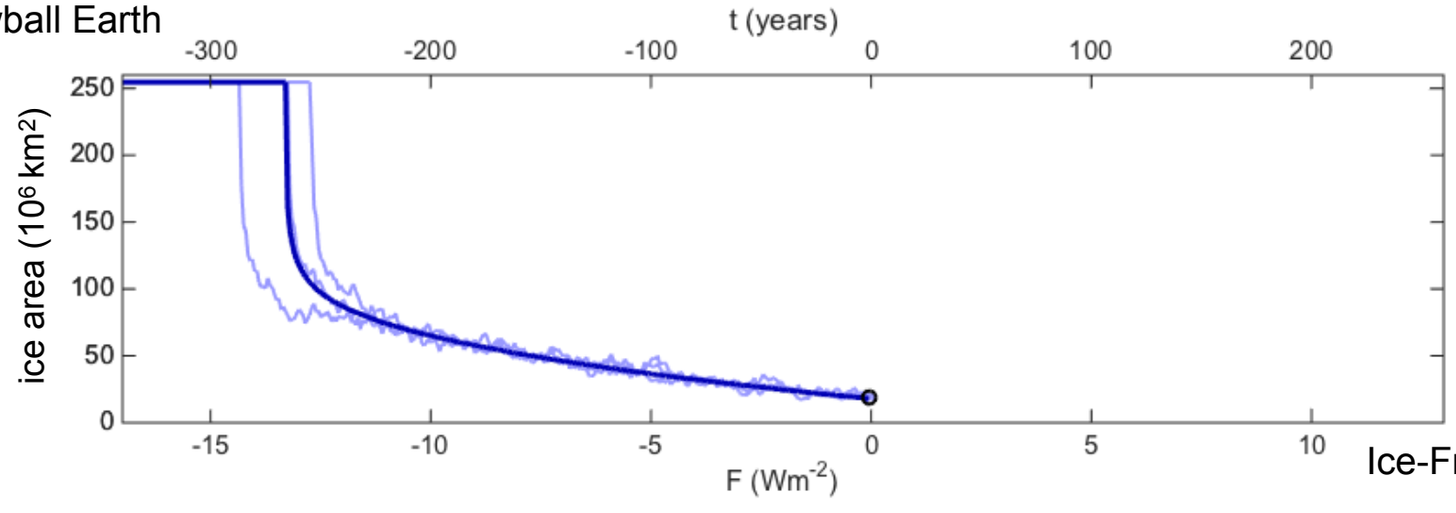
Snowball Earth



Ice-Free Earth

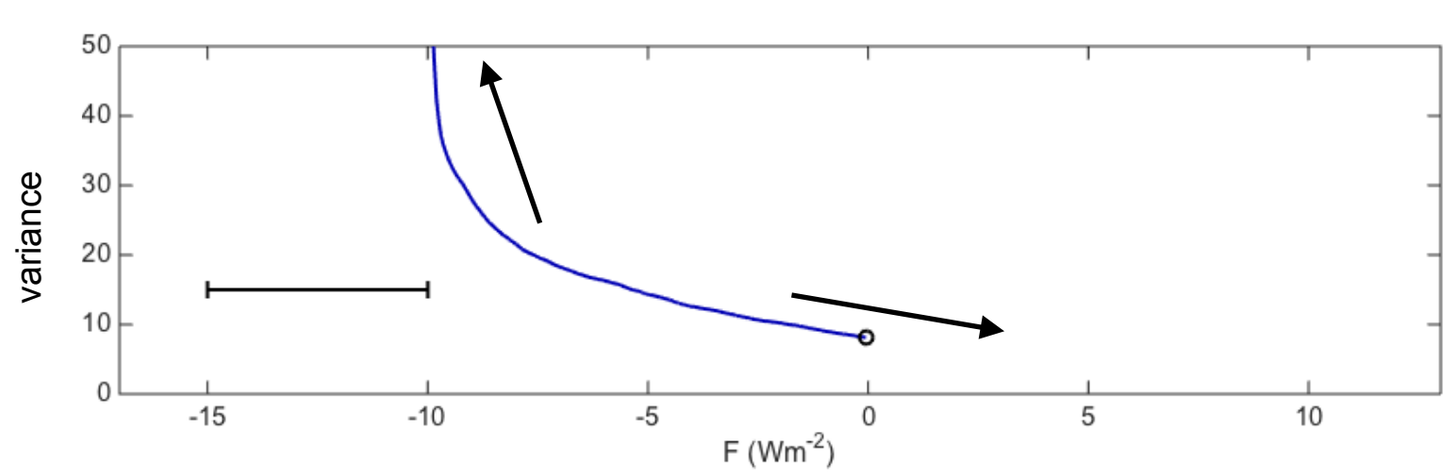
$$\frac{\partial E}{\partial t} = \underbrace{aS}_{\text{solar}} - \underbrace{(A+BT)}_{\text{OLR}} + \underbrace{D\nabla_x^2 T}_{\text{transport}} + \underbrace{F_b}_{\text{ocean heating}} + \underbrace{F}_{\text{climate forcing}} + \underbrace{N.}_{\text{noise}}$$

