Abrupt cooling over the North Atlantic in modern climate models

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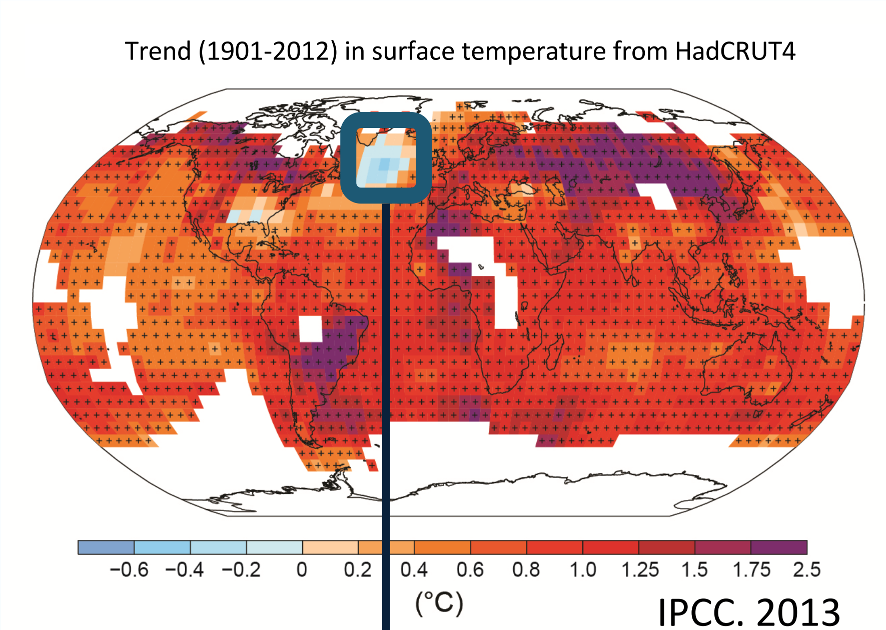
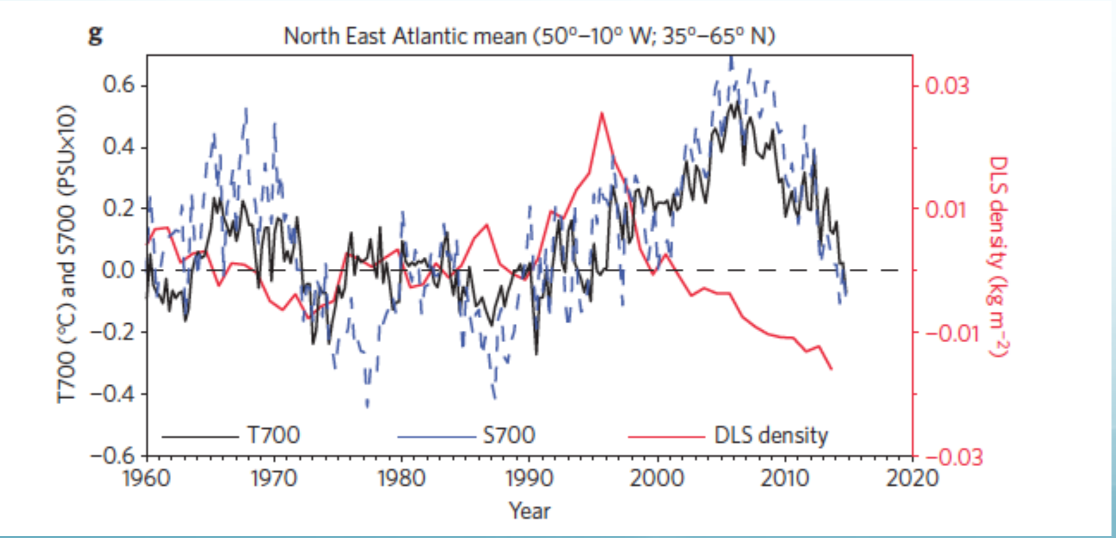
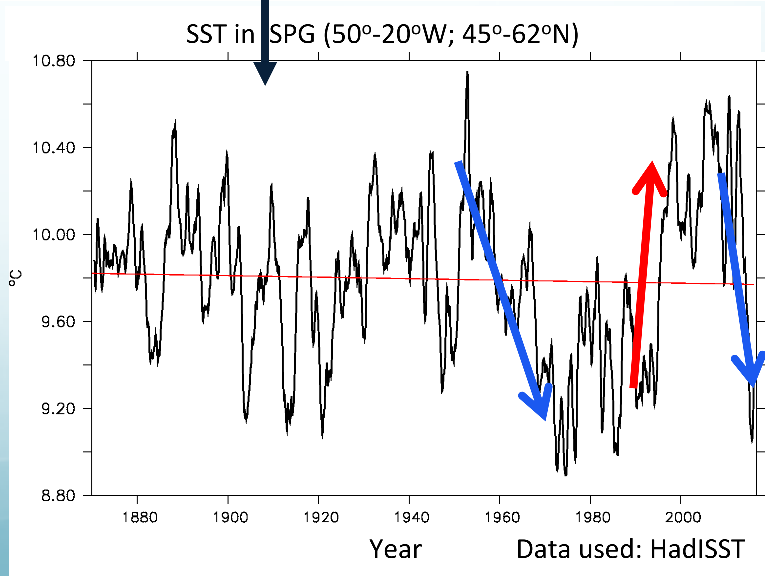
Blue Action kick-off meeting, the 19th of January 2017

A cold blob in the North Atlantic?

- Warming hole in the North Atlantic over the 20th century
- Abrupt SST variations in the subpolar gyre (Thompson et al. 2010)
- Robson et al. (2016): link with anomalous surface heat flux and Labrador Sea convection







Catalogue of abrupt shifts in Intergovernmental Panel on Climate Change climate models

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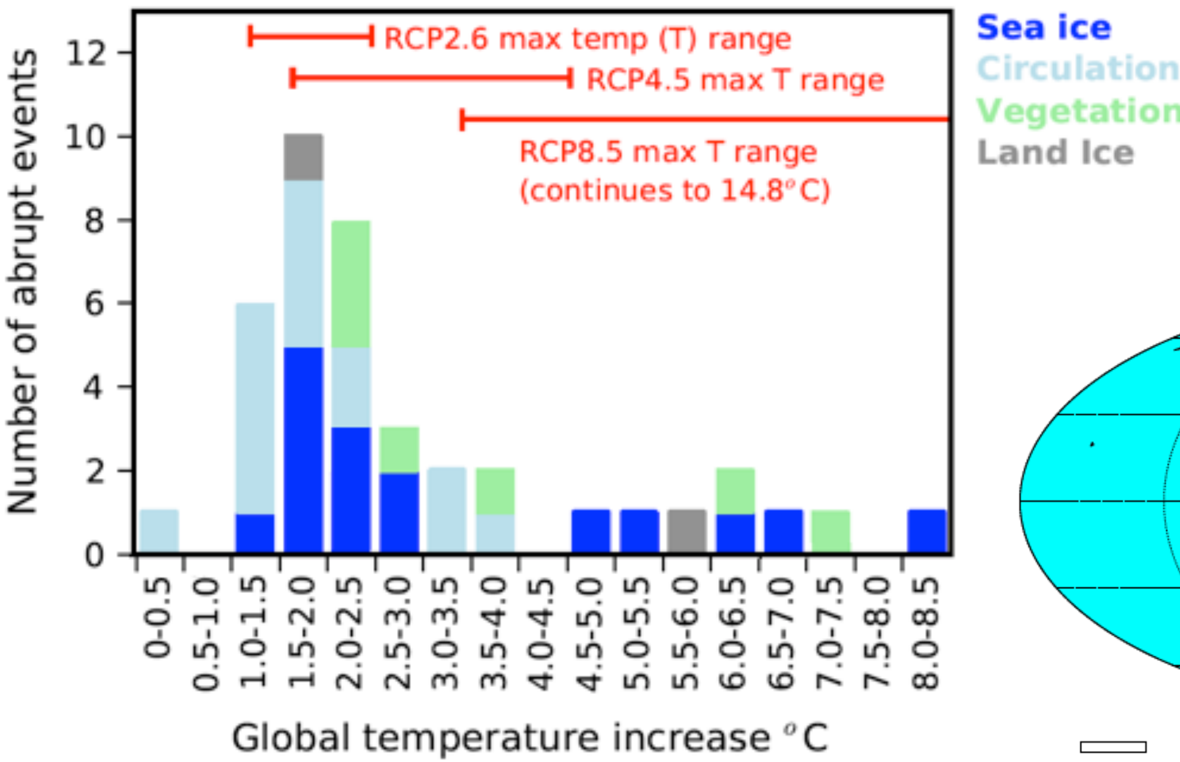
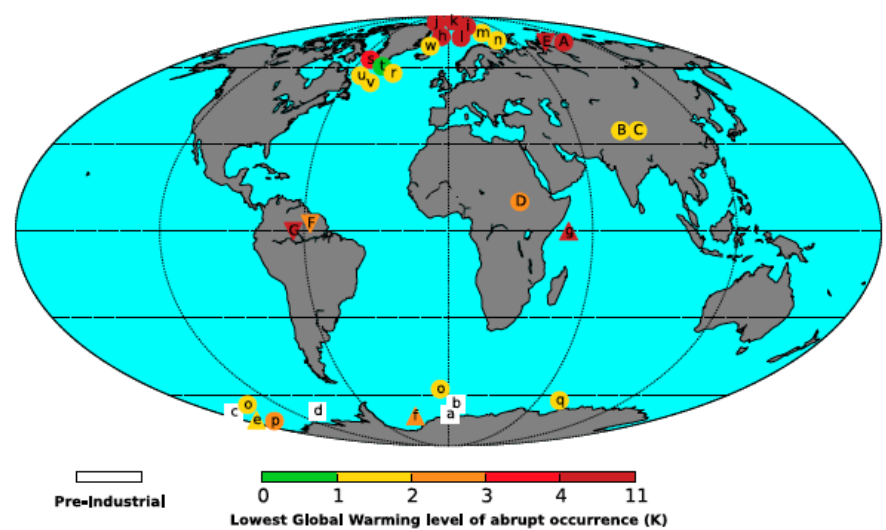
Are the model showing abrupt changes in the subpolar gyre trustworthy?

