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Physical analysis of the model drift in the North Atlantic: the role of the atmosphere in the bias adjustment

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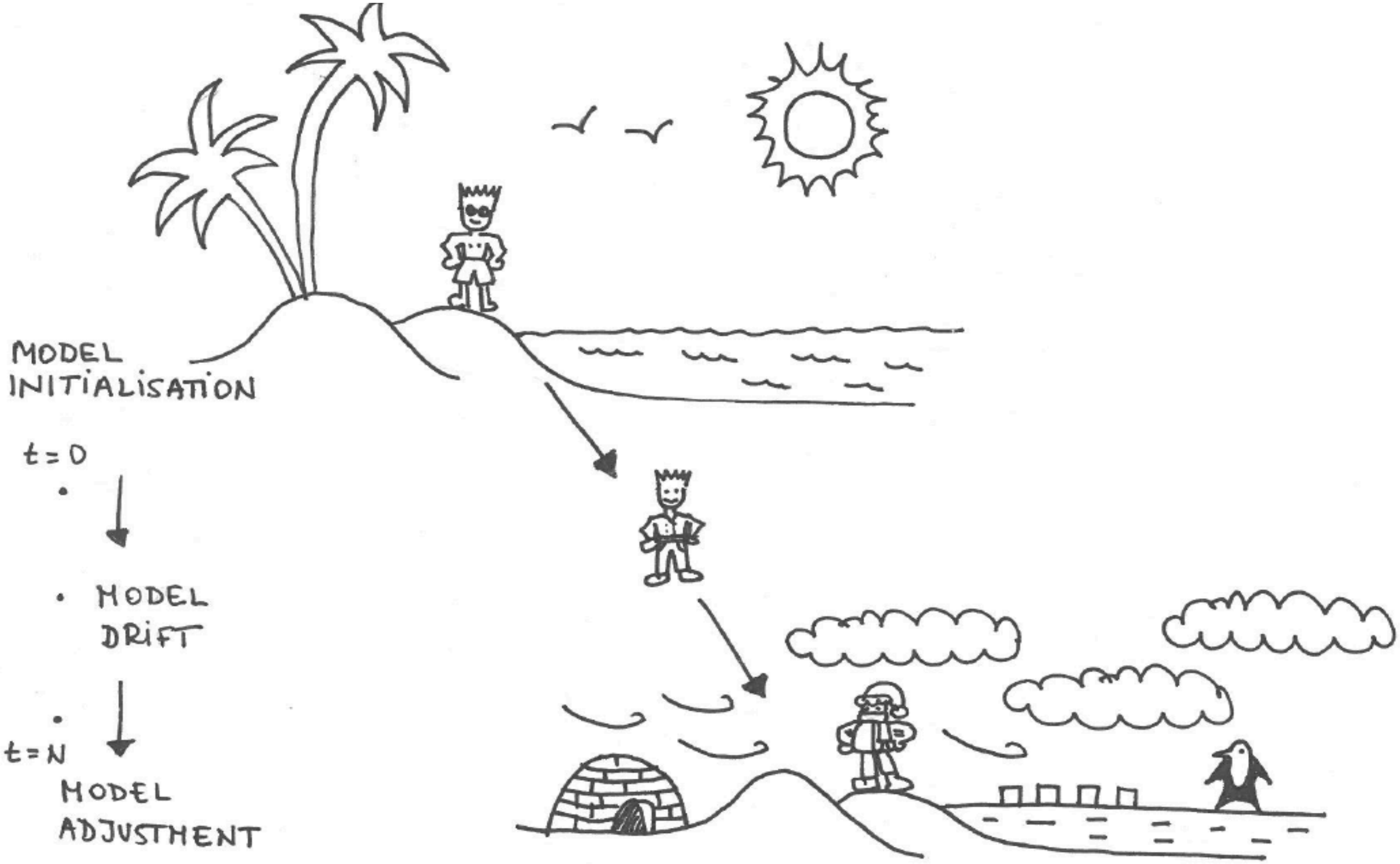
Sanchez-Gomez et al., Clim.Dyn. 2015

The model drift

An illustration of the model drift in a climate prediction.

Observed Climate

Model Climate



The model (the guy) is initialised from an observed state, which is warmer than the model mean climate. Hence, the 'model guy' progressively adjusts (he wraps up) by to finally reach the equilibrium state.

