Risks and impacts of abrupt changes in the North Atlantic

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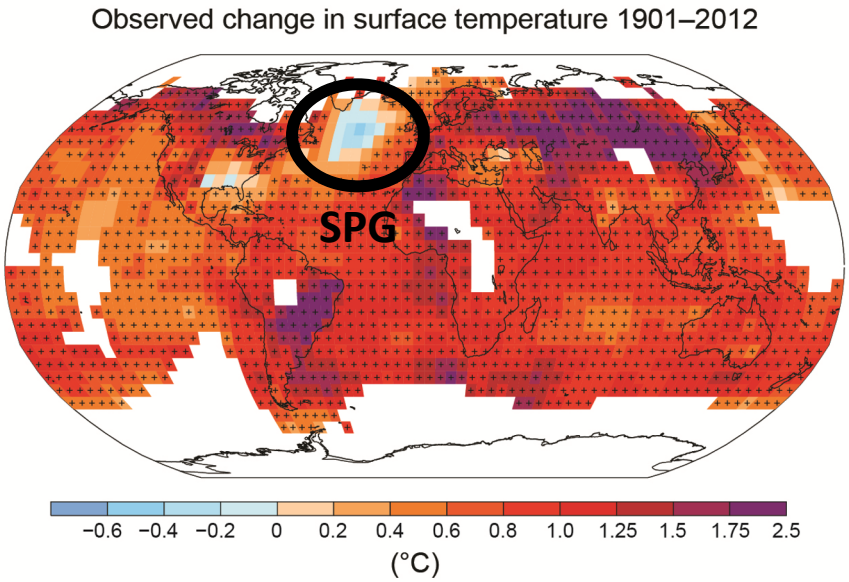
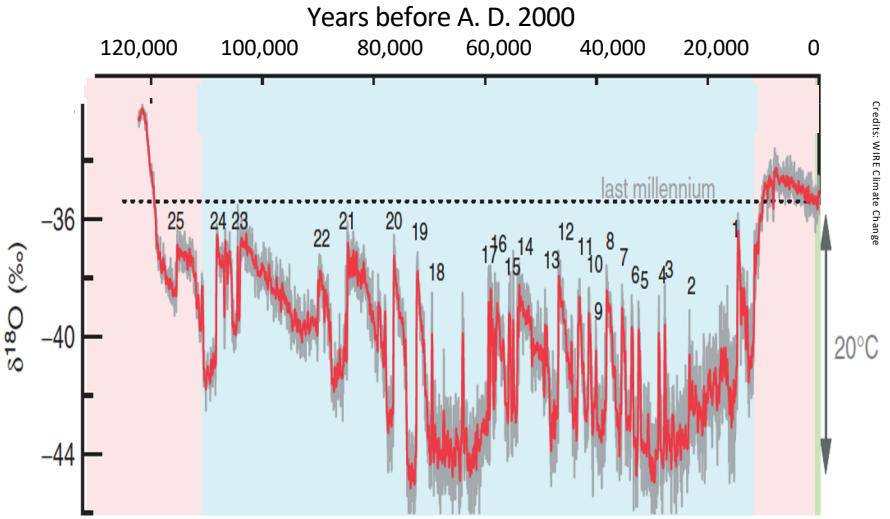
Where are we now?

- There is an observed cooling and freshening of the subpolar gyre (SPG) over the last century
- This might be a fingerprint of an on-going weakening of the Atlantic ocean circulation
- Lessons from the past both in glacial and interglacial periods highlight that abrupt changes/instabilities/tipping points are possible

