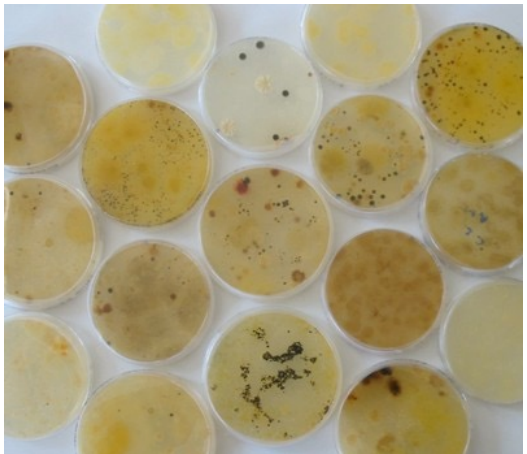
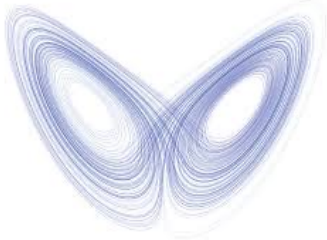
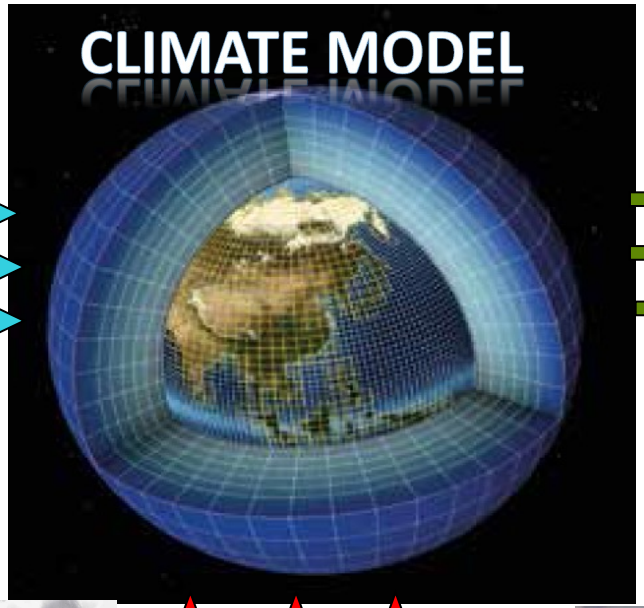
Bridging the gap between paleodata and climate projections

Didier Swingedouw



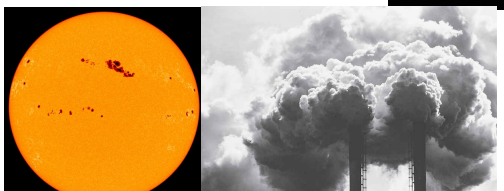
The Earth in a Petri dish?



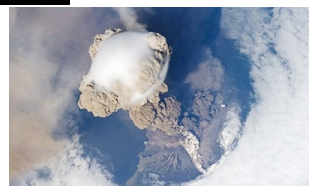


Input (initial conditions)

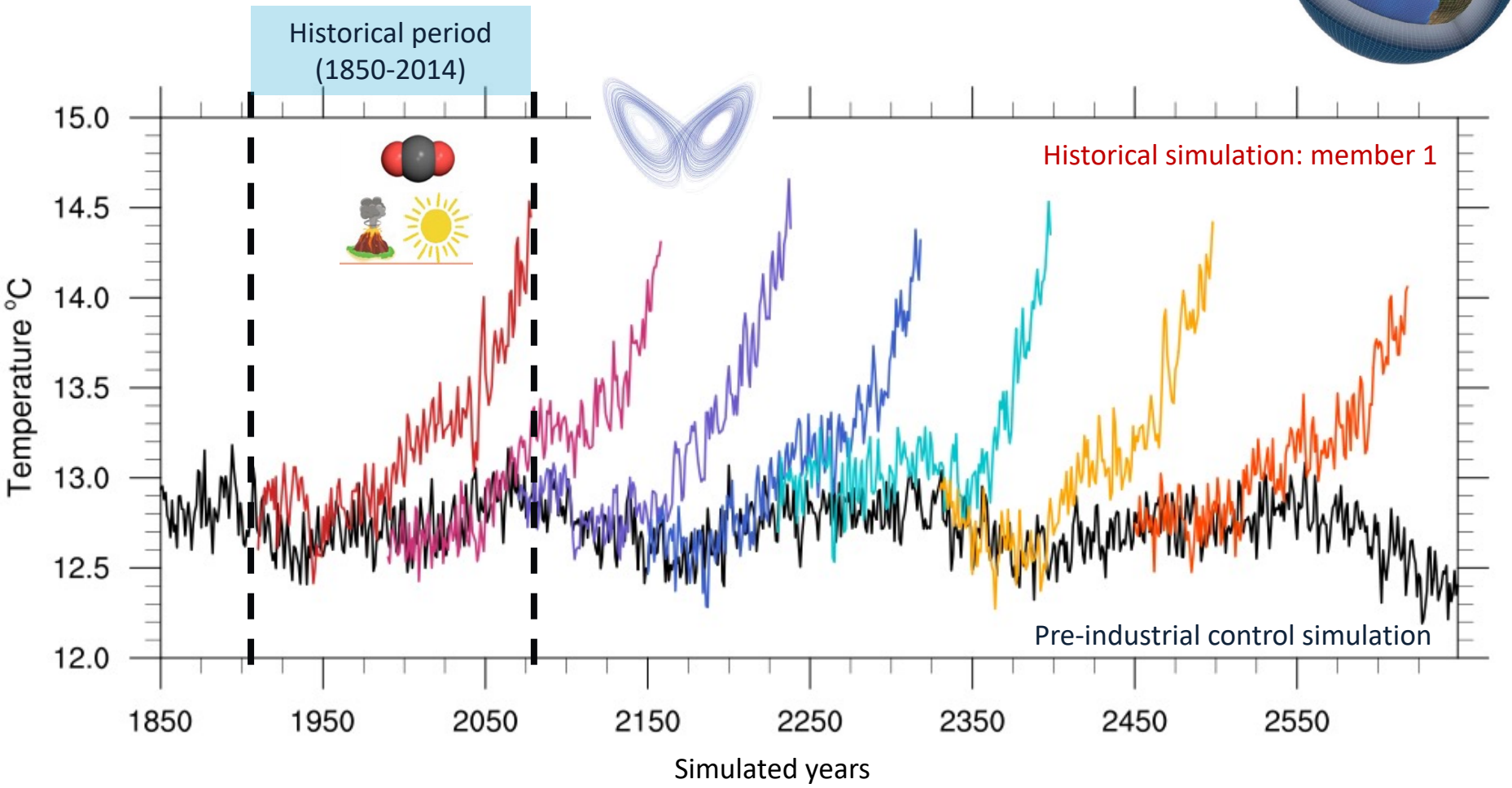
Output (climate variables)