Motivation and goals

- The **drift** *is the sequence of physical processes by which model adjust to its* *<u>equilibrium state or attractor</u>*

- Model drifts are removed from predictions for forecast verification and rarely analysed …but the drift analysis can provide useful information on the **physical processes involved in the development of model systematic biases.**

- **The goal:** To investigate some of the physical processes involved in the model drift to understand the mechanisms leading to the model systematic errors

Focus on the North Atlantic

Numerical experiments

Coupled Model: CNRM-CM5 (Voldoire et al. 2013)
atmosphere: ARPEGEv5 (T127, 1.8º)
ocean: NEMOv3.2-ORCA1
sea-ice: GELATOv5.2

❖ **Initial conditions (IC)**

- *Coupled experiment in which the ocean is nudged towards NEMOVAR ocean reanalysis*

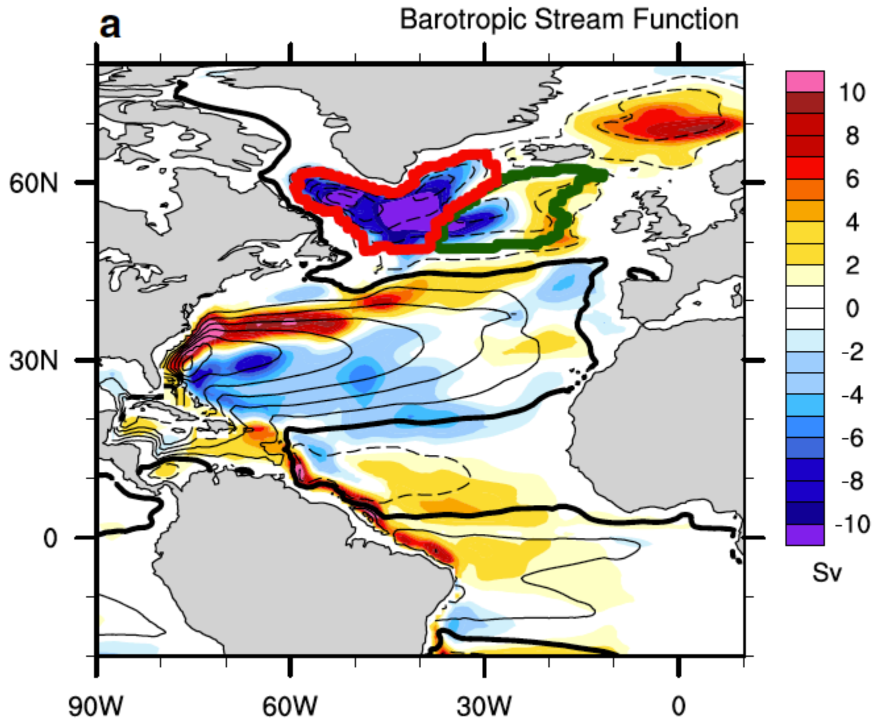
❖ **Decadal experiments (DEC)**

- *Initialised every 5 years within 1960-2000 (10 years, 10 members)*
- *Full field initialisation using IC (Sanchez-Gomez et al. 2015)*

