Tipping points in the Earth System

Climate Thursdays, SDU, Sept, 2023

Peter Ditlevsen, Niels Bohr Institute, University of Copenhagen

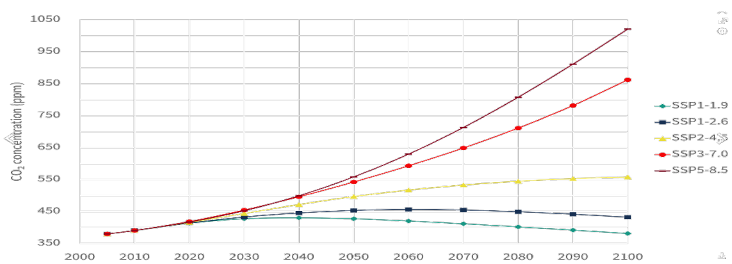
UNIVERSITY OF COPENHAGEN

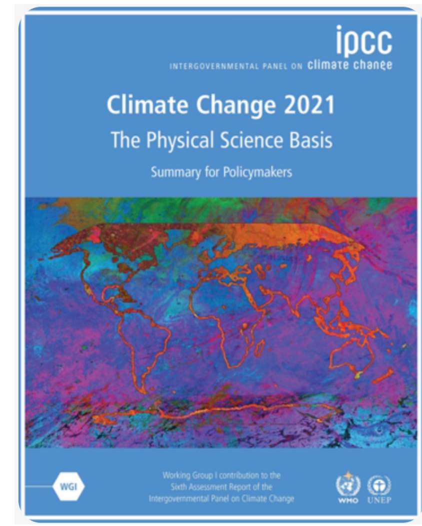
TIPPING POINTS IN THE EARTH SYSTEM

CriticalEarth

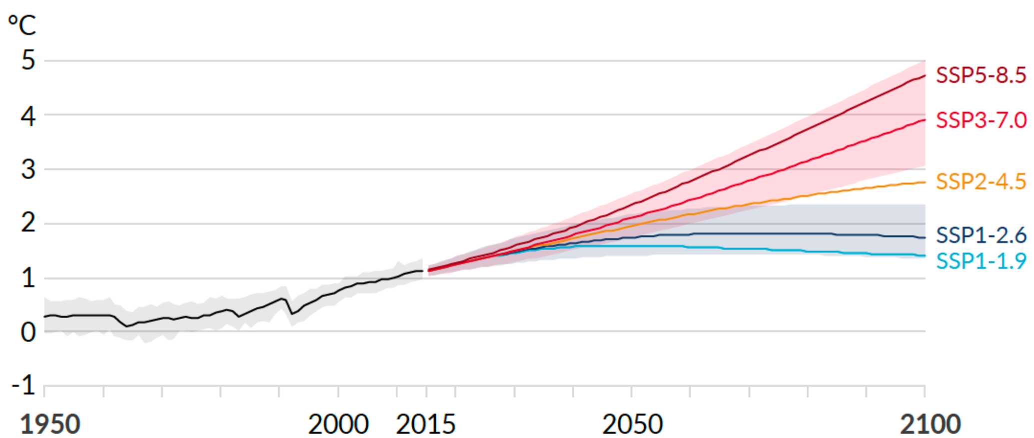
European Commission

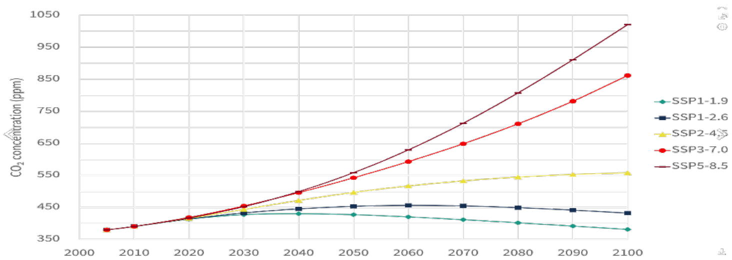
Horizon 2020
European Union funding
for Research & Innovation

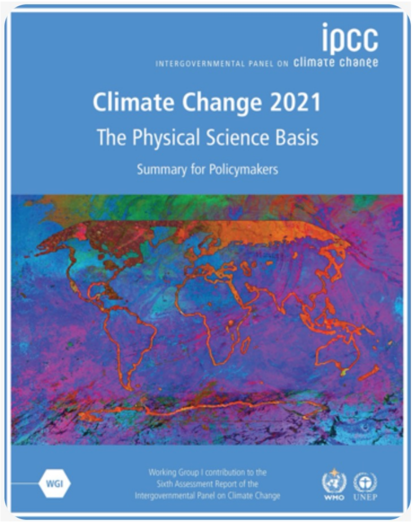




a) Global surface temperature change relative to 1850-1900







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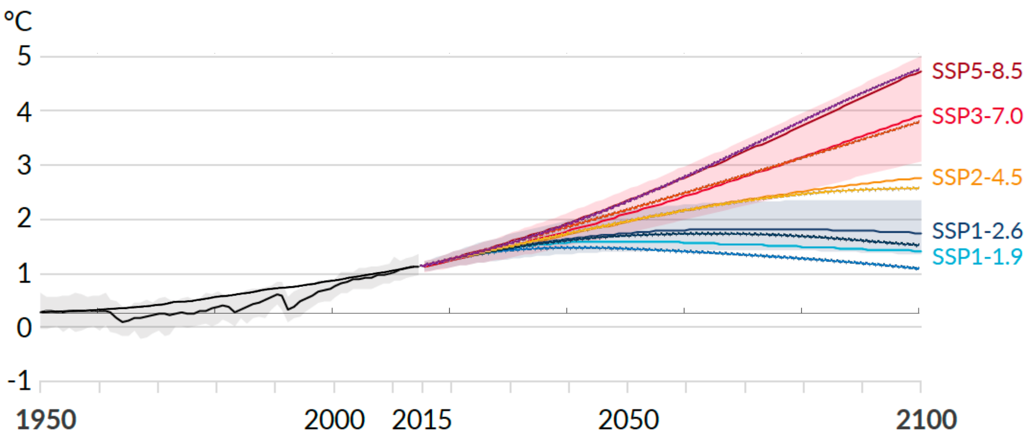


PNAS

PERSPECTIVE | EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES

Climate Endgame: Exploring catastrophic climate change scenarios

Luke Kemp, Chi Xu, Joanna Depledge, Kristie L. Ebi, Goodwin Gibbins, Timothy A. Kohler, Johan Rockström, Marten Scheffer, Hans Joachim Schellnhuber, Will Steffen, and Timothy M. Lenton -7 Authors

Abstract

Prudent risk management requires consideration of bad-to-worst-case scenarios. Yet, for climate change, such potential futures are poorly understood. Could anthropogenic climate change result in worldwide societal collapse or even eventual human extinction? At present, this is a dangerously underexplored topic. Yet there are ample
suspect that climate change could result in a global catastrophe. Analyzing the
mechanisms for these ex
resilience, and inform pol
knowledge about the like
bad-to-worst cases is vita
define key terms, and put
main questions: 1) What i
events? 2) What are the m
morbidity? 3) What are hu
such as from conflict, poli
multiple strands of evider
synthesized into an "integ
community to grapple wi
change.

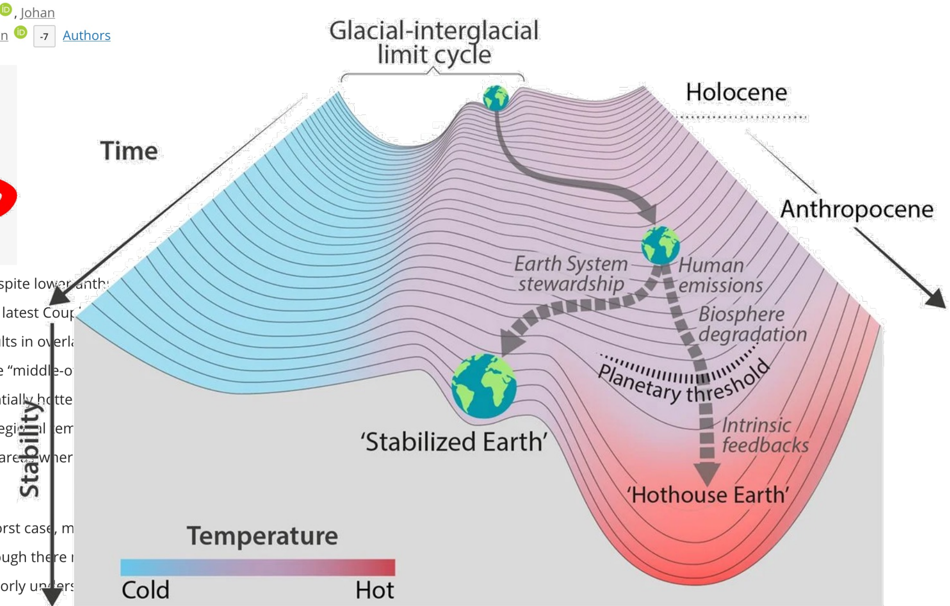
The potential for tipping points and higher concentrations despite lower anth
emissions is evident in existing models. Variability among the latest Coup
Intercomparison Project Phase 6 (CMIP6) climate models results in overla
scenarios. For example, the top (75th) quartile outcome of the "middle-o
(Shared Socioeconomic Pathway 3-7.0, or SSP3-7.0) is substantially hotte
(25th) quartile of the highest emissions (SSP5-8.5) scenario. Regional tem
between models can exceed 5 °C to 6 °C, particularly in polar areas wher
points can occur (*SI Appendix*).