External forcing

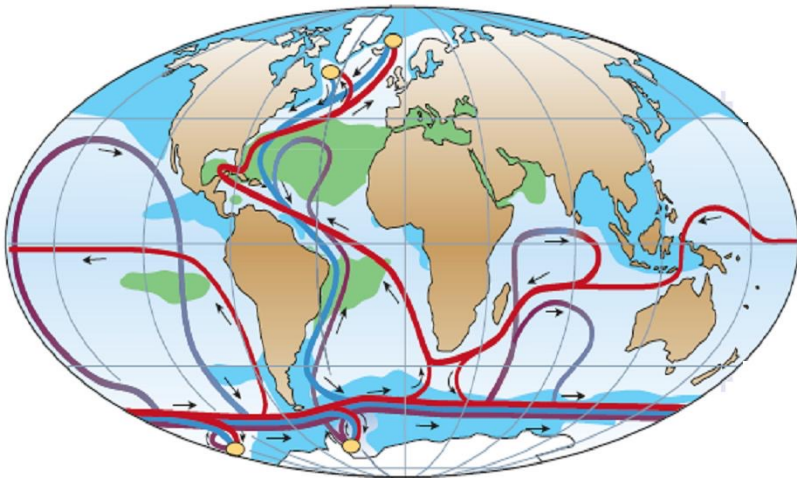


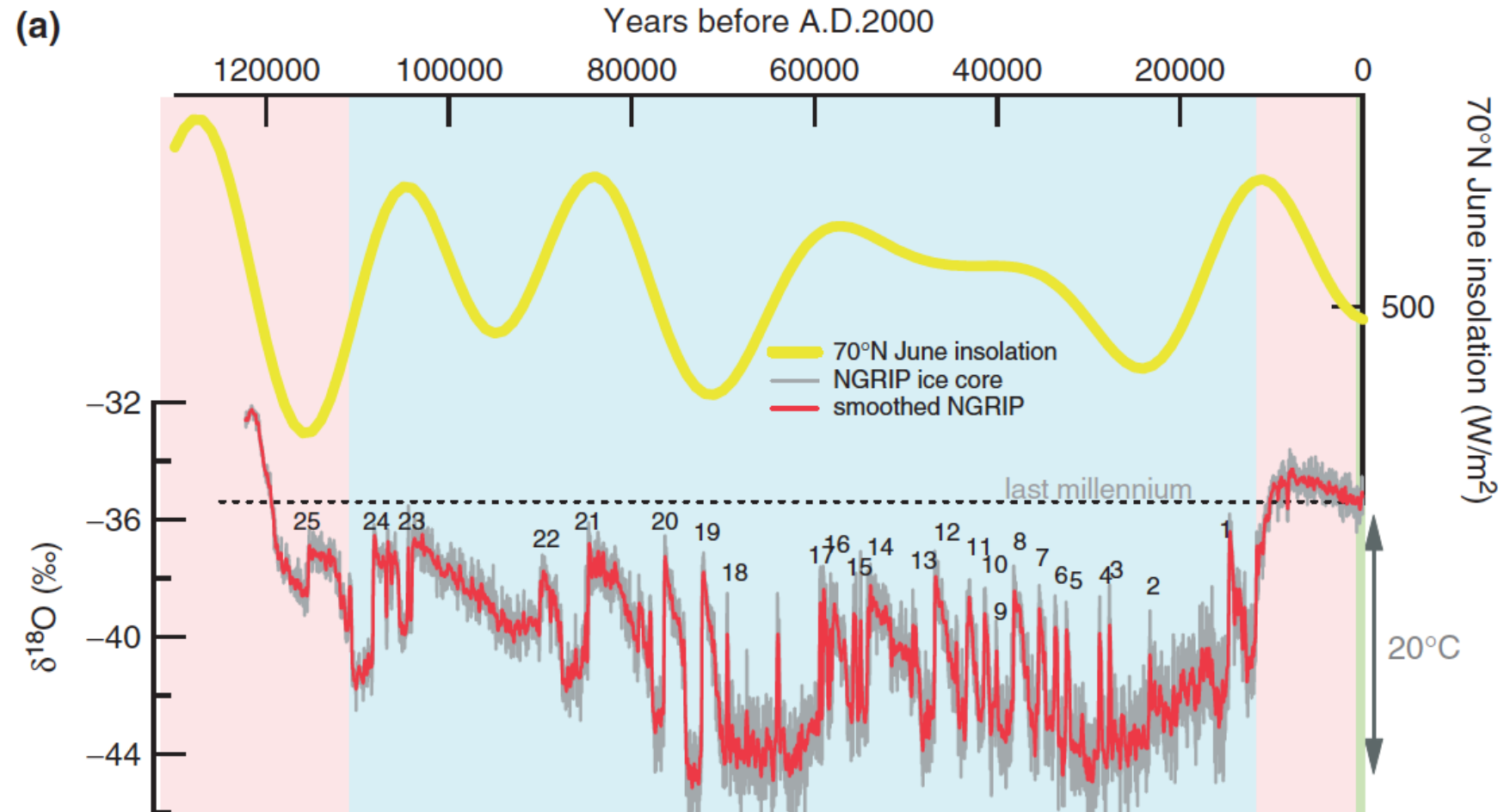
Internal variability & forced response



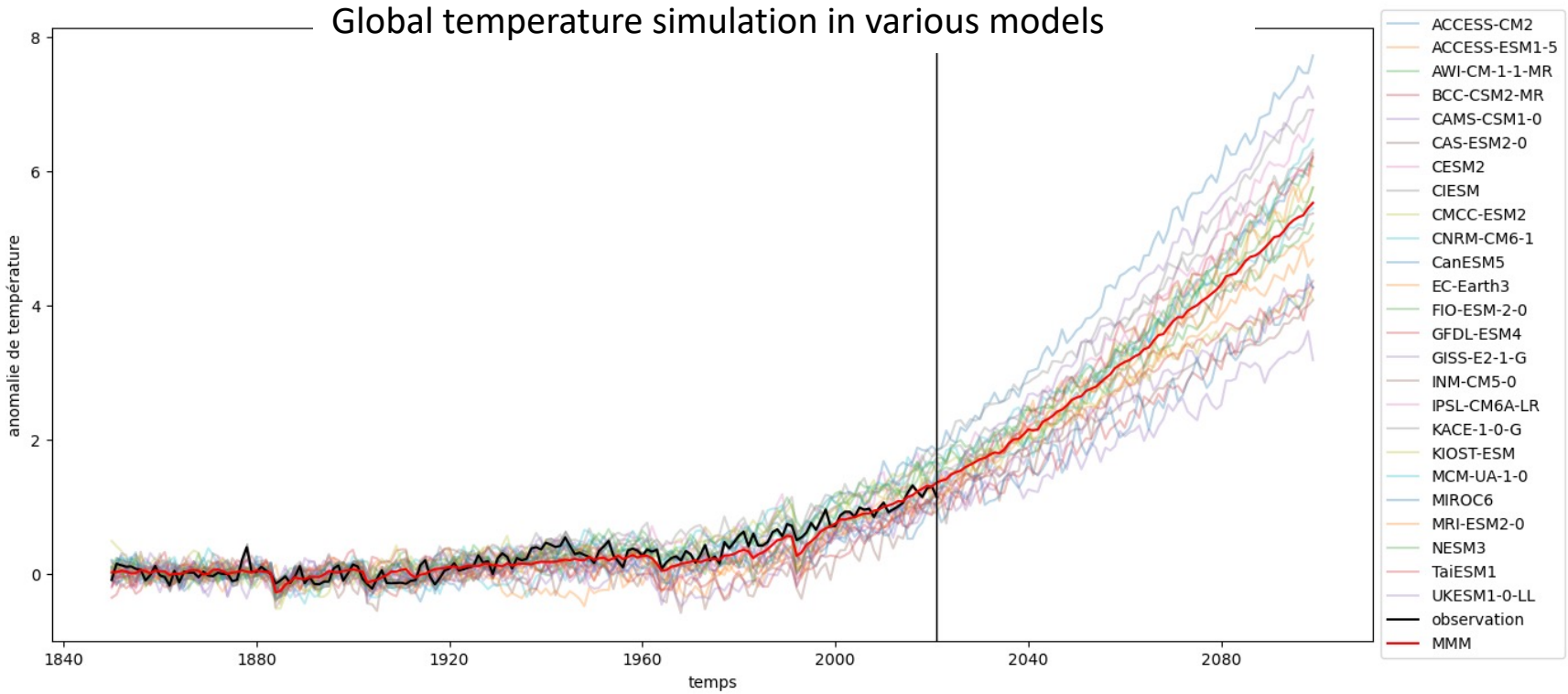
Instabilities and bifurcation

Spontaneous change of temperature and Atlantic Meridional Overturning Circulation (AMOC) in pre-industrial simulation of EC-Earth model (Drijfhout et al. 2013)





Uncertainty in future climate



- Two main modelling sources of uncertainty for the future (Hawkins & Sutton 2009):
  1. Model disagreement (e.g. climate sensitivity from about 2 to 6°C in CMIP6!)
  2. Internal variability
- AMOC uncertainty is also huge and is a key source of climate uncertainty for the North Atlantic sector (Bellomo et al. 2021)

What can paleo-data tell us about future climate?

1. Knowledge of internal variability and bifurcation risks

2. Bed-test for model response to external forcing changes

3. Emergent constraint methods as a statistical way to bring model and (paleo?)-data together

Courtesy of Valentin Portmann

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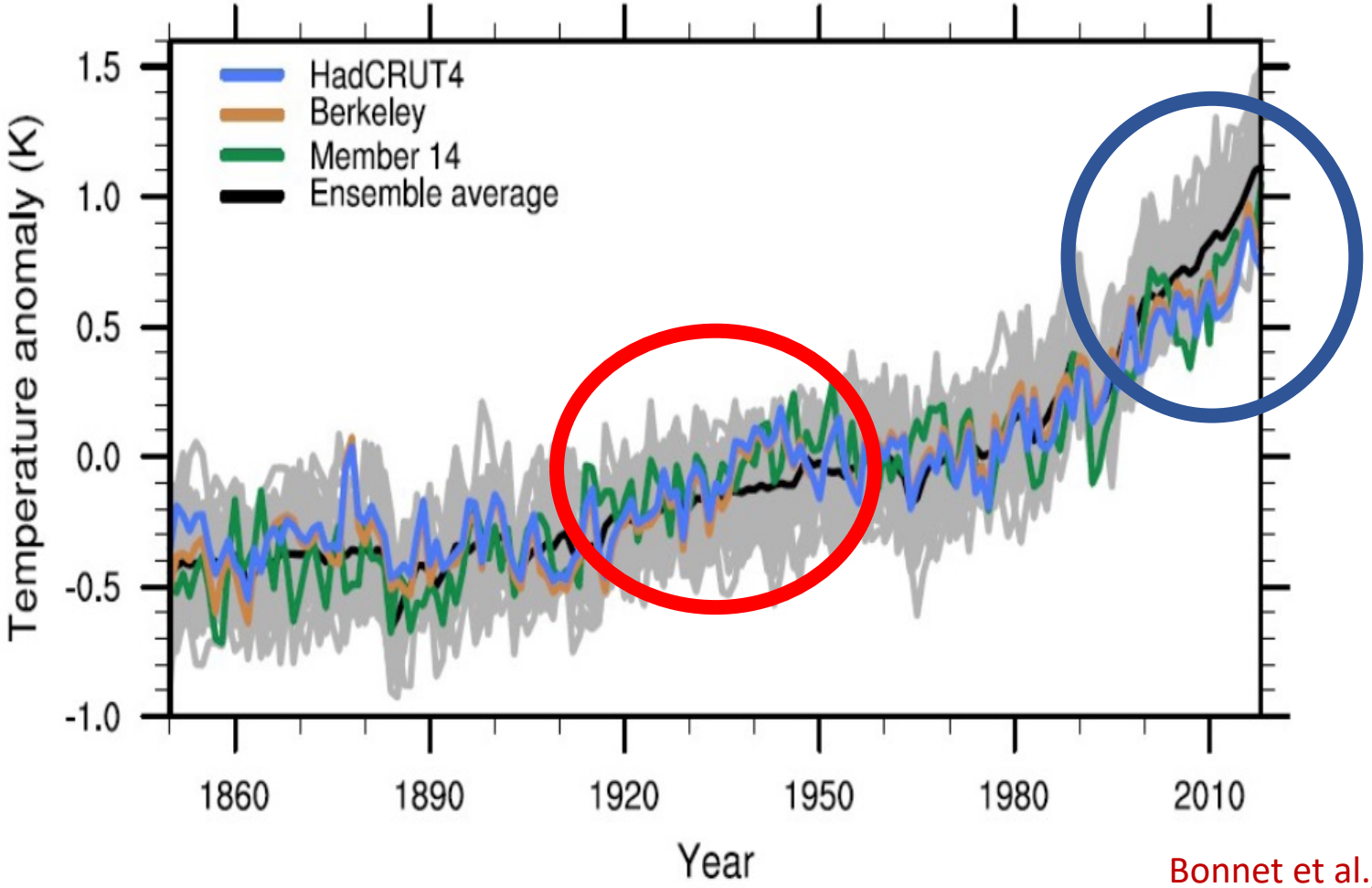
Internal variability and climate sensitivity