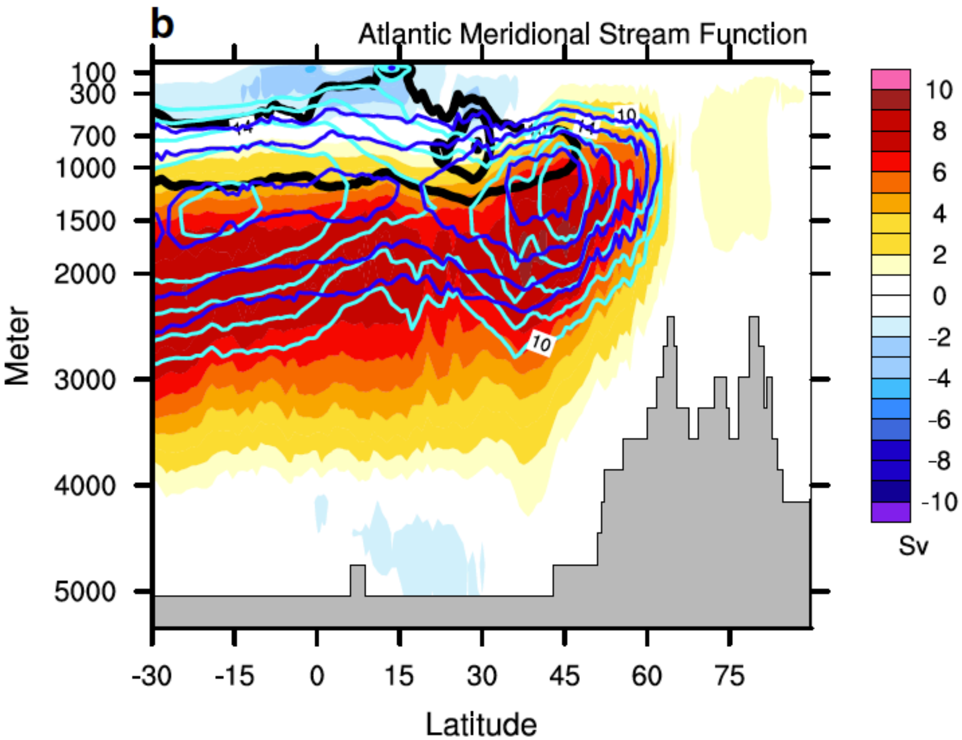
❖ **Historical experiments (HIST) :**

- *Non initialized, 1960-2005, 10 members*
- *Used to estimate the model attractor*