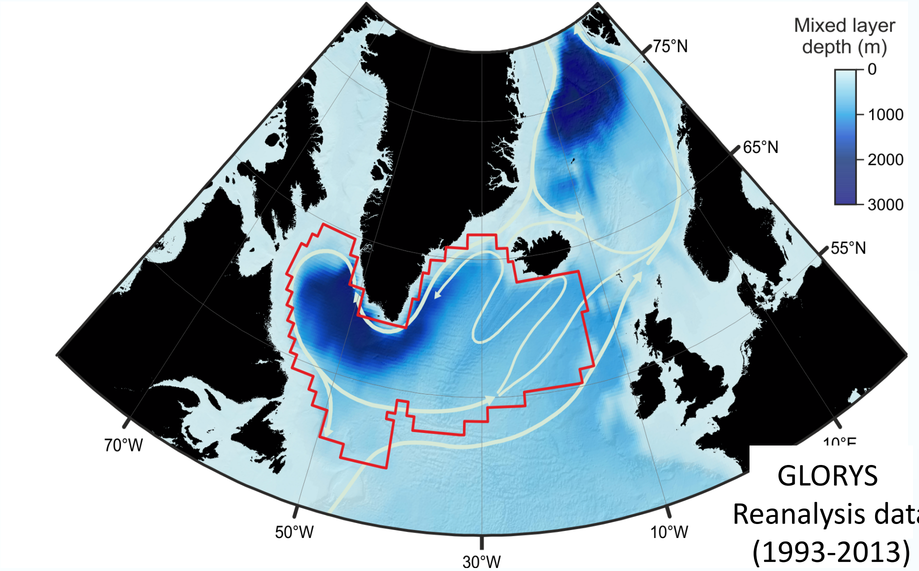
39 abrupt events (in 36% of the realizations)



EMBRACE



Methods



GLORYS Reanalysis data (1993-2013)

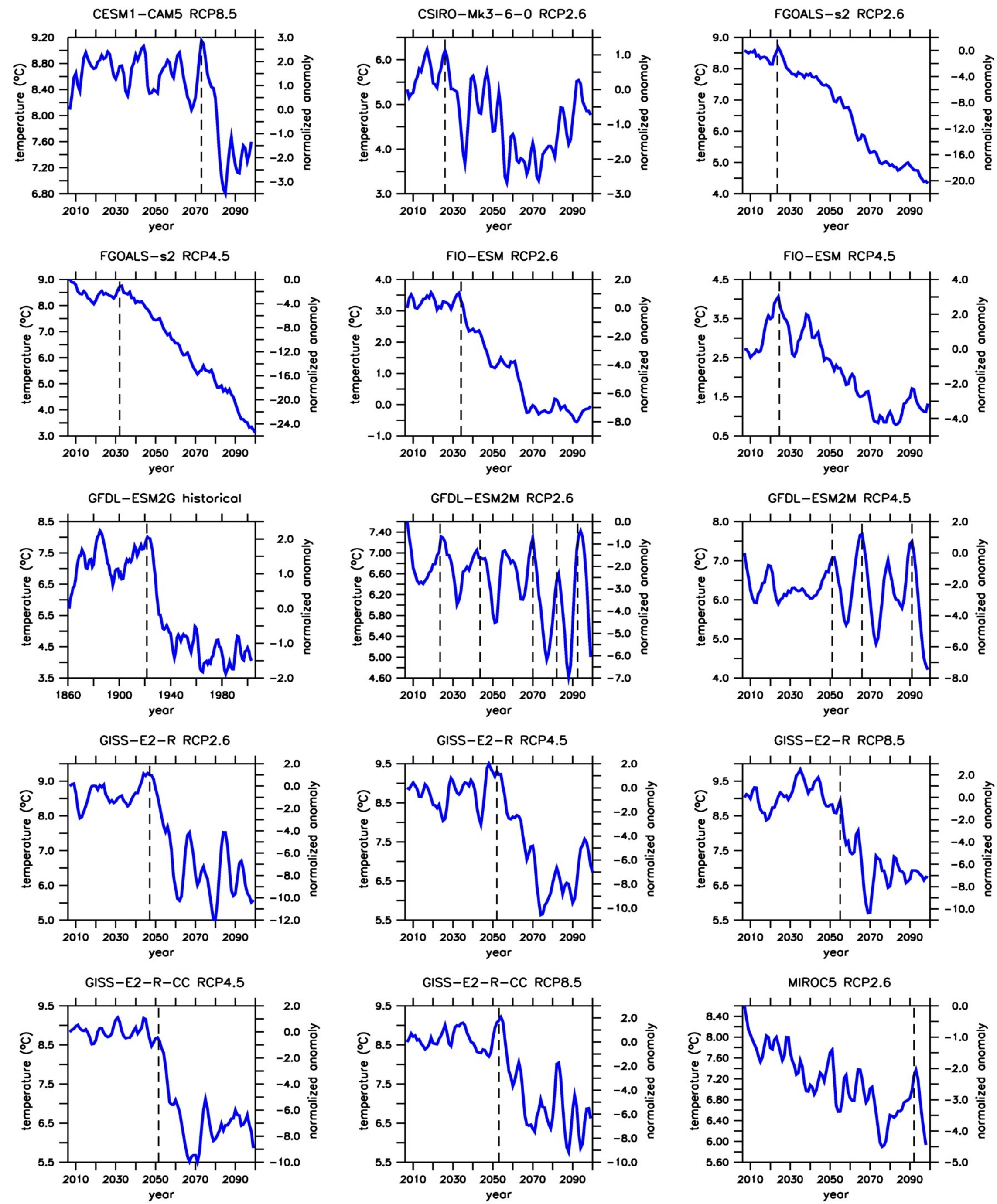
- Analyse of CMIP5 models with a focus on the subpolar gyre (**SPG**)
- Definition of abrupt change for a given metric: if a 10-year trend > 3 standard deviation computed from annual mean in piControl
- Systematic scan of the CMIP5 archive: 40 models (40 piControl simulations, 27 historical + RCP2.6, 39 historical + RCP4.5, 40 historical + RCP8.5 for a total of 146 simulations)