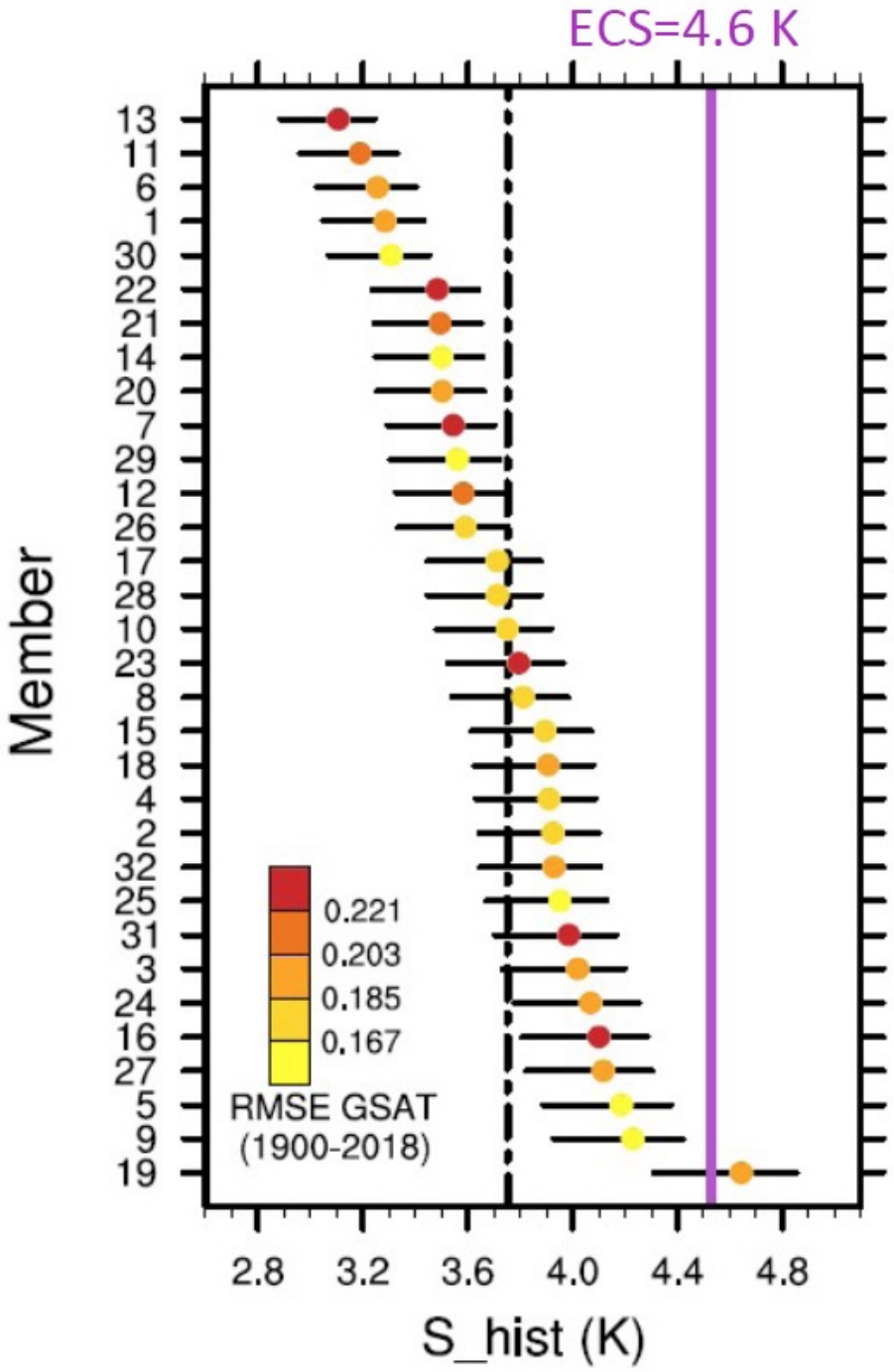
Global near-surface temperature (GSAT) in IPSL-CM6A large ensemble

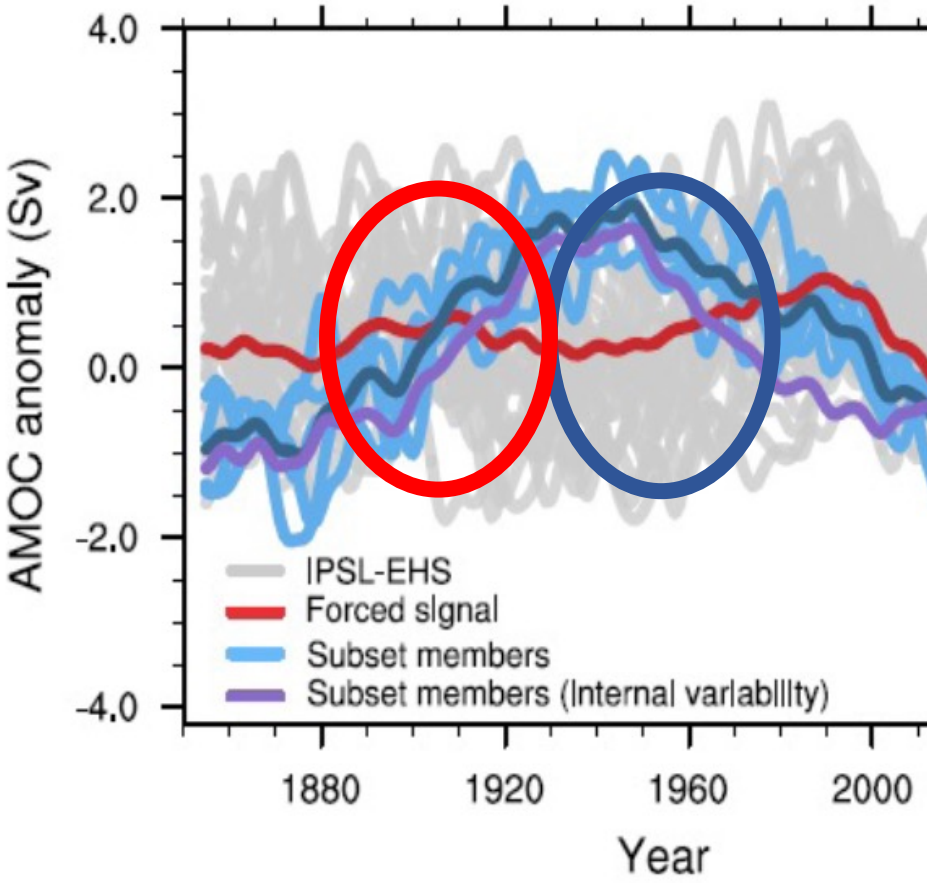


Bonnet et al., *Nat Com.*, 2021

climate sensitivity

Is this multi-centennial variability found in this (and other) model(s) realistic?



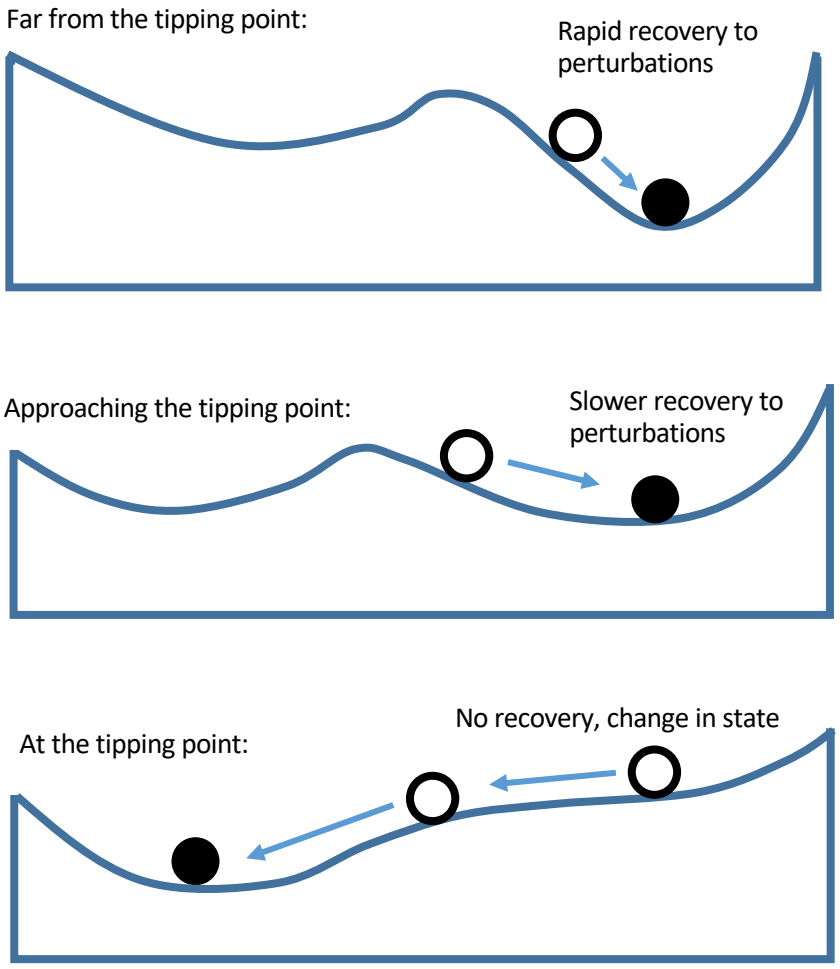


Bonnet et al., *Nat Com.*, 2021

How to have early warnings of a potential abrupt change?

