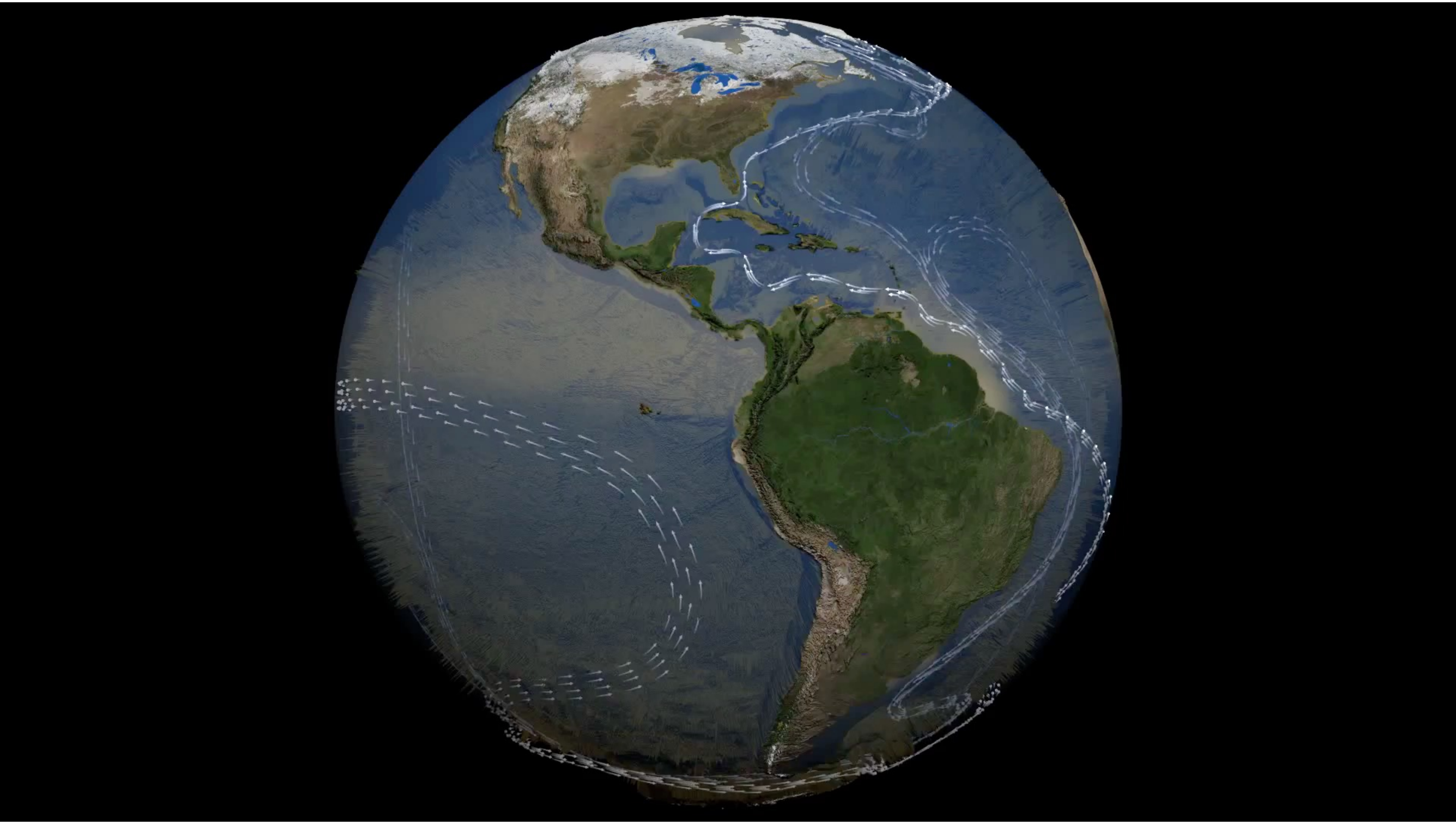
Is the "day after" for tomorrow?

Tales from the Gulf Stream

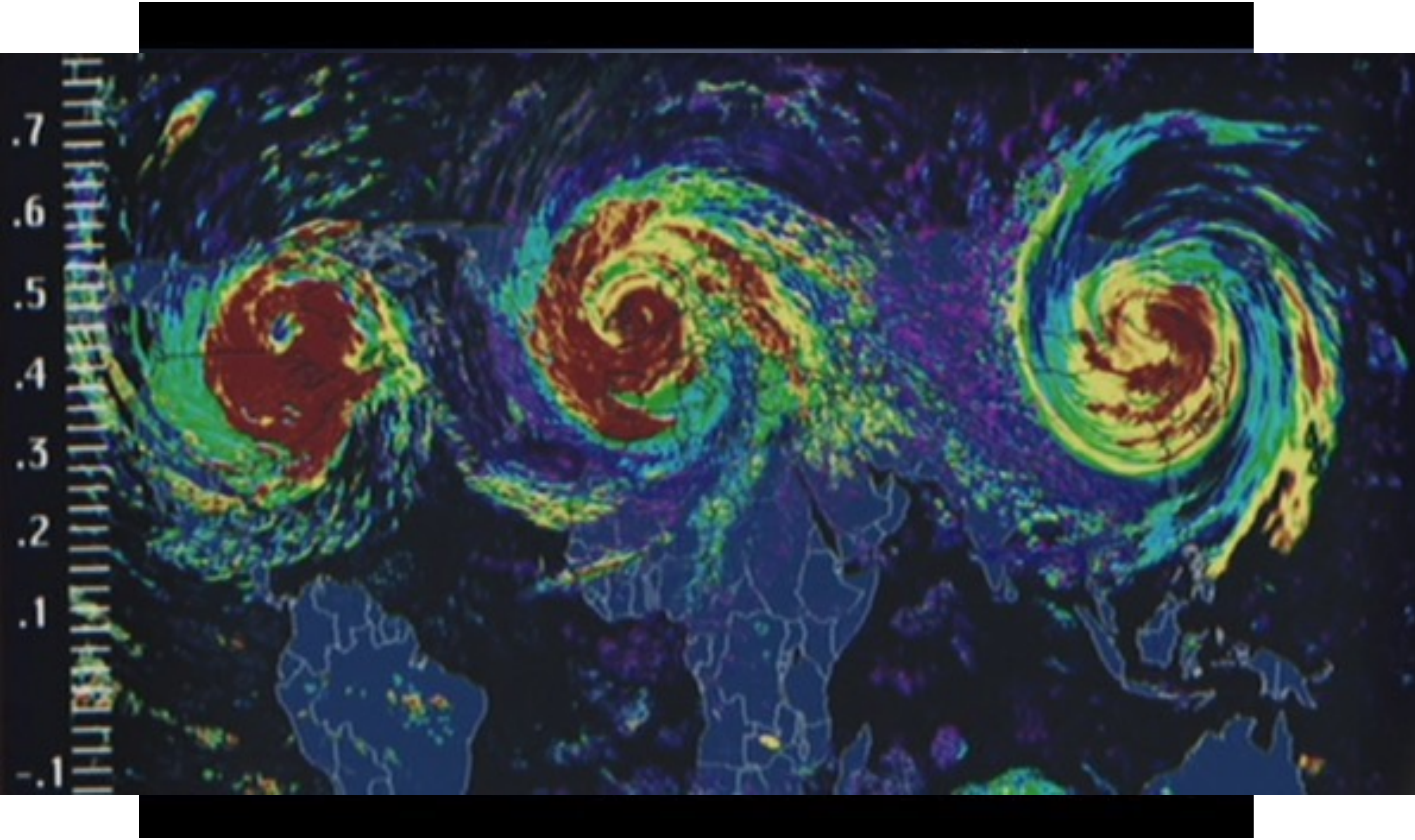
Didier Swingedouw

Ocean circulation

Atlantic meridional overturning circulation (AMOC)



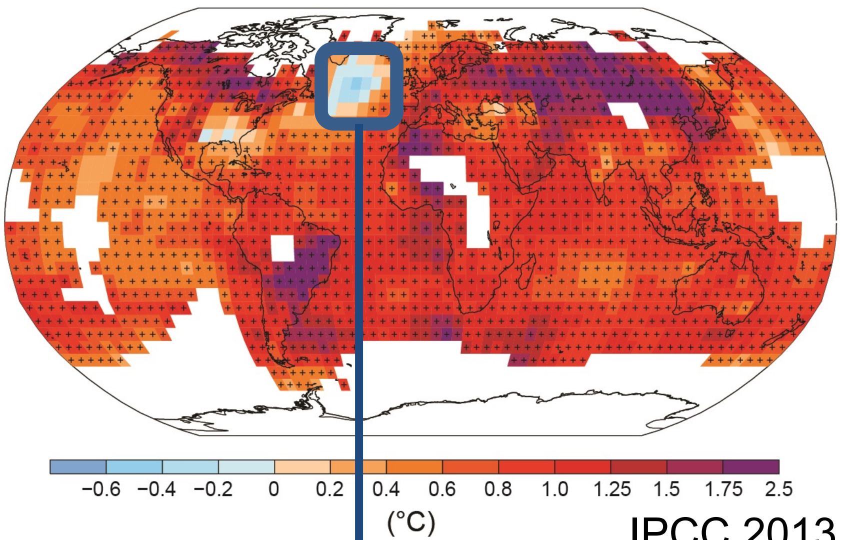
A glaciation of the Earth in a few weeks?



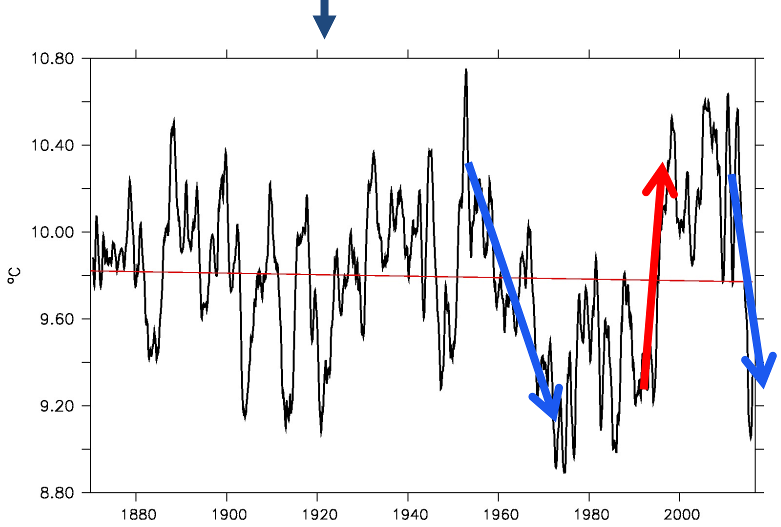
A warming climate everywhere?

- Most of the regions clearly warms over the last century
- The Atlantic subpolar gyre is one of the few regions that experienced a cooling
- This slight weakening trend is also marked by large multi-decadal variations :
  - A cooling in the 1960s, 1970s
  - A rapid warming around 1995
  - A cooling event in 2015 and after

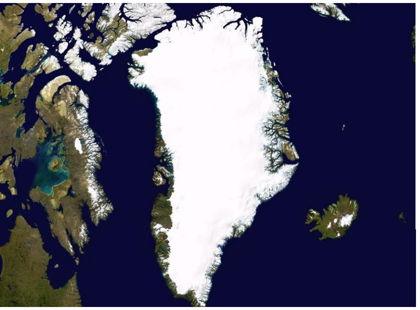
Tendance (1901-2012) de temperature de surface (HadCRUT4)



IPCC 2013



Rapid climatic variability in the past



Rapid Reductions in North Atlantic Deep Water During the Peak of the Last Interglacial Period

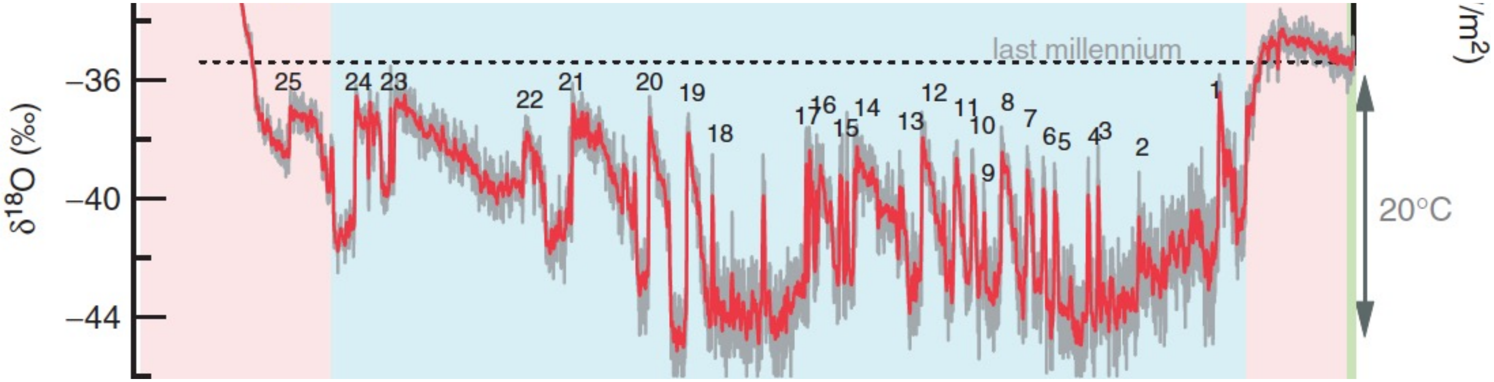
Eirik Vinje Galaasen,[1*] Ulysses S. Ninnemann,[1,2] Nil Irvalı,[2] Helga (Kikki) F. Kleiven,[1,2]
Yair Rosenthal,[3] Catherine Kissel,[4] David A. Hodell[5]

www.sciencemag.org SCIENCE VOL 343 7 MARCH 2014

commentary

Built for stability

Paul Valdes



Non linearities in the climate system

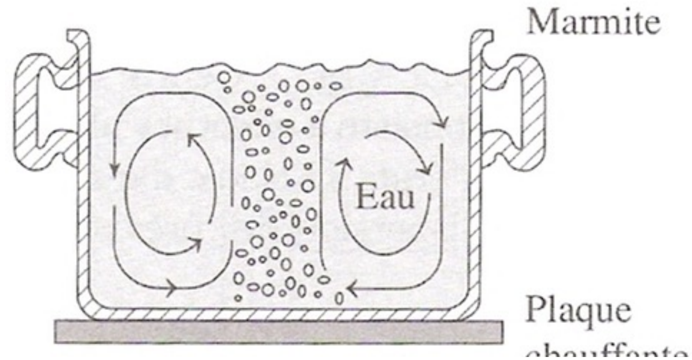
- Lorenz (1963) model:

Deterministic Nonperiodic Flow[1]

Edward N. Lorenz

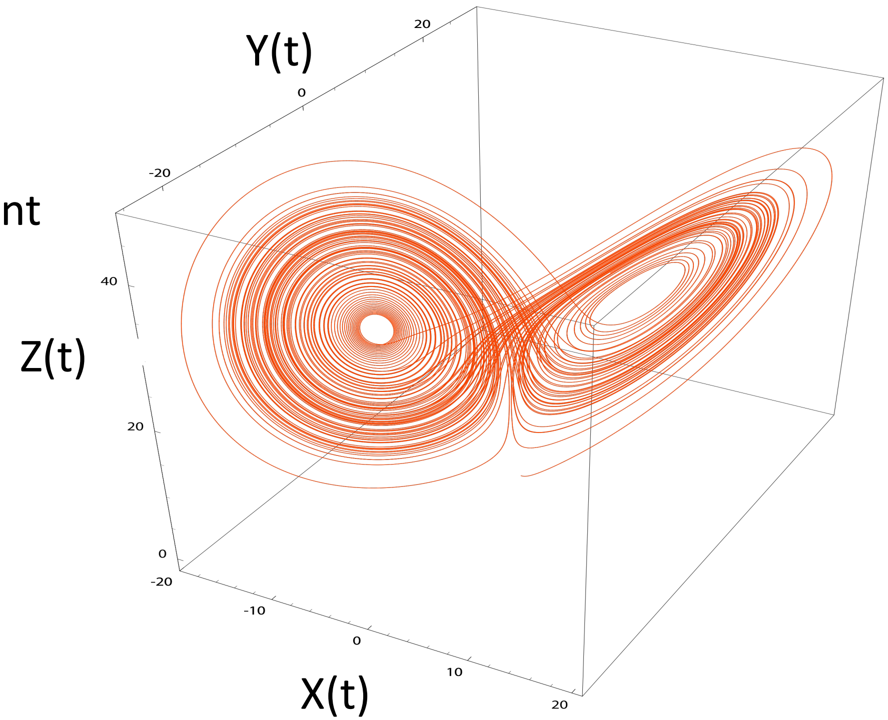
Massachusetts Institute of Technology

(Manuscript received 18 November 1962, in revised form 7 January 1963)