There are even more uncertain feedbacks, which, in a very worst case, m
irreversible transition into a "Hothouse Earth" state (21) (although there
feedbacks that help buffer the Earth system). In particular, poorly unders
might trigger sudden and irreversible global warming (22). Such effects remain underexplored and largely speculative "unknown unknowns" that are still being discovered. For instance, recent simulations suggest that stratocumulus cloud decks might abruptly be lost at CO_2 concentrations that could be approached by the end of the century, causing an additional ~8 °C global warming (23). Large uncertainties about dangerous surprises are reasons to prioritize rather than neglect them.

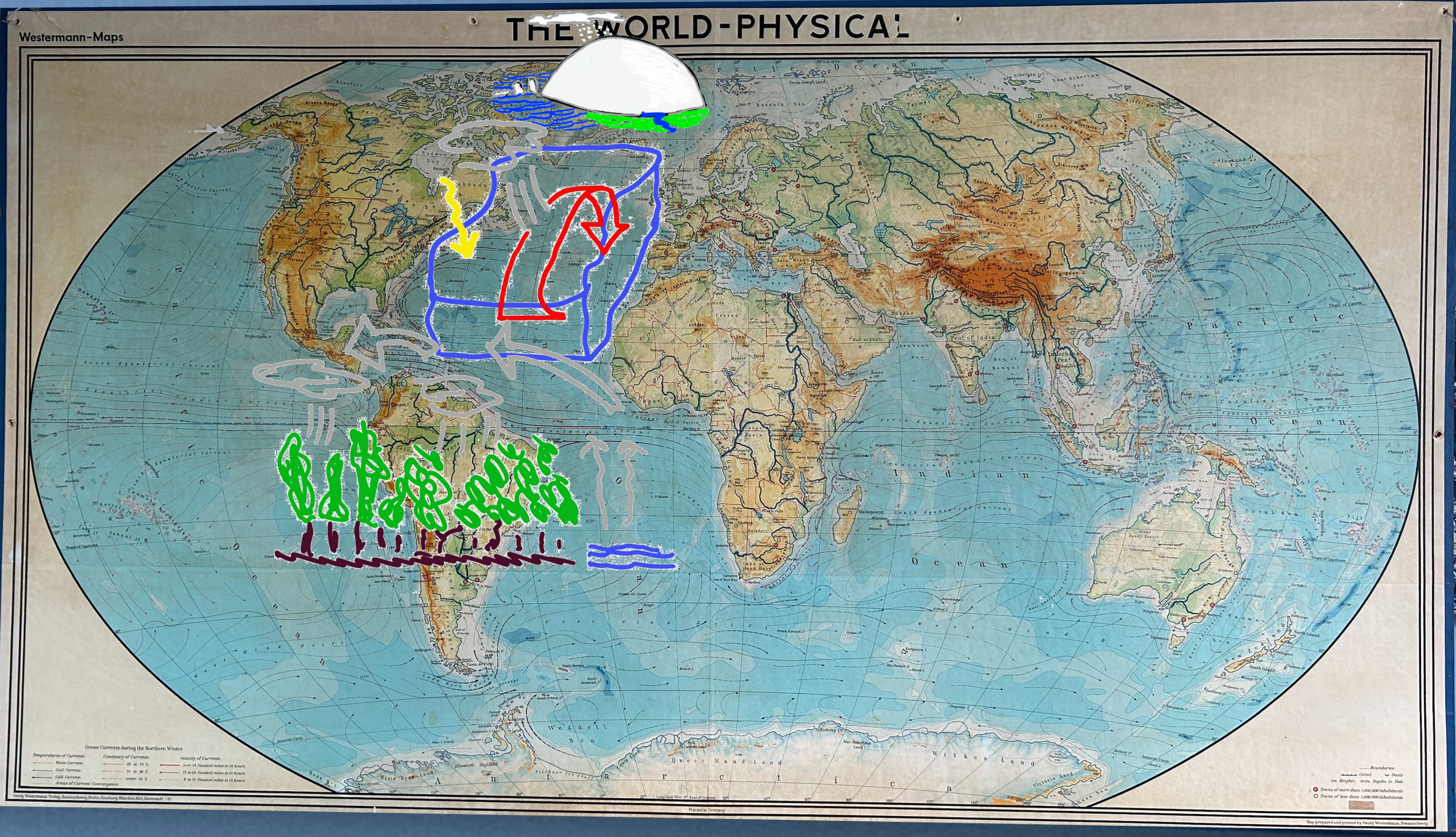
PERSPECTIVE | EARTH, ATMOSPHERIC, AND PLANETARY SCIENCES

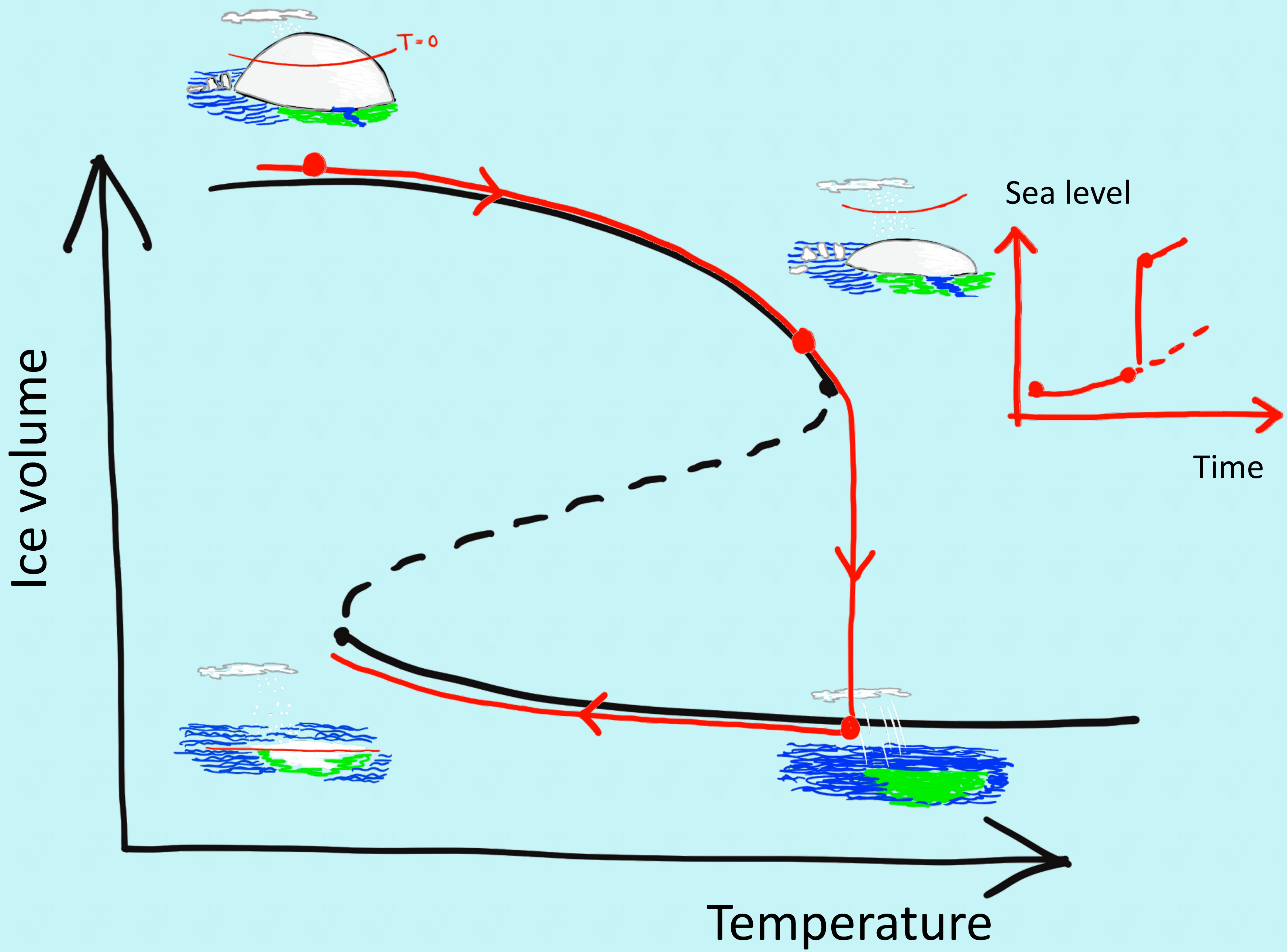
Trajectories of the Earth System in the Anthropocene

Will Steffen, Johan Rockström, Katherine Richardson, +12, and Hans Joachim Schellnhuber Authors In
Affiliations