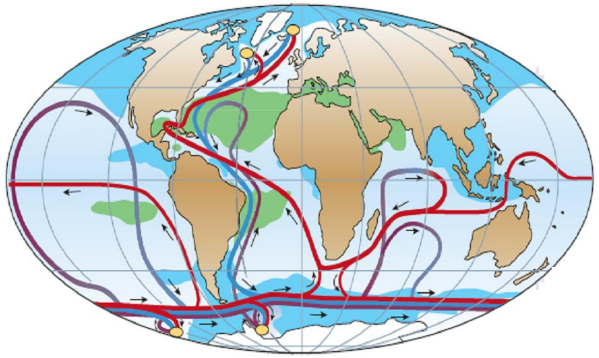


Ice core reconstructions

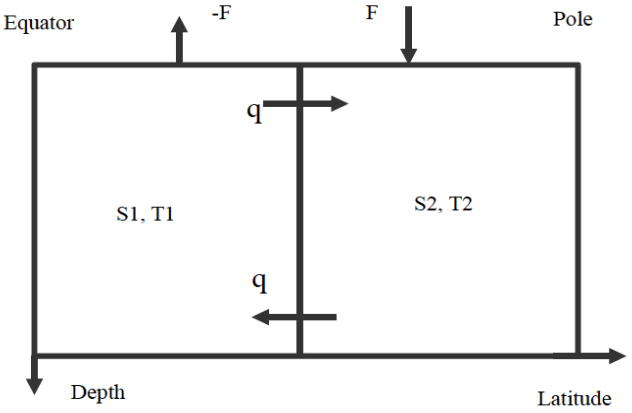


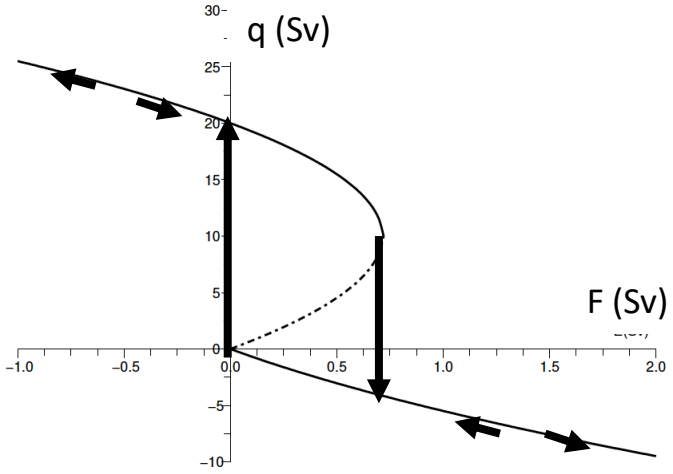
Masson-Delmotte et al. 2012

Non linearity of the Atlantic Overturning (AMOC)?



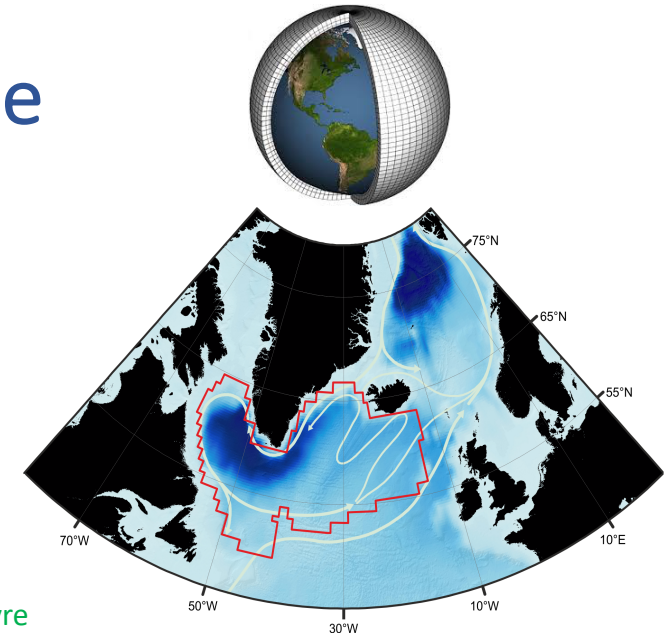
- Stommel (1961) early showed that the AMOC may exhibit strongly non-linear response to surface freshwater forcing
- His simple analytical model showed that the AMOC may have multiple solutions for a given freshwater forcing and hysteresis behavior
- Still true in higher resolution models (cf. Rahmstorf et al. 2005, Jackson et al 2018…)





This is a steady state response! (potentially implying millennial scale)