Model climatology versus initial conditions

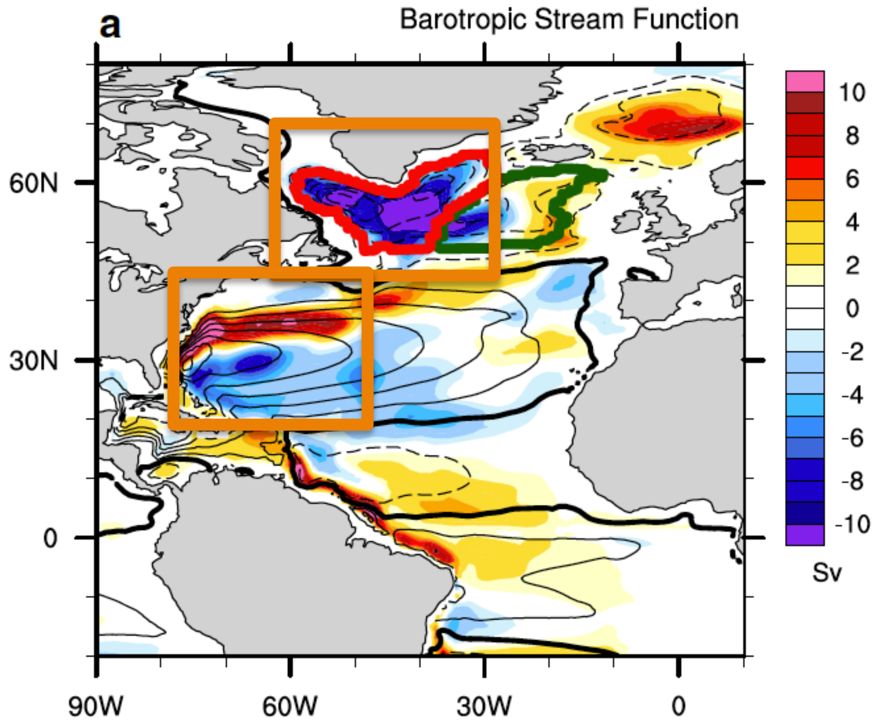


HIST – IC difference
Black contours: HIST climatology



HIST – IC difference
Black contour: HIST climatology
Dark Blue: IC climatology

Model climatology versus initial conditions



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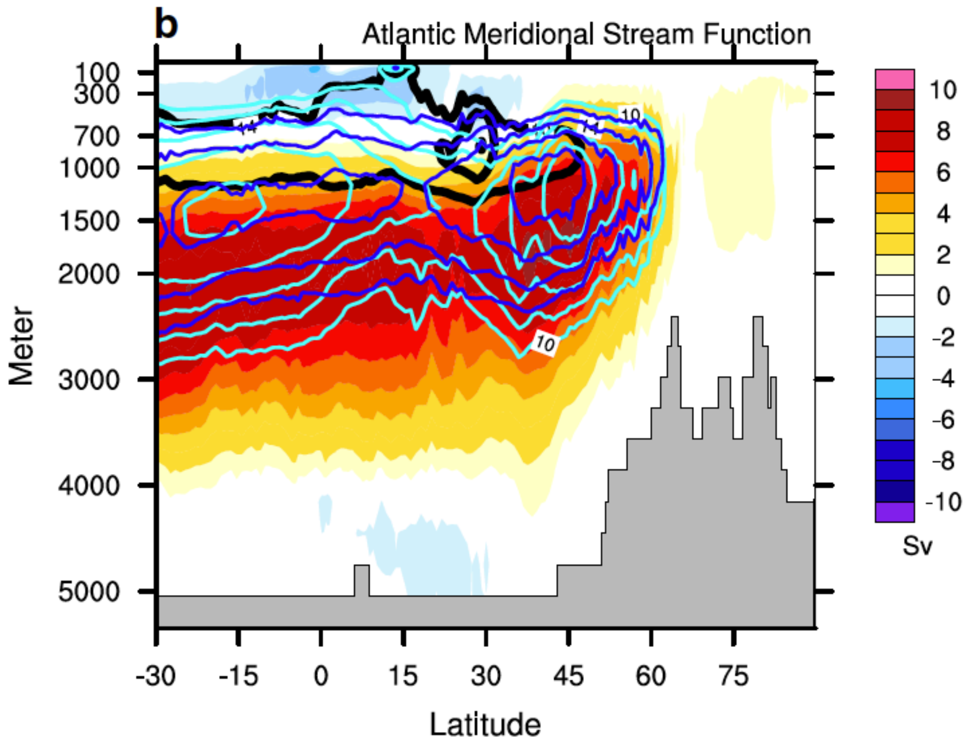
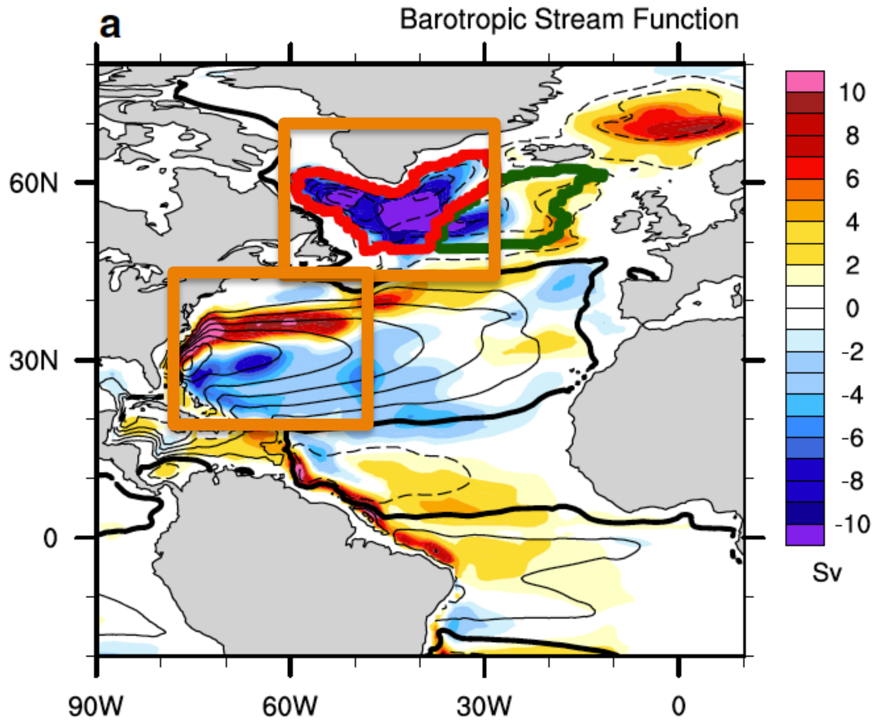