Tipping elements





T=0
Sea level
Time
Ice volume
Temperature

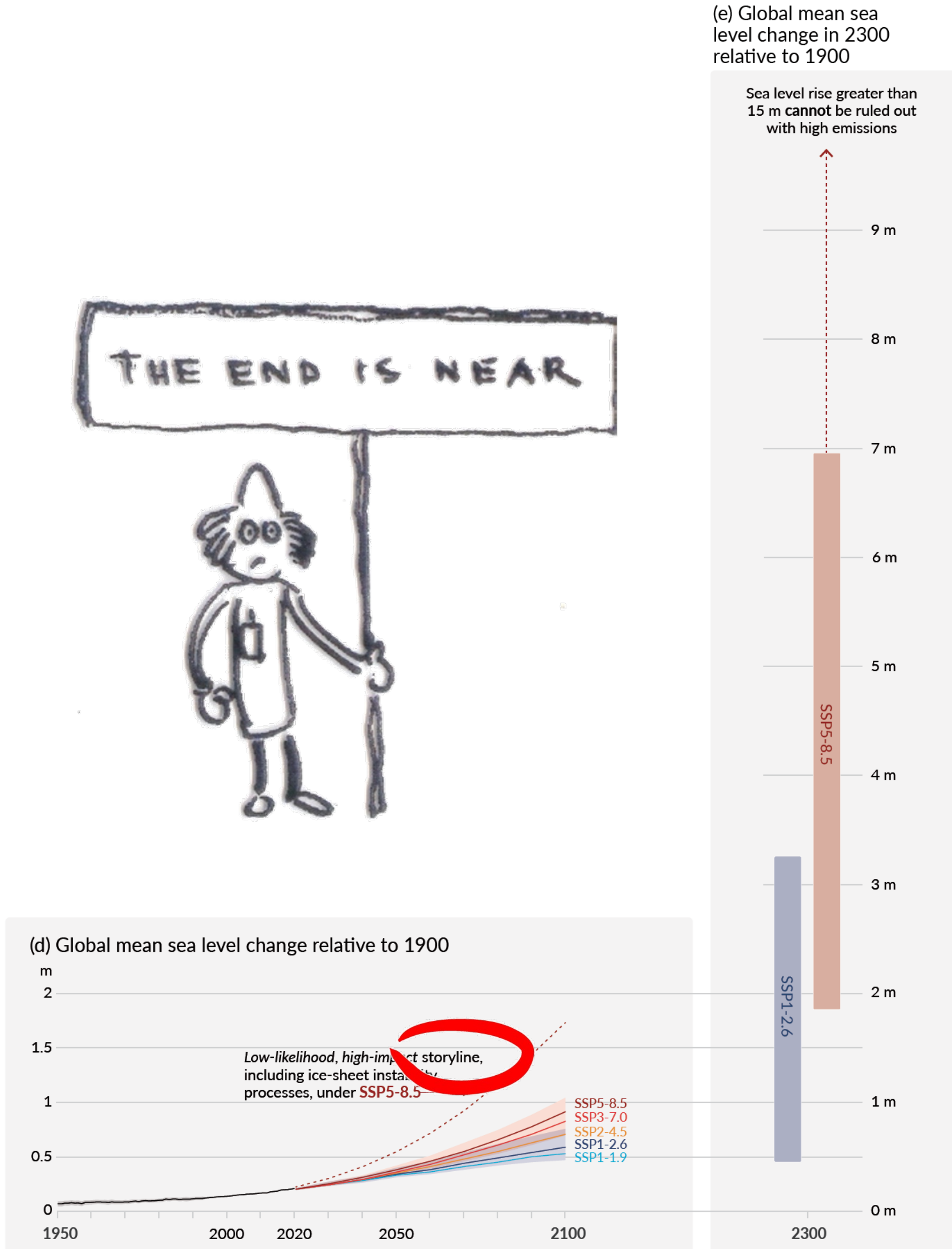
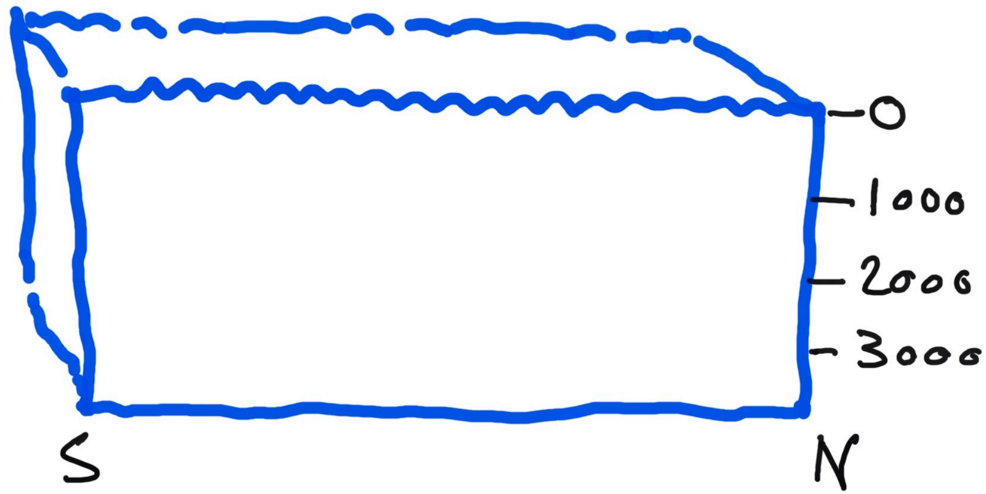
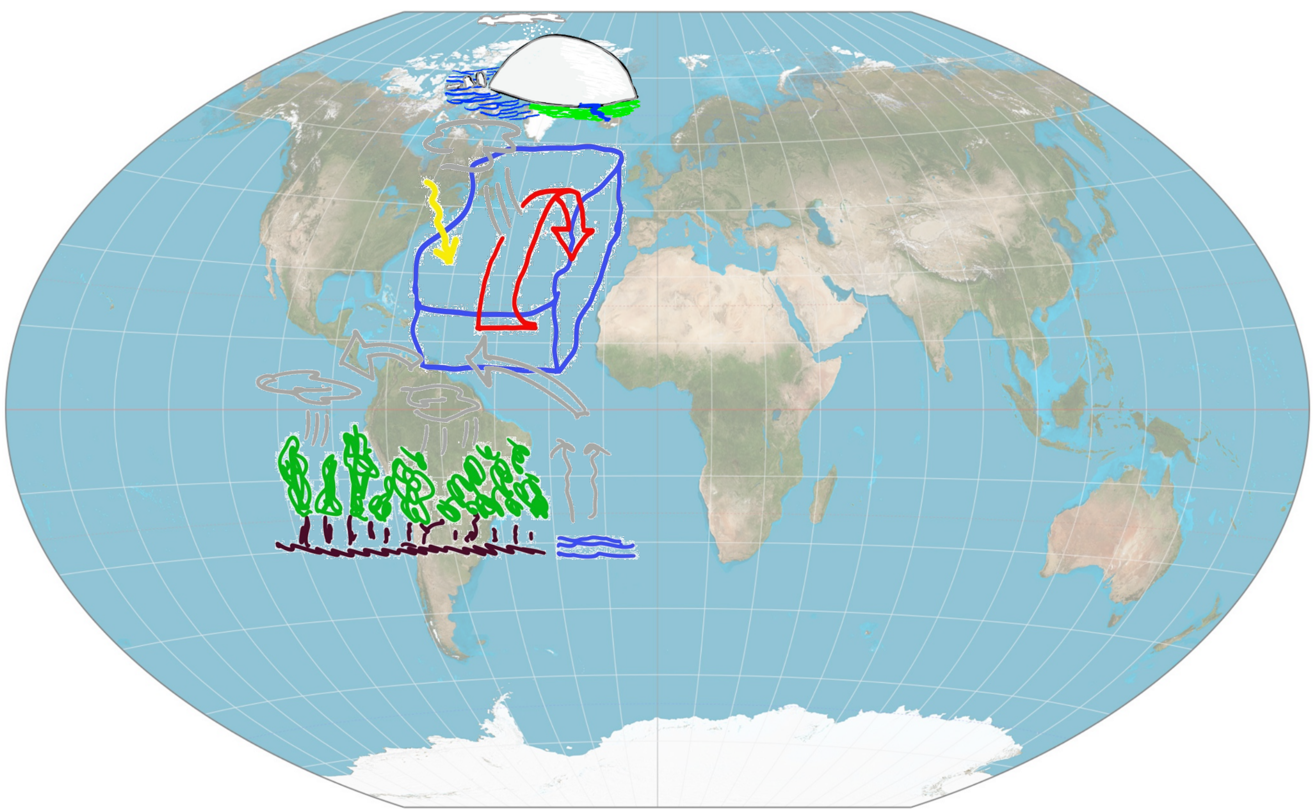


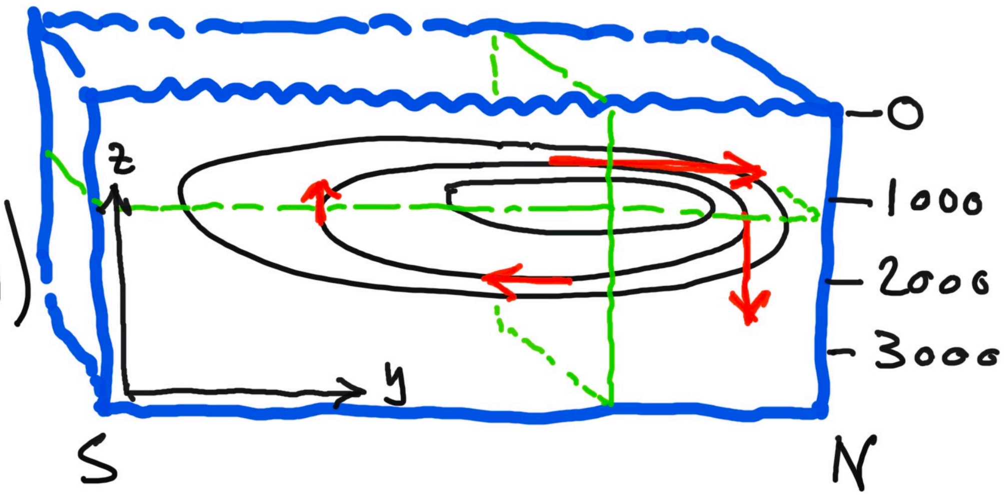
Figure SPM.8 | Selected indicators of global climate change under the five illustrative scenarios used in this Report