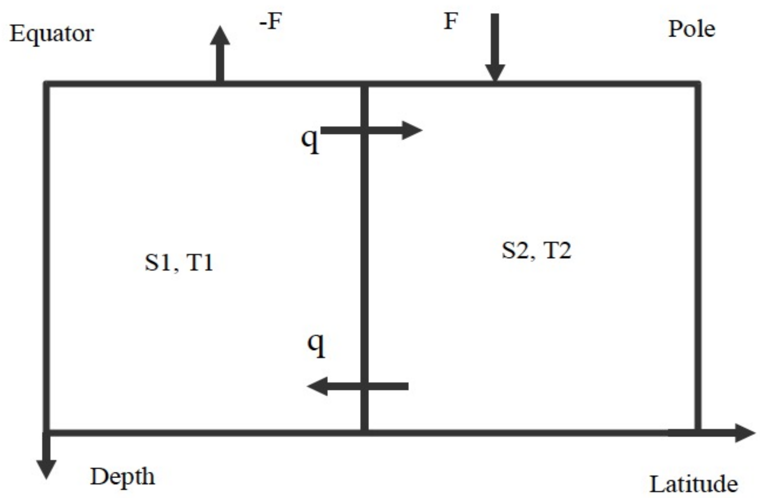
- Rayleigh-Bernard convection
  - X(t) is the speed is upward convection
  - Y(t) is the horizontal temperature gradient
  - Z(t) is the vertical temperature gradient

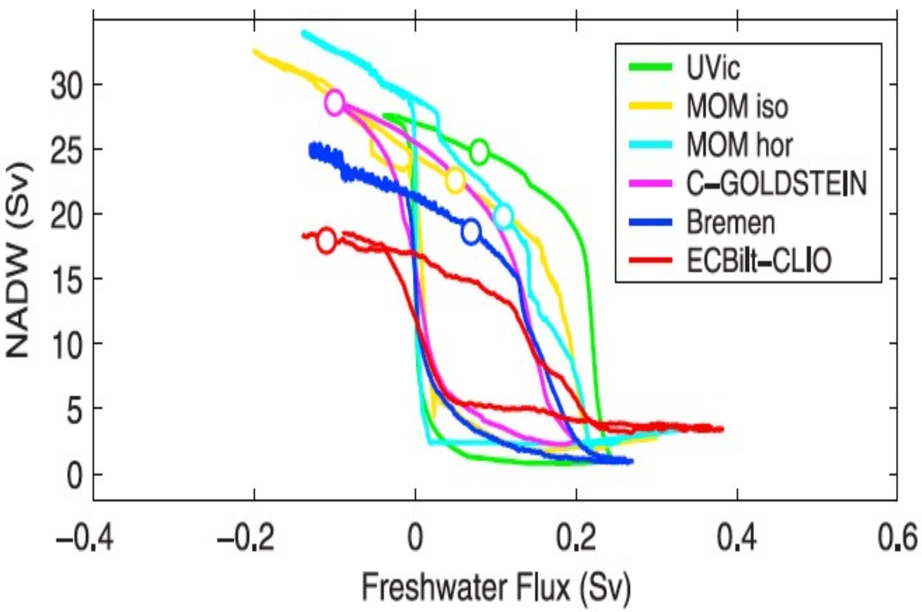
$$\begin{cases} \frac{dx(t)}{dt} = \sigma\left(y(t) - x(t)\right) \\ \frac{dy(t)}{dt} = \rho\, x(t) - y(t) - x(t)\, z(t) \\ \frac{dz(t)}{dt} = x(t)\, y(t) - \beta\, z(t) \end{cases}$$



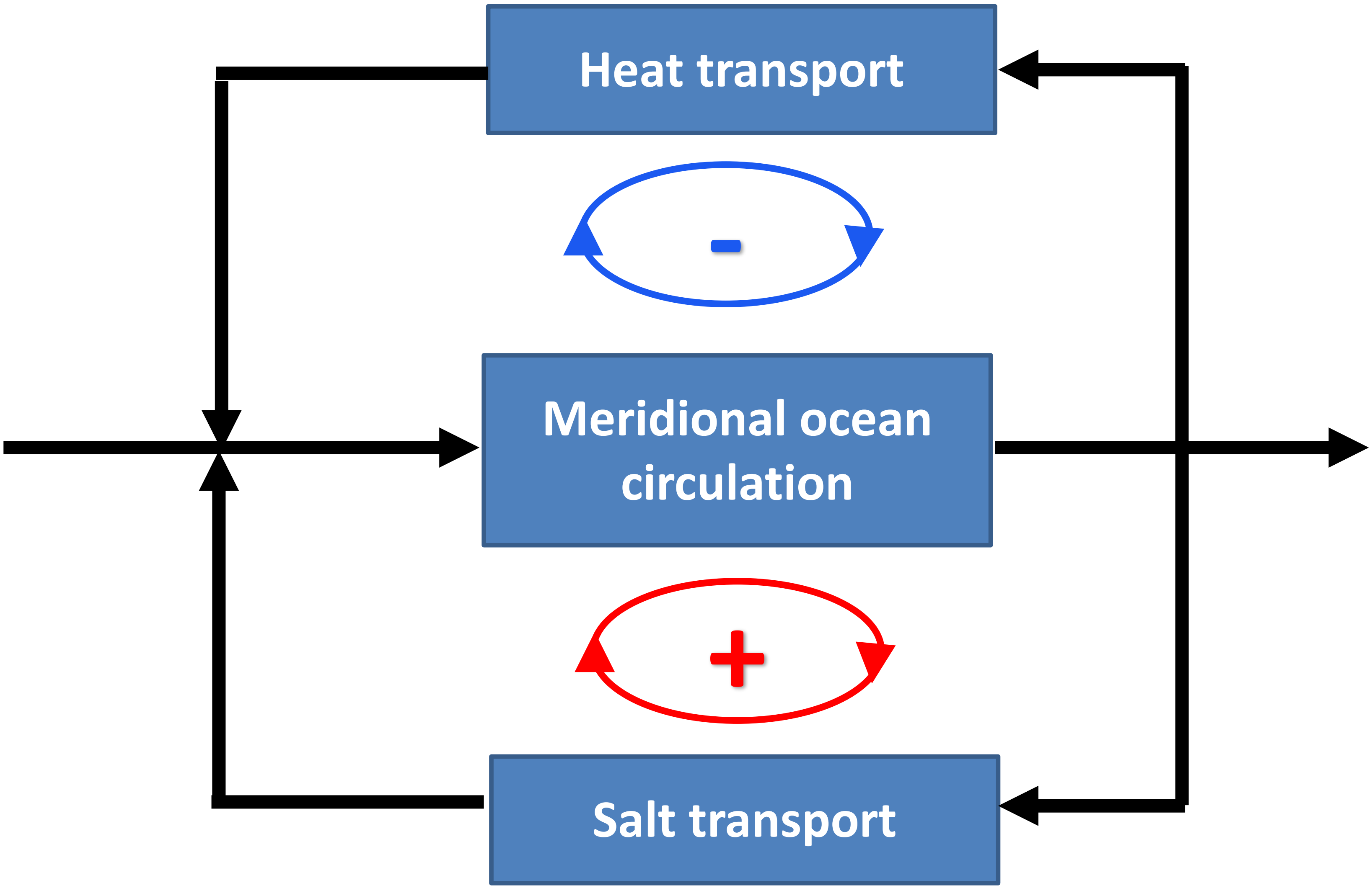
Non linearities in the climate system

- Stommel (1961) model
- Volume transport between the equator and the pole proportionnal to the density gradient
- Salinity budget in one of the boxes leads to a non-linear equation
- 2 possible solutions for the same freshwater forcing F
- Also true in state-of-the-art models (Rahmstorf et al. 2005, Hawkins 2011, Mecking et al. 2017)



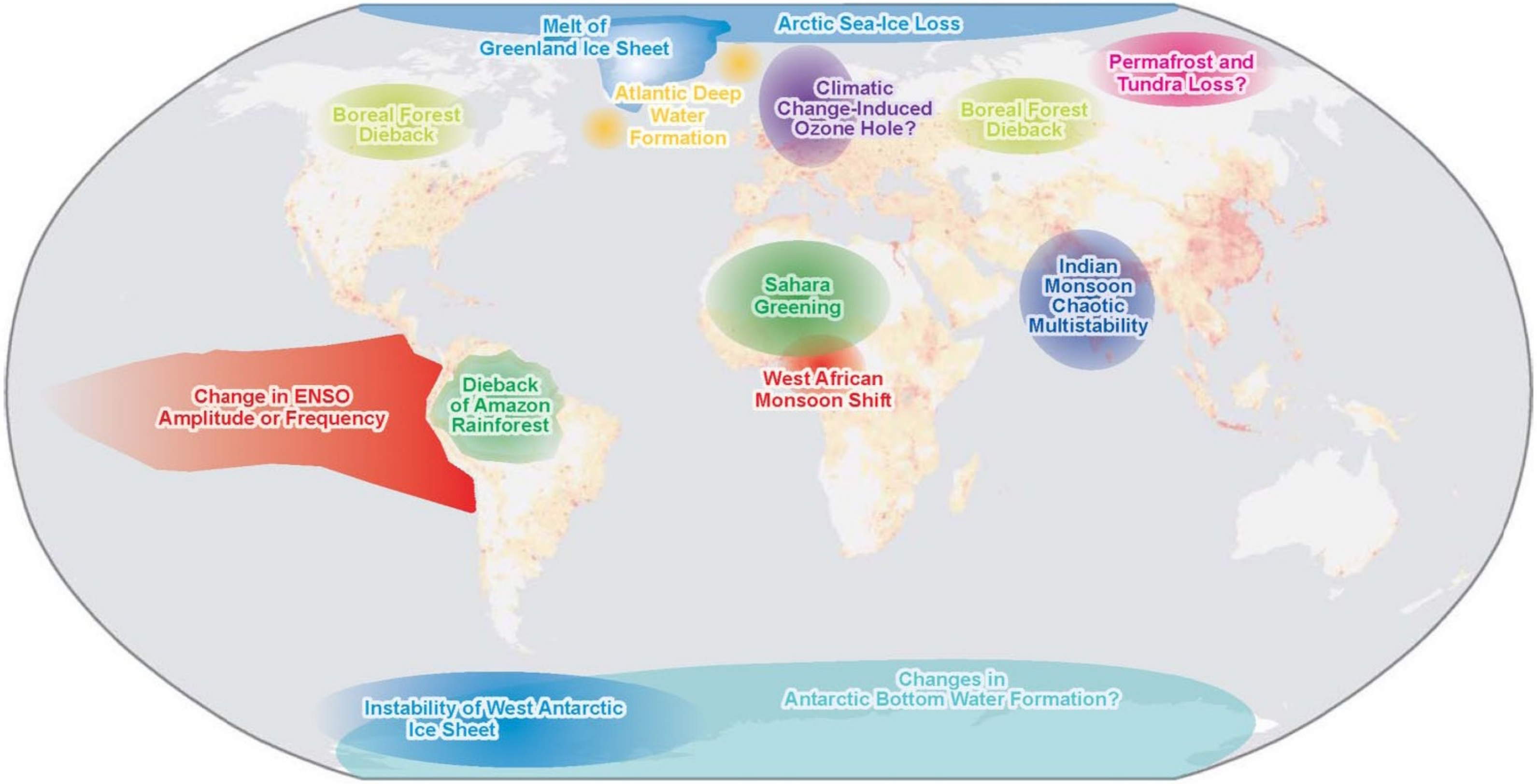


Positive and negative feedbacks



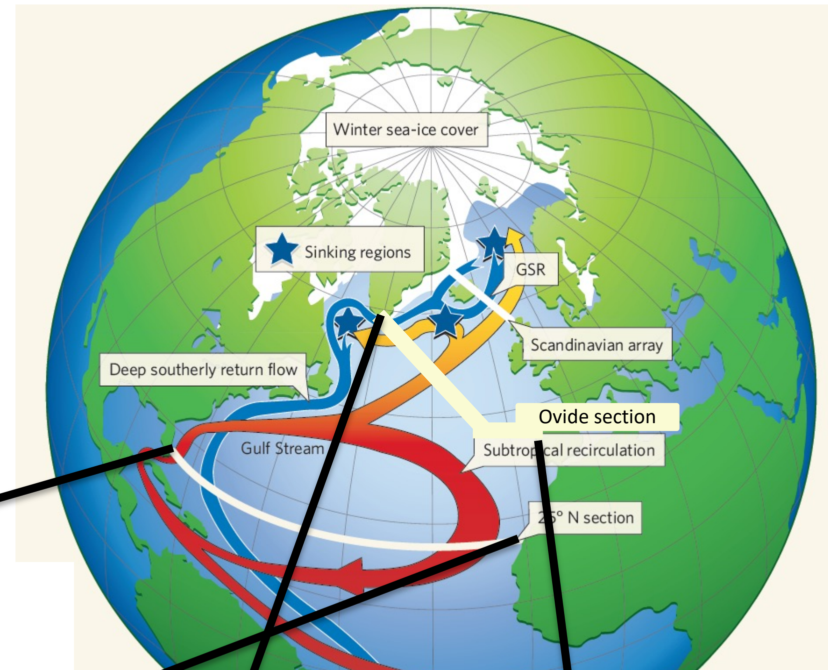
Tipping elements of the climate system

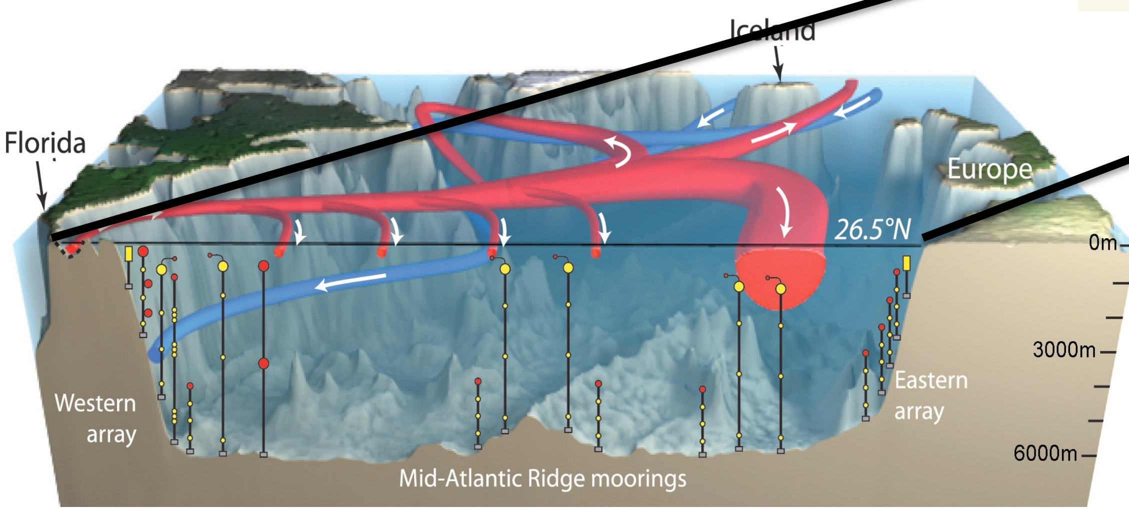
Lenton et al. (2008) : The word ‘‘tipping point’’ refers to a critical threshold beyond which a small perturbation can qualitatively modify the state of a system.