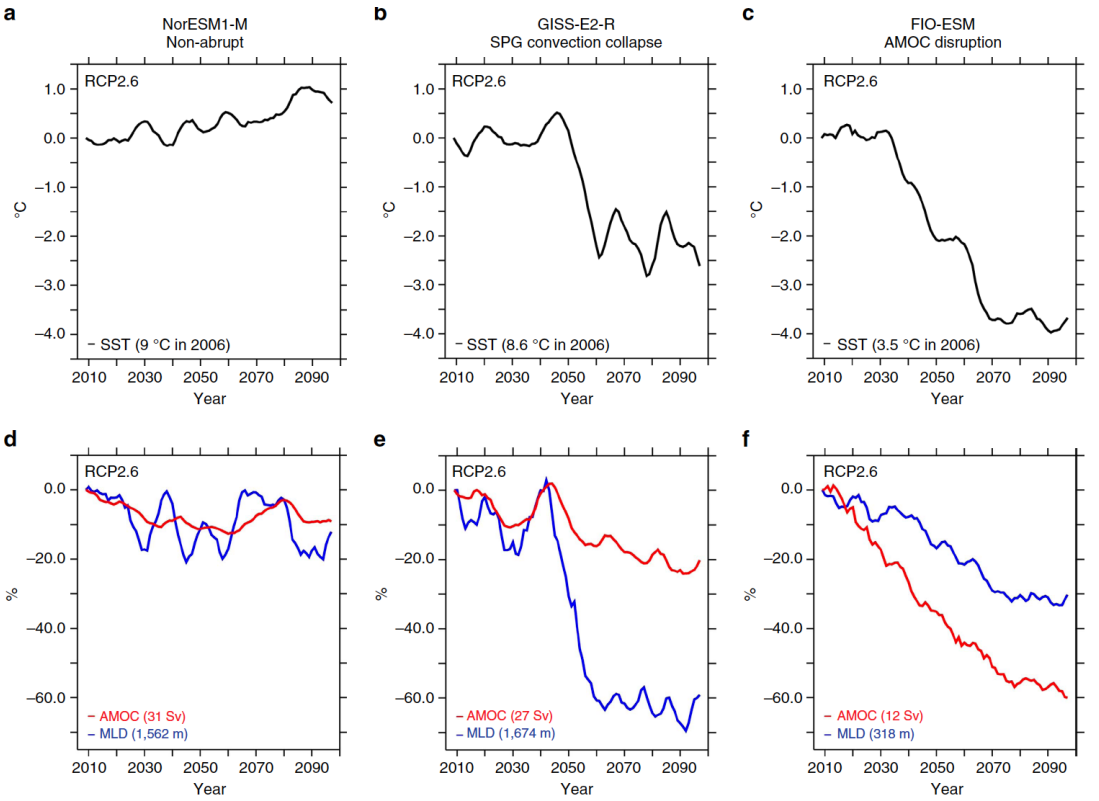
Possibility of Abrupt Changes in the North Atlantic in climate models



- Some CMIP models do show abrupt (<10 years) cooling in the subpolar gyre (SPG)

- Two different processes
  - Disruption of the AMOC (strong decrease of convection both in the Labrador and Nordic Seas)
  - Collapse of convection in the Labrador Sea : can occur in only one decade => **the SPG a new tipping element**
- The probability for such a SPG rapid change can be estimated between about **10-45%** both in CMIP5 and CMIP6 in 2100

Changes in the subpolar gyre



Credits: Nature Communications

Sgubin et al. 2017, Swingedouw et al. sub.