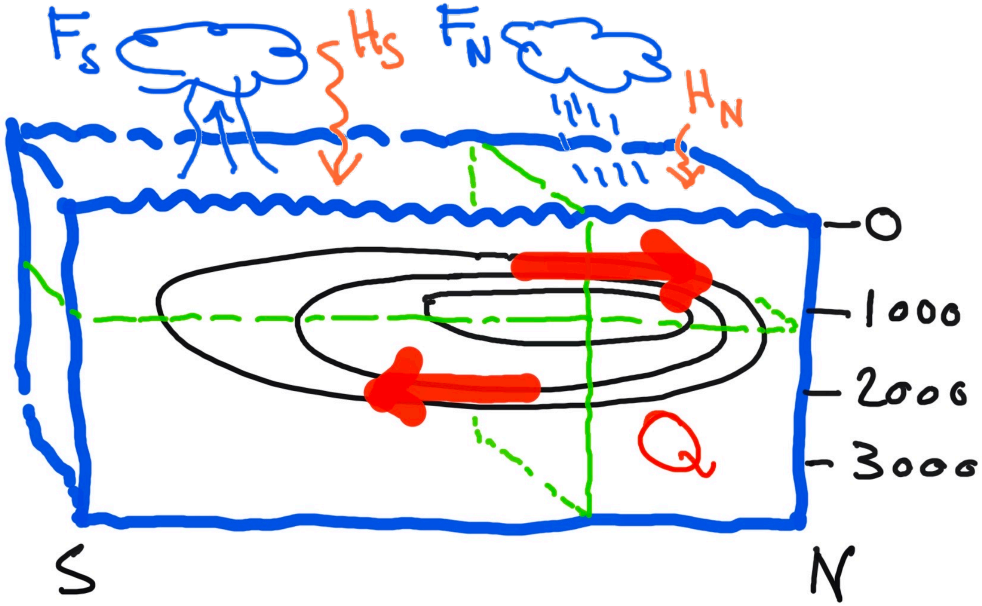

0
1000
2000
3000
S
N



$$\nabla \psi = \begin{pmatrix} \partial_y \psi \\ \partial_z \psi \end{pmatrix}$$

$$-\hat{\nabla} \psi = \begin{pmatrix} -\partial_z \psi \\ \partial_y \psi \end{pmatrix} = \begin{pmatrix} v \\ w \end{pmatrix}$$





$$\kappa_T \dot{T}_N = Q(\Delta\rho)(T_S - T_N) + H_N$$

$$\kappa_S \dot{S}_N = Q(\Delta\rho)(S_S - S_N) - F_N$$

$$\kappa_T \dot{T}_S = Q(\Delta\rho)(T_N - T_S) + H_S$$

$$\kappa_S \dot{S}_S = Q(\Delta\rho)(S_N - S_S) - F_S$$

density:

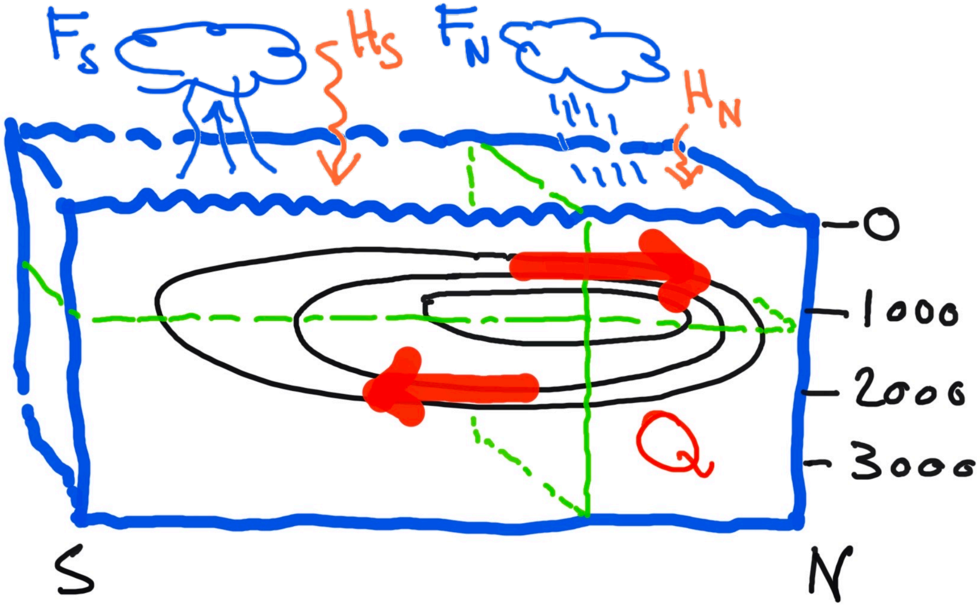
$$\rho(T,S) = \rho_0 - \alpha(T - T_0) + \beta(S - S_0)$$

$$\Delta\rho = -\alpha\Delta T + \beta\Delta S$$

$$\Delta T = T_S - T_N$$

$$\Delta S = S_S - S_N$$

$$Q(\Delta\rho) \sim (\Delta\rho)^2$$



density:

$$\rho(T,S) = \rho_0 - \alpha(T-T_0) + \beta(S-S_0)$$

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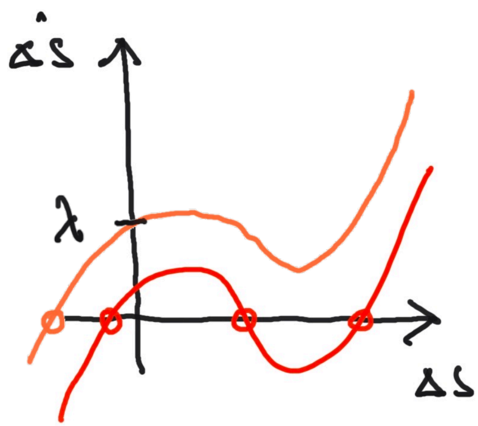
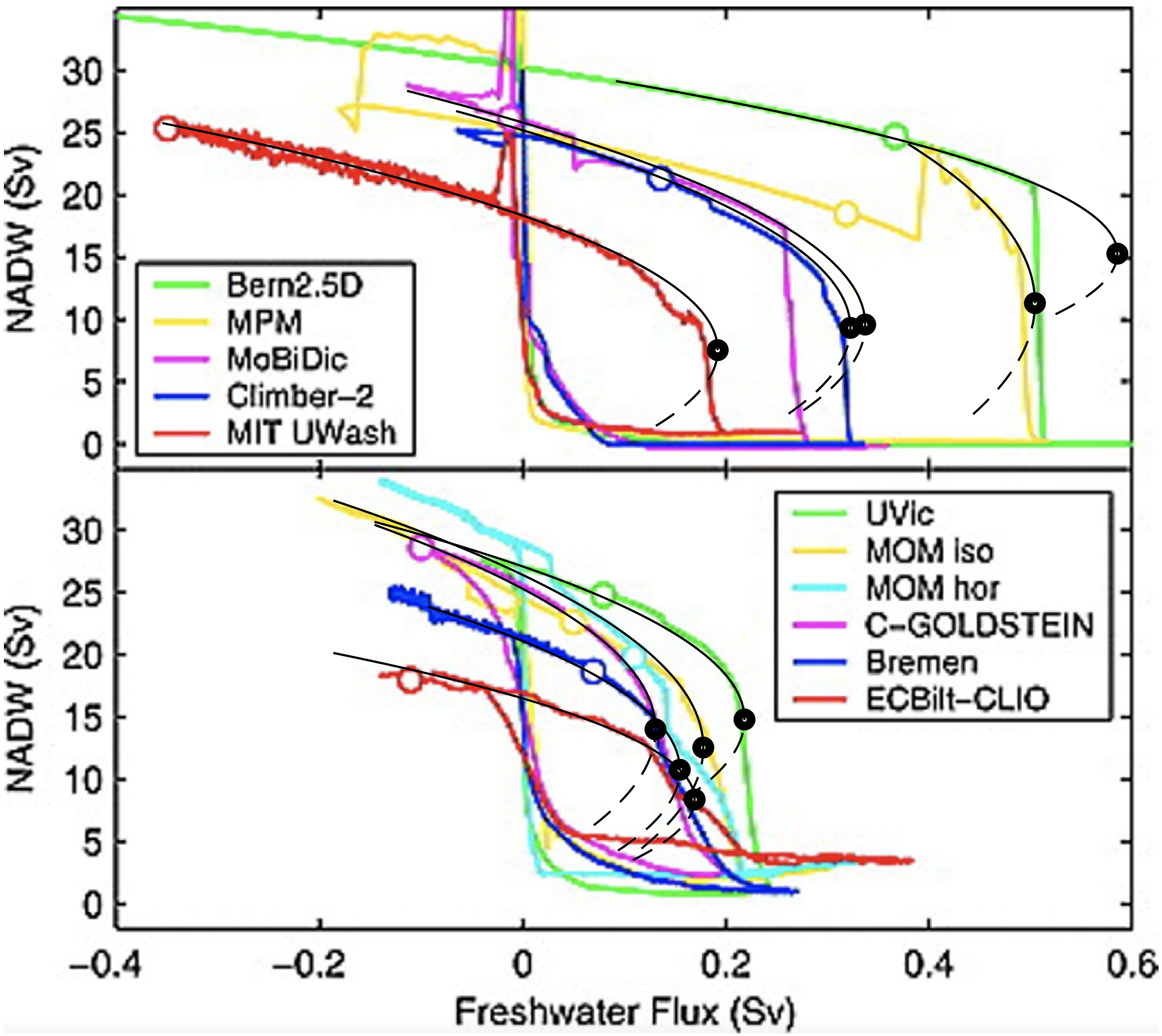


$$\dot{\Delta S} = -A\,\Delta S^3 + B\,\Delta S + \lambda$$


Bern2.5D
MPM
MoBiDic
Climber-2
MIT UWash
UVic
MOM iso
MOM hor
C-GOLDSTEIN
Bremen
ECBilt-CLIO
NADW (Sv)
NADW (Sv)
Freshwater Flux (Sv)
30
25
20
15
10
5
0
30
25
20
15
10
5
0
−0.4
−0.2
0
0.2
0.4
0.6