Abrupt cooling events in the SPG

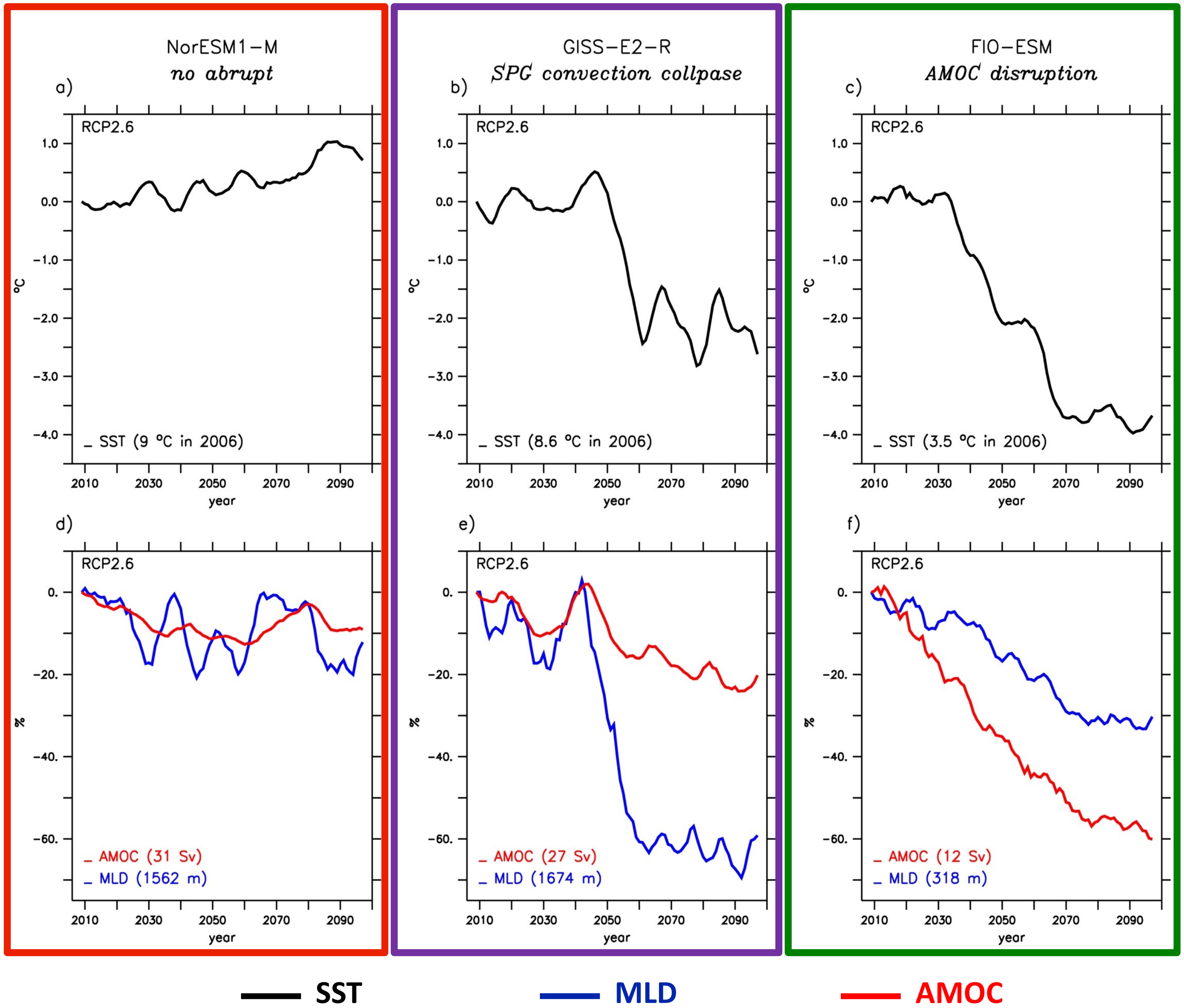
15 abrupt cooling events

1 historical
6 RCP2.6
5 RCP4.5
4 RCP8.5

9 models
(22.5% of the models)



Three main types of SPG changes



non-abrupt
subset
(31 models, *i.e.* 77.5%)

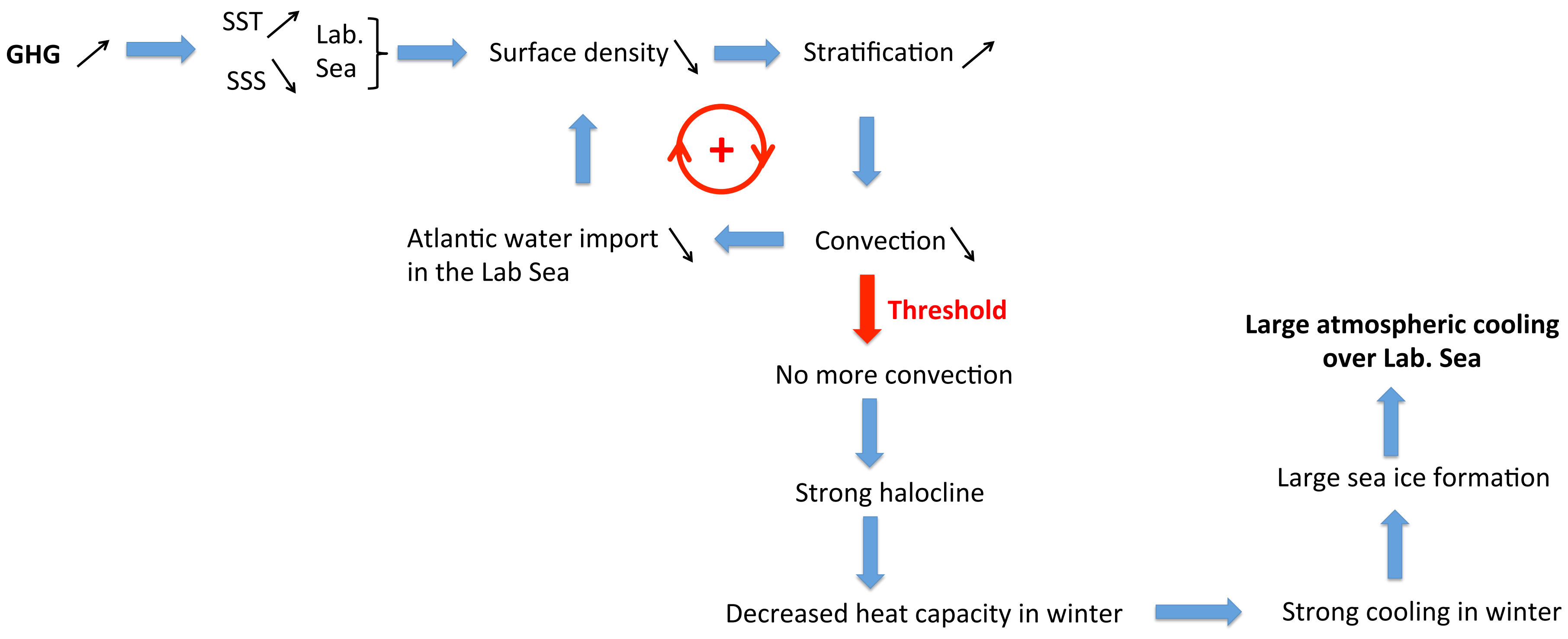
SPG convection collapse
subset
(7 models, *i.e.* 17.5%)

AMOC disruption
subset
(2 models, *i.e.* 5%)

Mechanisms of the convection collapse

From an analysis of key variables of the different convection collapse models, notably based on cross correlation diagnostics, we end up with the following mechanism to explain the 10-year abrupt cooling in the subpolar gyre, in agreement with proposed mechanisms by **Born et al.**

The collapse in convection is salinity driven !