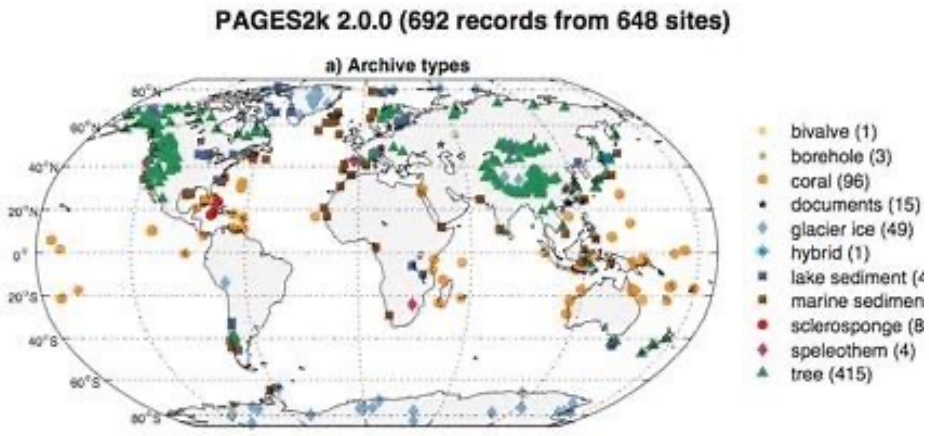
- Theory from dynamical system teaches us that approaching a tipping point, the system variability tend to increase
- Boulton et al. (2014) : we need **at least 250 years** to be able to apply it to the AMOC (model result)
- Bowers (2021) : we are approaching a tipping point (but using observed AMOC fingerprints **over only the last 150 years)**
- This might be a bit short, and the new EWS method of Boers (2021) has not been tested in "pseudo-proxy" approach

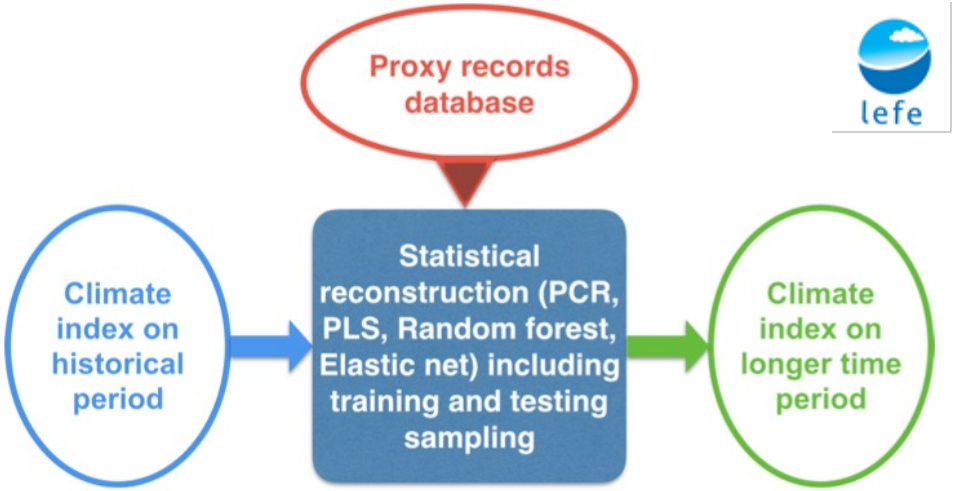
Change of temporal variability when approaching a tipping point



Adapted from: Lenton 2011

Proximity to an AMOC tipping point?



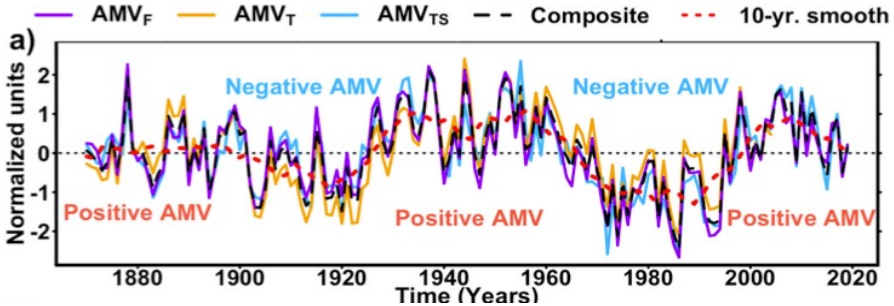


Validation:

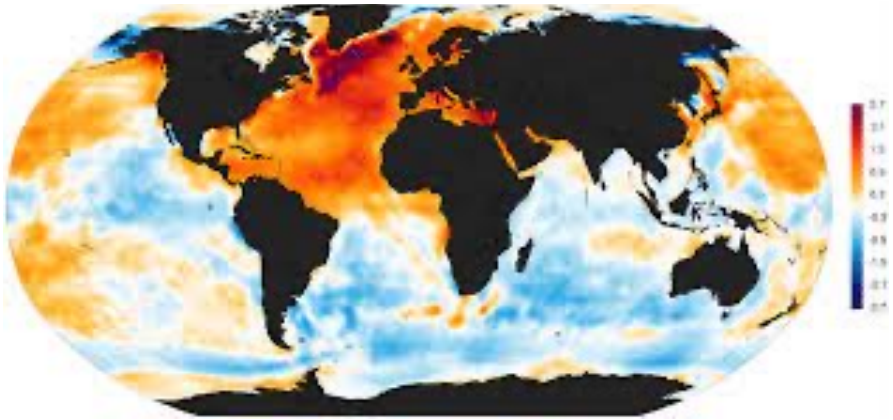
- Within the reconstruction through **leave-one-out** method
- Using **independent** ocean proxy records
- Using **pseudo-proxy** method: reconstructing the variability mode in a model simulation using the same sampling of proxy records and the same statistical regression method

Michel et al., Nat Com., 2022

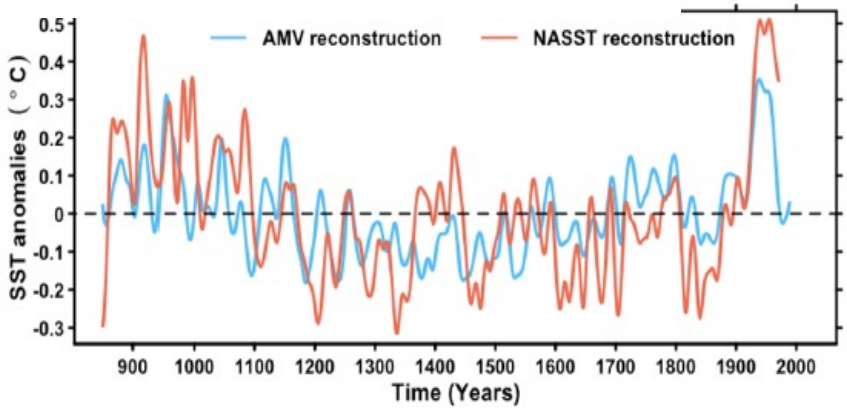
Proximity to a tipping point in the North Atlantic?



Regression the North Atlantic SST on AMV index

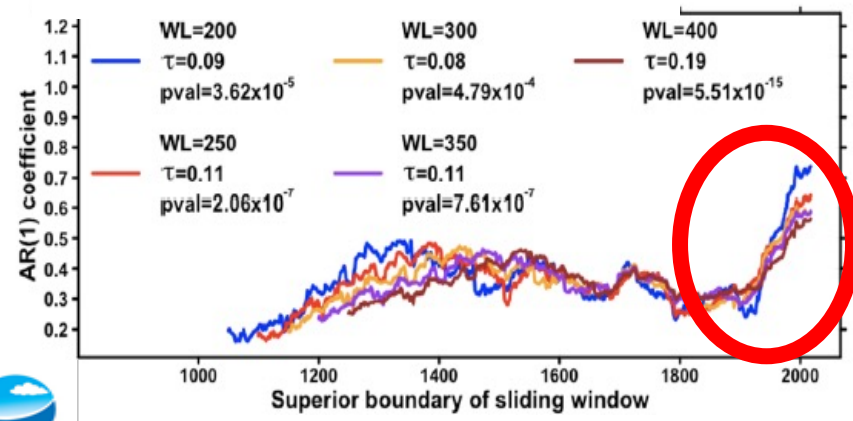


Reconstruction of the North Atlantic SST



- We use the Atlantic Multi-decadal Variability (AMV) index where external forcing has been removed (e.g. anthropogenic aerosols)
- We also remove it from proxy records
- This external forcing signal is estimated from CMIP5 ensemble
- By doing so, we might be able to isolate internal variability in the Atlantic sector
- Its reconstruction show that the North Atlantic system might be approaching an instability

Bifurcation test



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Michel et al., Nat. Com. 2022

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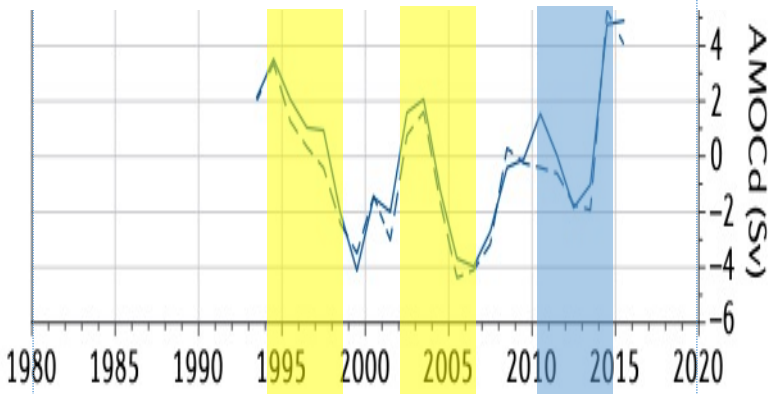
How can we explain recent AMOC variations?

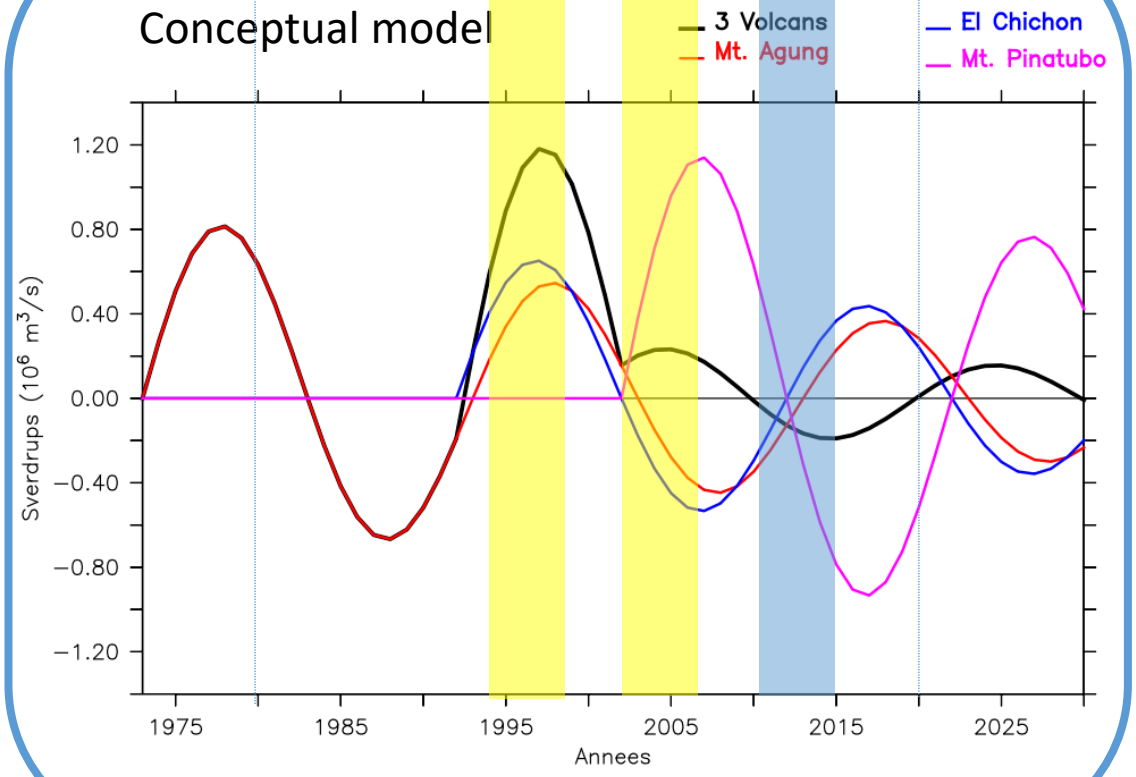
- Volcanic eruptions might be part of the AMOC variability on top that forced by the NAO (Swingedouw et al., *Nat. Com.*, 2015)
- It fits well with two Great Salinity anomalies timing since the late 1960s
- Does this work in paleo world?