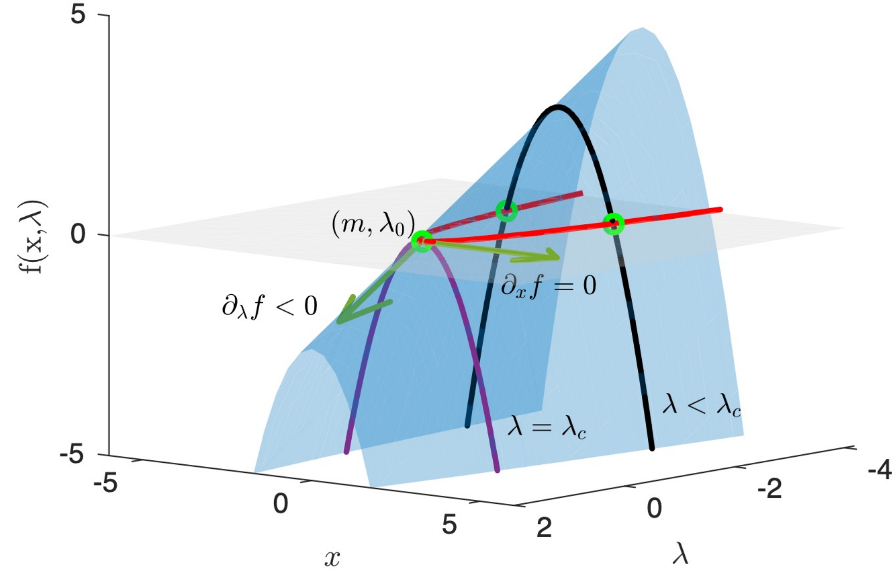
$$dx = f(x,\lambda)\,dt + \sigma\, dB$$

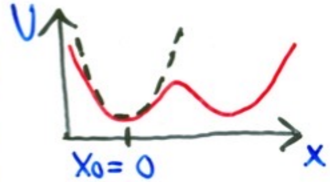
$$dx = -(x^2+\lambda)\,dt + \sigma\, dB$$

$$x_c = \sqrt{-\lambda}$$

$$dx = -2\sqrt{-\lambda}\, x\, dt + \sigma\, dB$$

$$\alpha = 2\sqrt{-\lambda}$$





$$\dot{x} = -\frac{dU}{dx} + \sigma\eta$$

$$\frac{x_{n+1} - x_n}{\Delta t} = f(x_n) + \sigma\varepsilon_{n+1}$$

Linear Approximation: $f(x) \simeq f(x_0) - \alpha(x - x_0) = -\alpha x$

$$-\alpha = \left.\frac{df}{dx}\right|_{x_0} = -\left.\frac{d^2U}{dx^2}\right|_{x_0}$$

$$x_{n+1} = (1 - \alpha\Delta t)x_n + \sigma\varepsilon_{n+1} \quad \text{(AR(1) process)}$$

Variance & Noise intensity

$$\langle x_{n+1}^2\rangle = \langle((1-\alpha\Delta t)x_n + \sigma\varepsilon_{n+1})^2\rangle$$

$$= (1-\alpha\Delta t)^2\langle x_n^2\rangle + \sigma^2\langle\varepsilon_{n+1}^2\rangle + 2(1-\alpha\Delta t)\sigma\langle x_n\varepsilon_{n+1}\rangle$$

$$= \langle x_n^2\rangle - (2\alpha\langle x_n^2\rangle - \sigma^2)\Delta t \; (+\alpha^2\Delta t^2\langle x_n^2\rangle)$$

$$\Rightarrow \boxed{\langle x_n^2\rangle = \frac{\sigma^2}{2\alpha}} \quad \text{Fluctuation-Dissipation Theorem}$$

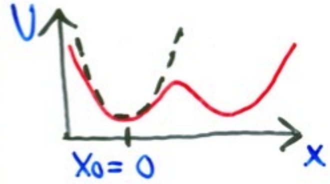
Autocorrelation

$$c(1) = \langle x_{n+1}x_n\rangle = \langle((1-\alpha\Delta t)x_n + \sigma\varepsilon_{n+1})x_n\rangle$$

$$= (1-\alpha\Delta t)\langle x_n^2\rangle = (1-\alpha\Delta t)\,c(0)$$

$$c(k) = \langle x_{n+k}x_n\rangle = \dots = (1-\alpha\Delta t)^k c(0)$$

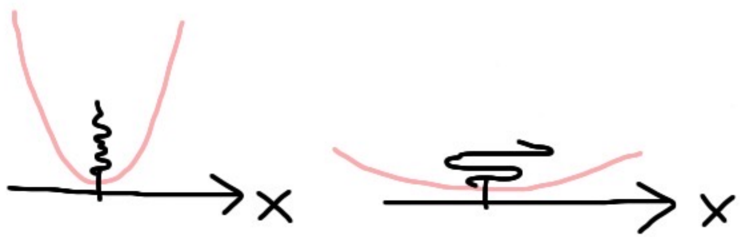
$$\Rightarrow \boxed{c(t) = c(0)\,e^{-\alpha|t|} = \langle x^2\rangle\, e^{-\alpha|t|}}$$



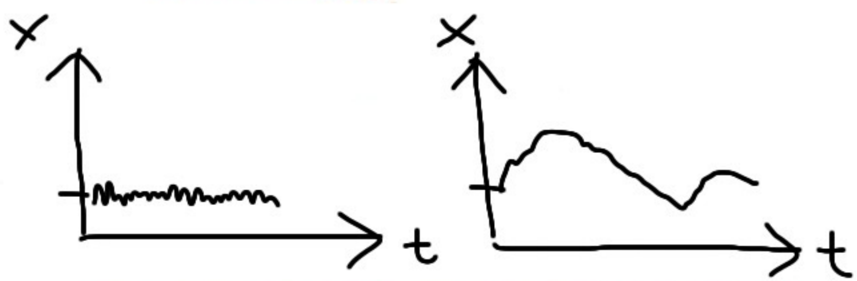
$$\dot{x} = -\frac{dU}{dx} + \sigma \eta$$