Risk of AMOC substantial weakening

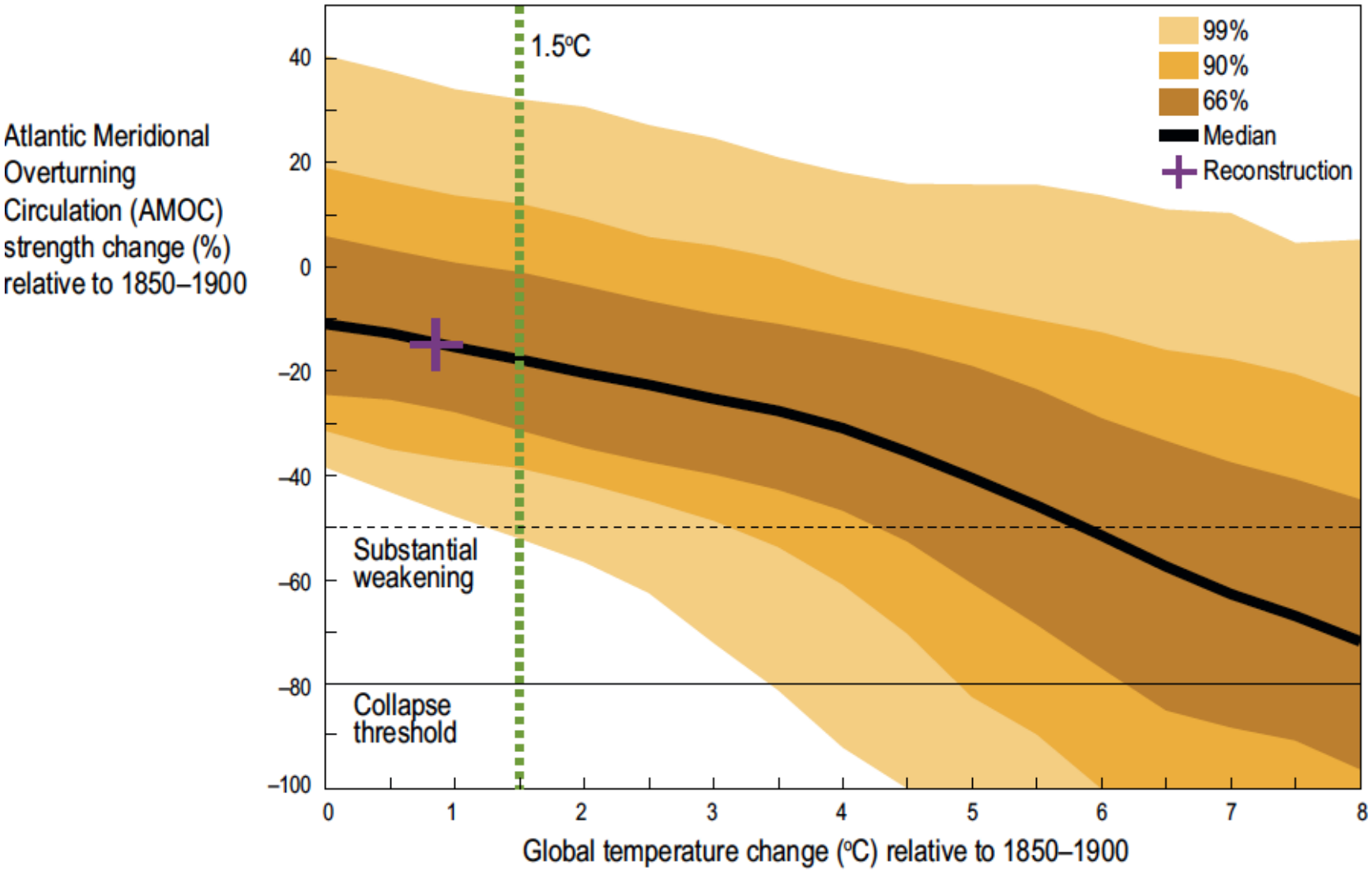
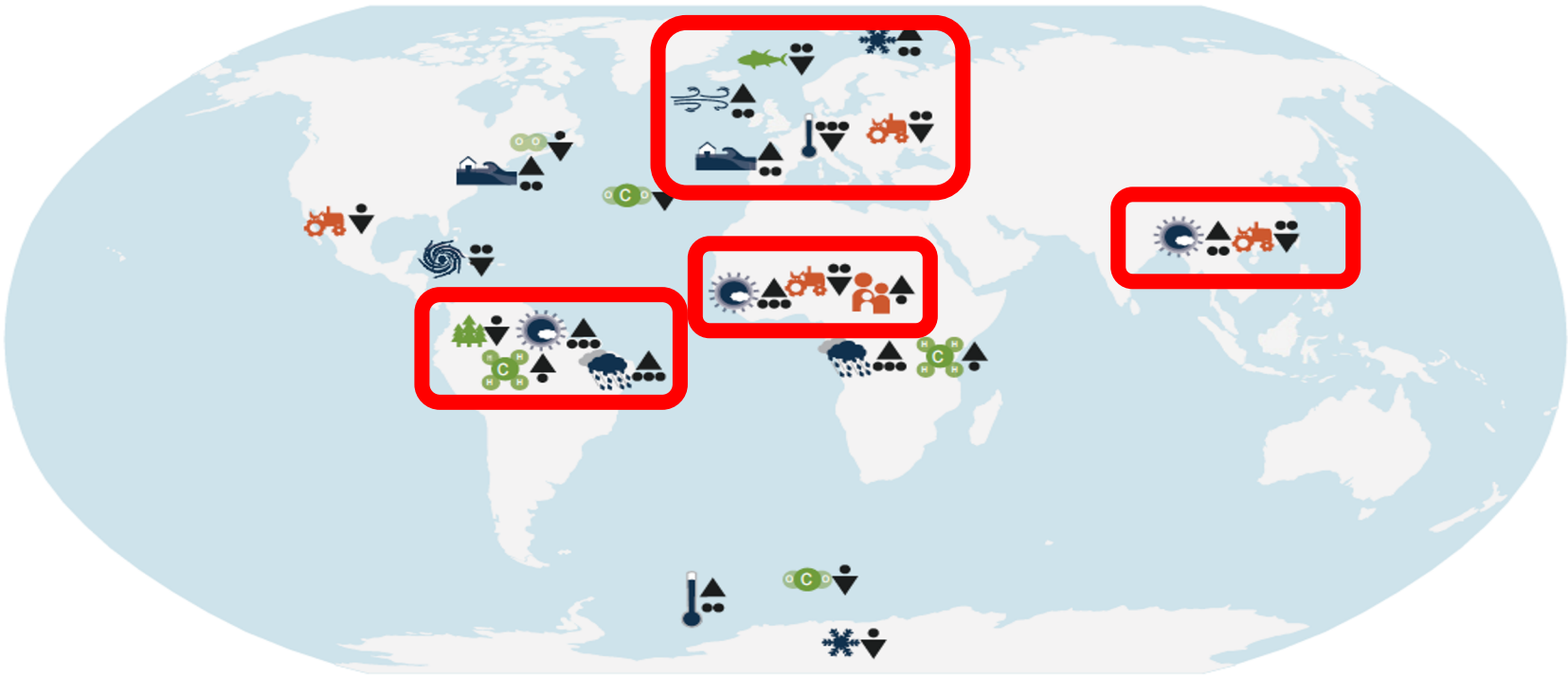