Snowball Earth

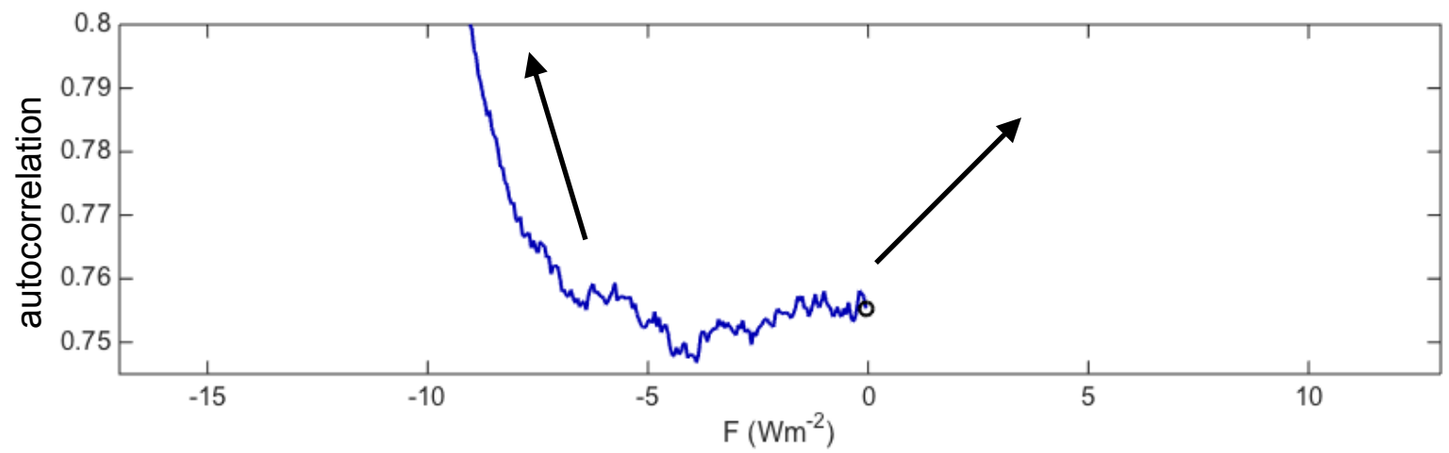


Ice-Free Earth

No Tipping Point Under Warming!