$$\frac{x_{n+1} - x_n}{\Delta t} = f(x_n) + \sigma \varepsilon_{n+1}$$

α large $\qquad$ α small



$$\langle x_n^2 \rangle = \frac{\sigma^2}{2\alpha}$$



$$c(t) = c(0)\, e^{-\alpha |t|} = \langle x^2 \rangle\, e^{-\alpha |t|}$$

$$dx = -(x^2 + \lambda)dt + \sigma\, dB$$

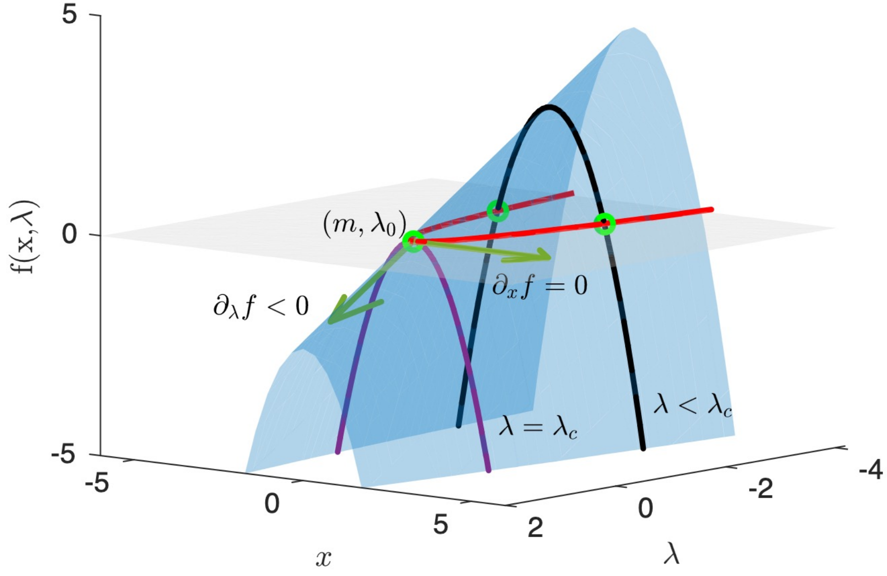
$$x_c = \sqrt{-\lambda}$$

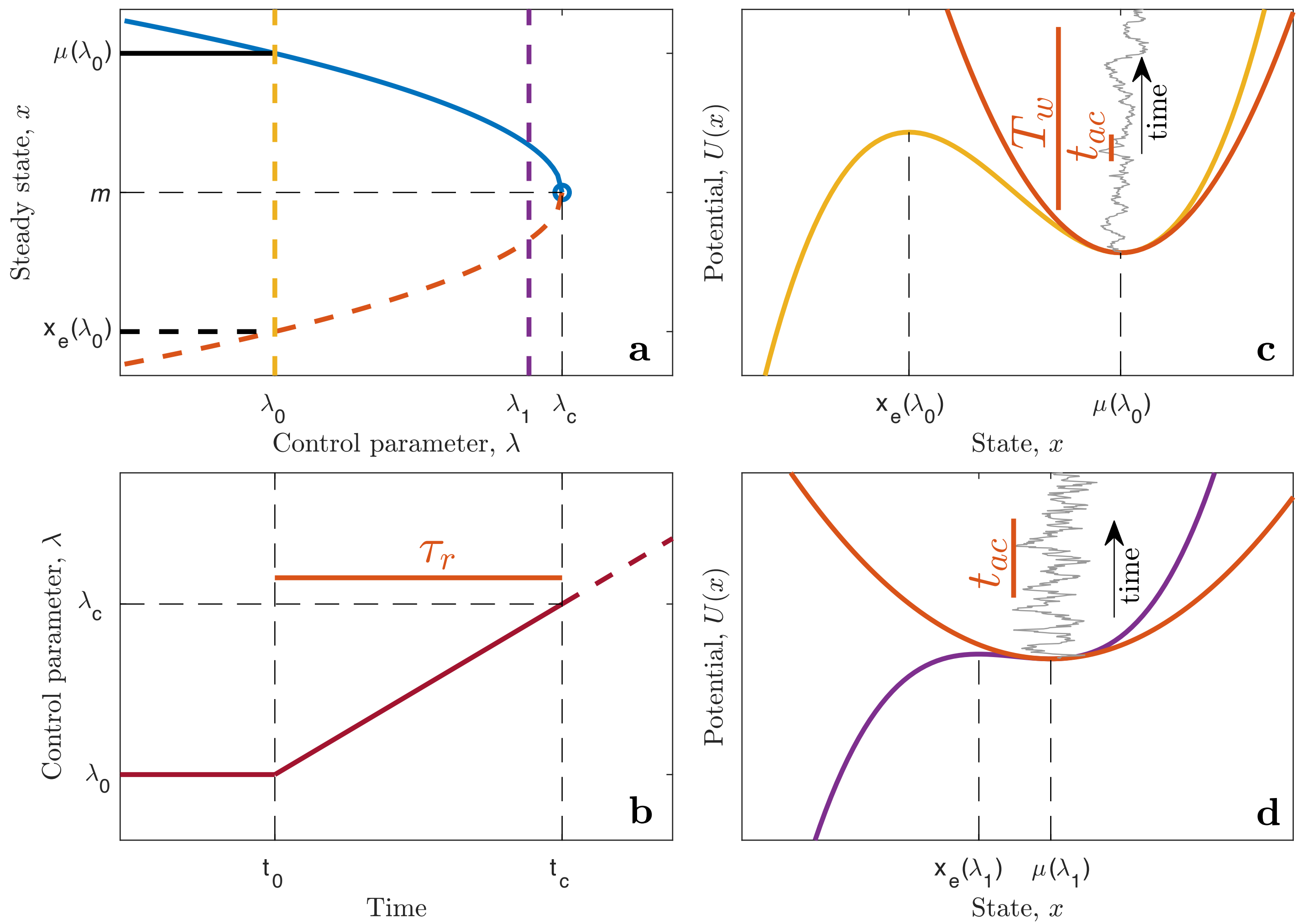
$$dx = -2\sqrt{-\lambda}\, x\, dt + \sigma\, dB$$

$$\alpha = 2\sqrt{-\lambda}$$

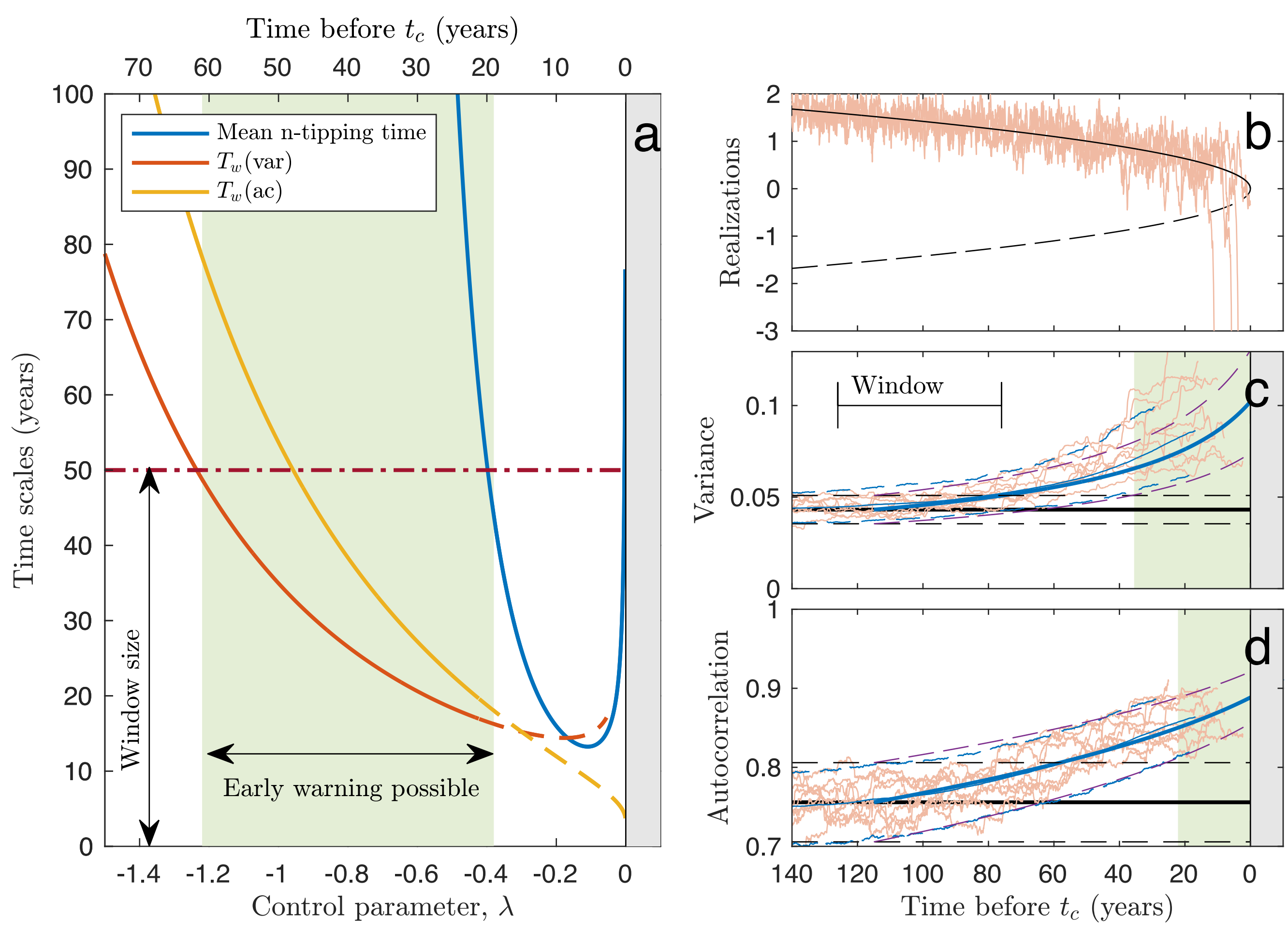
$$C(t) = C(0)e^{-\alpha|t|}$$

$$\langle x^2 \rangle = \frac{\sigma^2}{2\alpha}$$

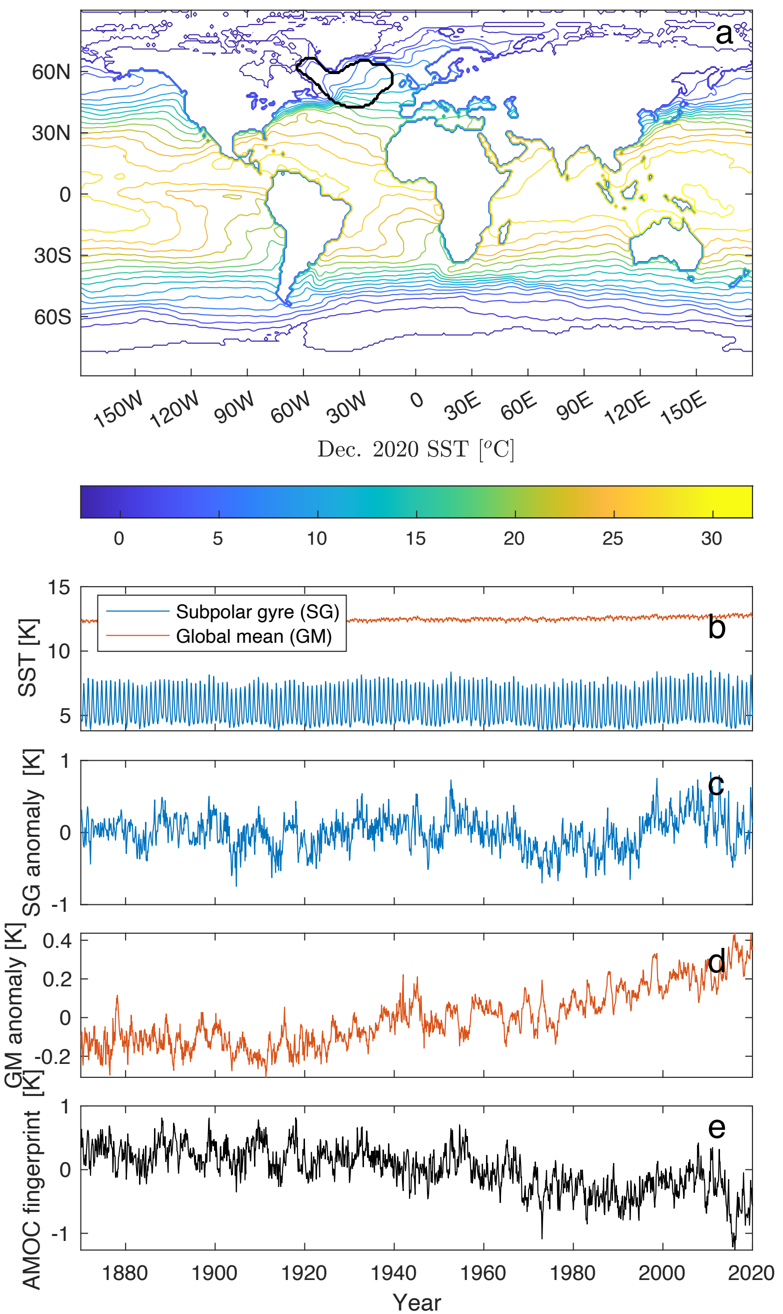




Steady state, x
$\mu(\lambda_0)$
m
$x_e(\lambda_0)$
λ_0
λ_1
λ_c
Control parameter, λ
a
Potential, $U(x)$
T_w
t_{ac}
time
$x_e(\lambda_0)$
$\mu(\lambda_0)$
State, x
c
Control parameter, λ
λ_c
λ_0
τ_r
t_0
t_c
Time
b
Potential, $U(x)$
t_{ac}
time
$x_e(\lambda_1)$
$\mu(\lambda_1)$
State, x
d