HIST – IC difference
Black contour: HIST climatology
Dark Blue: IC climatology

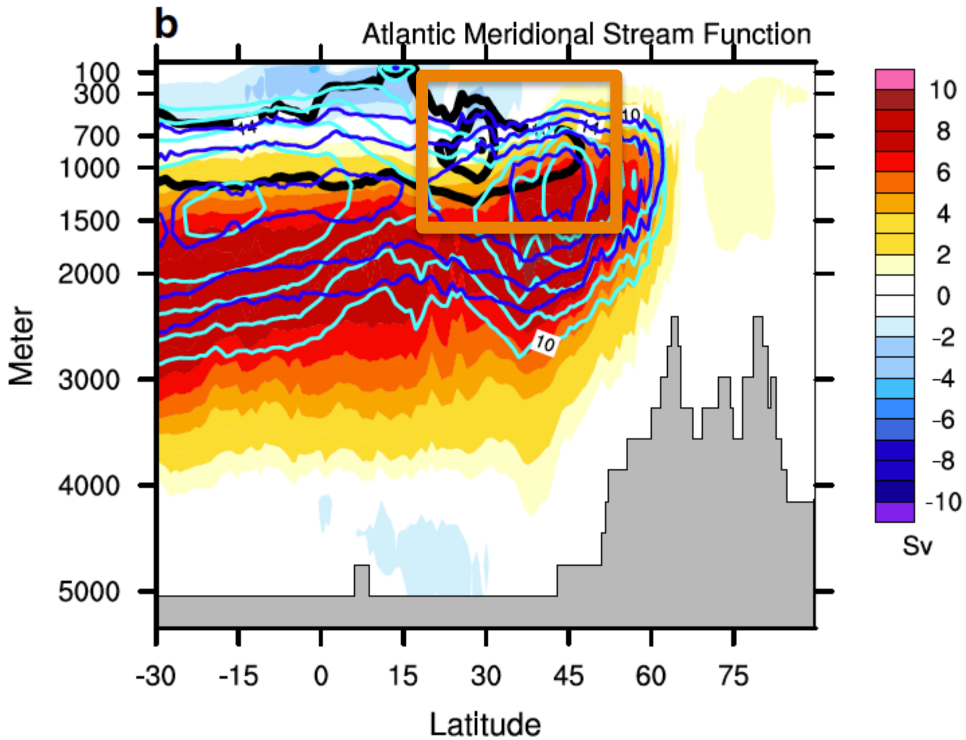
- **Stronger gyre circulation in IC**
- **Gulf Stream located northward in IC**
- **Gulf Stream and SPG stronger in IC (~ 10 Sv)**

Model climatology versus initial conditions



HIST – IC difference

Black contours: HIST climatology



HIST – IC difference

Black contour: HIST climatology

Dark Blue: IC climatology

- Stronger gyre circulation in IC
- Gulf Stream located northward in IC
- Gulf Stream and SPG stronger in IC (~ 10 Sv)

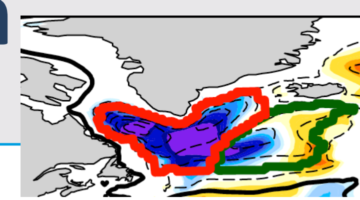
- Stronger AMOC in IC (~6 Sv)
- Maximum AMOC located at upper levels (750 m) in HIST

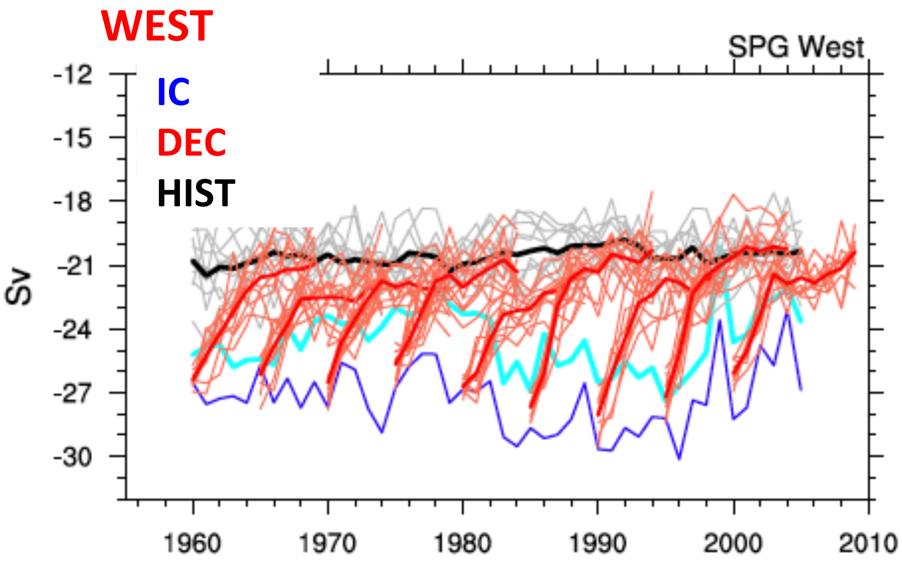
Model climatology versus initial conditions