AMOC from OVIDE instrumental reconstruction



AMOC response to volcanoes

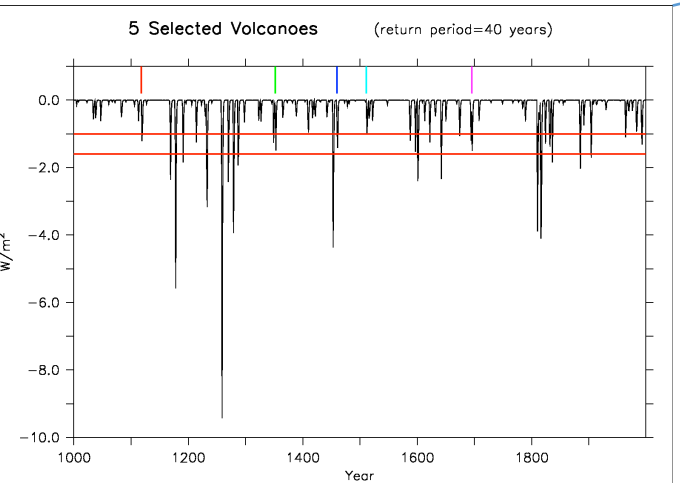
Conceptual model

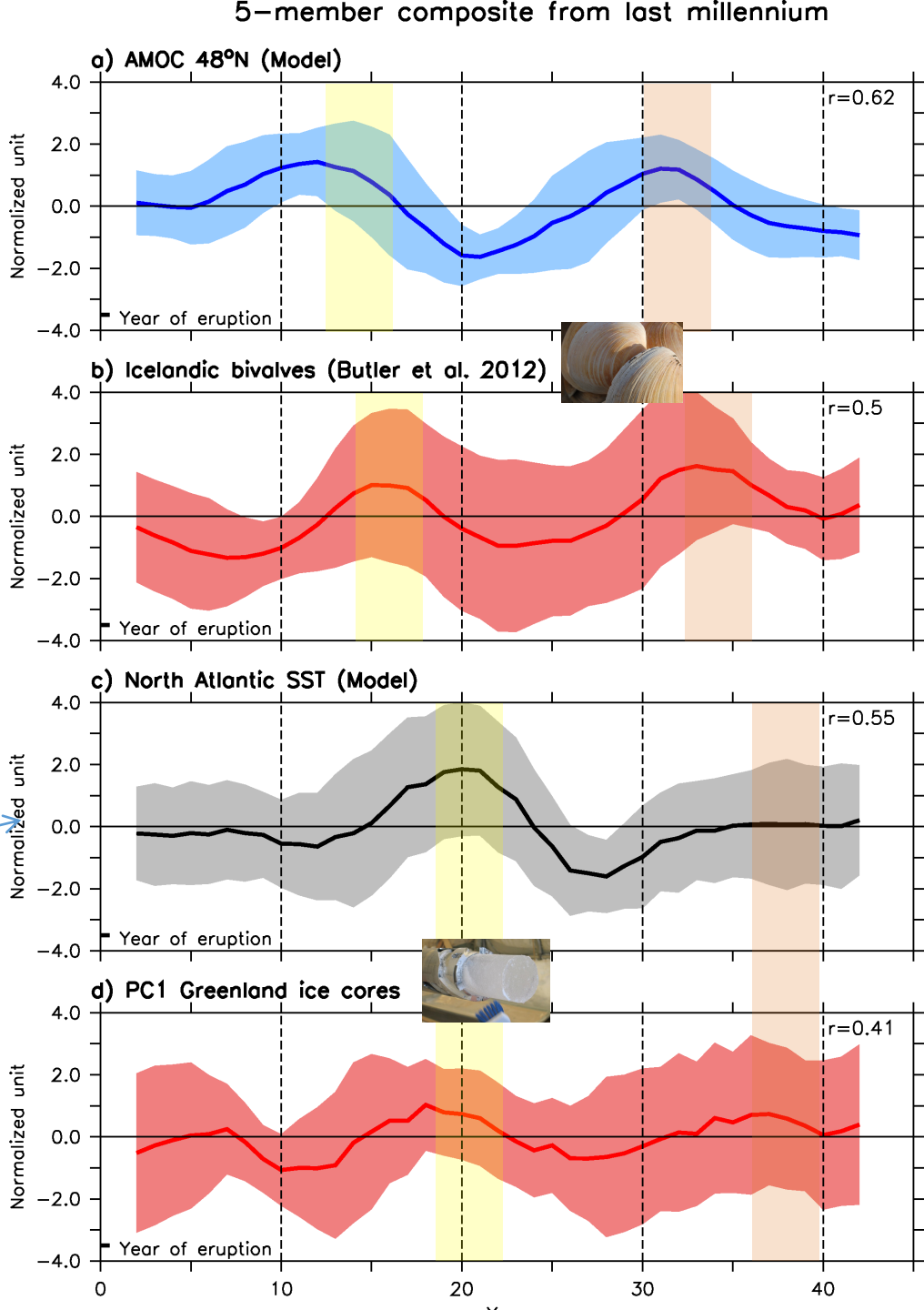


SPECS ANR Greenland

Last millennium perspective

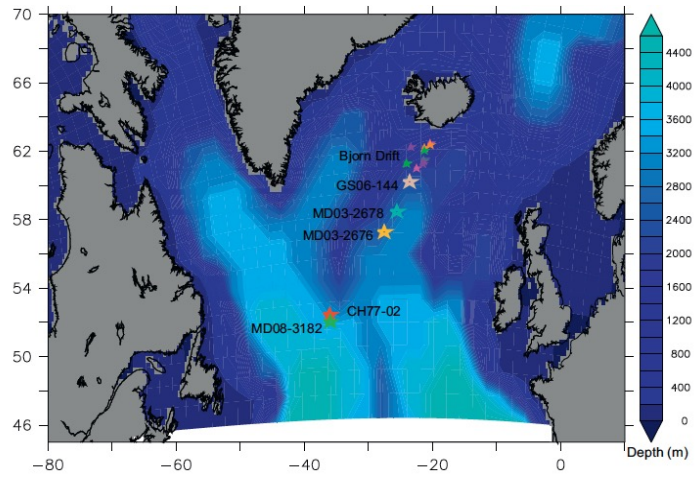
- We select the same timeseries following volcanoes in data and SST in the North Atlantic from the model
- Significant correlation both in model and data, following AMOC variations by around 5 years

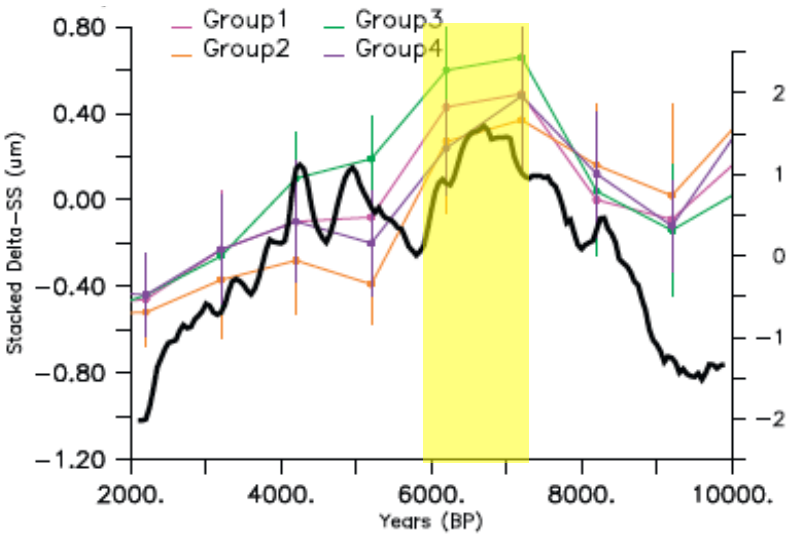


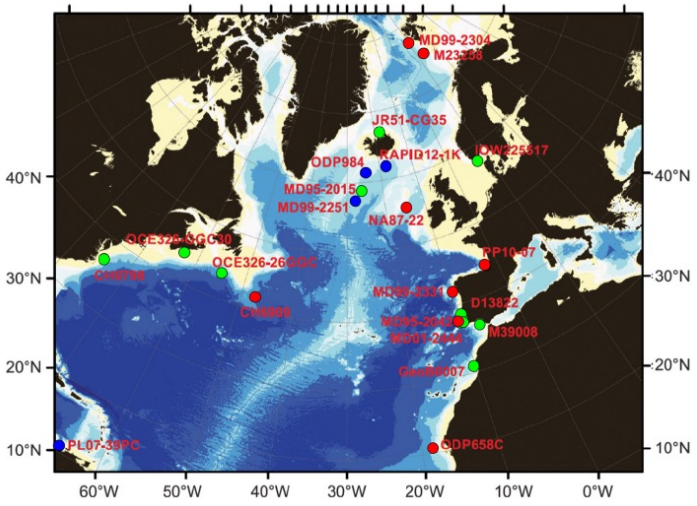


A new AMOC reconstruction over the Holocene

- Use of 22 sediment cores with SST proxy records (Eynaud et al. 2017)
- Use of EOF analysis to find consistent variability (Ayache et al.2018)