Fig. 6.9 from IPCC SROCC report, 2019

Large-scale impact of a substantial weakening in the Atlantic circulation



Physical system

- Droughts
- Temperature trend
- Sea level rise
- Cyclones frequency
- Sea ice and snow
- Precipitation and flooding
- Storminess

Biological system

- Vegetation
- Oxygenation
- Marine ecosystems
- Oceanic carbon and acidification
- Wetland methane

Human and managed systems

- Agriculture and food production
- Migration pressure due to degradation in livelihoods

Direction of the change

- Increase
- Decrease

Confidence in process understanding

- High
- Medium
- Low

IPCC
INTERGOVERNMENTAL PANEL ON climate change

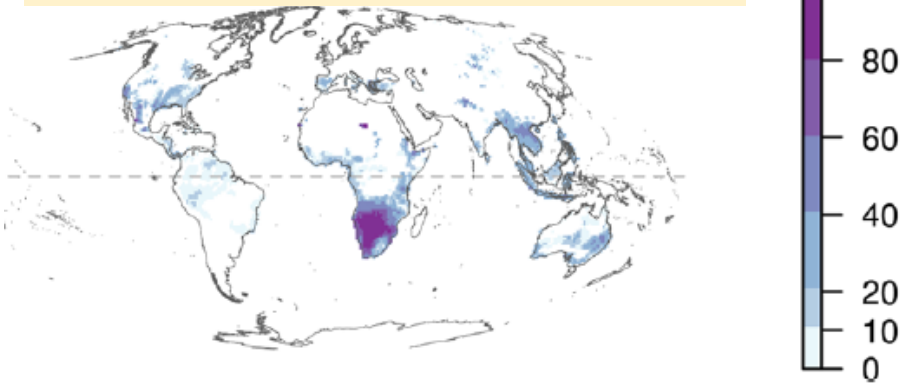
Fig. 6.10 from IPCC SROCC report, 2019

Even more potential impacts not assessed yet?

- Impacts on biodiversity: a new example of cascading tipping points: Velasco et al. (in press, 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