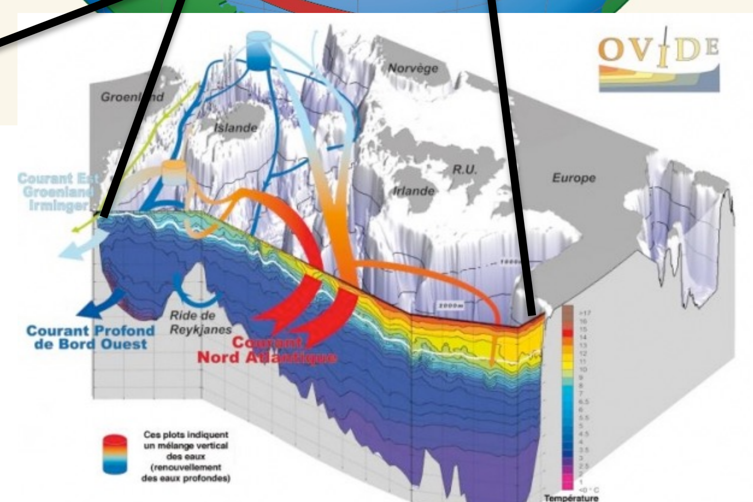


Atlantic meridional overturning circulation (AMOC)

- Measured every two years in June between Portugal and tip of Greenland since 2002 (OVIDE, France)
- Measured continously at 26°N since 2004 (RAPID array)

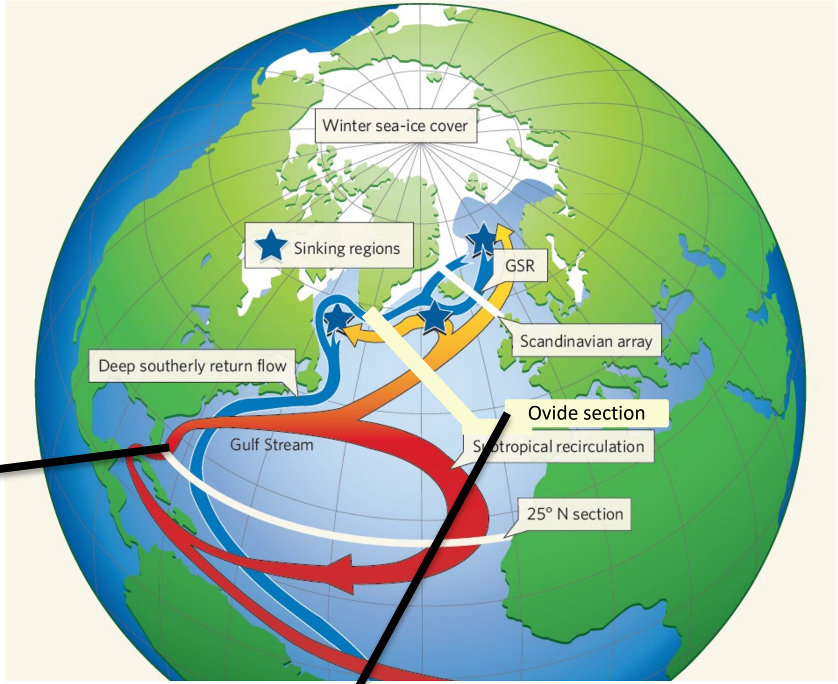


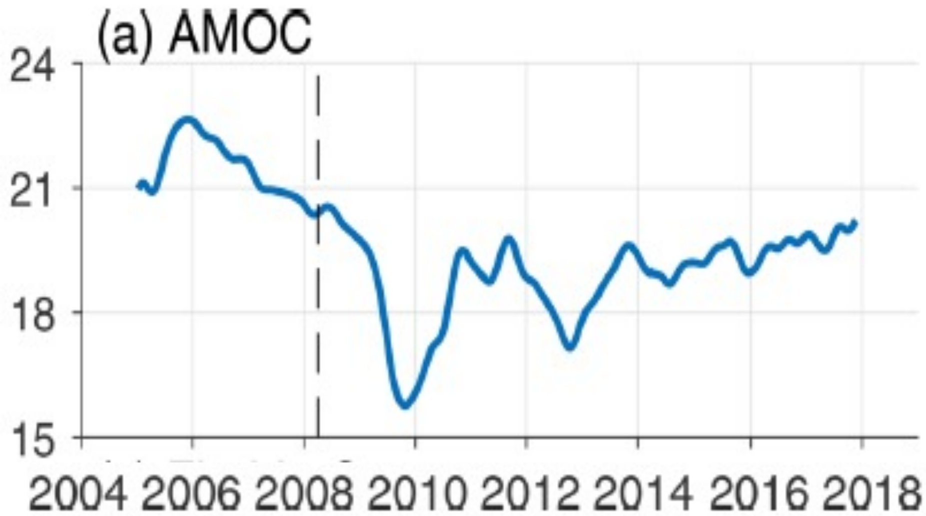




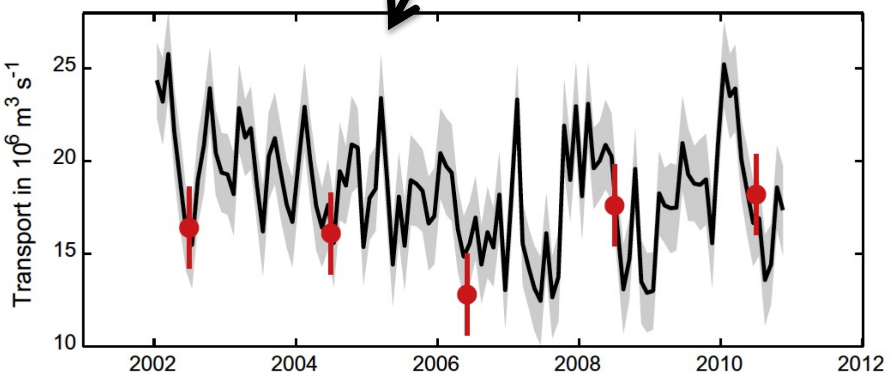
Recent evolution of the AMOC

No clear trend over 15 years



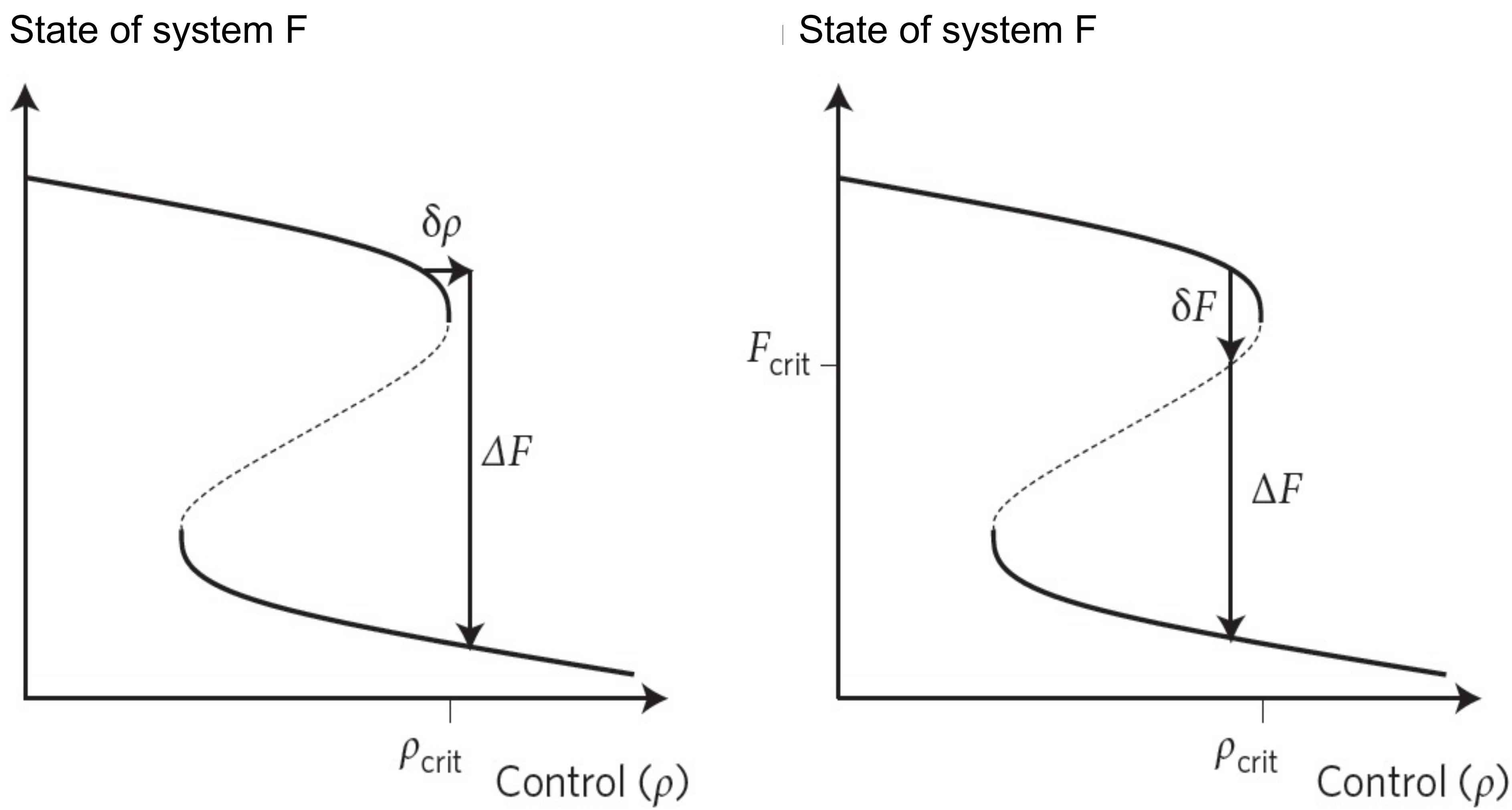


Moat et al. (2020)



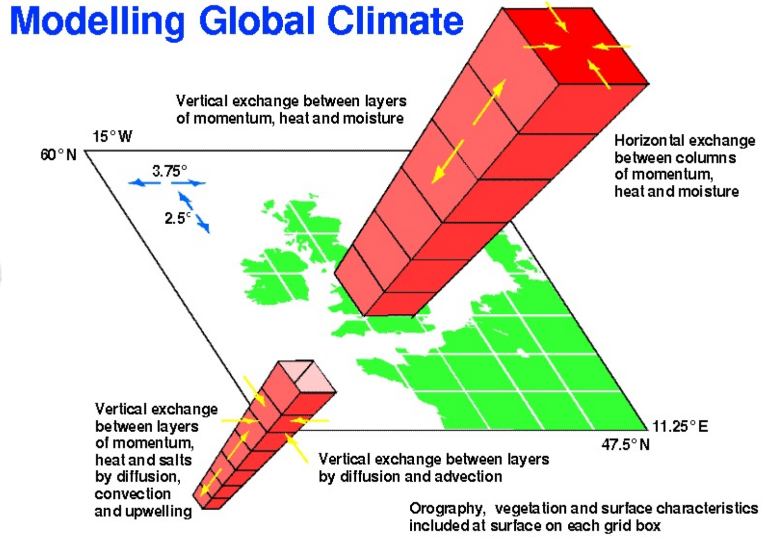
Mercier et al. (2015)

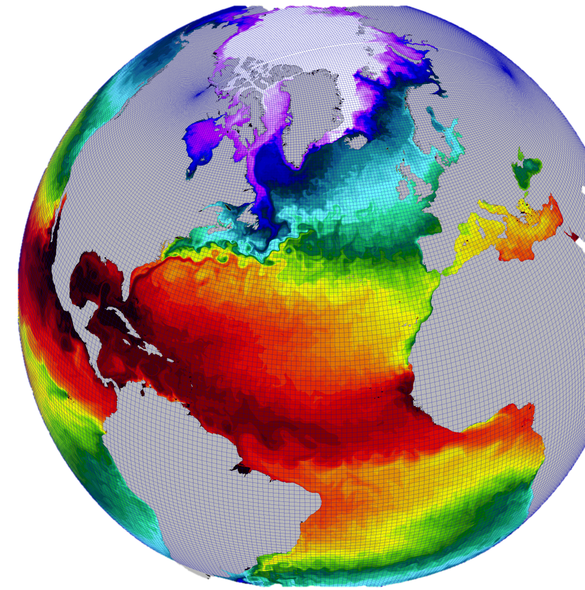
Internal changes in the AMOC

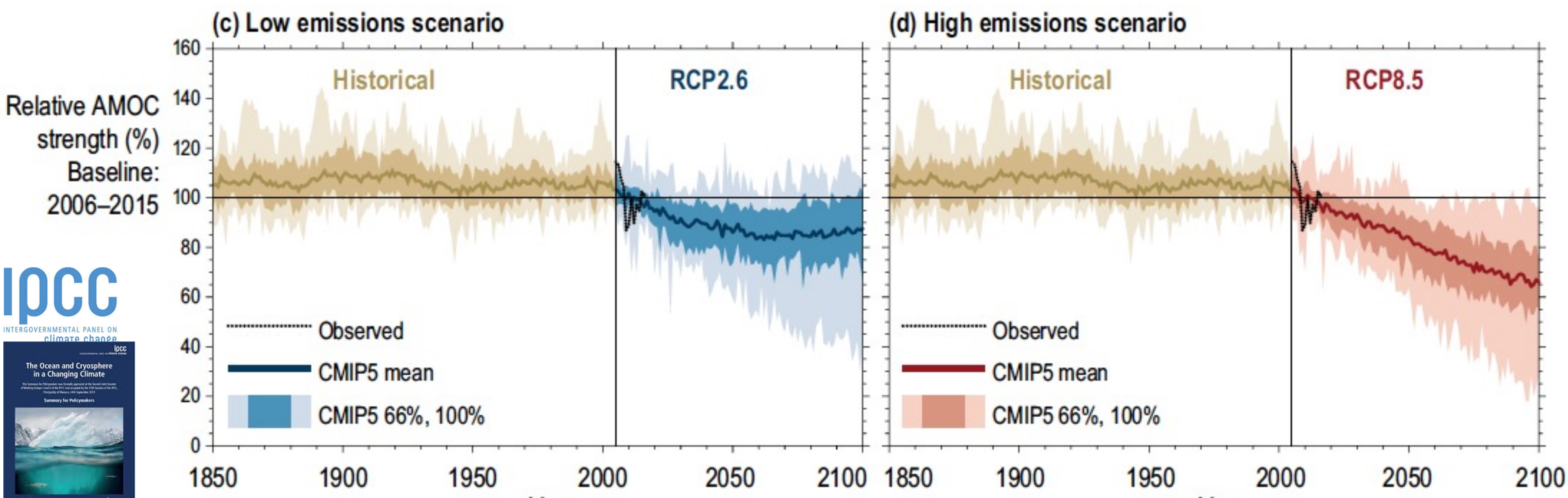


Lenton 2011

Future of the AMOC?