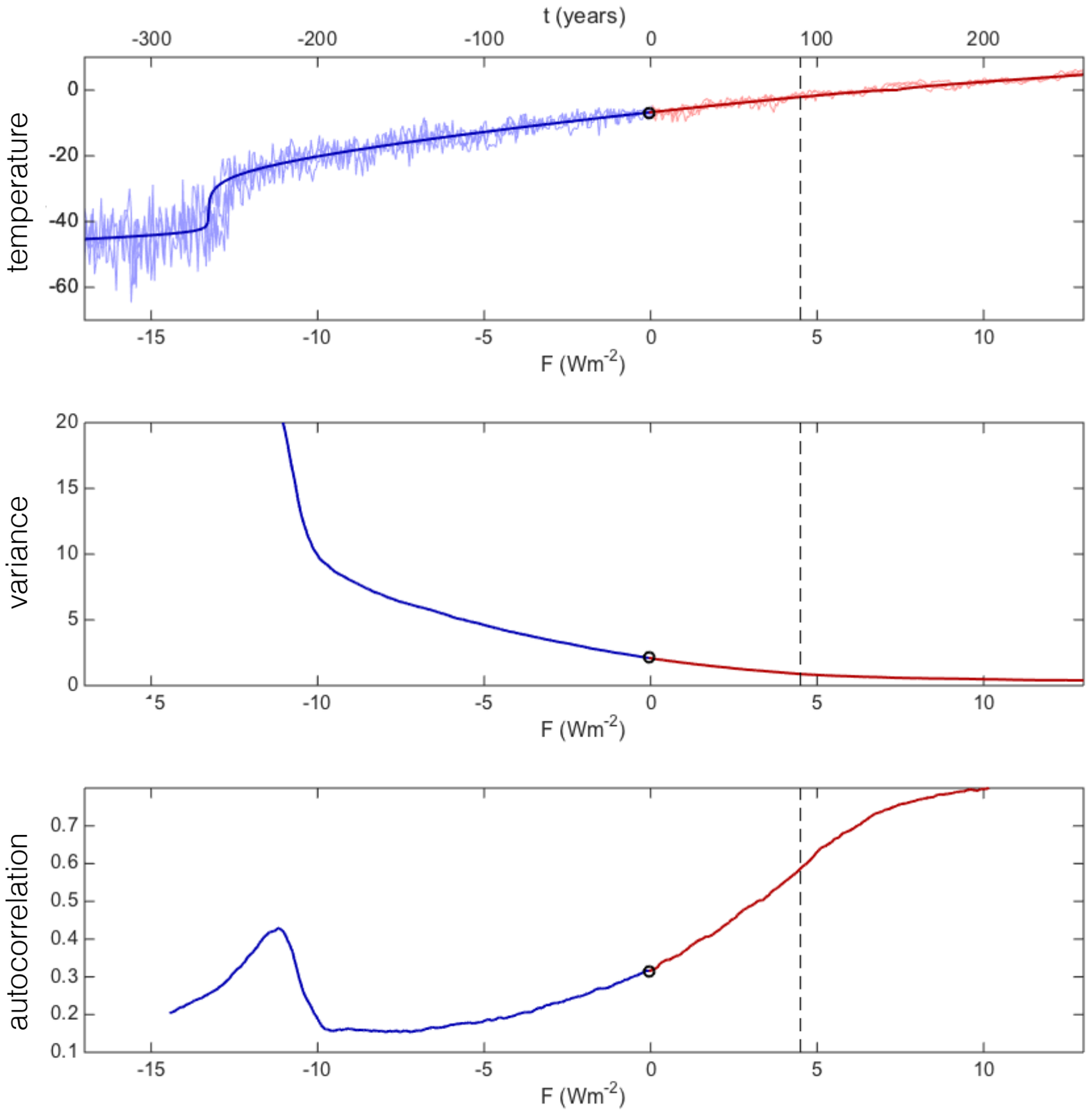


Steady Decrease in Variance



Increase in Autocorrelation!

The Same for Temperature at the Pole



- Clear Projection
- No spatial component

$$c\frac{dT}{dt} = aS - (A + BT) + F_b + F + N,$$

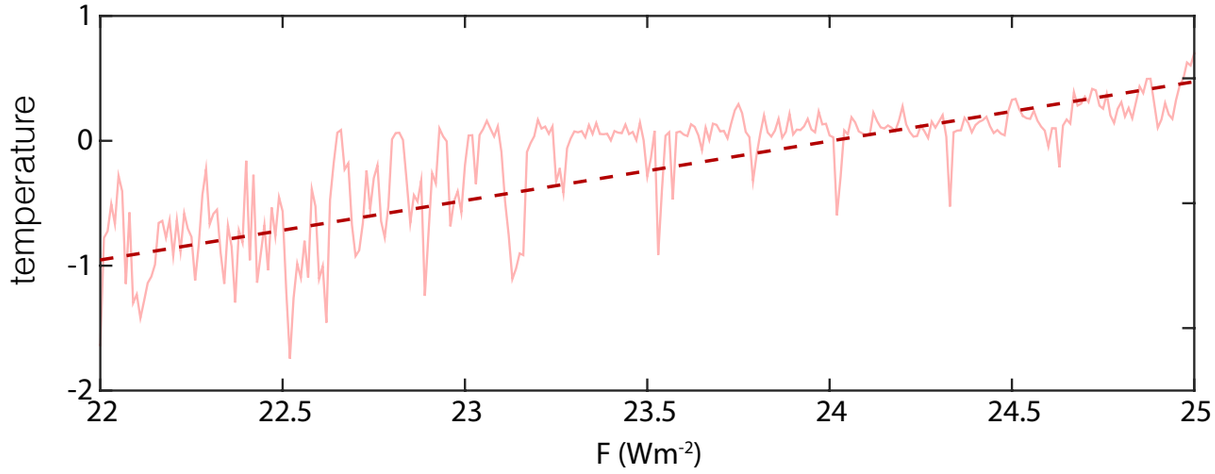
$$c = \begin{cases} c_w/5, & \text{for } T < 0 \text{ (“ice”)} \\ c_w, & \text{for } T > 0 \text{ (“water”)} \end{cases}$$