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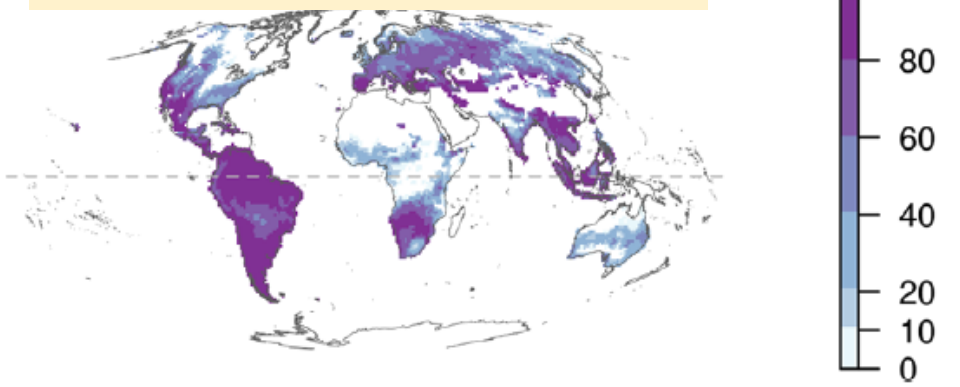
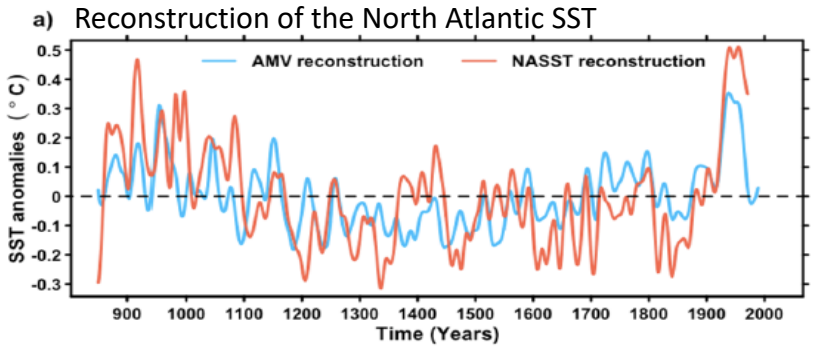


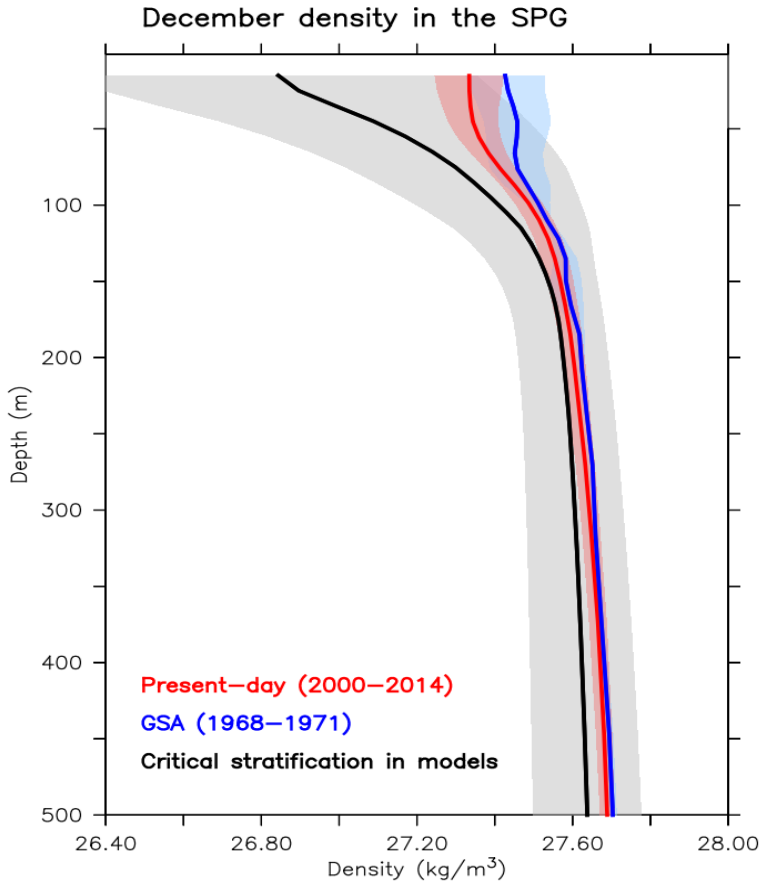
Proximity to oceanic tipping points?

Atlantic overturning (AMOC)



Boulton et al. 2014; Simon et al., in rev..

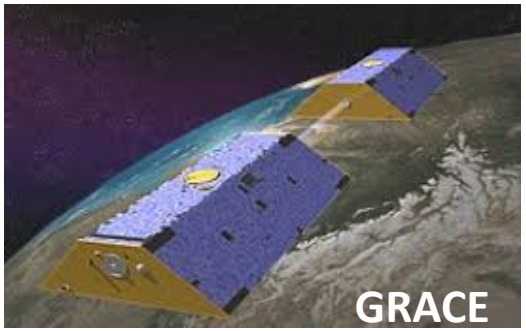
Subpolar gyre (SPG)