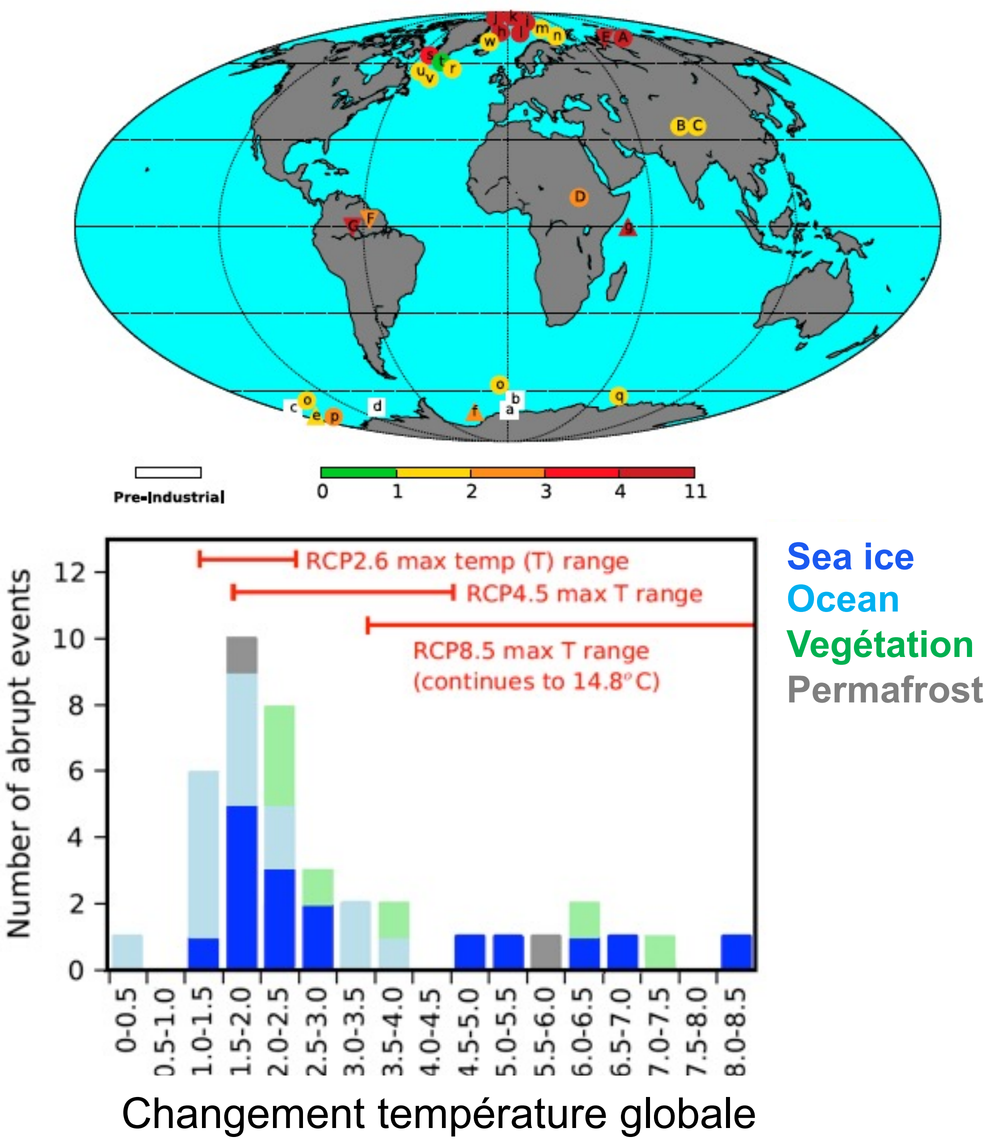


Remaining questions

- Are comprehensive climate models too stable?
- What is the timing and exact climatic impact of an AMOC change?
- What are the associated risks?

On the possibility of abrupt changes in models

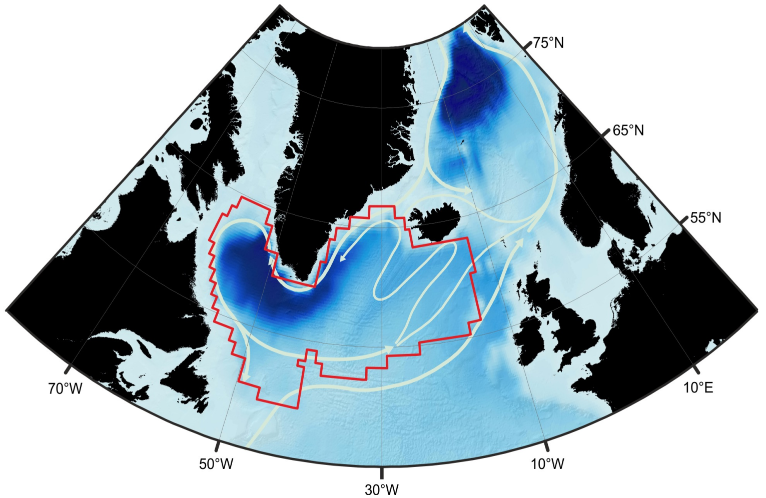
- We scaned CMIP5 model database and did find a number of abrupt events (Drijfhout et al., *PNAS* 2015)
- Criteria of search: a 10-year change in projection larger than 4 standard deviation of the control preindustrial simulation
- 39 abrupt events have been found or 36% of the simulations, but not only concerning the North Atlantic

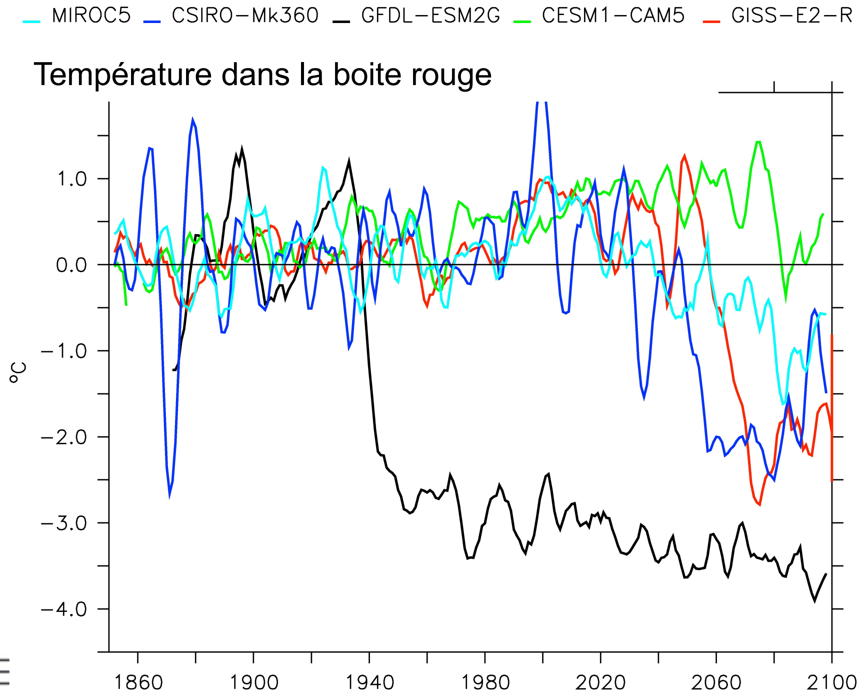


EMBRACE

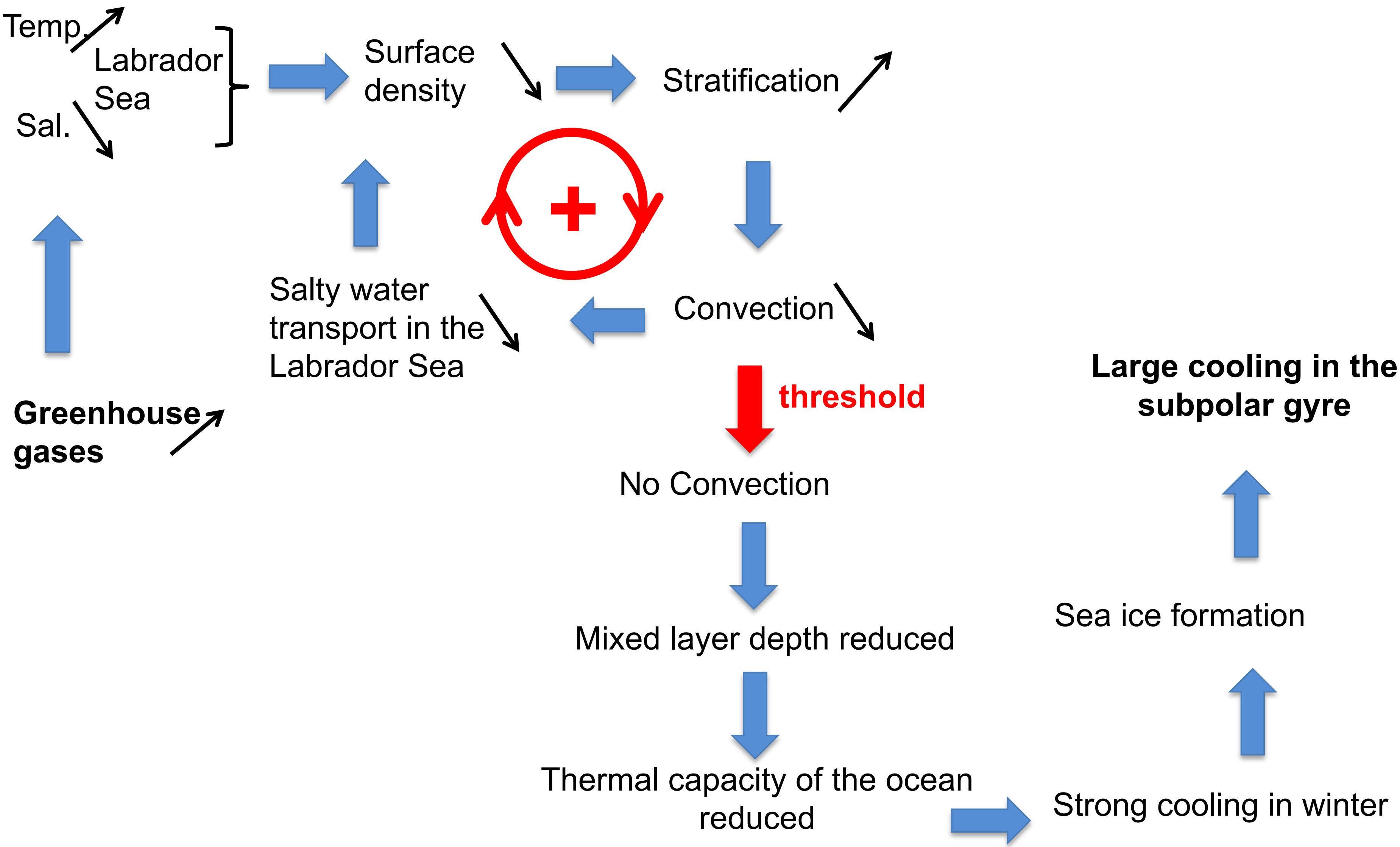
On the possibility of abrupt changes in models

- Then, we put the focus on the North Atlantic region (Sgubin et al., *Nat. Com.*, 2017)
- We did find a number of models with rapid cooling events (2-3°C cooling in less than 10 years !)





Mechanisms at play

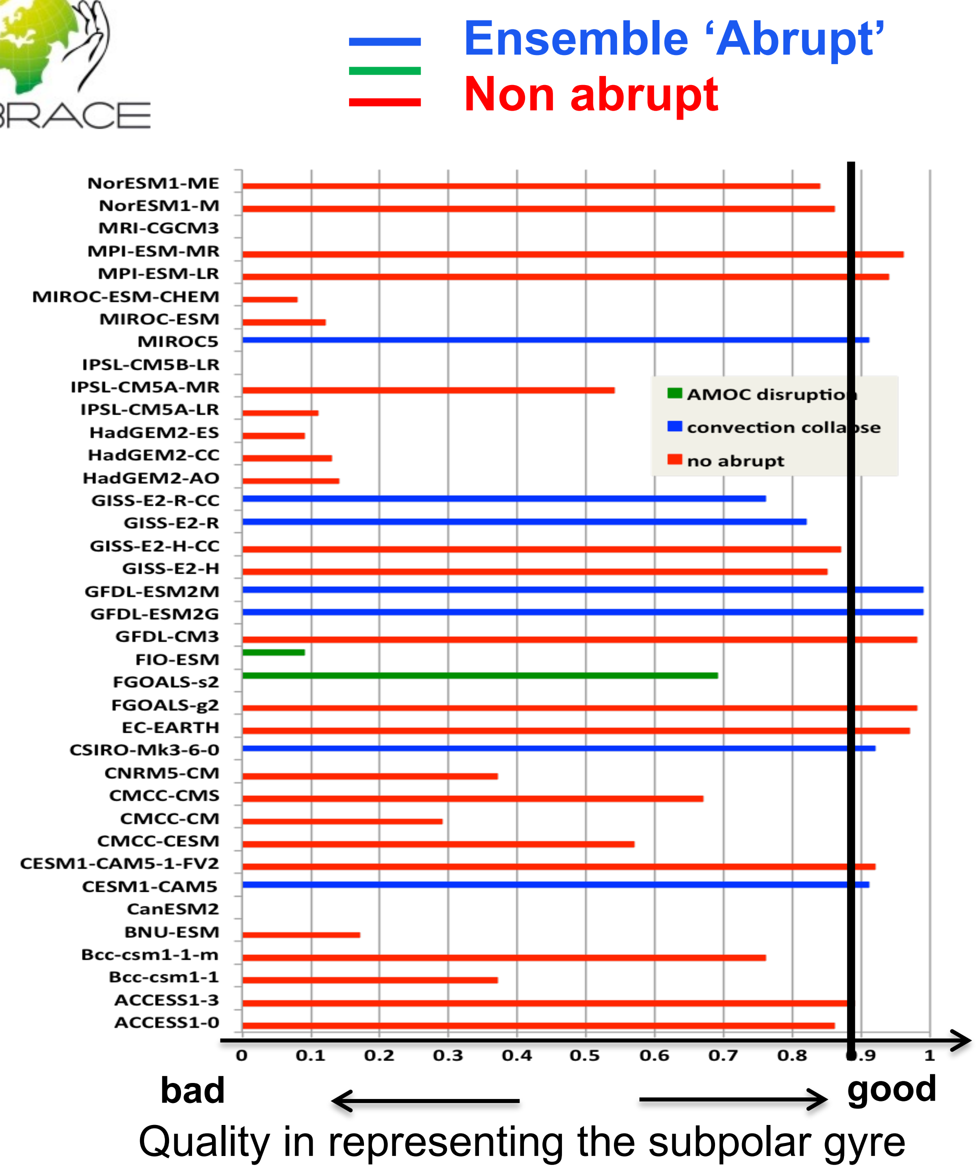


On the possibility of abrupt changes in models

- If we account for all models, there a **17% risk** **of having such a cooling in the on-going century**

- If we use the stratification to select models and we take the **11 best models, then the risk rises to 45%**