Three different climatic impacts

Surface temperature and precipitation trend (°C/century) of ensemble mean for RCP4.5 scenario

non-abrupt subset

77.5%

- Warming spread all over the globe

SPG convection collapse subset

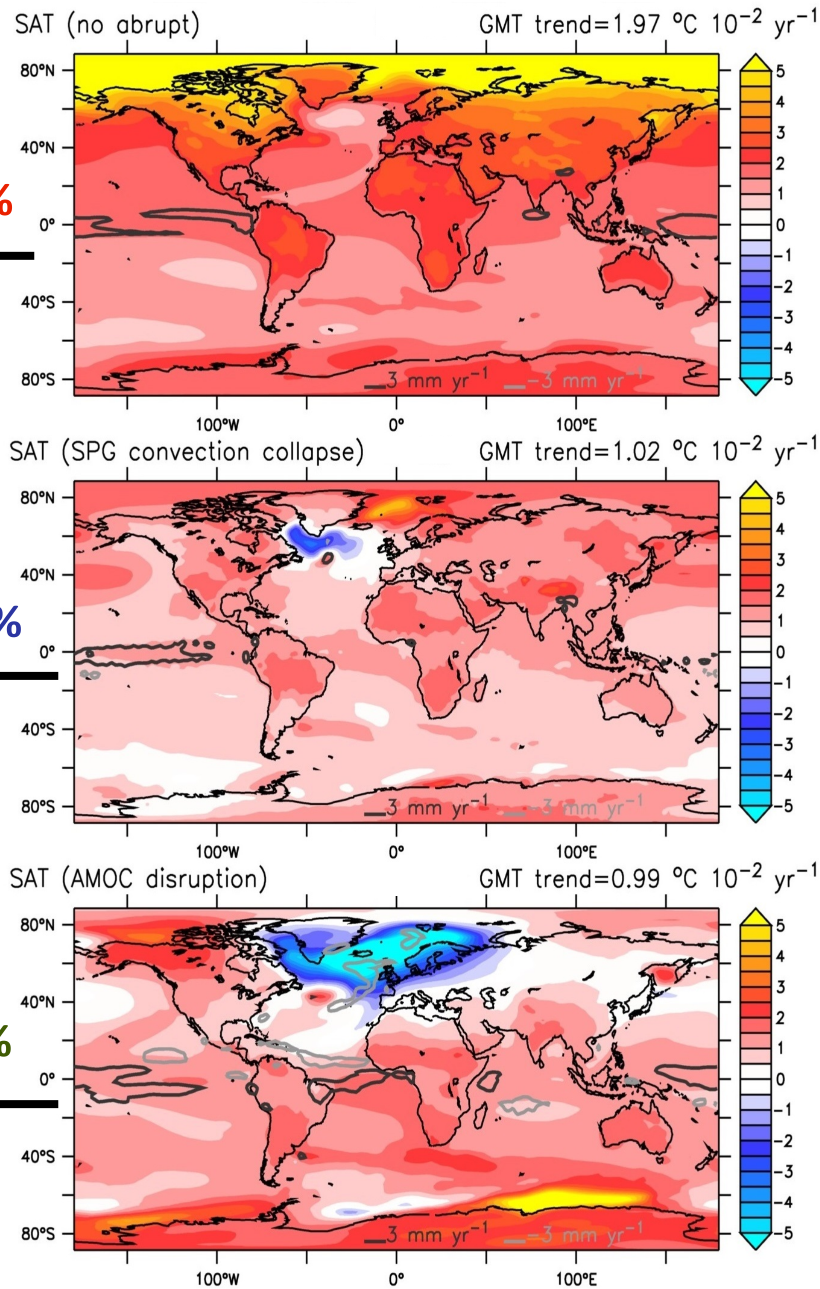
17.5%

- Cooling trend over the NA SPG despite a global warming trend
- Strong impact on SAT over highly inhabited regions

AMOC disruption subset

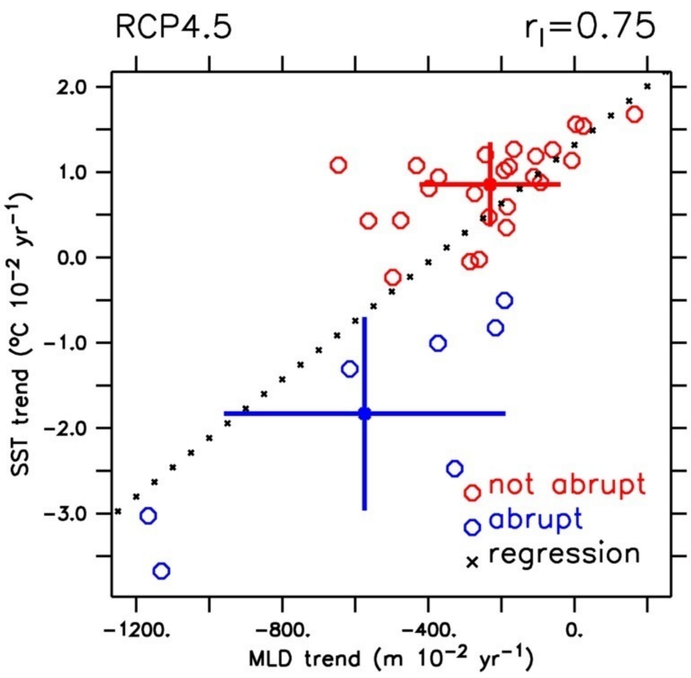
5.0%

- Strong cooling of all the NA
- Amplified warming in the southern hemisphere (bipolar see-saw effect)
- Shift of the position of the intertropical convergence zone



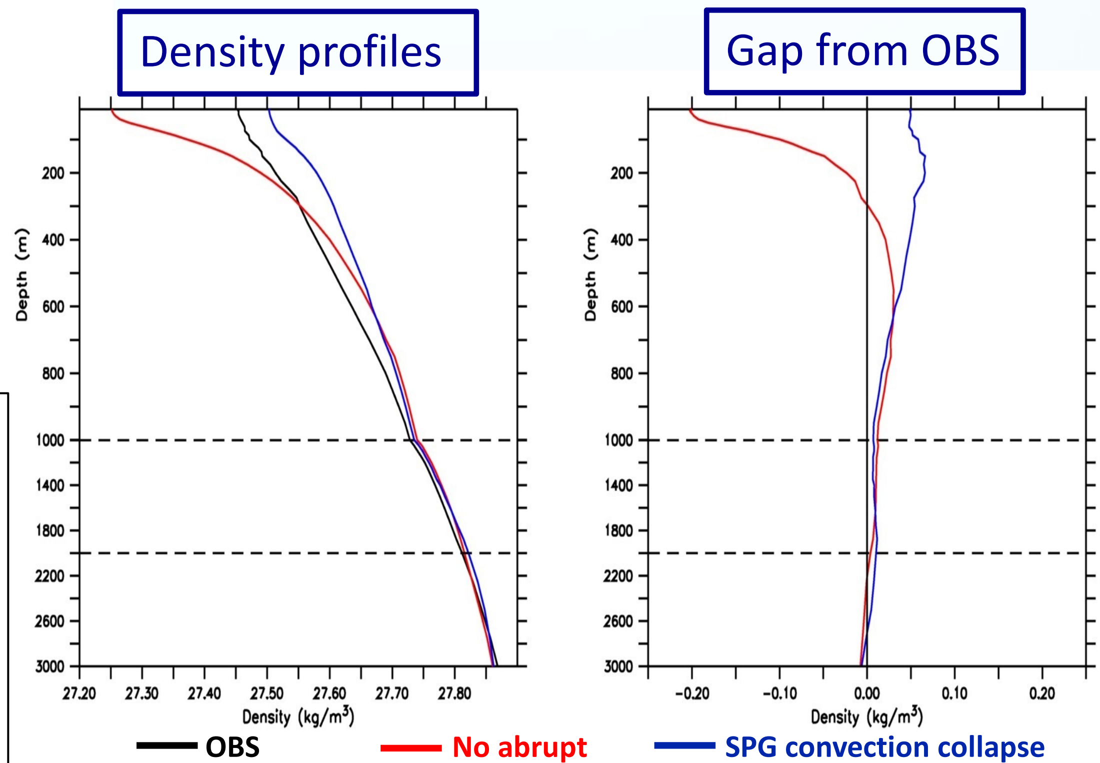
Source of model uncertainty

SST trend *vs* MLD trend



- SST trend over the subpolar NA is well correlated with the MLD trend

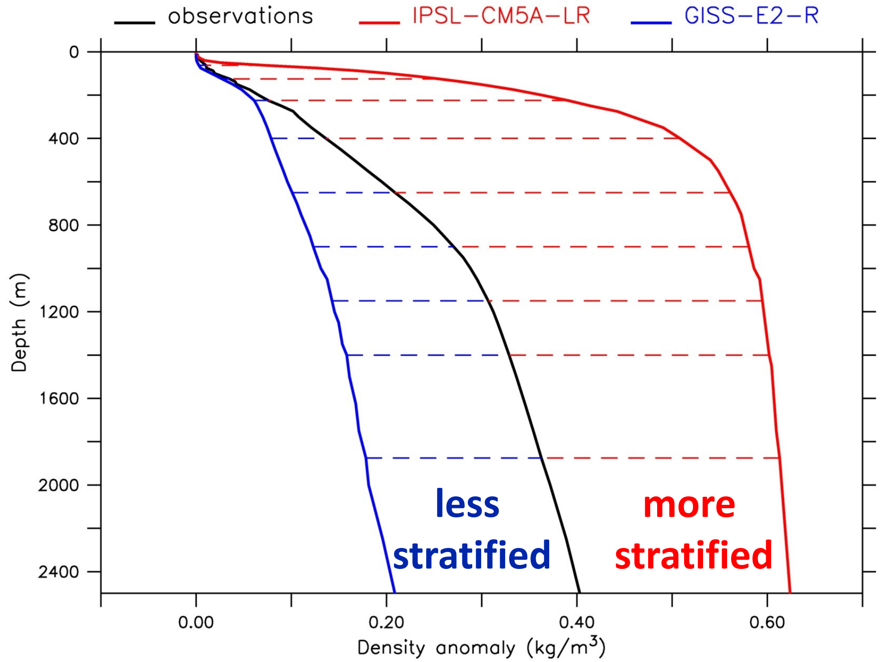
- Importance of the **background stratification**