Time before t_c (years)
70 60 50 40 30 20 10 0
100 90 80 70 60 50 40 30 20 10 0
Mean n-tipping time
T_w(var)
T_w(ac)
a
Time scales (years)
Window size
Early warning possible
-1.4 -1.2 -1 -0.8 -0.6 -0.4 -0.2 0
Control parameter, λ
b
Realizations
2 1 0 -1 -2 -3
c
Window
Variance
0.1 0.05 0
d
Autocorrelation
1 0.9 0.8 0.7
140 120 100 80 60 40 20 0
Time before t_c (years)

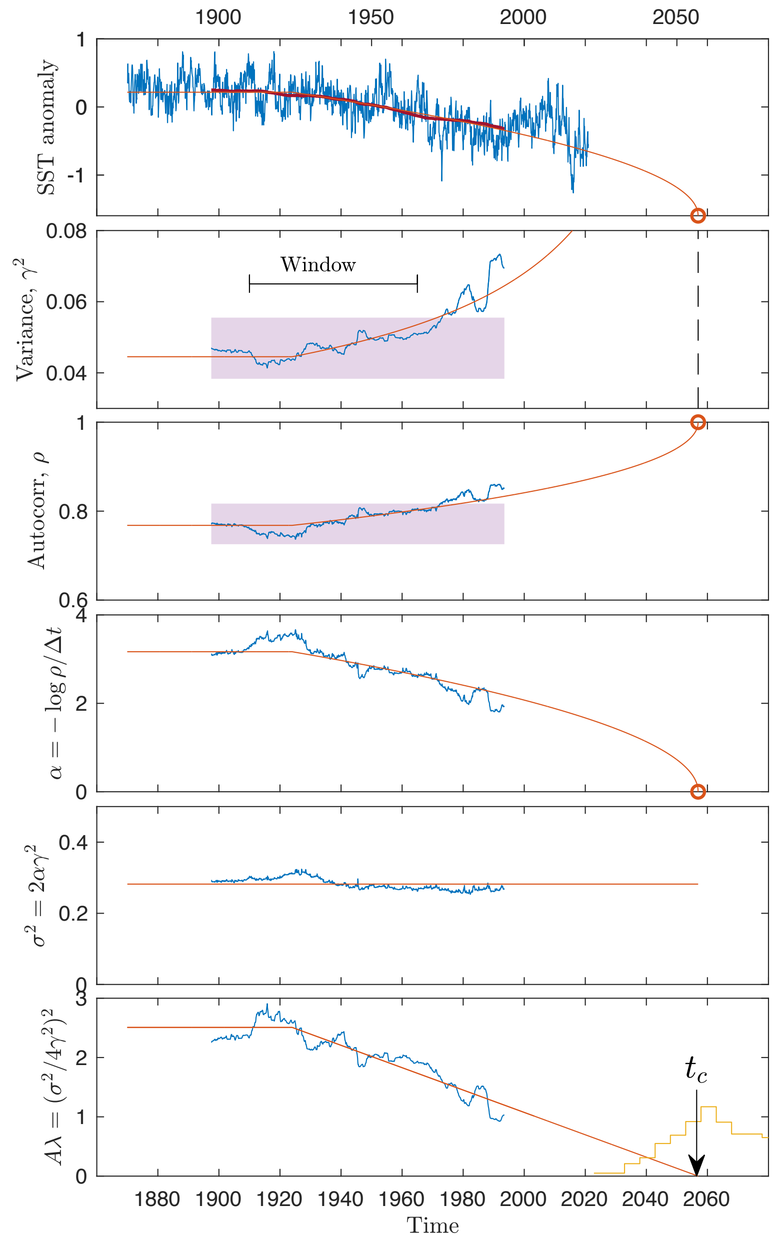


a
60N
30N
0
30S
60S
150W
120W
90W
60W
30W
0
30E
60E
90E
120E
150E
Dec. 2020 SST [^{o}C]
0
5
10
15
20
25
30
b
SST [K]
Subpolar gyre (SG)
Global mean (GM)
c
SG anomaly [K]
d
GM anomaly [K]
e
AMOC fingerprint [K]
1880
1900
1920
1940
1960
1980
2000
2020
Year

$$\alpha = 2\sqrt{-\lambda}$$

$$\langle x^2 \rangle = \frac{\sigma^2}{2\alpha}$$

$$C(t) = C(0)\, e^{-\alpha |t|}$$



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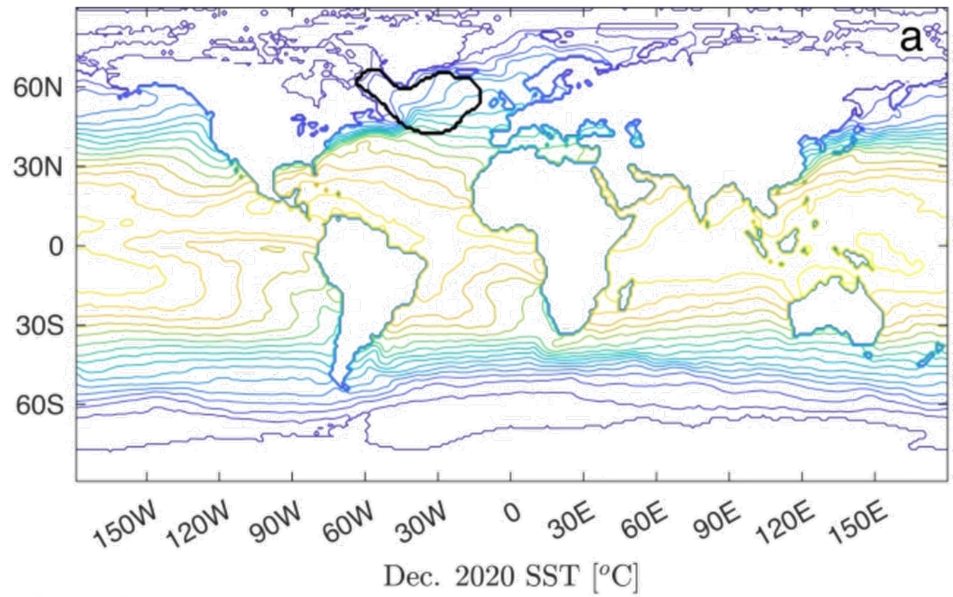
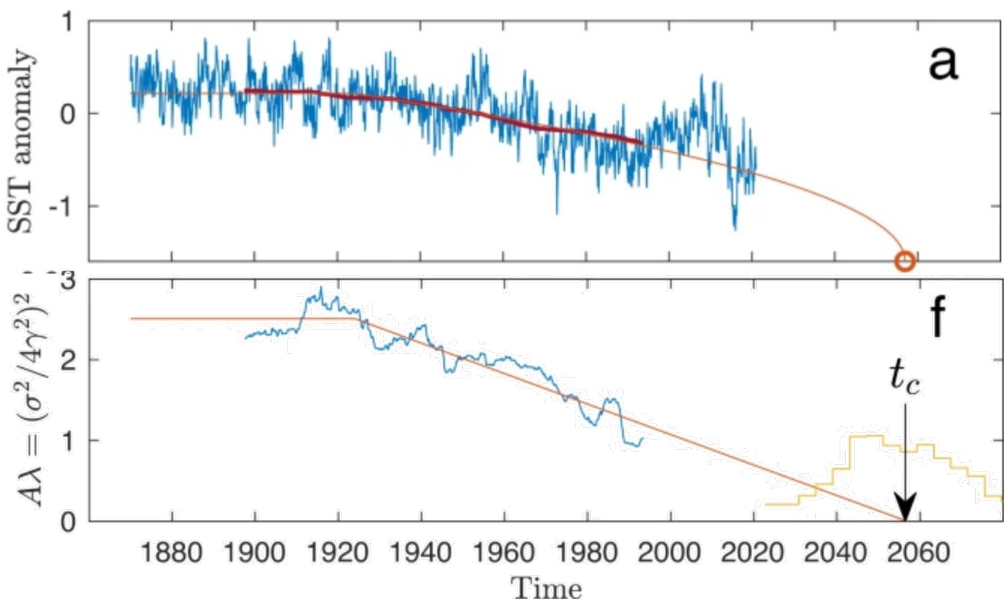
Warning of a forthcoming collapse of the Atlantic meridional overturning circulation

Peter Ditlevsen & Susanne Ditlevsen

Nature Communications **14**, Article number: 4254 (2023) | Cite this article





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Warning of a forthcoming collapse of the Atlantic meridional overturning circulation