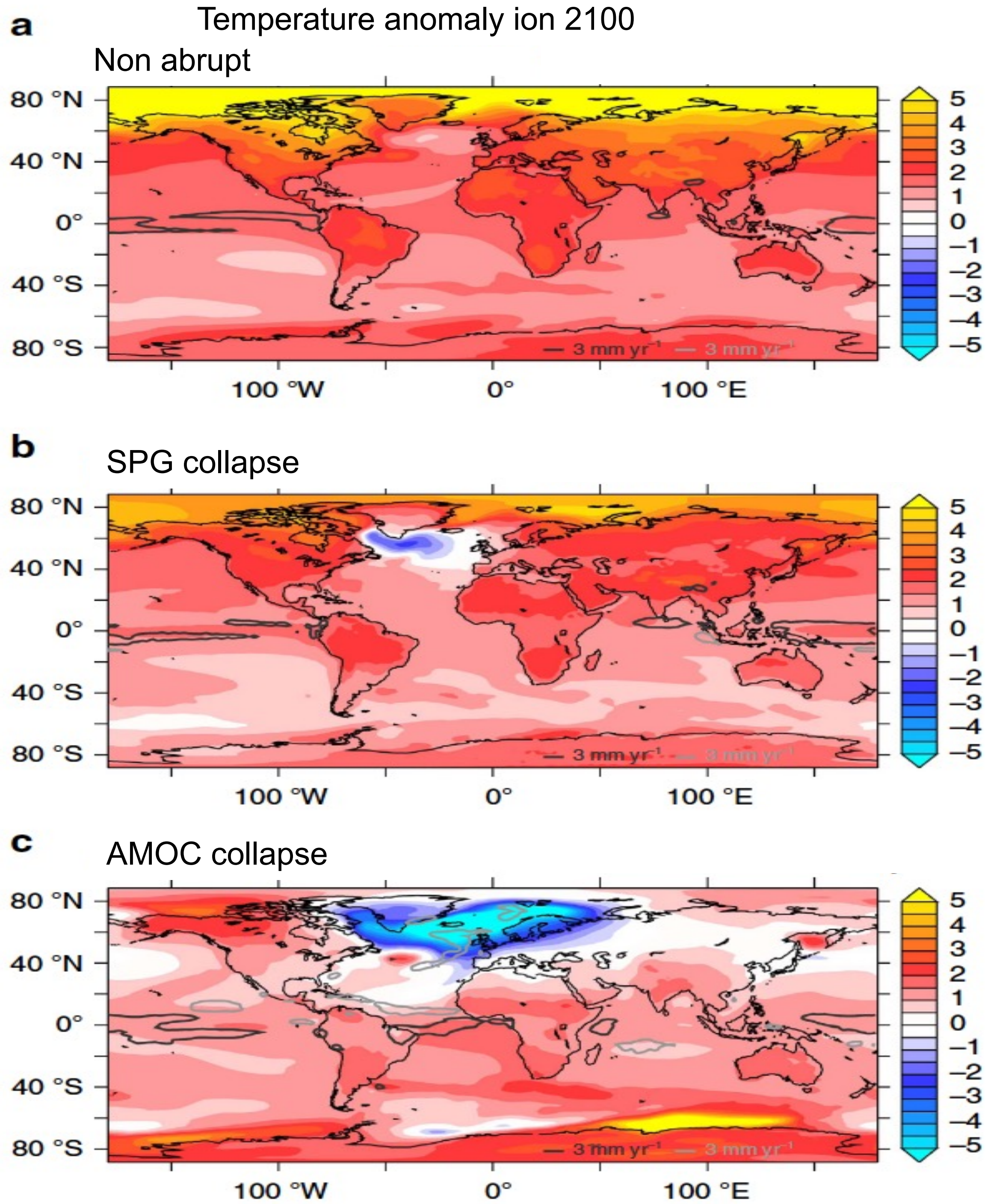
- There is a similar, but a bit weaker risk, in CMIP6 (around **35%**)



Sgubin et al., Nat. Com. 2017

Climatic impact

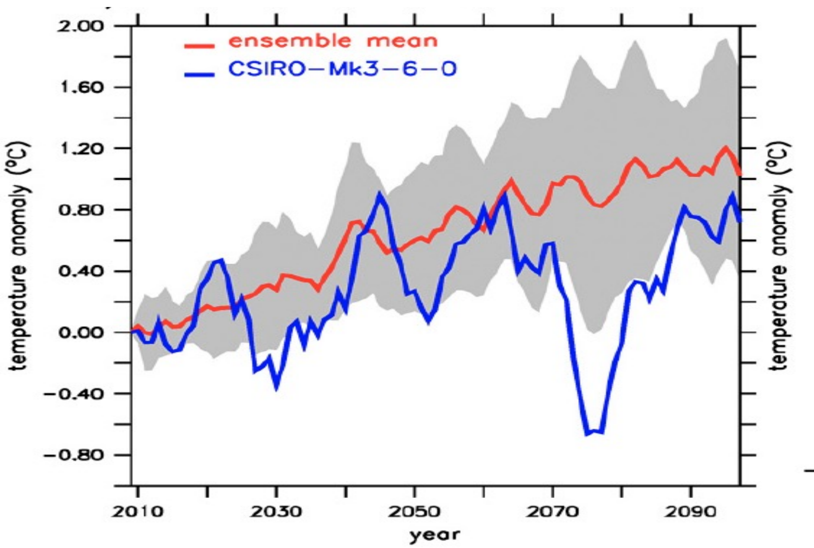
The response in the North Atlantic strongly influences the neighbouring regions



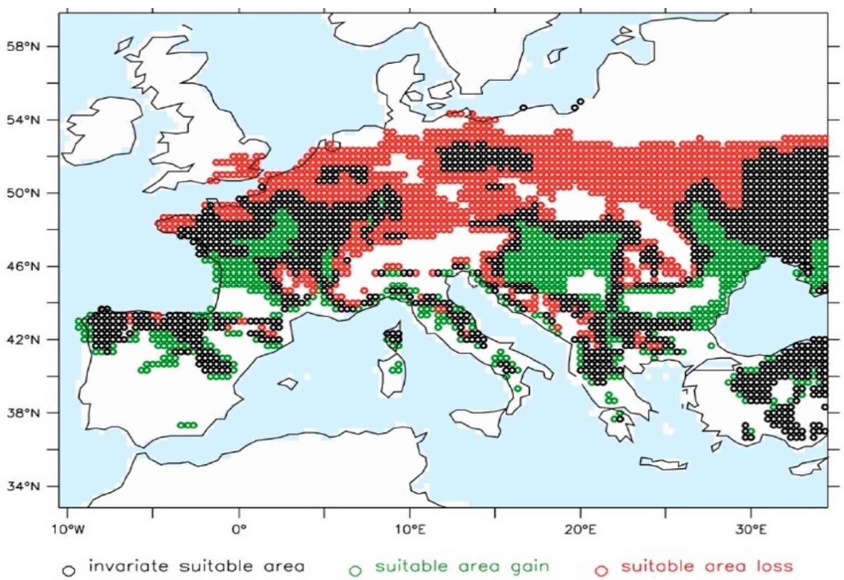
Impacts of abrupt decadal cooling

- Decadal climate variability can play a a key role for uncertainty at the regional scale (Hawkins et Sutton 2009)
- Such impacts can be very fast (<10 years)
- They might affect climate of Europe for at least a decade with various consequences on adaptation plans, e.g. agriculture

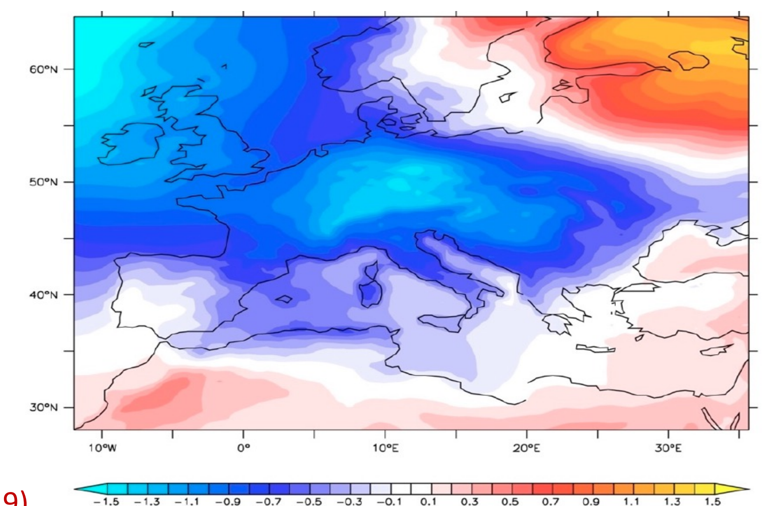
Temperature in the UK



Suitability of Chardonnay
2069-2978 vs 2059-2068



Temperature difference 2069-2078 vs 2059-2068



Sgubin et al. (2019)

Last millennium

Bruegel : Les chasseurs dans la neige (1565)

A rapid change in the AMOC or simply in the subpolar gyre (SPG) might explain the beginning of the little ice age in the 14th century (Sicre et al. 2008, Miller et al. 2009, Moreno-Chamaro 2017, Moffa-Sanchez et al. 2017, Michel et al., in rev.)

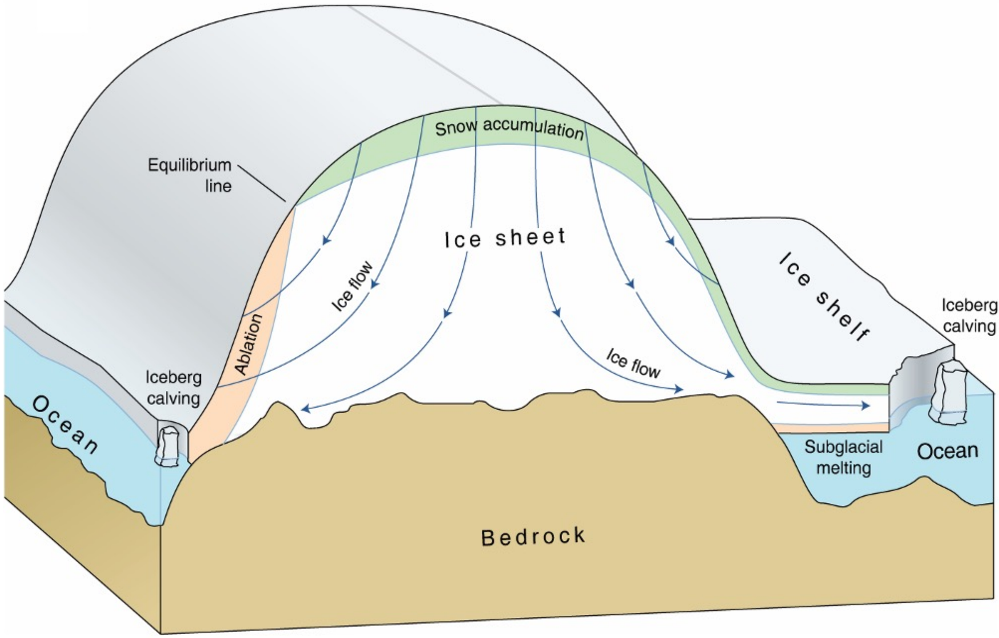
What about Greenland melting?

Greenland ice sheet as another tipping element

- Greenland: Risk of complete melting as soon as **2-3°C** of global warming

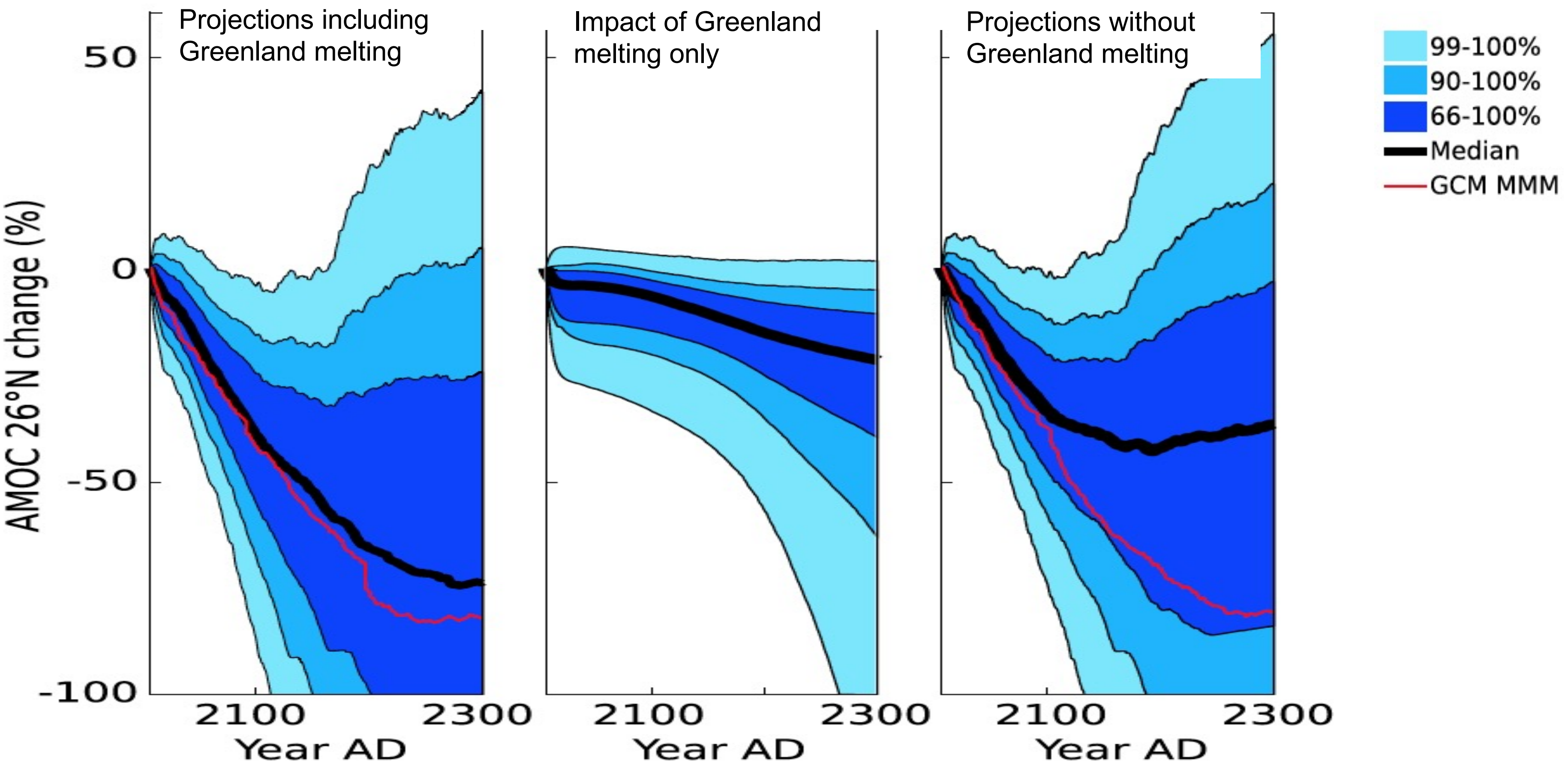
⇒ Total melting represents about **6-7 meters** of global sea level rise

- Timing for the melting difficult to estimate but might request centuries to millennia