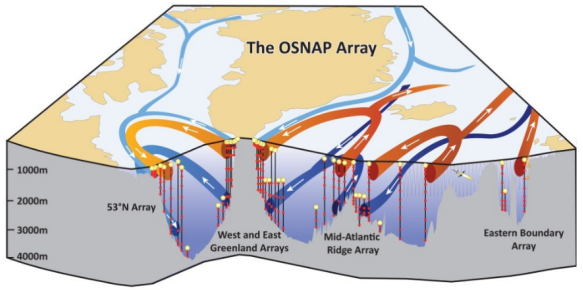


Swingedouw et al., *Surv. Geoph*. 2020

Earth Observations utility

- Sea level is related with oceanic currents : Altimetry can help to reconstruct the AMOC (Frakja-Williams et al. 2017)
- Surface salinity is a key variable for ocean circulation stability : AQUARIUS and SMOS are offering avenues to better monitor it (Estella-Perez et al. 2020)
- Ocean bottom pressure is key for ocean circulation: GRACE is allowing to reconstruct of Lower North Atlantic Deep Water (LNADW) between 3000-5000 m depth (Landerer et al. 2015)
- But there is still an urgent need for intermediate level *in situ* ocean monitoring (Lozier et al. 2019)





Decadal predictions to gain insights on early warnings of abrupt changes

Initial conditions

External forcing

Weather forecast | **Seasonal prediction** | **Decadal prediction** | **Centennial projections** | **Glacial cycles**

day | week | month | year | decade | century | millennium

Time scale

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!

What are the research gaps?

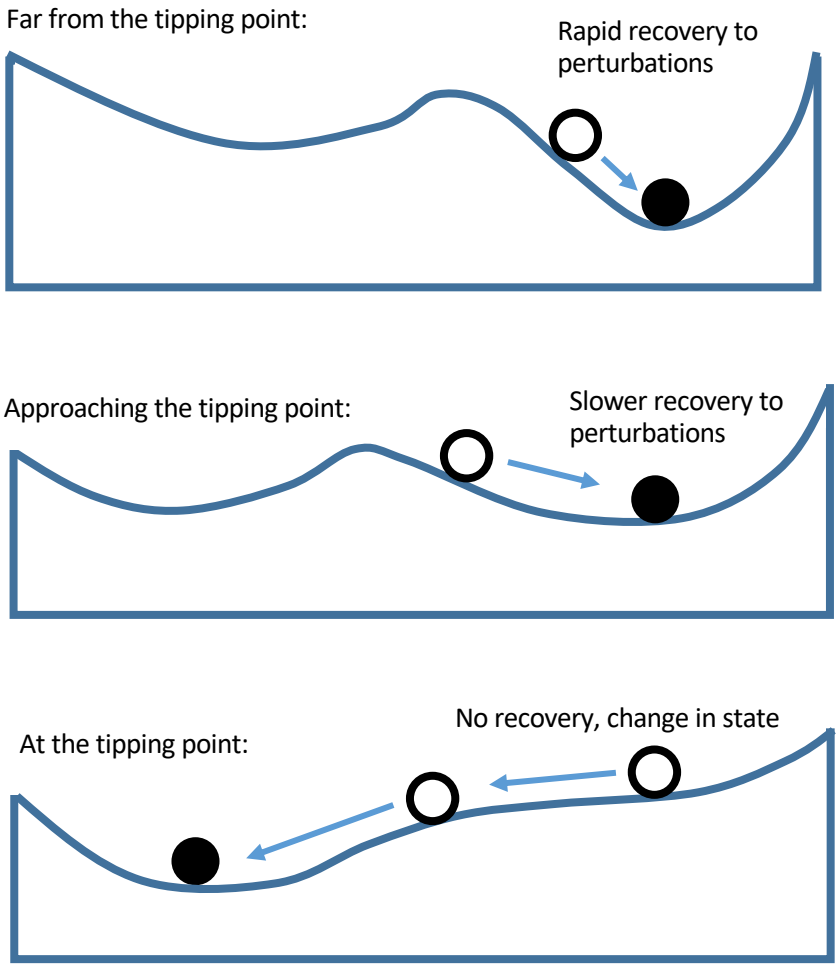
- **Observation systems** are needed for an efficient early warning system
  - Continue on-going *in situ* arrays and monitoring systems
  - Include more oceanic observations below 2000m
- **Decadal prediction systems** still need further development to:
  - Diminish their offset to observations
  - Avoid drift when launched from observed ocean
  - Better predict recent cooling in the subpolar gyre since 2015
- Need for **reconstructions of the last few thousands of years** to have better insights on “natural variability” and the approach of a tipping point
- Assessment of the impact of **such low probability - high impact scenario** in **adaptation plans** are poorly accounted for up to now.