- Two different configurations for present-day conditions
- If compared with ***OBS***:
- ***No abrupt*** excessively stratified
- ***SPG convection collapse*** models less stratified

The stratification indicator

- We define a stratification index as the density difference with surface density
- We estimate the differences in stratification for each model with observation-based estimate of the stratification in the SPG



-5.88 (kg/m^3) +12.41 (kg/m^3)

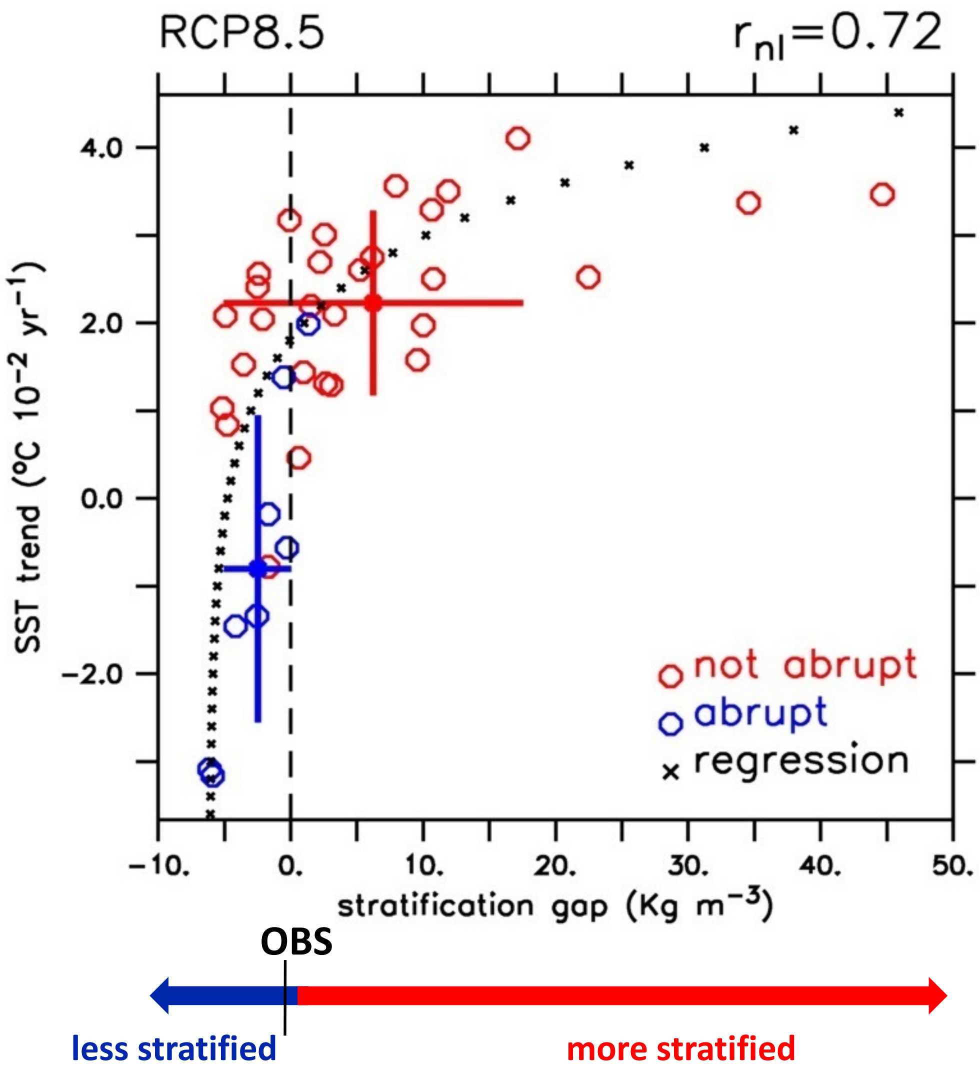
stratification index

$$\Sigma_z \{ (\rho_z - \rho_0)_{model} - (\rho_z - \rho_0)_{OBS} \}$$

Observations: average between GLORYS Reanalysis data (1993-2013) and EN3 Analysis data (1950-2013)
Models: mean during the period 1976-2005 of historical simulations

Stratification as an emergent constraint for SST response

- SST trend over the SPG is (non linearly) correlated with the modeled present-day stratification
- *SPG convection collapse* models show a stratification closer to observations than in *no abrupt* models
- A realistic background stratification is a necessary (but not sufficient) condition for the local convection collapse

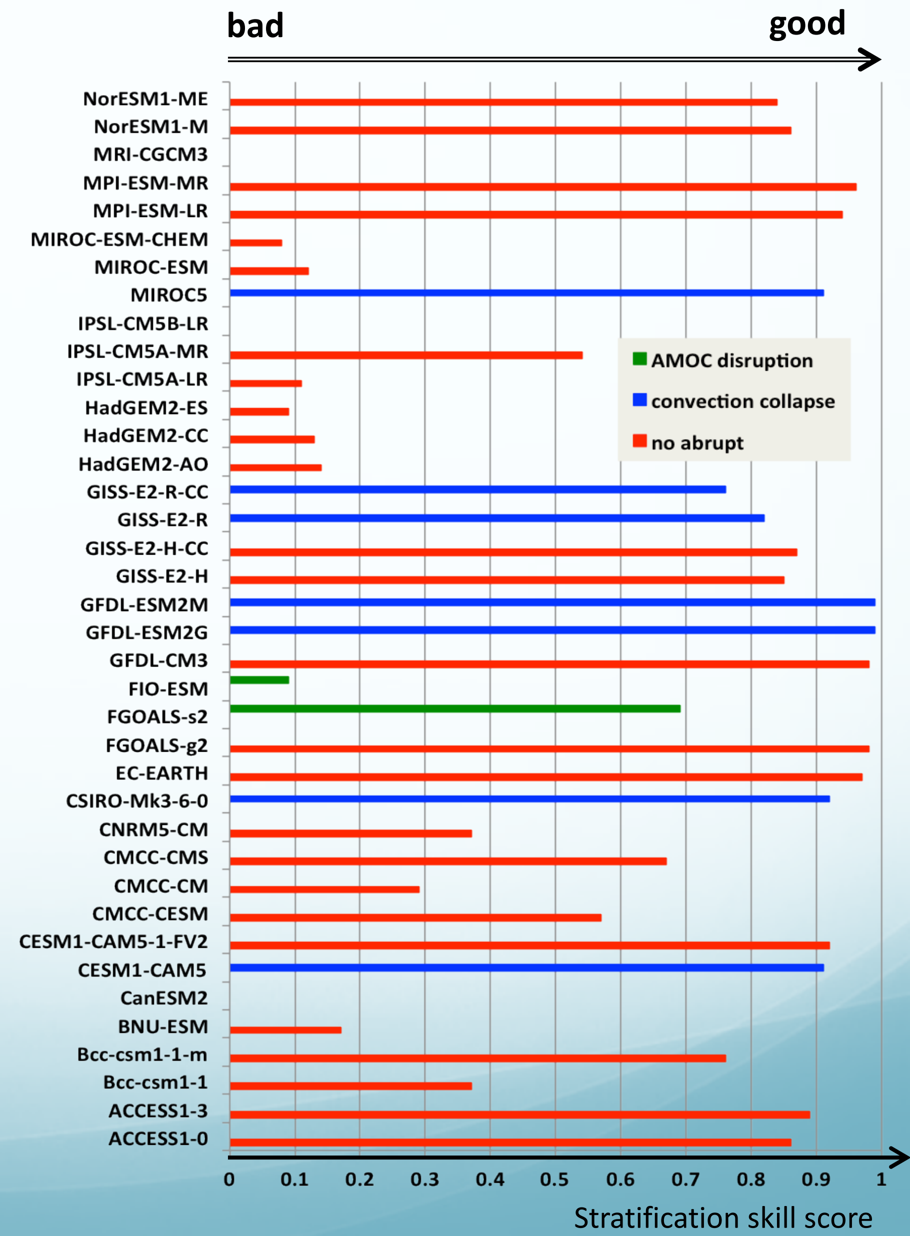


Model evaluation

We defined a model **skill score S** (value between 0 and 1) based on the modeled stratification for present-day conditions