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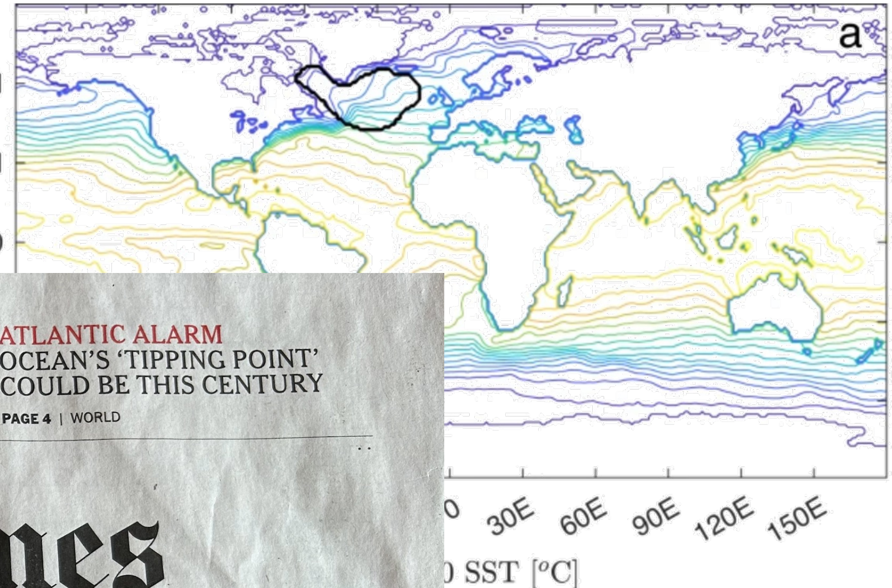

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By Sarah Kaplan

July 25, 2023 at 11:02 a.m. EDT

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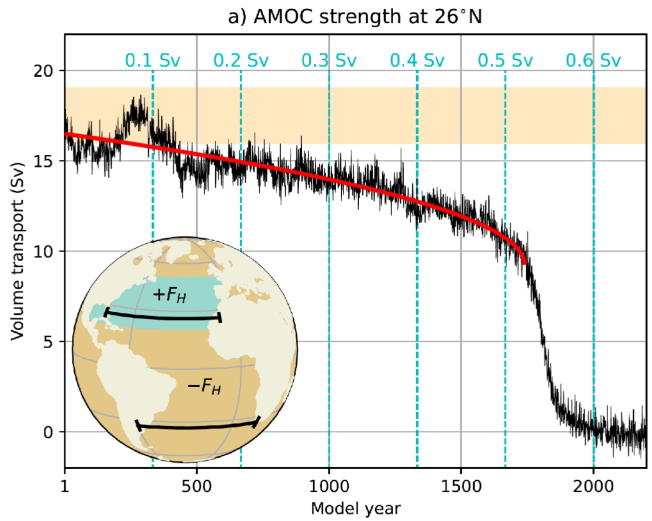

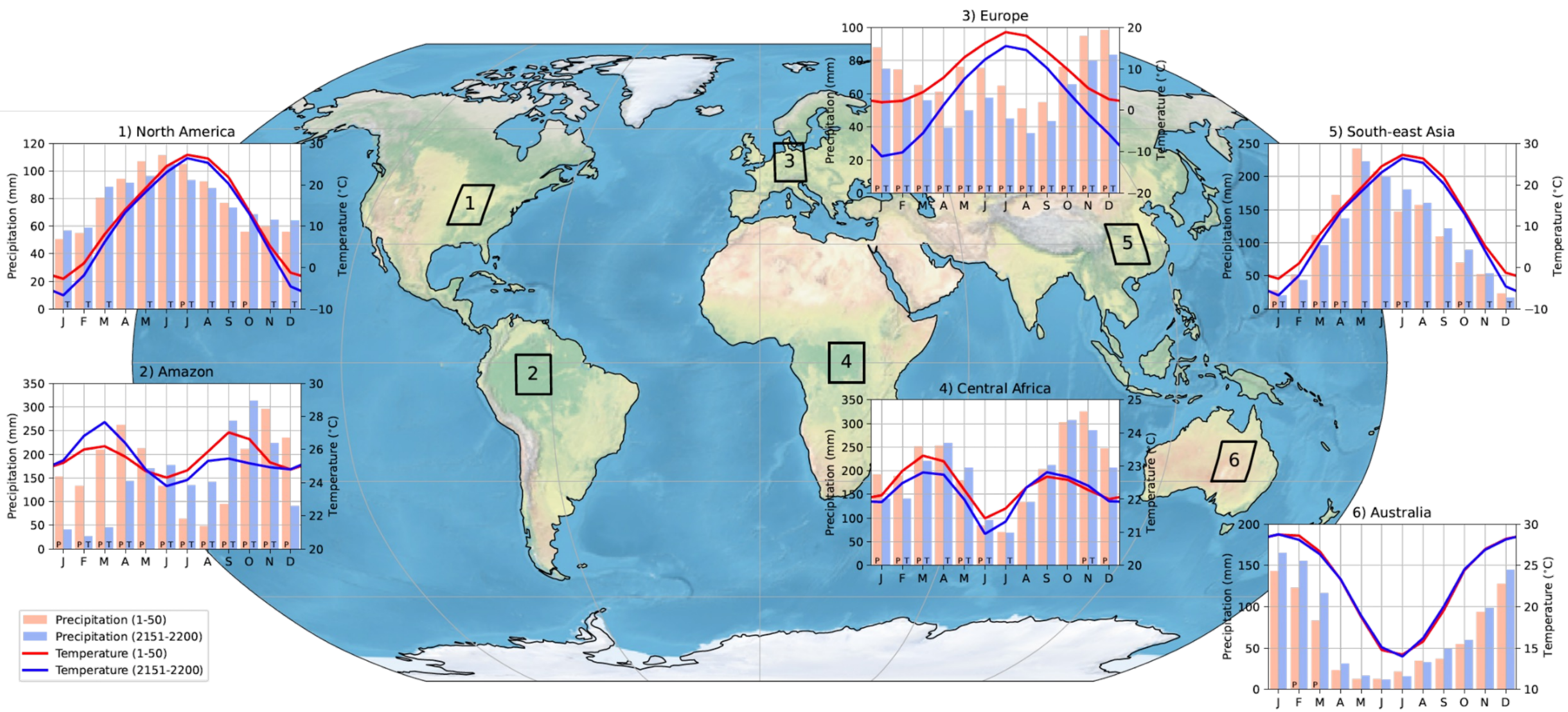

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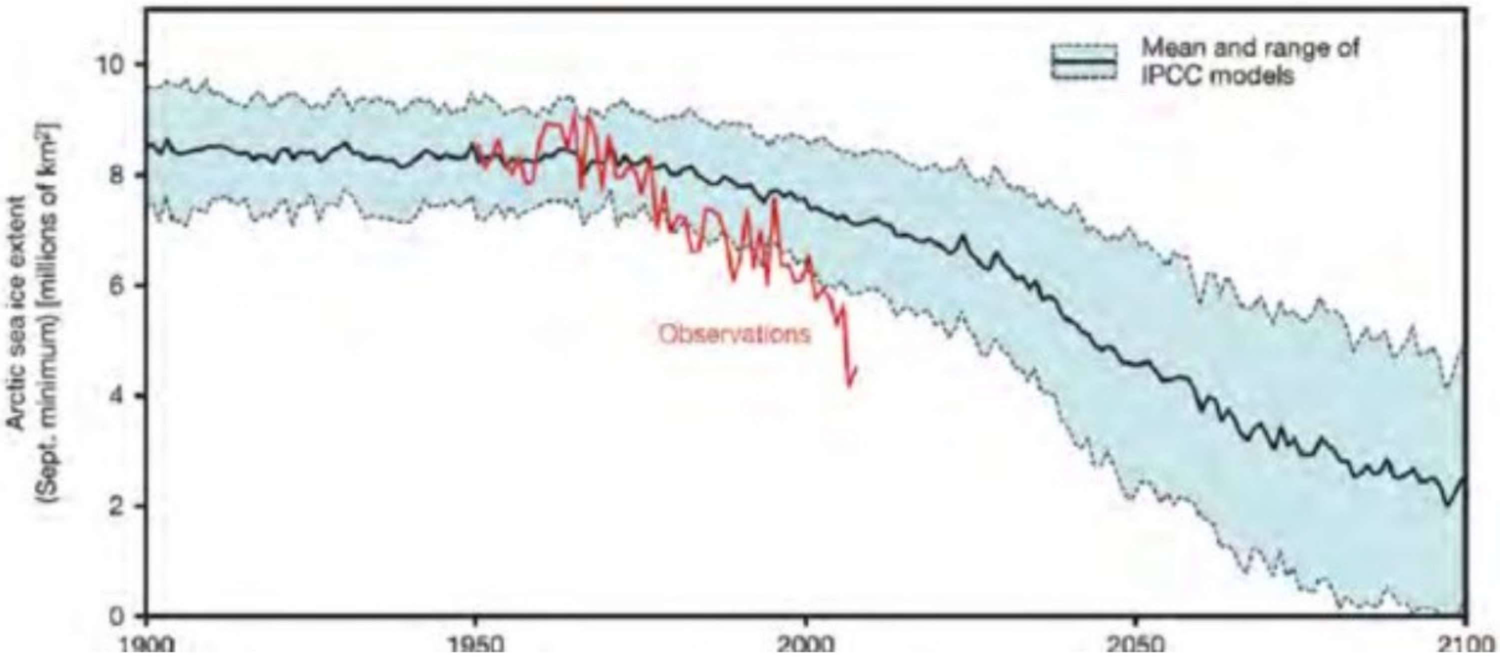

Mean and range of
IPCC models
Observations
Arctic sea ice extent
(Sept. minimum) [millions of km²]
10
8
6
4
2
0
1900
1950
2000
2050
2100