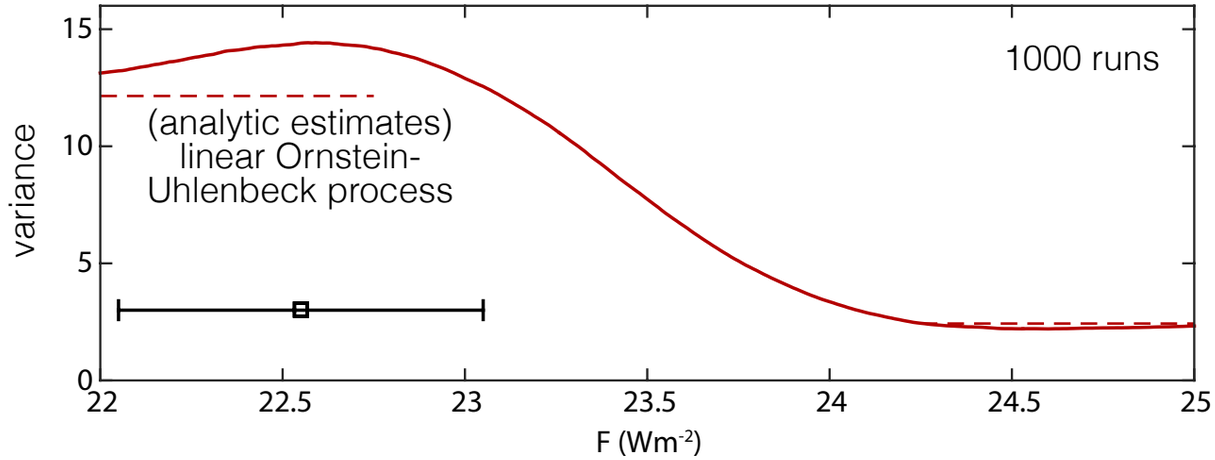
- no albedo jump
- no seasonal dependence
- no spatial dependence
- no jump in state

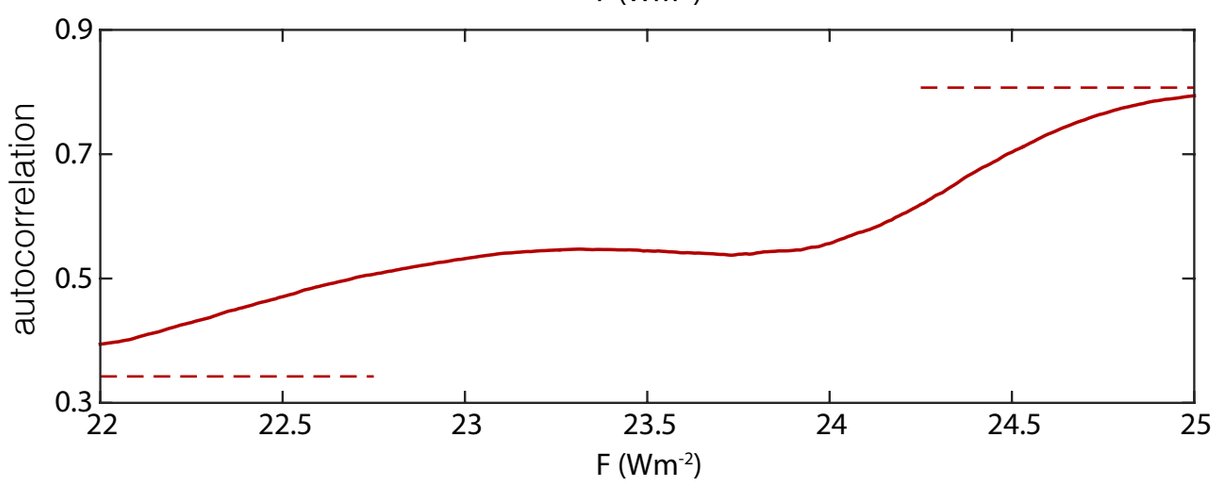
yet:

- rising autocorrelation

↳ due to change in the physical conditions, not a transition to a different stable state







$$c_w \frac{d\tilde{T}}{dt} = aS - \varepsilon\sigma_S \tilde{T}^4 + F_b + F + N,$$

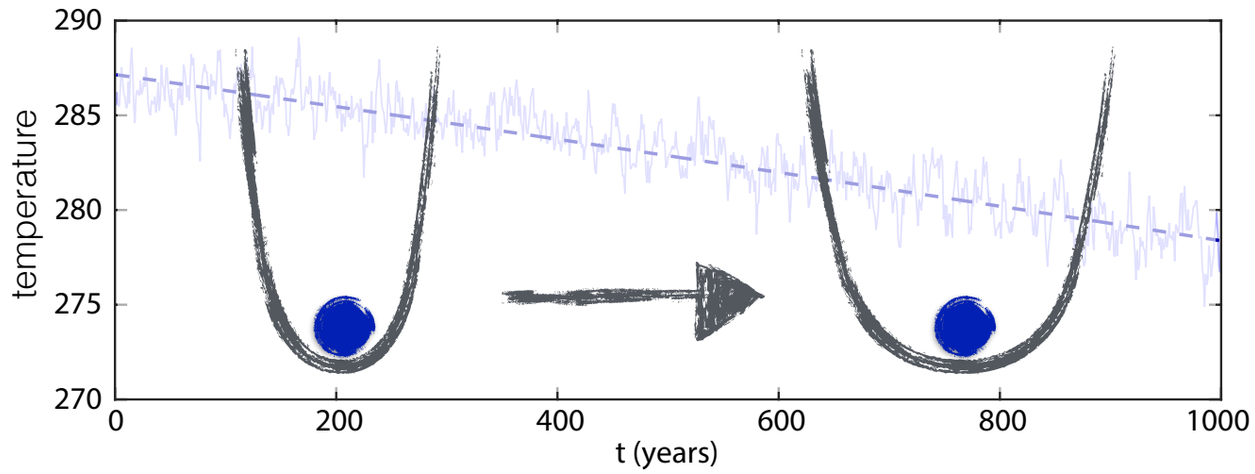
held constant

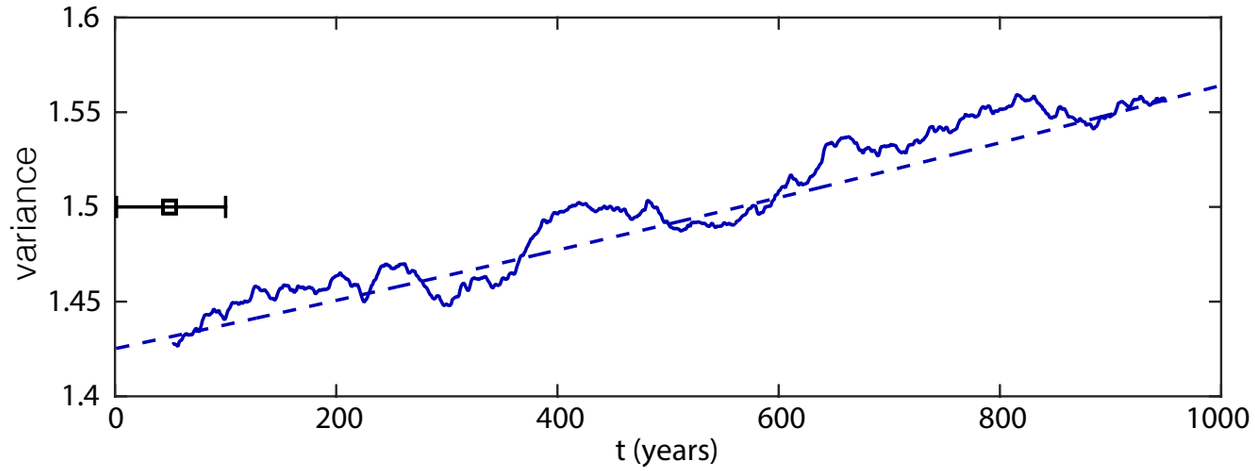
nonlinear Planck feedback

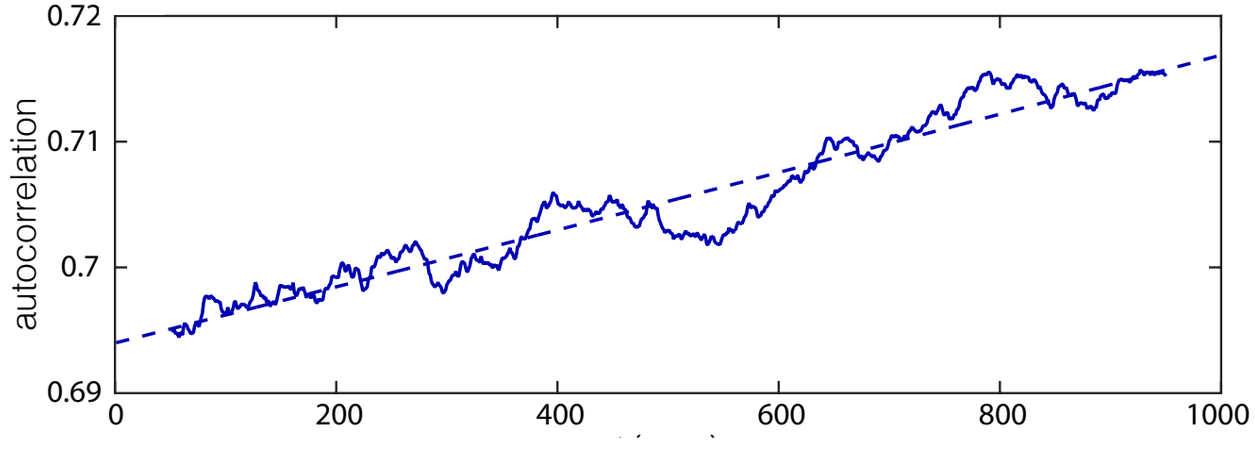
- no abrupt changes in the system

yet:

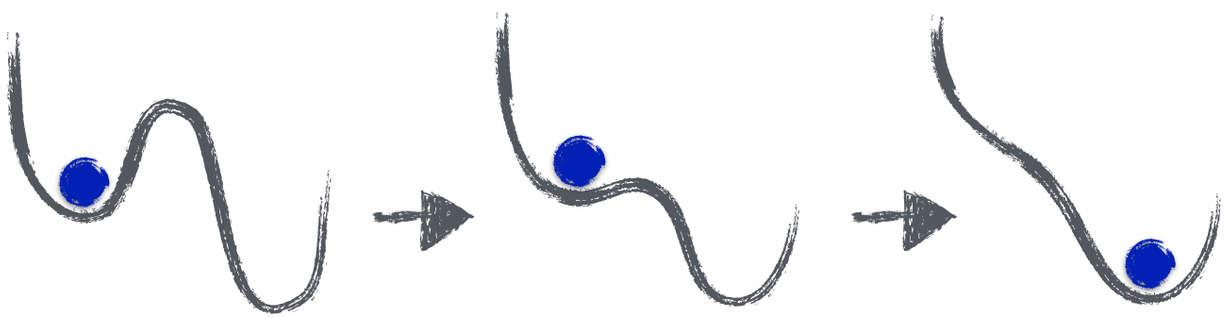
- increase in *both* variance and autocorrelation
- simple widening of the potential well



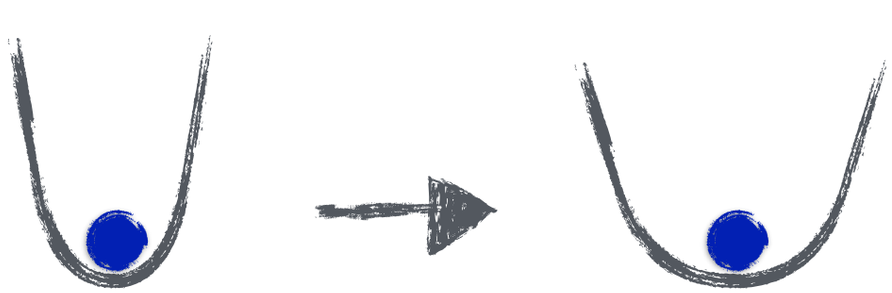




- Rise in autocorrelation is the leading candidate to act as an early warning indicator.



- Our model results find increasing autocorrelation *without* abrupt change.



- The slowing down is due to the physical system changing from *ice-covered* (fast response) to *open water* (slow response)

↳ may serve as a cautionary tale that the *underlying physics* may cause slow down without the system preparing to jump

FALSE ALARM