Subset ranking	average S	unweighted occurrence	Occurrence (S>0.9)
1. SPG convection collapse	0.90	17.5%	45.5%
2. non-abrupt	0.54	77.5%	54.5%
3. AMOC disruption	0.39	5.0%	0.0%

When considering only the 11 most skilled models for background stratification, the probability of occurrence of a SPG convection collapse is of 45.5%



Conclusions

- The SPG convective system should be considered as a **tipping element** of the climate system (different from AMOC)
- A first assessment on the probability of future occurrence of a SPG convection collapse: **17.5%**
- By accounting only for the 11 **most skilled models**, the probability of occurrence of a future SPG convection collapse sensibly increases, i.e. **45.5%**
- An SPG convection collapse may **have strong climatic impacts** over highly inhabited regions (e.g. western Europe and Eastern North America)
- Potentially strong implications in terms of climate change **adaptation policies**
- **Need for searching for such potential events in initialised forecasts**
- **No Greenland freshwater release in CMIP5 simulations…**

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ARTICLE

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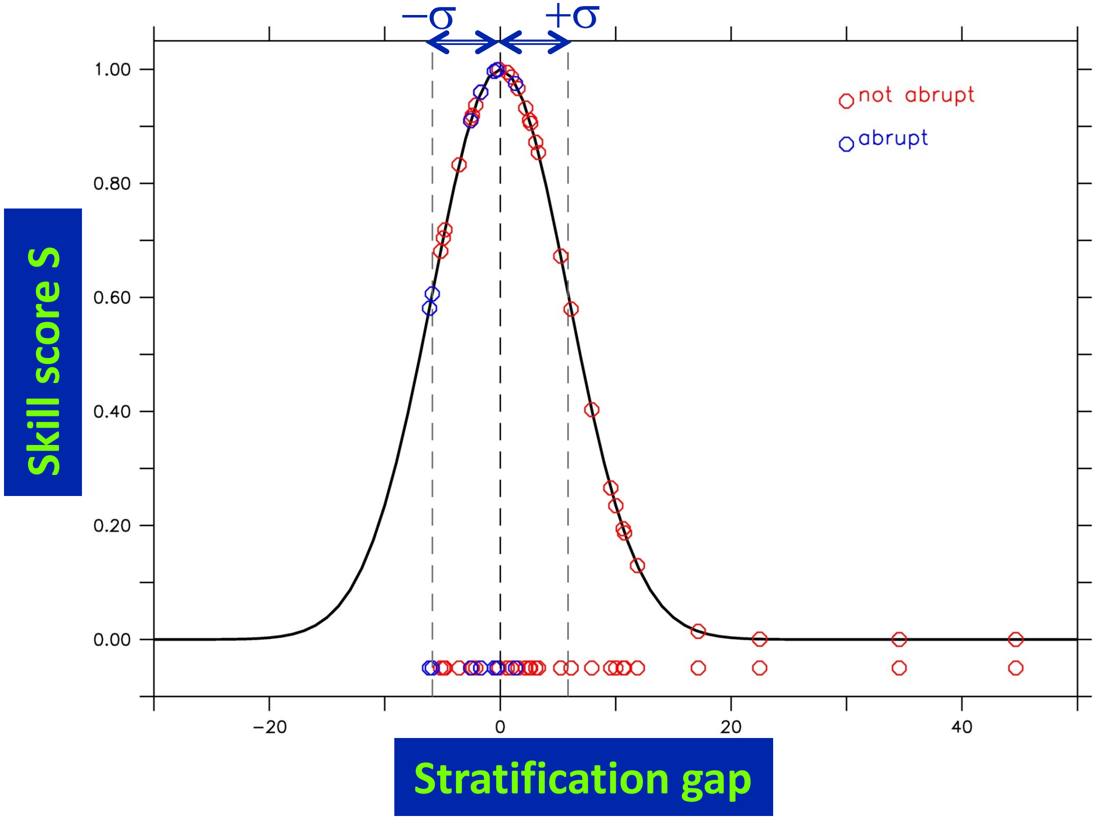
Definition of a model skill score S



Hp:

1) The probability that model results matches the reality follows a normal distribution

$$S_m = e^{\frac{-(\text{stratification gap}_m)^2}{2\bar{\sigma}^2}}$$

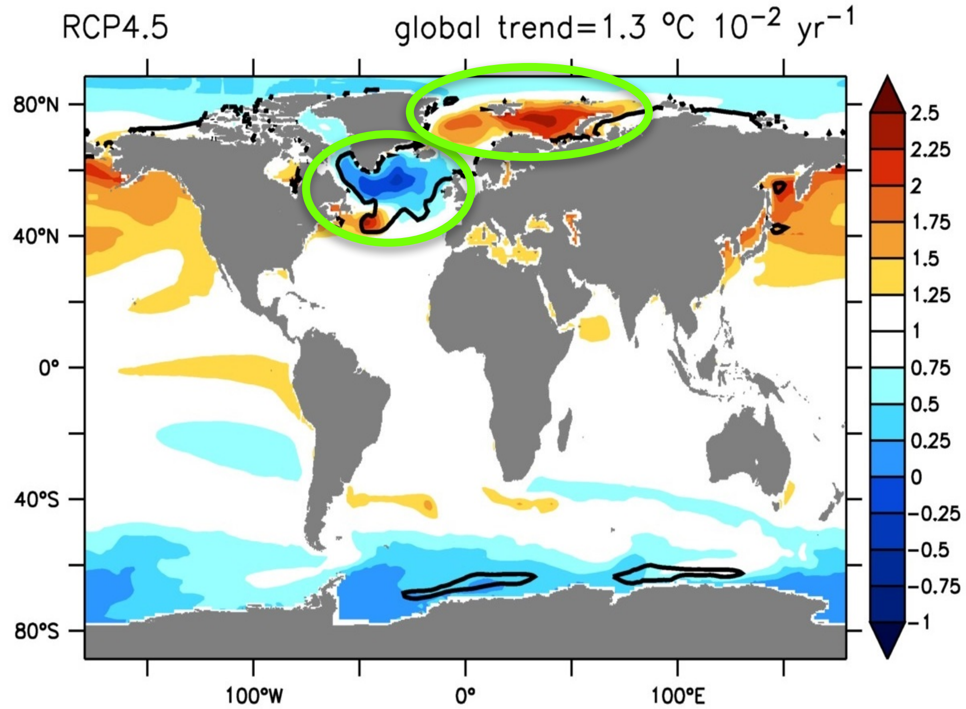
2) The standard deviation σ is such that 67% of model results lies within the interval [-σ,σ]

Ensemble mean and spread of SST from CMIP5 model simulations

Changes in SST are not uniform:

- **amplified warming in Nordic Seas**
- Subdued warming in the subpolar gyre

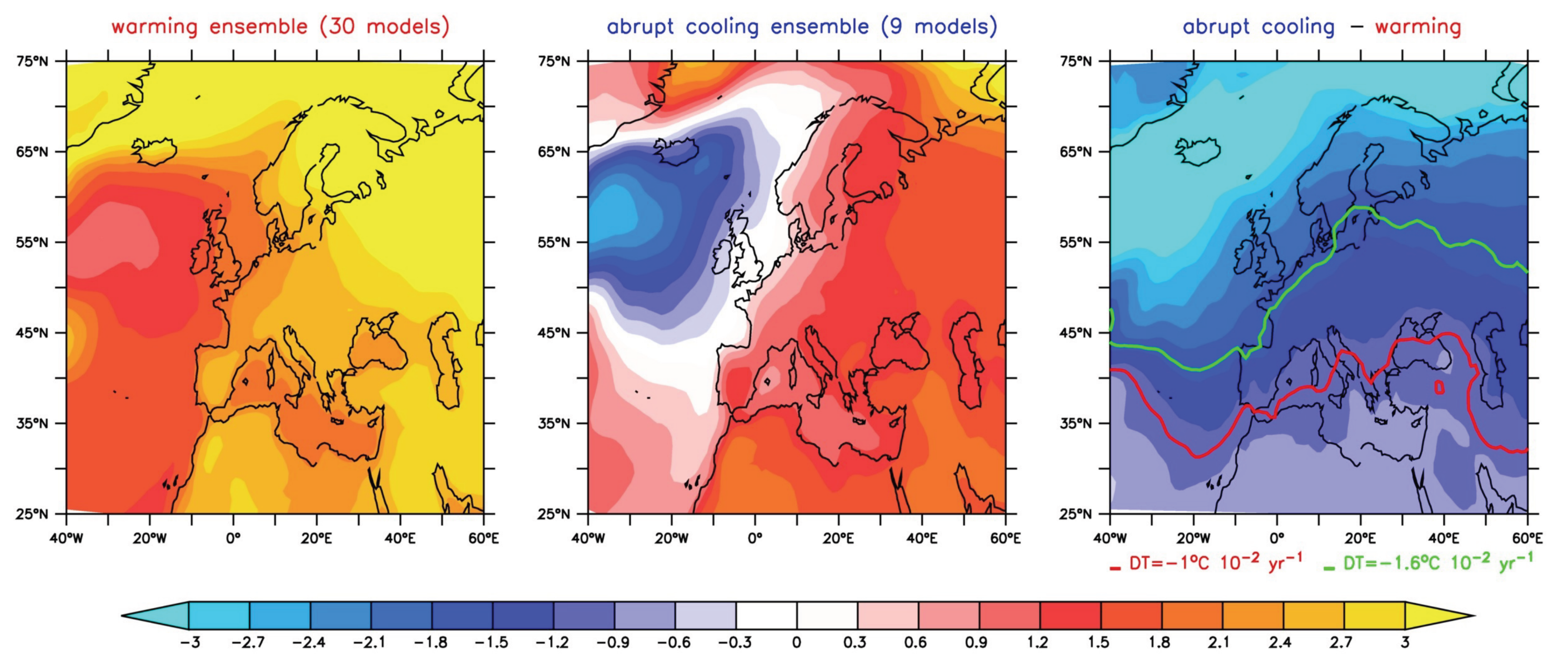
SST trend normalized by global mean trend



Conclusions and perspectives

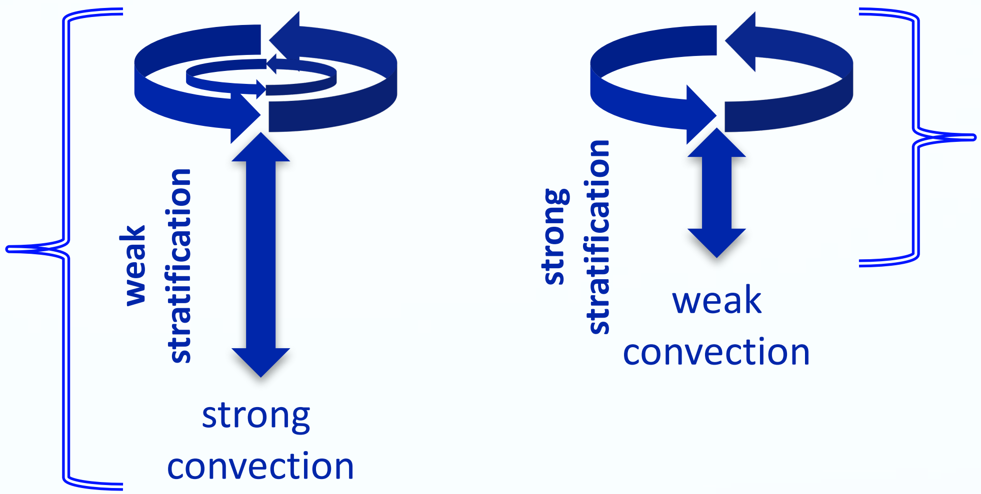
- Need to consider the possibility of a SPG convection collapse for more specific impact assessments (e.g. agriculture, water management, energy consumption etc.)

Surface air temperature trends over Europe in the different subsets of models

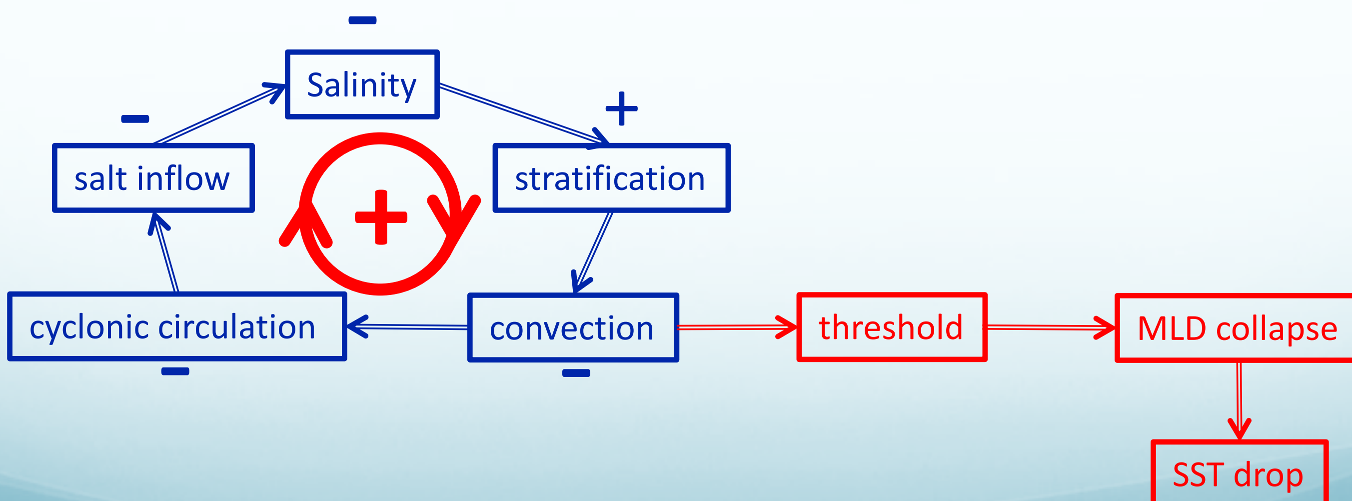


Mechanisms of SST drop due to a SPG convection collapse

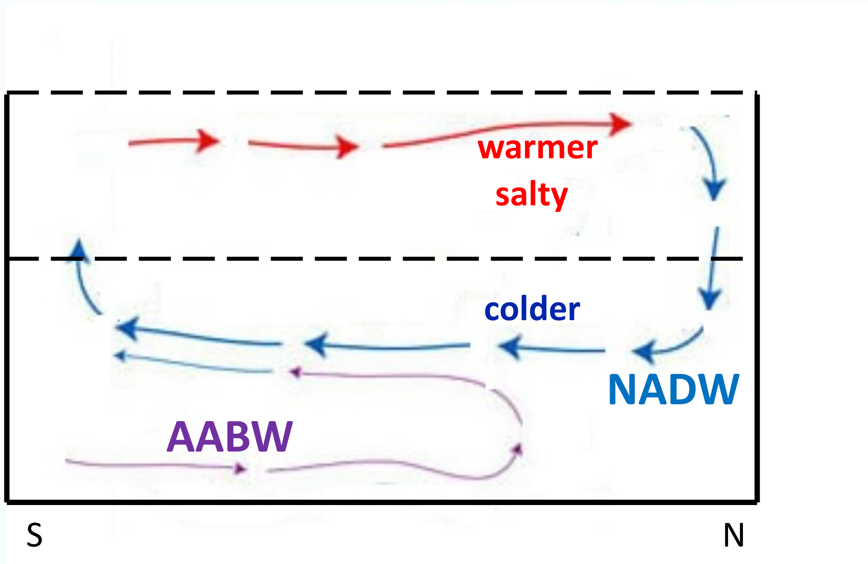
Deeper MLD:
heat exchanges with atmosphere involving depths