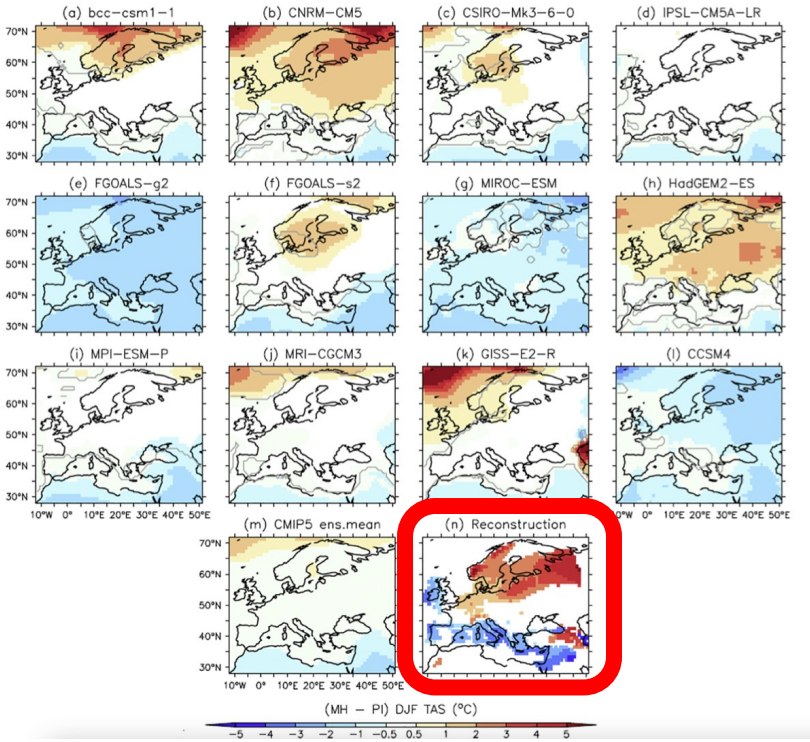


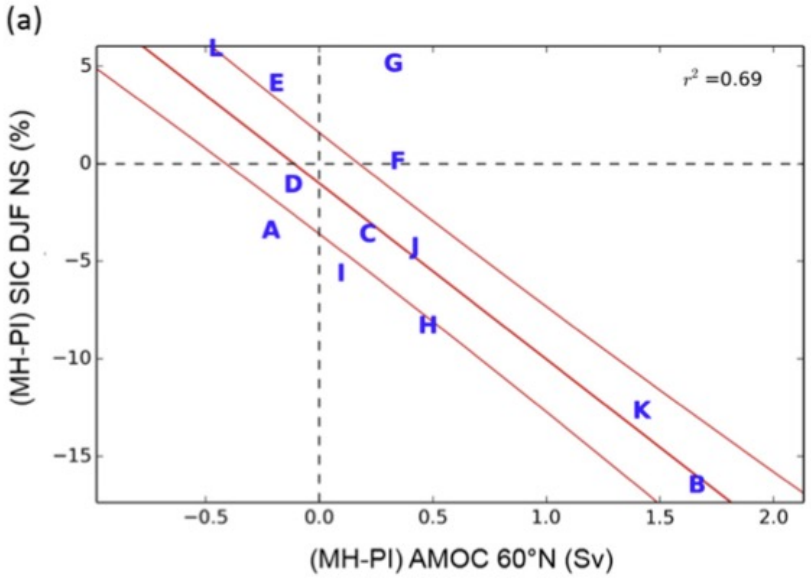


- Validation using pseudo-proxy (does the method work in the model “world”?)
- Validation using independent of deep ocean circulation, glaciers’ evolution…
- Calibration in Sverdrup using North Hemisphere reconstruction (Jomelli et al., *Nat. Com.*, 2022)

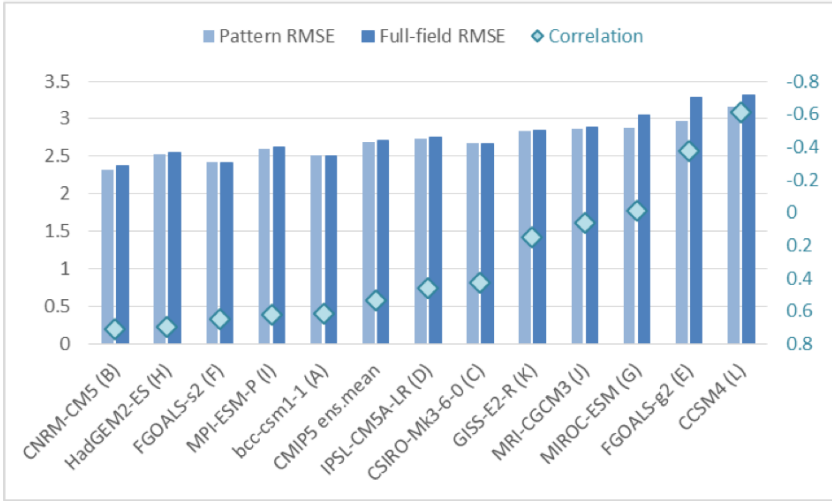
A stronger AMOC at the mid-Holocene?

- Born et al. (2011): this is because less sea ice is formed and transported in the SPG at 6 ka BP
- Gainusa-Bogdan et al. (2021): the spread in AMOC response might explain the spread in T2M response over Europe In PMIP
- **An emergent constraint?**





➢ « Best models » are the ones with largest AMOC enhancement



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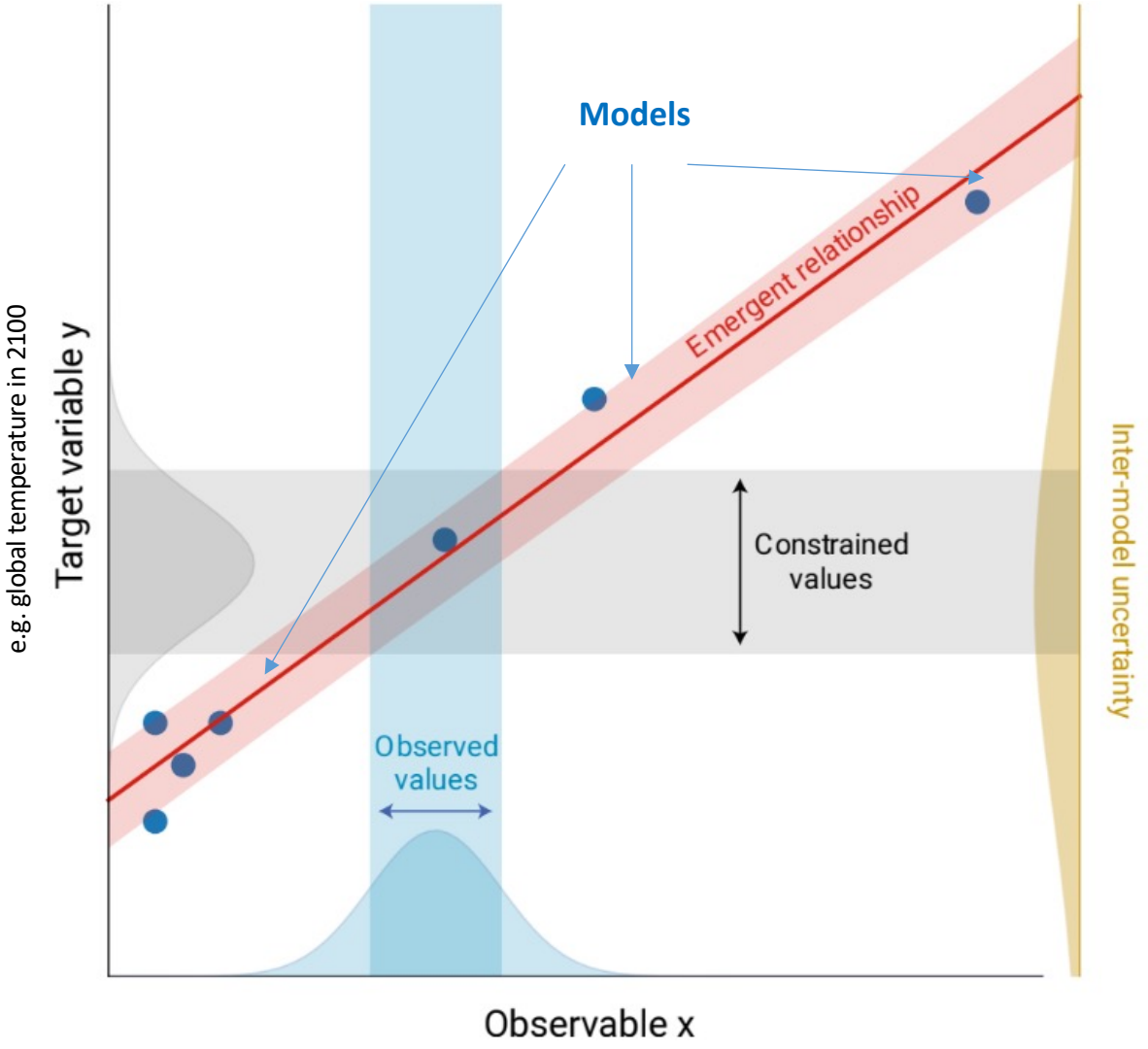
How to constrain future climate projections by using observations?