How to have early warnings of such a change?

Change of temporal variability when approaching the tipping point

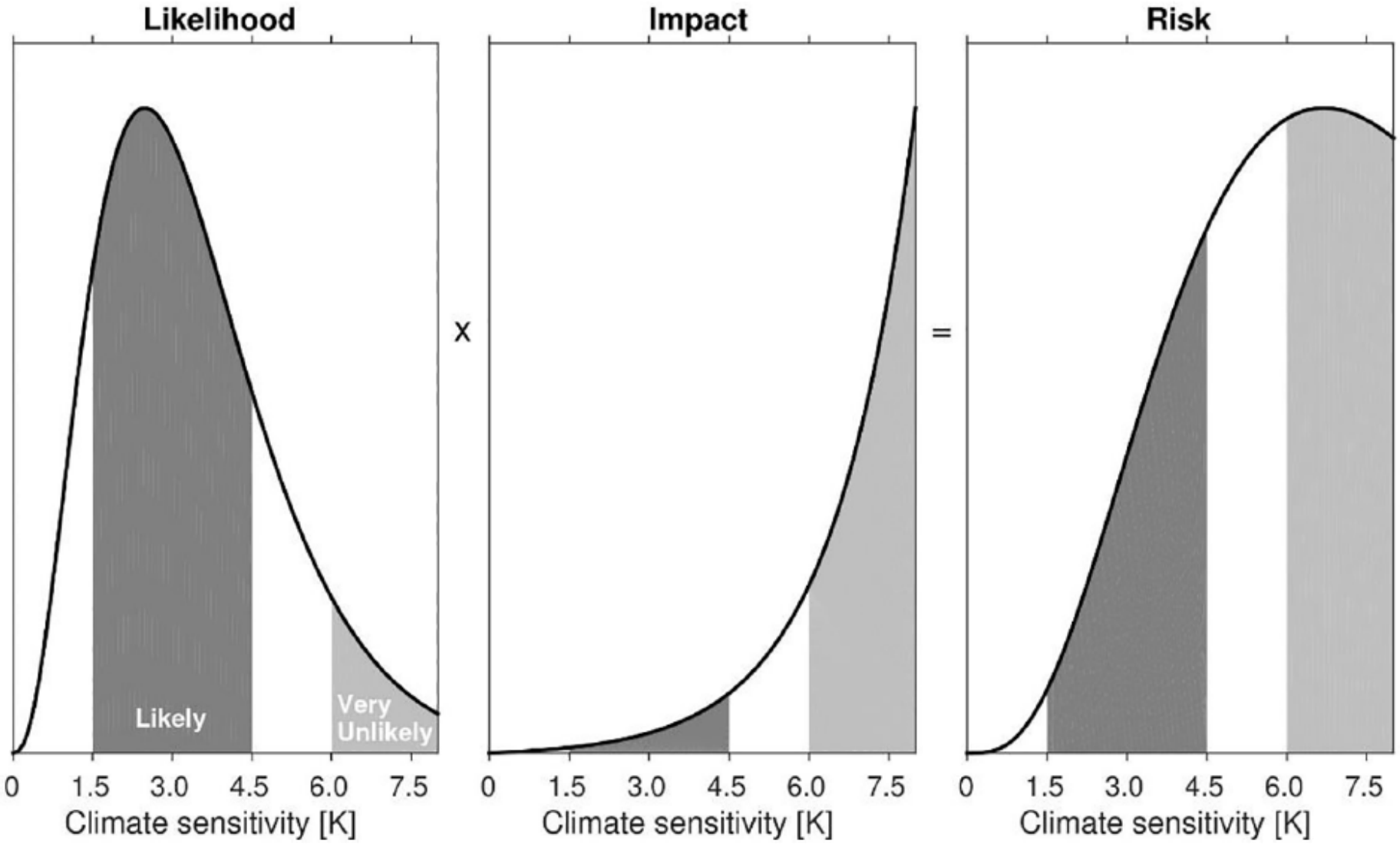
- Theory from dynamical system teaches us that approaching a tipping point, the climate variability tend to increase

- Recent results (Michel et al. sub.) reconstructing the circulation over the last millennium indicate that we might indeed approach such a change in variability and therefore of the tipping point



Adapted from: Lenton 2011

Low probability-high impact event



Sutton et al. 2018