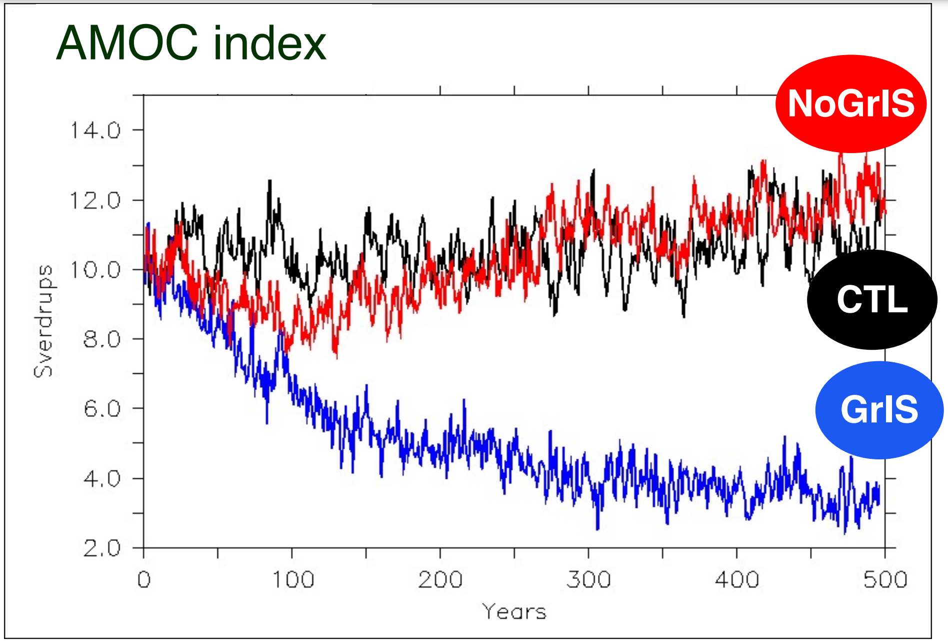


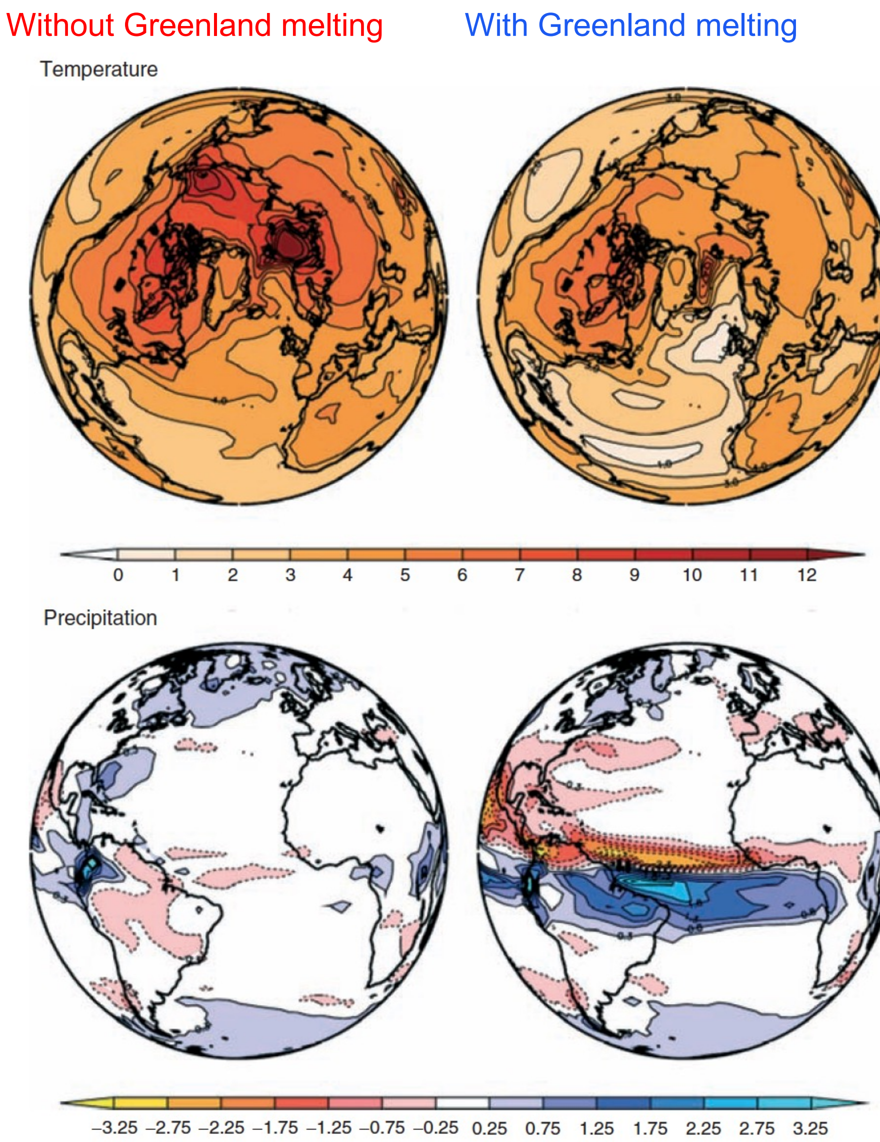
Response of the AMOC to Greenland melting

Response of the AMOC in projections including a realistic Greenland ice sheet melting scenario (Bakker et al., *GRL,* 2016)



Climatic impacts



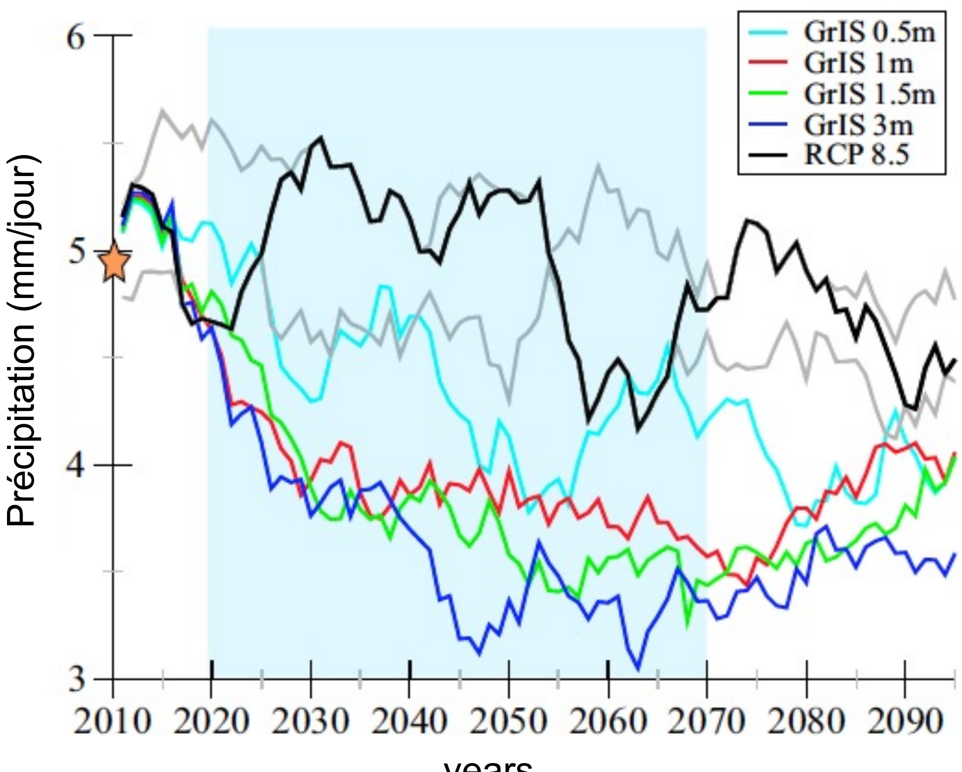


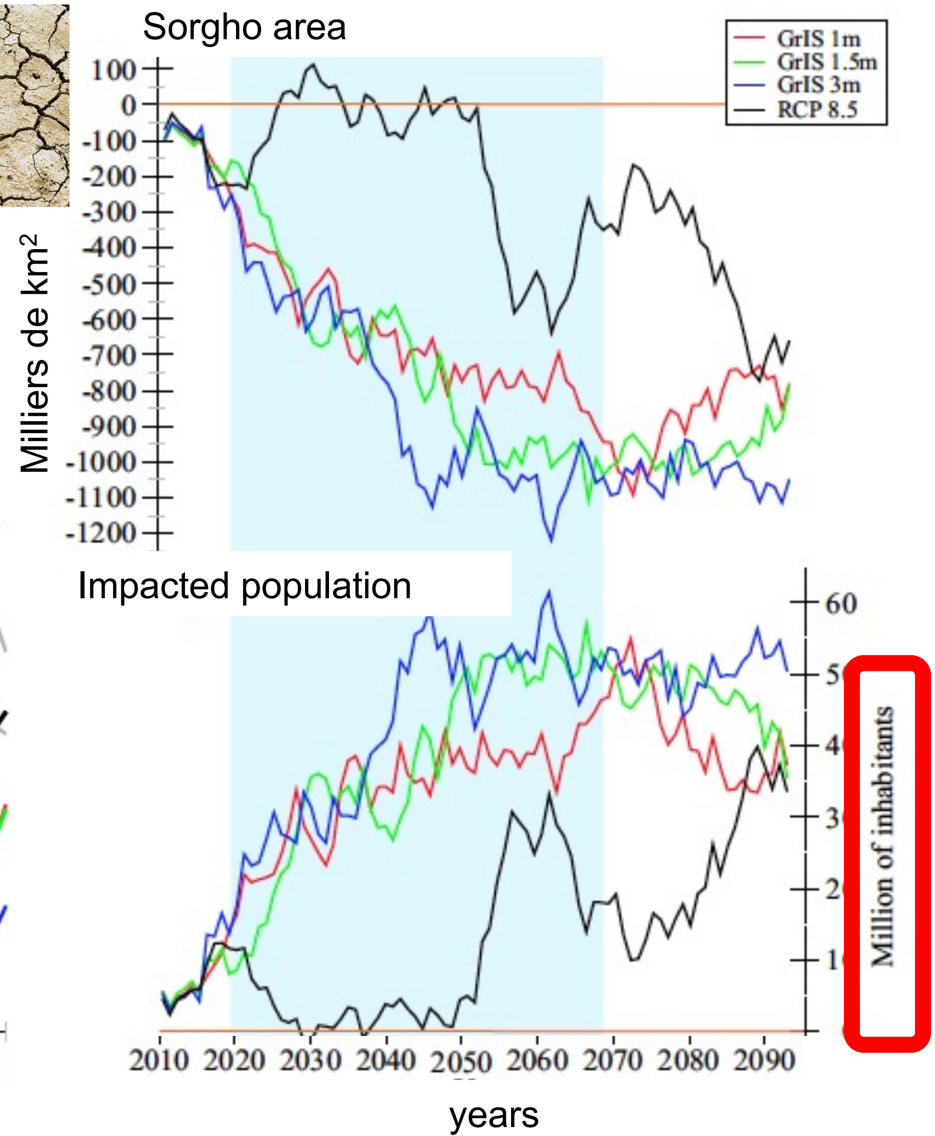
- Greenland melting can induce a strong climate impact (Swingedouw et al. 2007)
- less warming around the North Atlantic (but model dependent)
- Southward migration of Intertropical convergence zone (ITCZ)

Impact on the Sahel region

Scenario of a rapid melting of Greenland (DeFrance et al. PNAS 2017)

Rainfall change in Sahel





Impacts of a substantial change in the AMOC

IPCC
INTERGOVERNMENTAL PANEL ON climate change

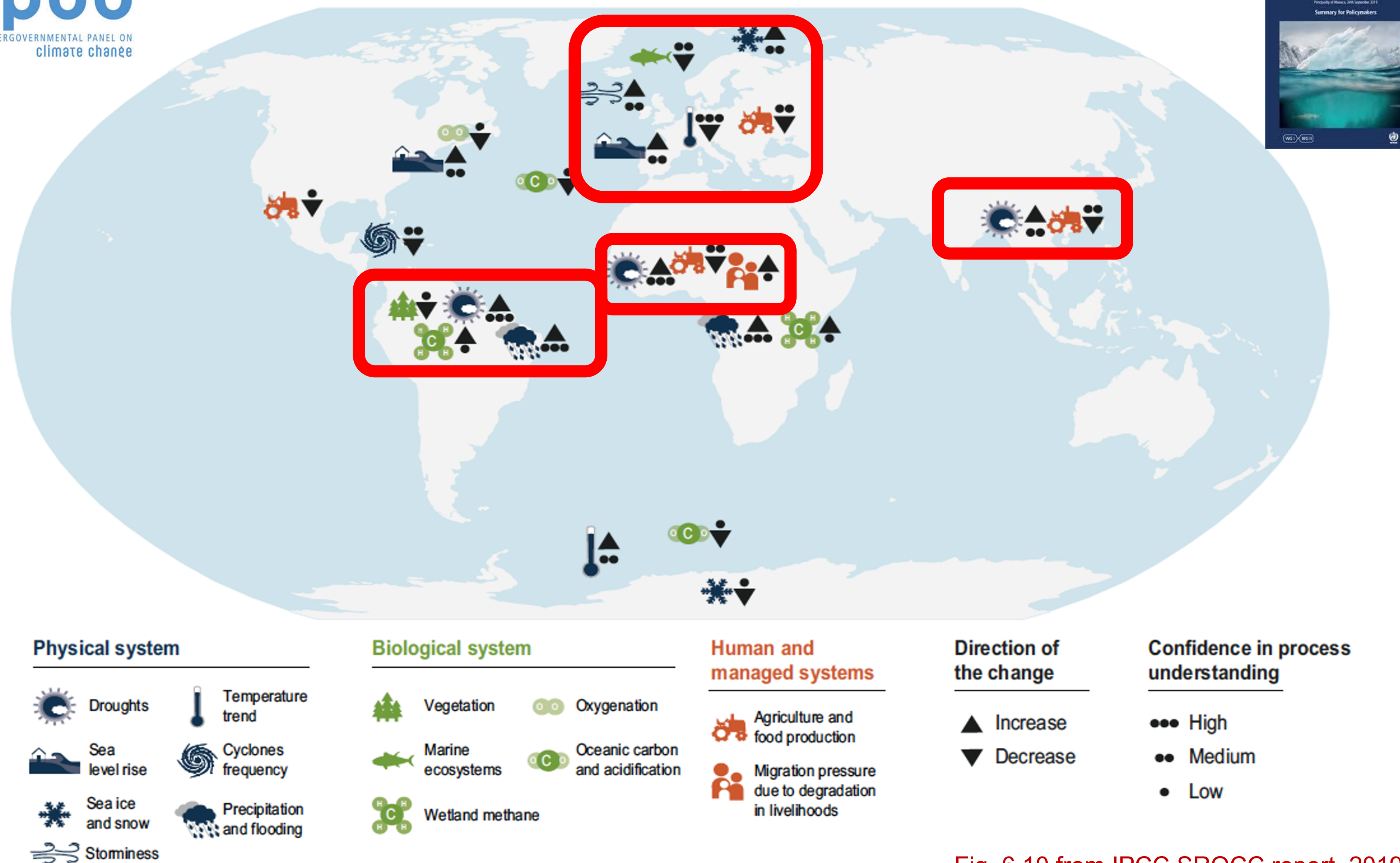
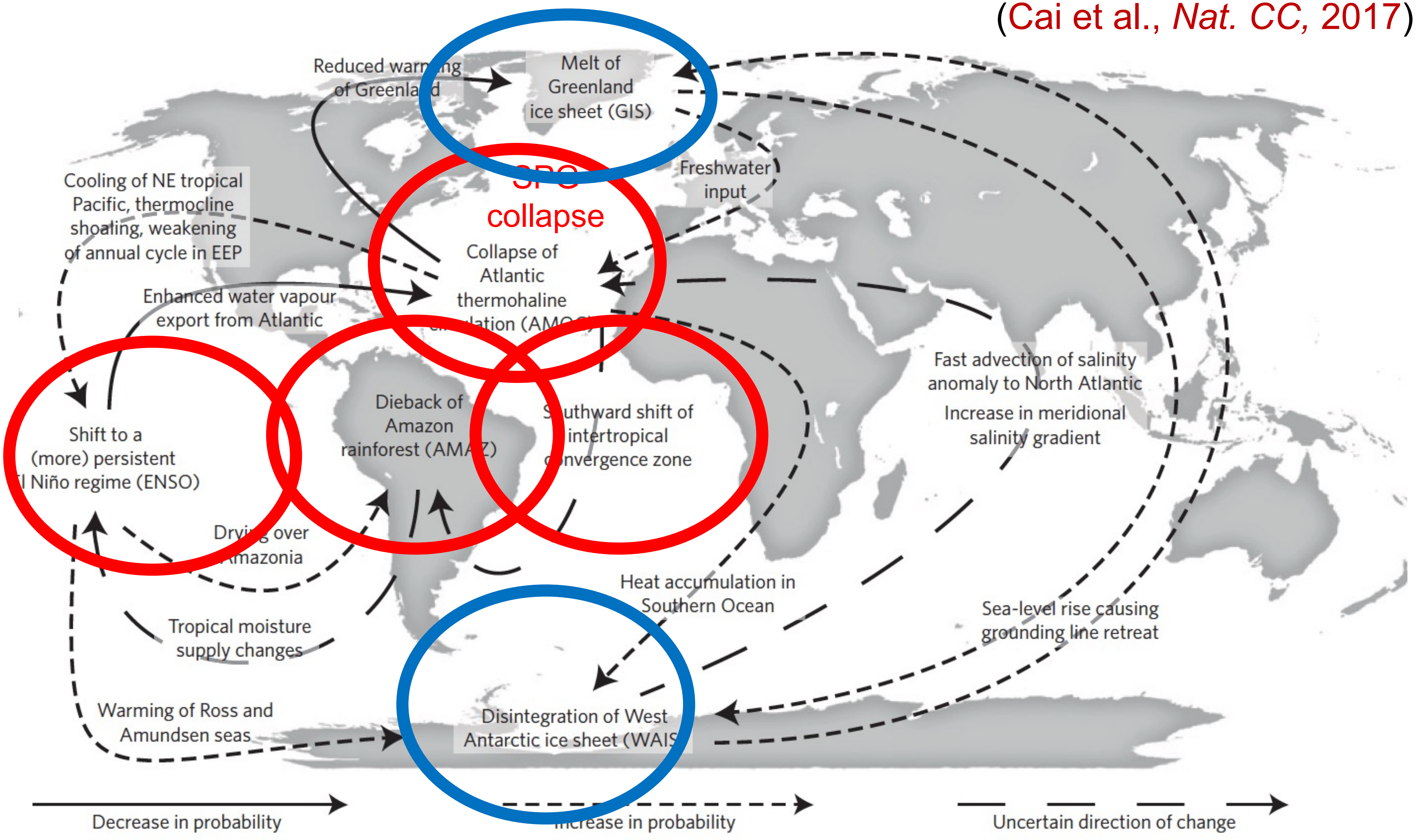


Fig. 6.10 from IPCC SROCC report, 2019

Cascading of tipping points

(Cai et al., *Nat. CC*, 2017)



Even more potential impacts not assessed yet?