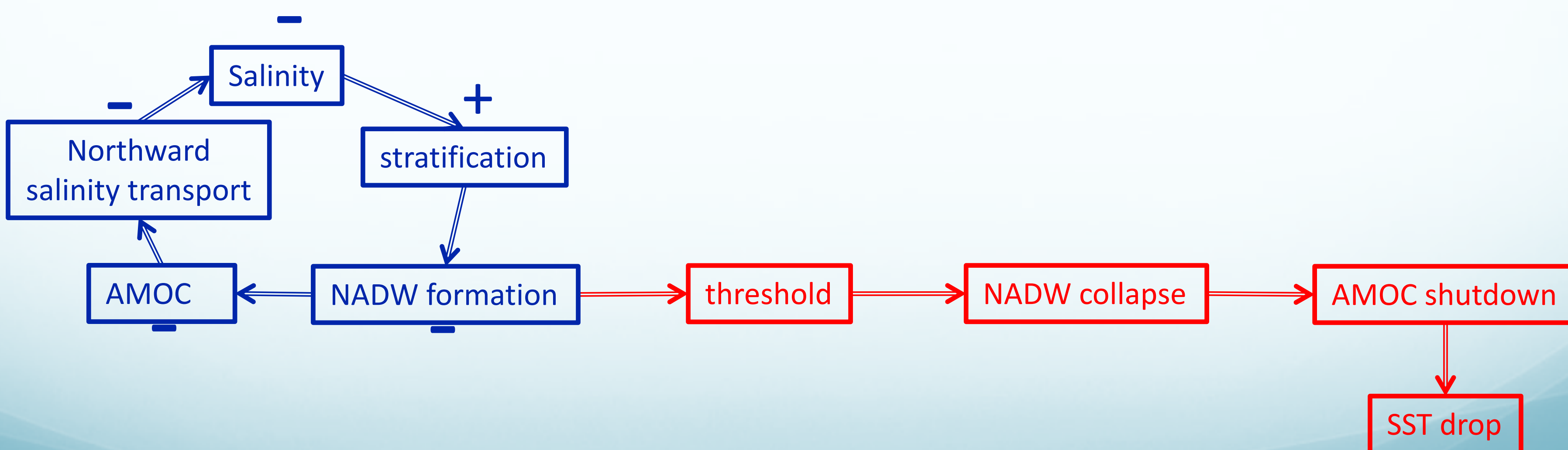


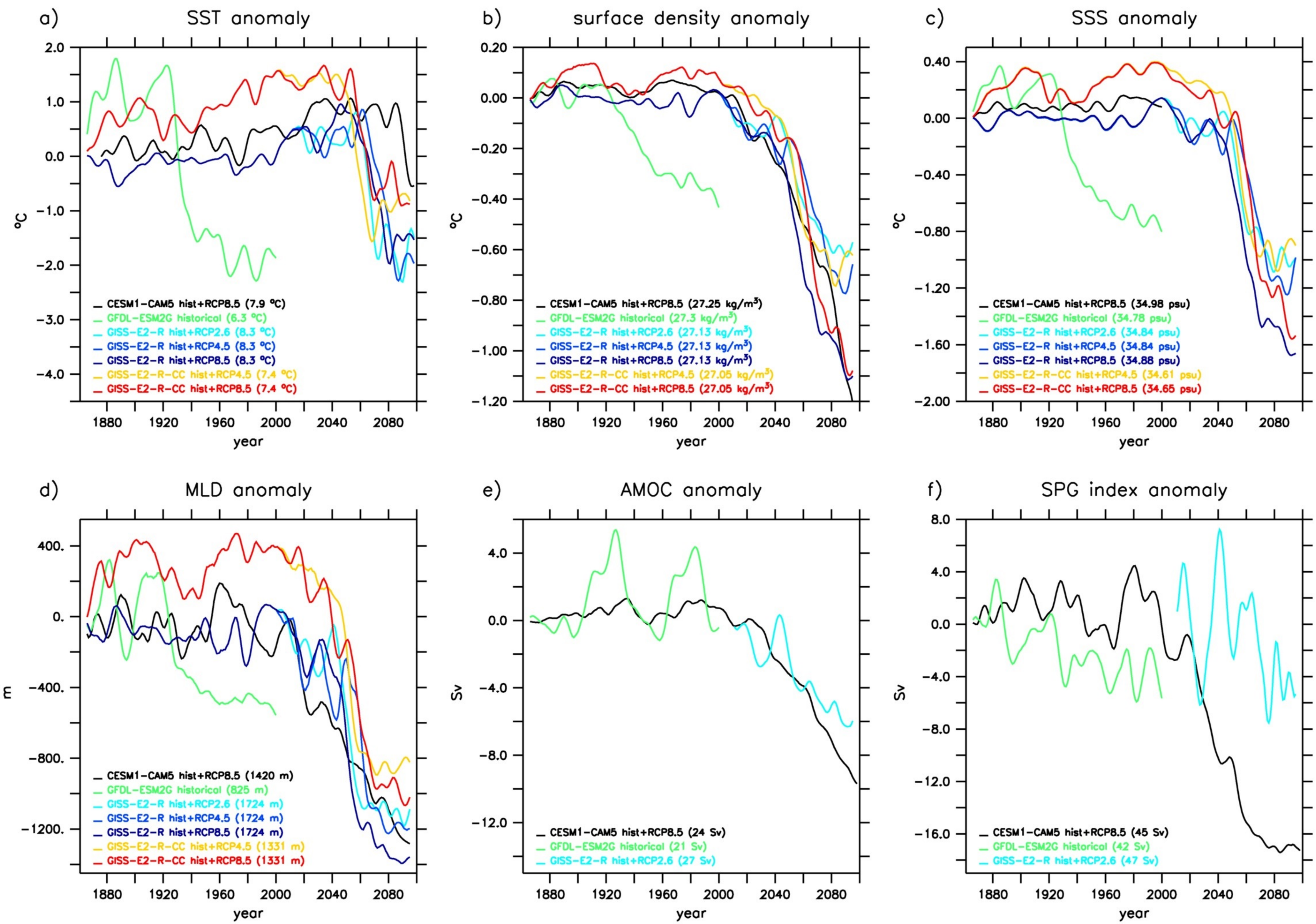
Shallower MLD:
heat exchanges with atmosphere confined at surface



Mechanisms of SST drop due to an AMOC disruption






a)
SST anomaly
°C
year
CESM1-CAM5 hist+RCP8.5 (7.9 °C)
GFDL-ESM2G historical (6.3 °C)
GISS-E2-R hist+RCP2.6 (8.3 °C)
GISS-E2-R hist+RCP4.5 (8.3 °C)
GISS-E2-R hist+RCP8.5 (8.3 °C)
GISS-E2-R-CC hist+RCP4.5 (7.4 °C)
GISS-E2-R-CC hist+RCP8.5 (7.4 °C)
b)
surface density anomaly
°C
year
CESM1-CAM5 hist+RCP8.5 (27.25 kg/m3)
GFDL-ESM2G historical (27.3 kg/m3)
GISS-E2-R hist+RCP2.6 (27.13 kg/m3)
GISS-E2-R hist+RCP4.5 (27.13 kg/m3)
GISS-E2-R hist+RCP8.5 (27.13 kg/m3)
GISS-E2-R-CC hist+RCP4.5 (27.05 kg/m3)
GISS-E2-R-CC hist+RCP8.5 (27.05 kg/m3)
c)
SSS anomaly
°C
year
CESM1-CAM5 hist+RCP8.5 (34.98 psu)
GFDL-ESM2G historical (34.78 psu)
GISS-E2-R hist+RCP2.6 (34.84 psu)
GISS-E2-R hist+RCP4.5 (34.84 psu)
GISS-E2-R hist+RCP8.5 (34.88 psu)
GISS-E2-R-CC hist+RCP4.5 (34.61 psu)
GISS-E2-R-CC hist+RCP8.5 (34.65 psu)
d)
MLD anomaly
m
year
CESM1-CAM5 hist+RCP8.5 (1420 m)
GFDL-ESM2G historical (825 m)
GISS-E2-R hist+RCP2.6 (1724 m)
GISS-E2-R hist+RCP4.5 (1724 m)
GISS-E2-R hist+RCP8.5 (1724 m)
GISS-E2-R-CC hist+RCP4.5 (1331 m)
GISS-E2-R-CC hist+RCP8.5 (1331 m)
e)
AMOC anomaly
Sv
year
CESM1-CAM5 hist+RCP8.5 (24 Sv)
GFDL-ESM2G historical (21 Sv)
GISS-E2-R hist+RCP2.6 (27 Sv)
f)
SPG index anomaly
Sv
year
CESM1-CAM5 hist+RCP8.5 (45 Sv)
GFDL-ESM2G historical (42 Sv)
GISS-E2-R hist+RCP2.6 (47 Sv)

Forecasting the future of the ongoing cold blob

- IPSL-CM5A-LR decadal prediction system
- Correct predictability of the SST a few years ahead (Mignot et al. 2016)
- 3-member ensemble of forecasts starting in 31December 2015