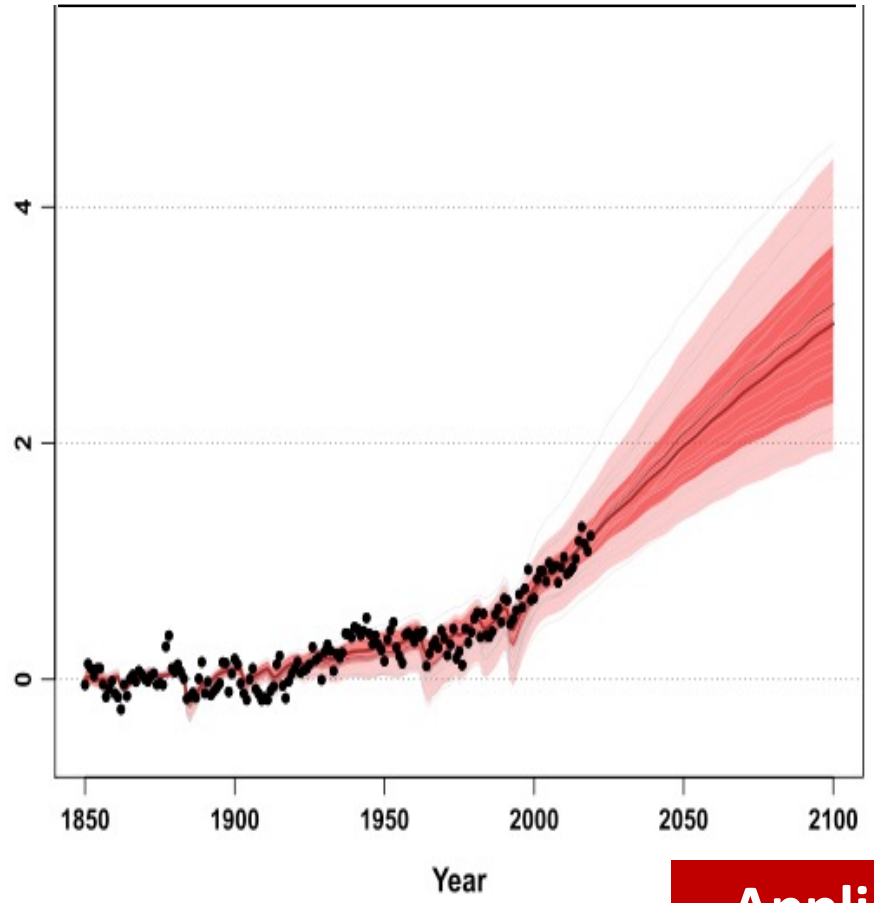
Now used in IPCC assessment reports (since 2021)

Eyring et al. 2019

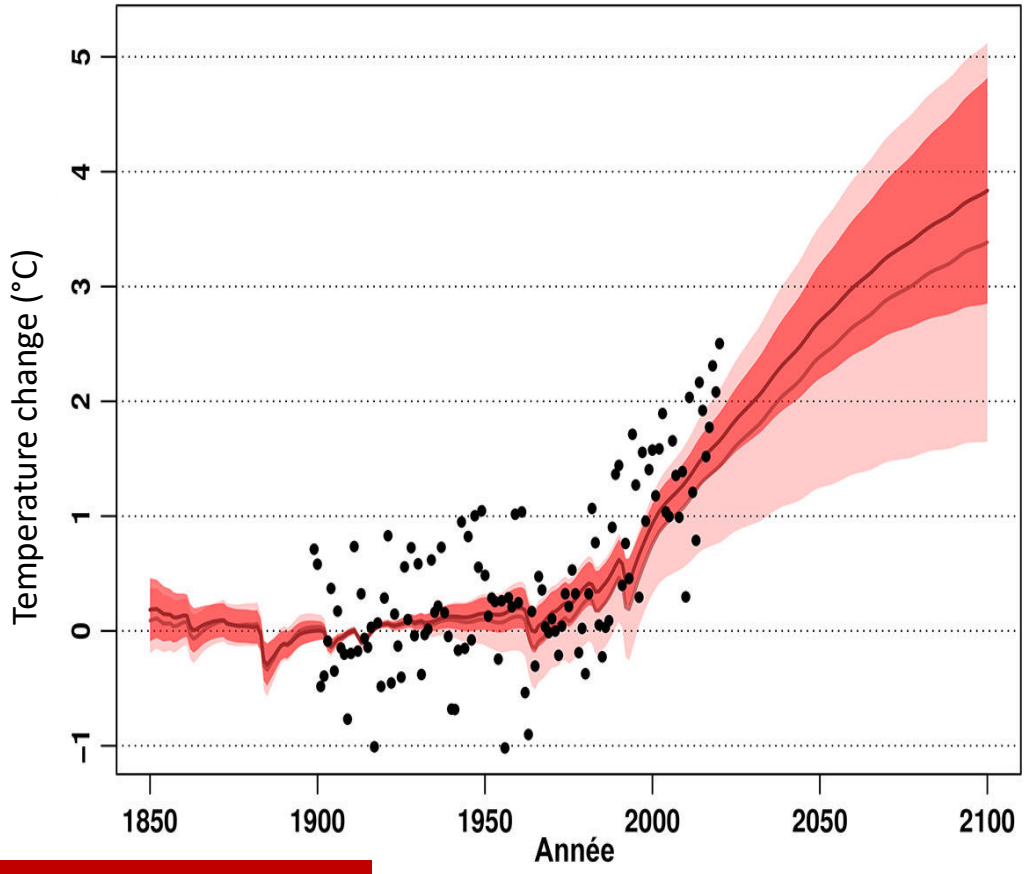
Two examples

Observations
Original model estimate
Contrained model estimate

Global temperature change (SSP2-4.5)



Temperature change over France



Application using paleo-data?

Ribes et al., Sc. Adv. 2021

Ribes et al. ESD 2022

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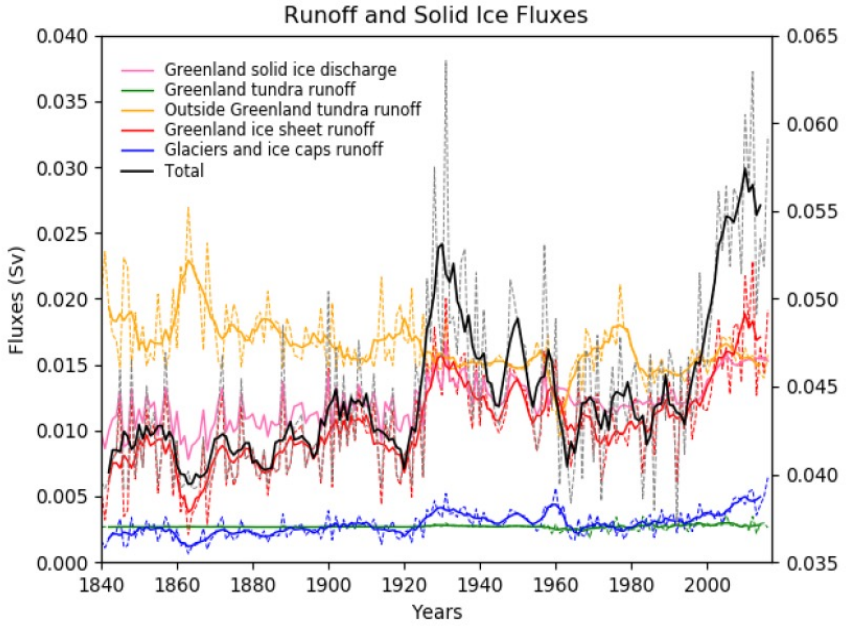
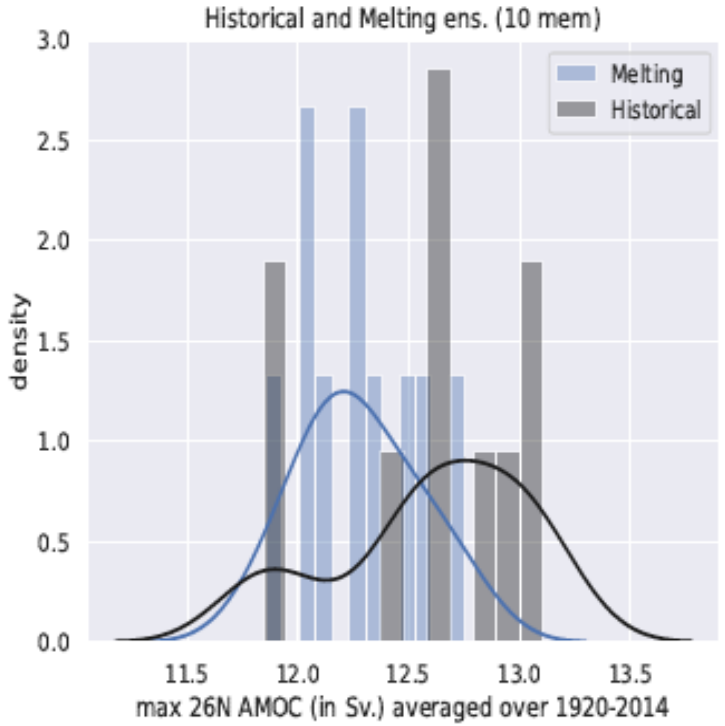
4. Known unknown

What about GrIS melting?





- Greenland melting is poorly accounted for in historical simulations and projections
- Use of 10 members of IPSL-CM6A-LR including this melting as compared to historical simulations show little impact