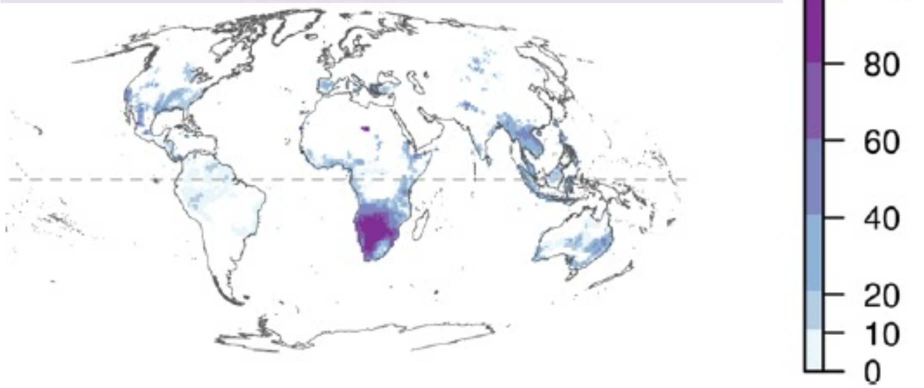
- Impacts on biodiversity: a new example of cascading tipping points (Velasco et al. 2021, Communications Biology)

- Amphibians are indicators of ecosystems' health because of their high sensitivity to novel climate conditions

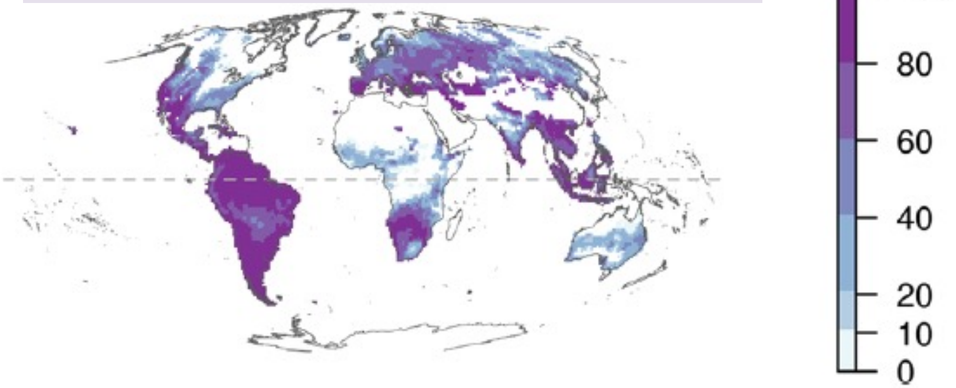
- A strong weakening of the AMOC can push these animals to cross their own tipping point = a new example of cascading tipping points

Percentage of amphibian species loss

2070: RCP8.5 without AMOC collapse

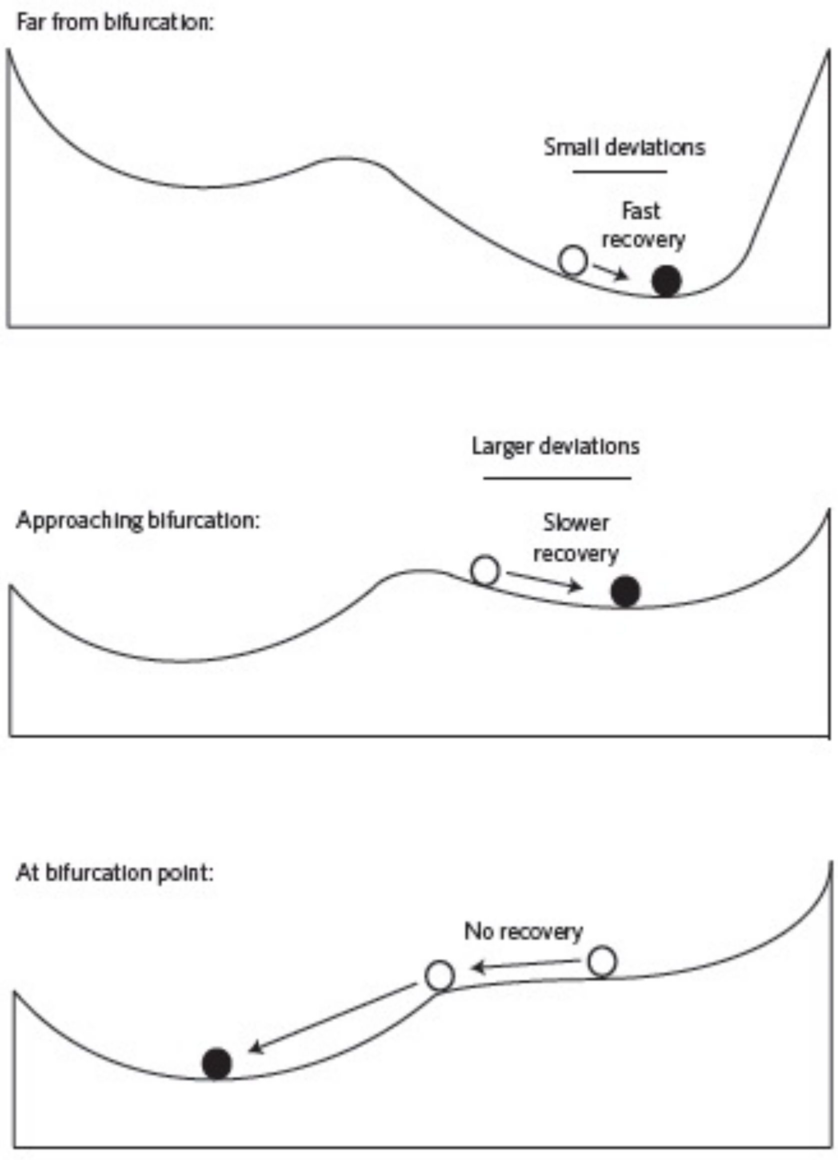


2070: RCP8.5 with AMOC collapse



Early warning of tipping points

- When approaching a tipping point, classical models do show more inertia
- As a consequence, their variations are slower in time
- This type of behavior can be used as an early warning: when a system is showing wider, longer variability, it might be approaching a tipping point



Lenton (2011)

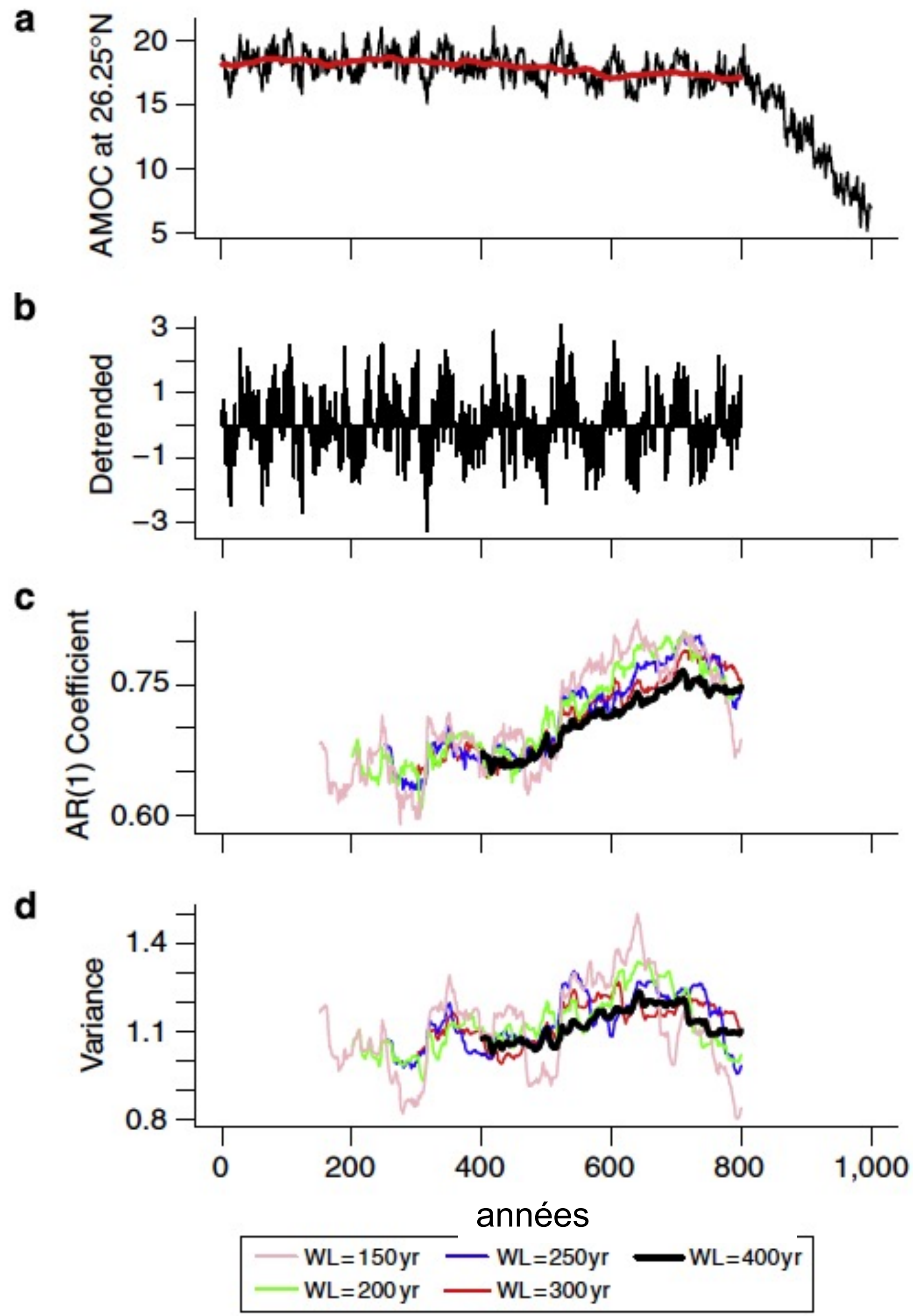
Early warning

- Boulton et al. (2014): This property is true for the AMOC in a comprehensive climate model where the AMOC collapses

- But it requires to know the state of the AMOC for more than 250 years

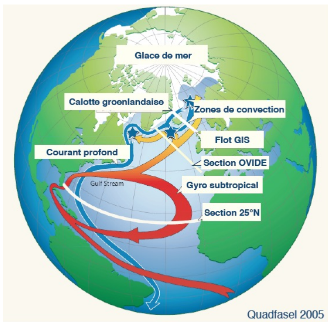
- We have less than 15 years of direct measurement available

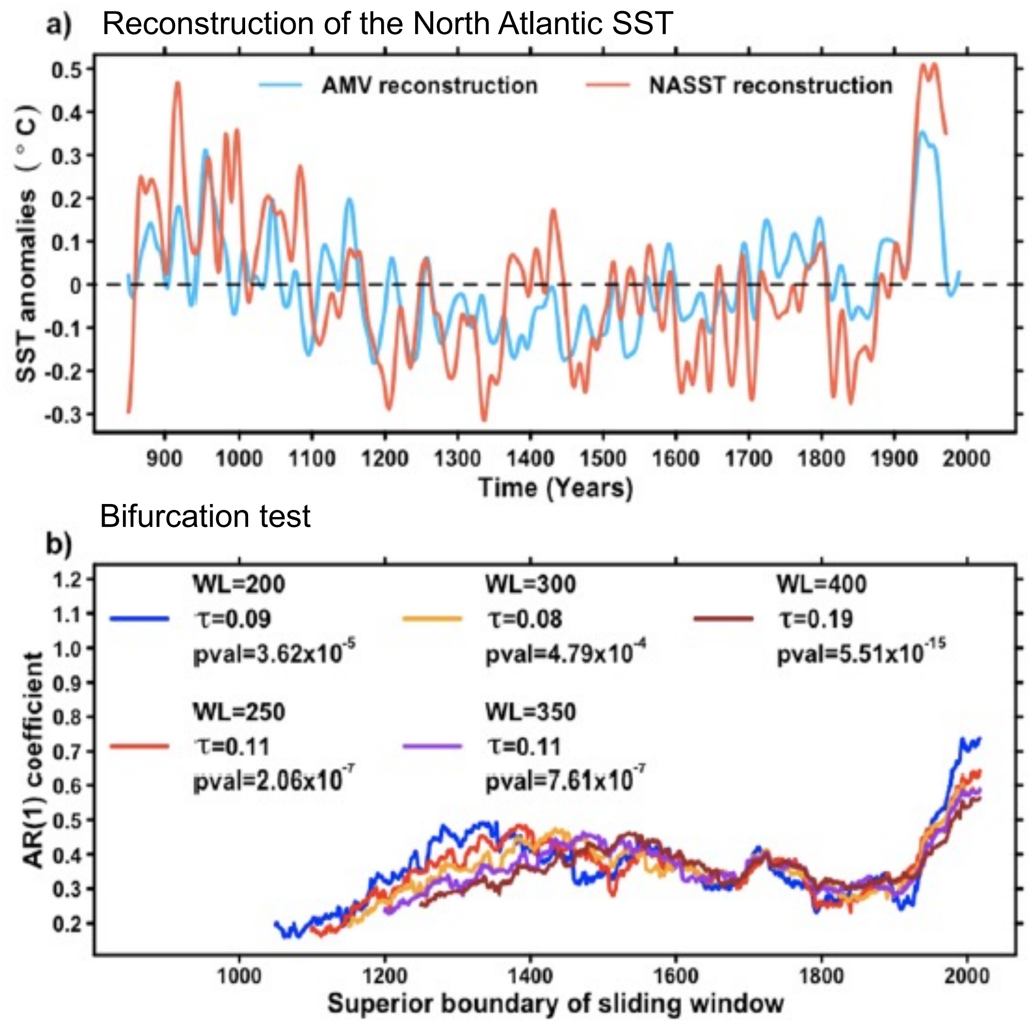
- Need for reconstruction of past AMOC on long enough timeframe



Proximity to oceanic tipping points?