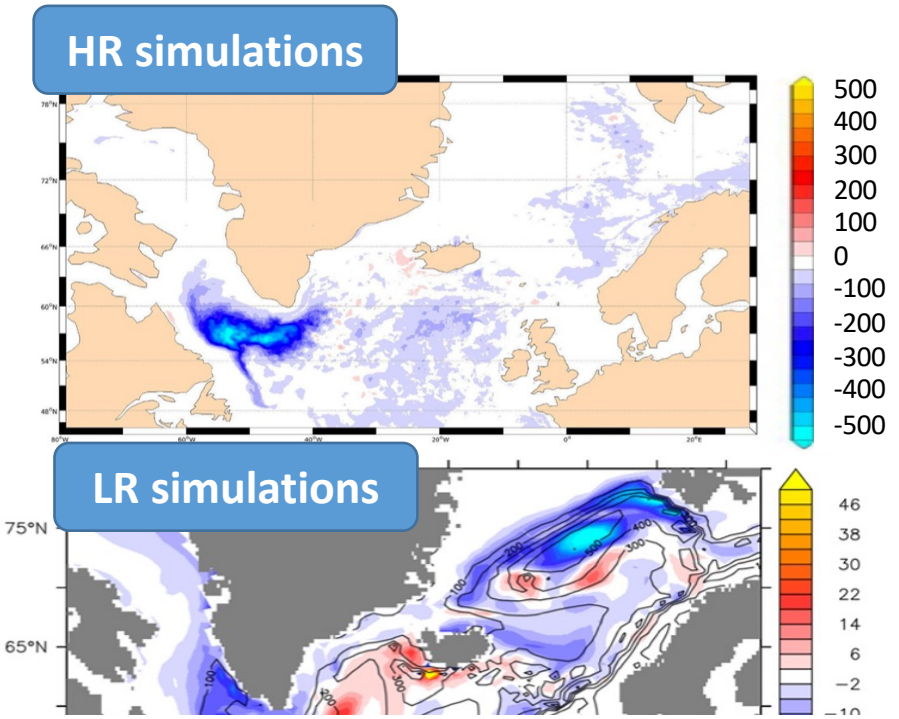
Devilliers et al., Clim. Dyn. 2021

BLUE ACTI

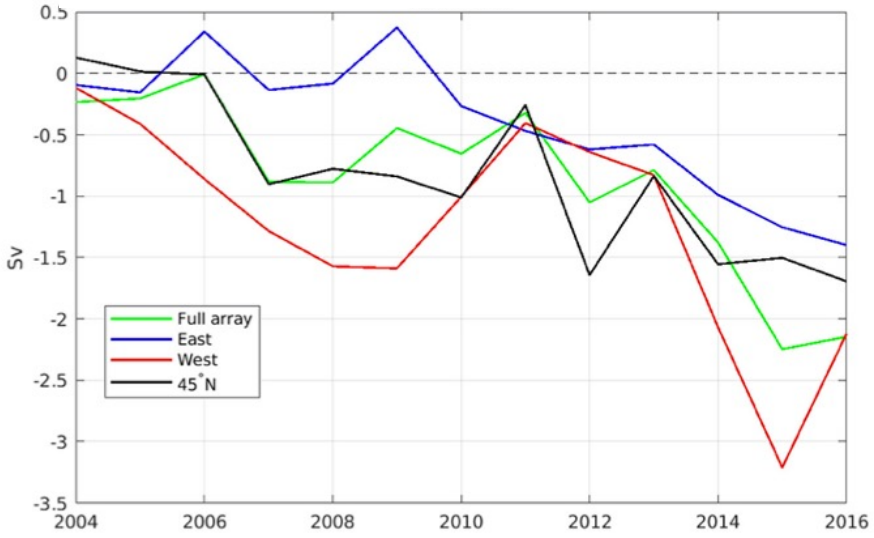
Impacts of oceanic resolution on GrIS impact

- We compare IPSL-CM6A Low Resolution (**LR, 50-60 km**) run with very High Resolution (**HR, 2-3 km**) simulations from an ocean-only model (Swingedouw et al., Frontiers, 2022)
- Higher impact of Greenland melting on the AMOC in the HR runs

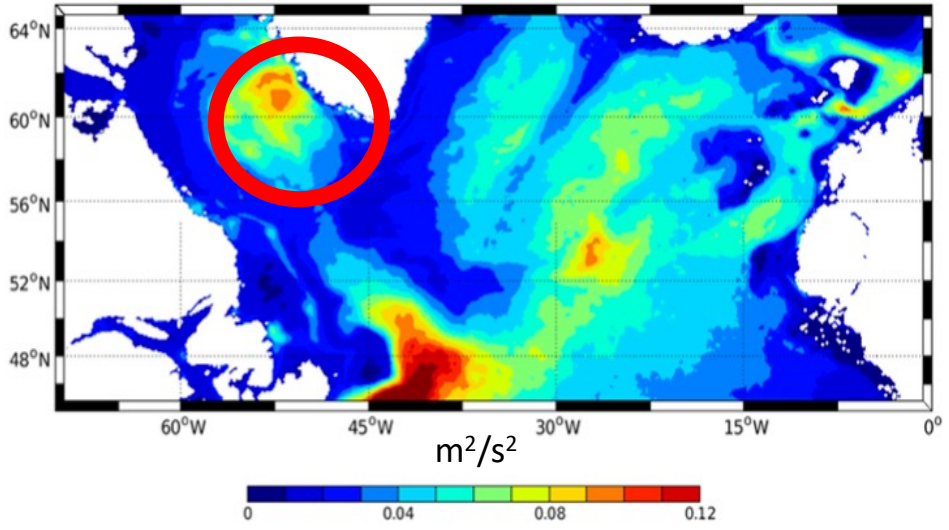
Mixed layer depth anomalies



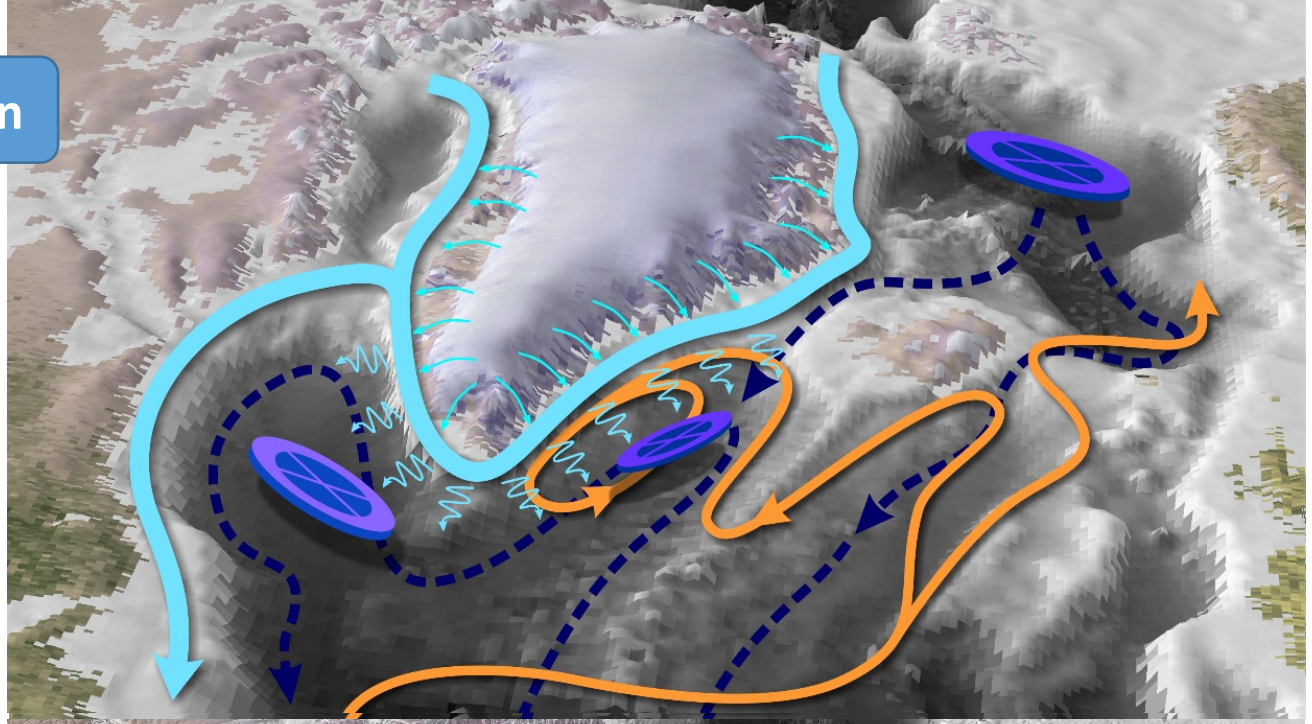
AMOC anomalies in HR simulations



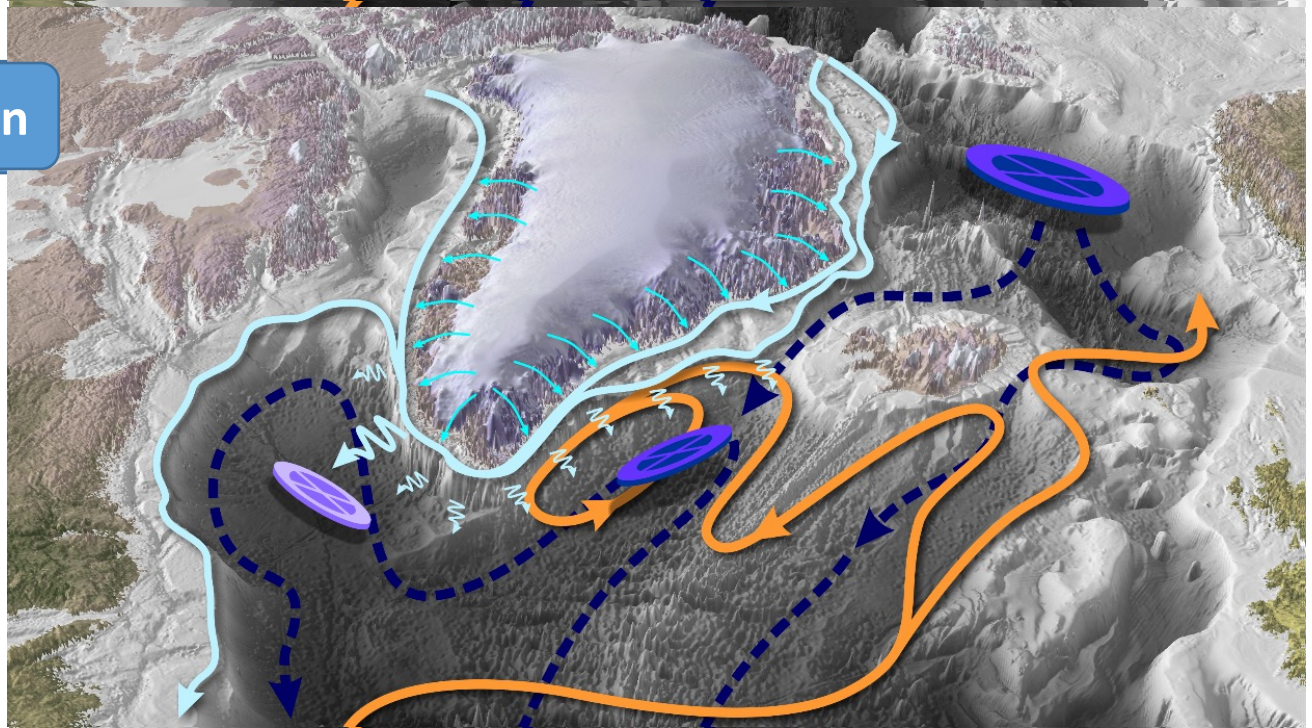
Eddy Kinetic energy in HR simulation



Low Resolution



High Resolution



Courtesy of
Vincent Hanquiez

Key take-home messages

- Climate can substantially change without being forced by any external forcing!
- Paleo-data and models can be used together to test reconstruction method (e.g. pseudo-proxy approach)
- Paleo-data can strongly help our understanding of recent climate change, its future response to external forcing and better evaluate the risk of bifurcation
- Some new methods (emergent constraint) are now being adopted by IPCC to try to quantitatively reduce uncertainty in model projections: paleo-reconstruction can clearly contribute to this new paradigm
- There still exists huge uncertainty in our representation of the climate system within our model, which obliges us to humility

Thank you!