Atlantic overturning (AMOC)

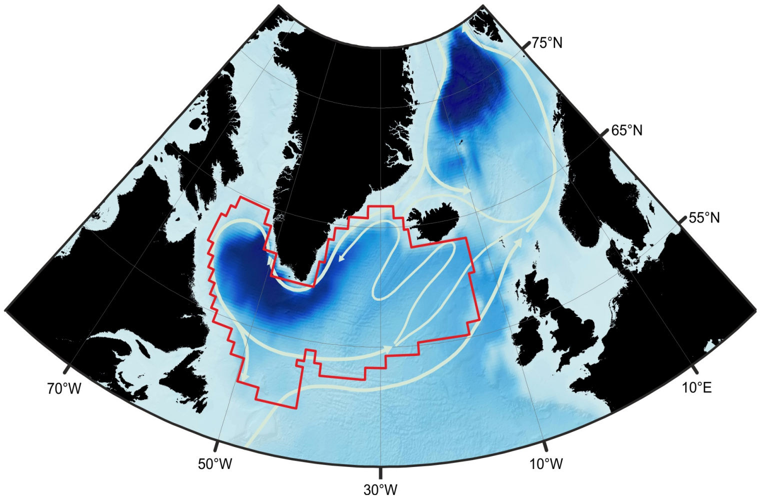


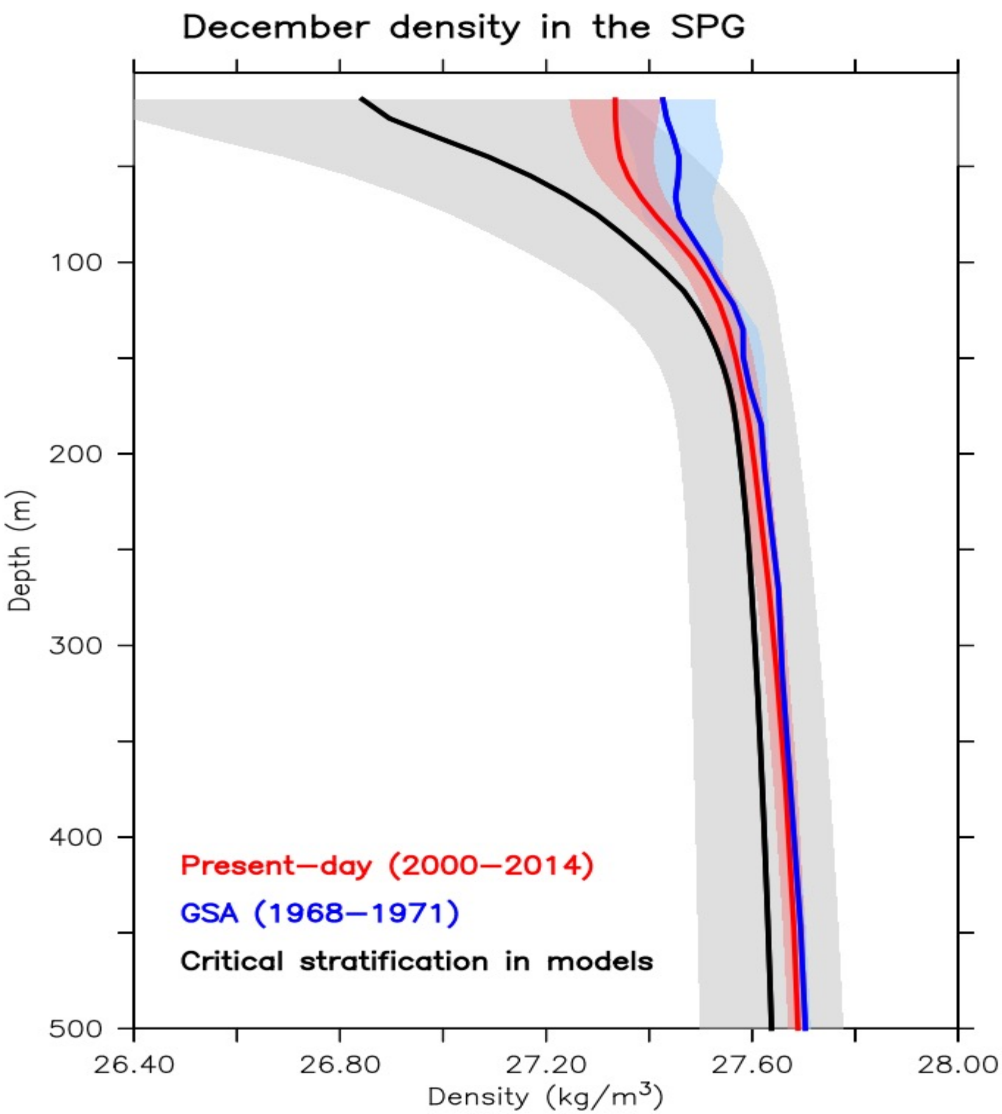


Simon et al., in rev..

Proximity to oceanic tipping points?

Subpolar gyre (SPG)





Swingedouw et al., *Surv. Geoph*. 2020

Research perspectives

Decadal predictions

Decadal predictions might help to gain insights on early warnings of abrupt changes

Initial conditions

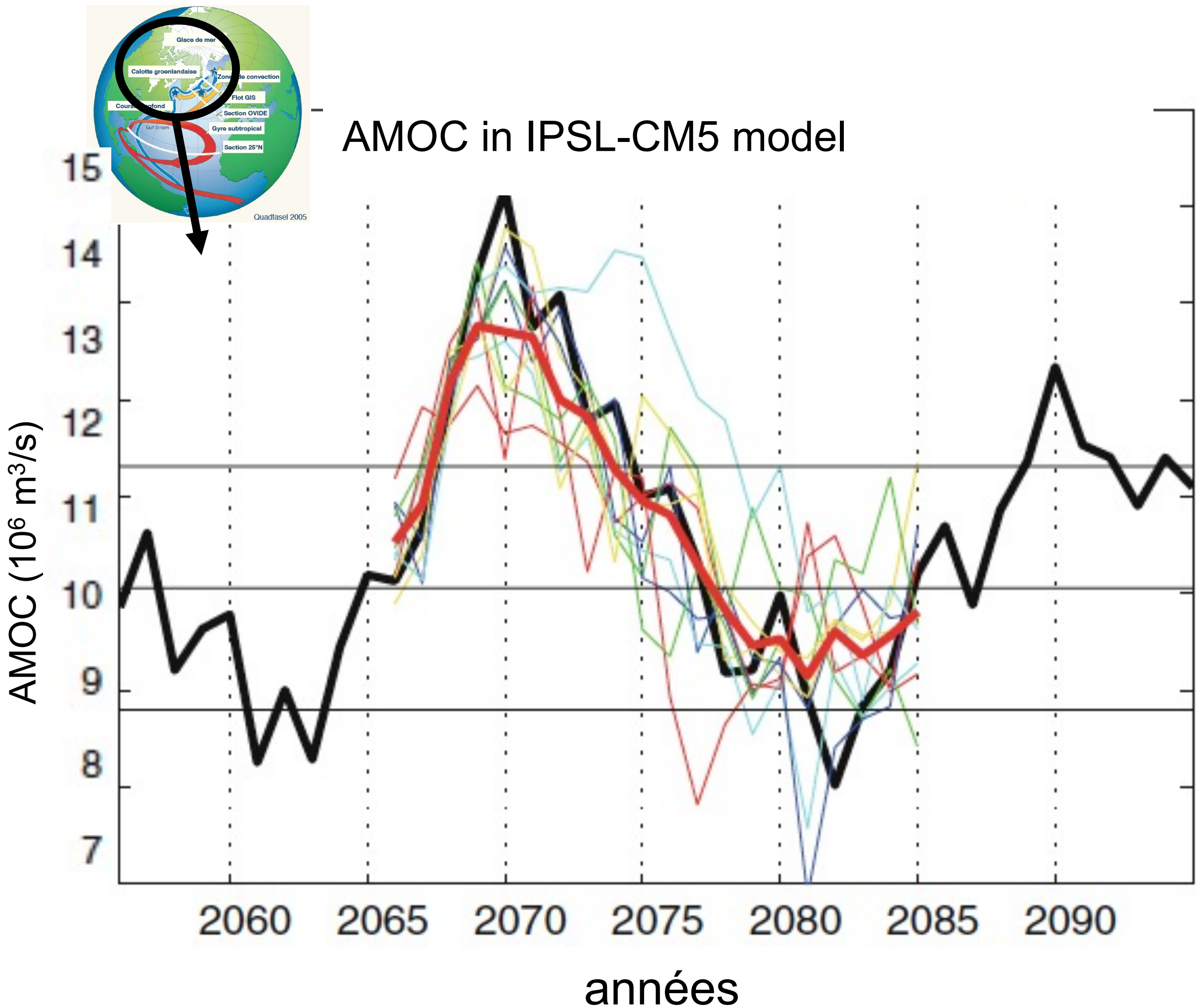
External forcing

Weather forecasts	Seasonal predictions	Decadal predictions	Centennial projections	Glacial cycles

day — week — month — year — decade — century — millennium →

Time scale

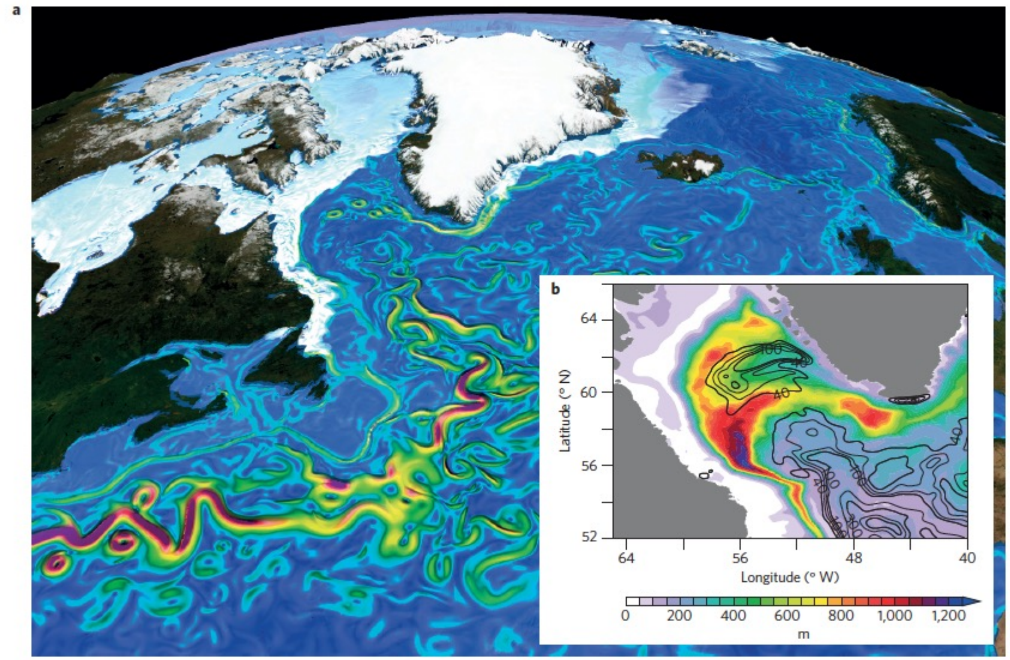
Decadal prediction



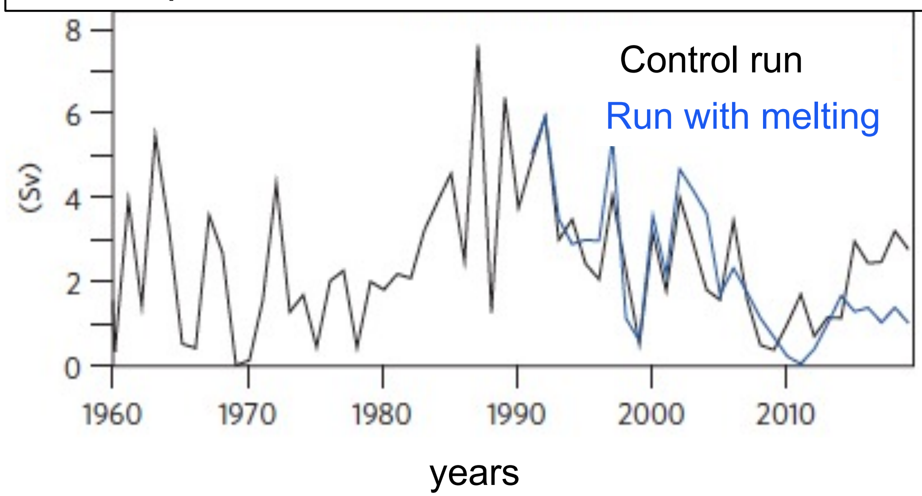
Persechino et al. (*Clim. Dyn.*, 2013)

Include Greenland melting in decadal predictions

- Greenland melting might already be affecting the Labrador Sea (Böning et al. 2016)
- We are including this melting in the IPSL-EPOC decadal prediction system in order to estimate its potential impact in the near future

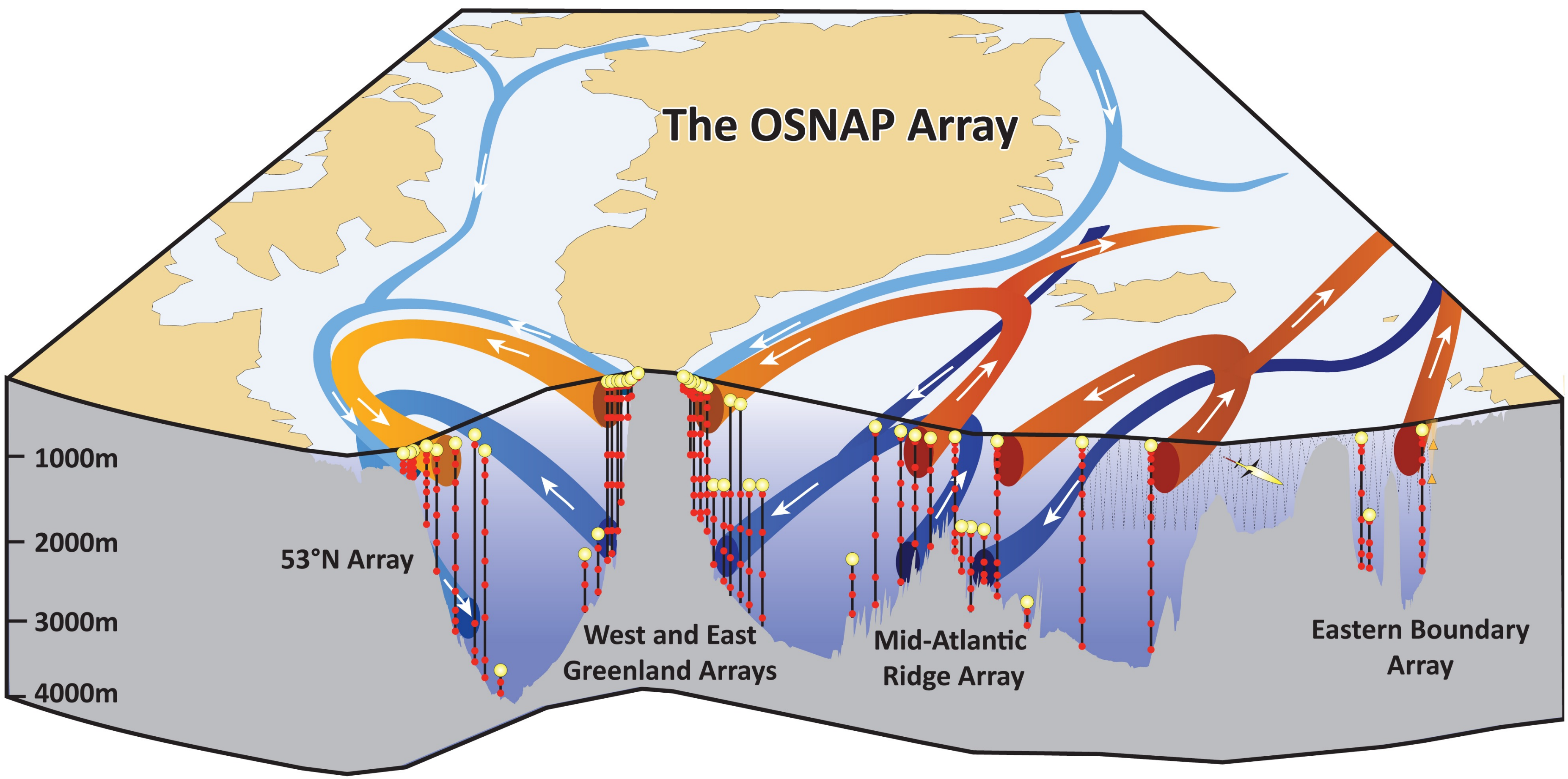


Deep water formation in the Labrador Sea



BLUE ACTION

New OSNAP array



Key take-home messages

- Possibility of Abrupt Changes in the North-Atlantic/Arctic in IPCC-type climate models

- They have global impacts (marine life, Sahel region, European heat waves, storms, viticulture/agriculture, Asian monsoon shift…)

- Decadal prediction systems, fed by Earth Observations, need to be further developed to have early warnings of such potential abrupt changes


Thank you!