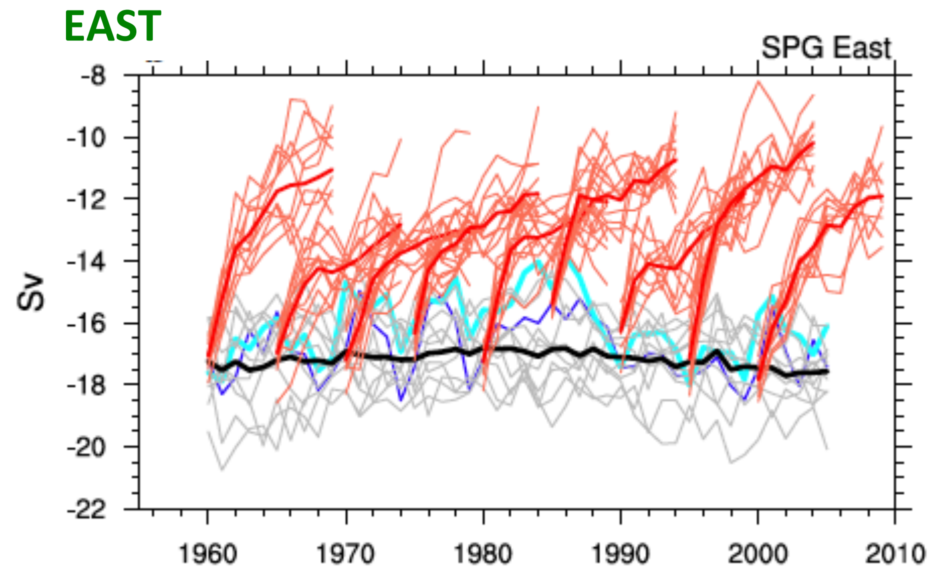
During the model drift, the SPG and the AMOC in DEC will weaken to get close to the HIST values…

What are the physical mechanism and timescales involved in this drift process ?

Subpolar Gyre: circulation



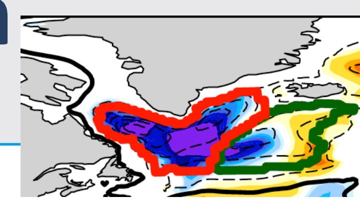




Slackening of the SPG circulation:

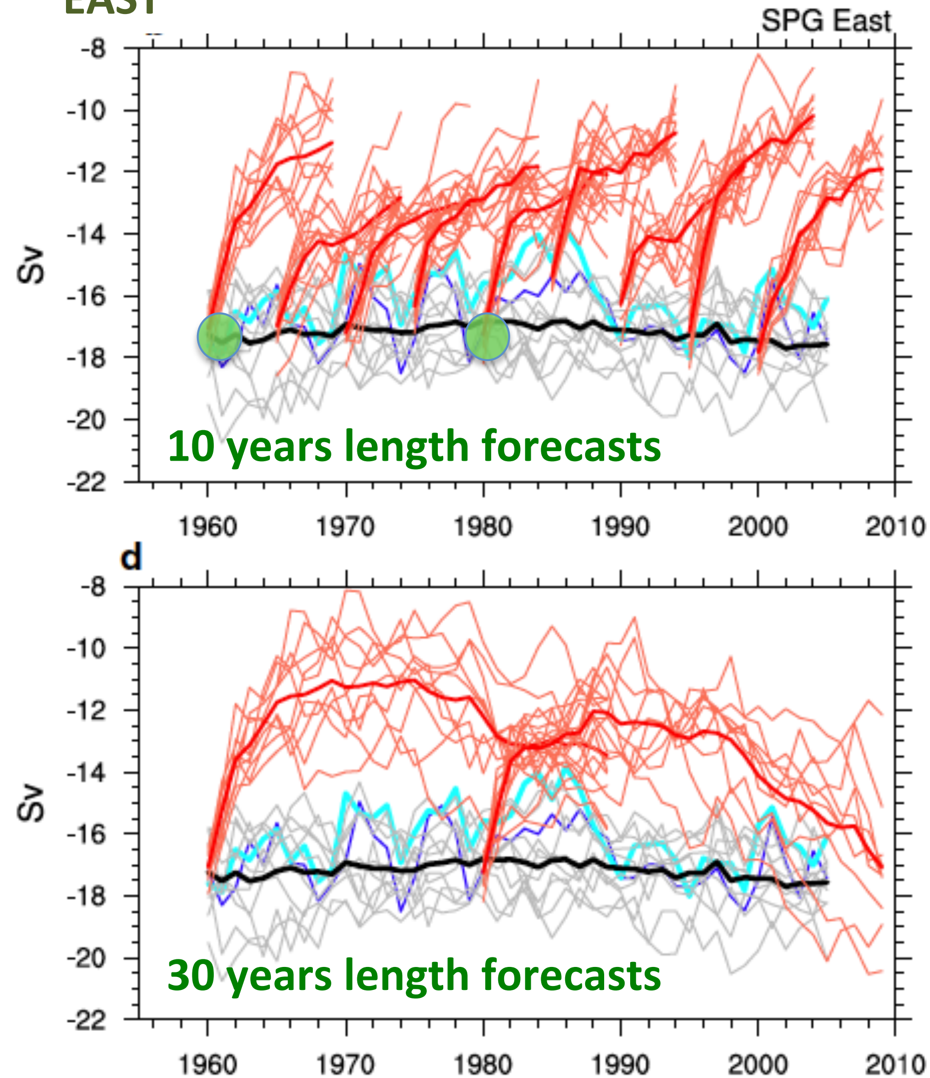
- **The west SPG in DEC rapidly weakens to reach HIST after around 5 years.**
- **The east SPG weakens and unexpectedly drifts away from HIST**

Subpolar Gyre: circulation



IC
DEC
HIST

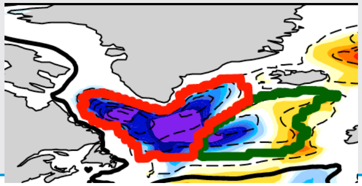
EAST

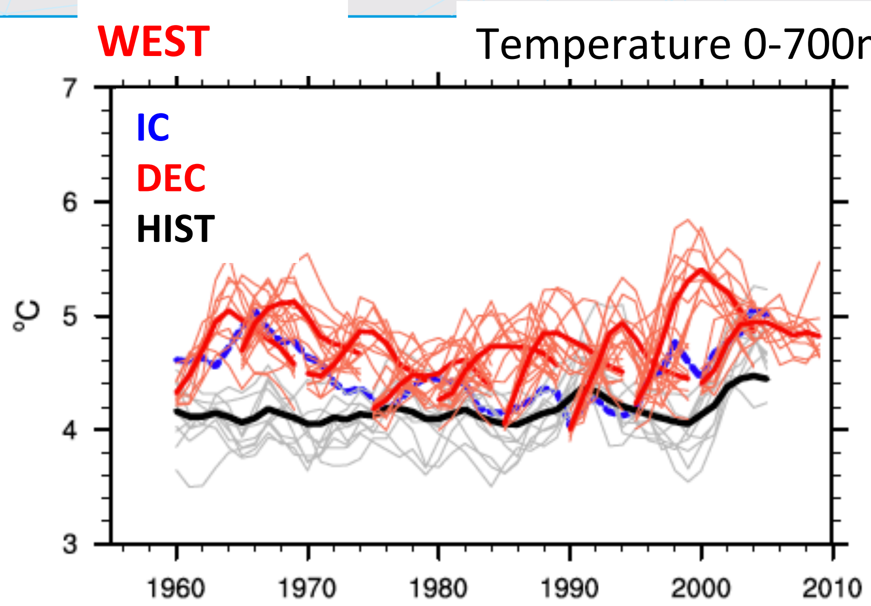


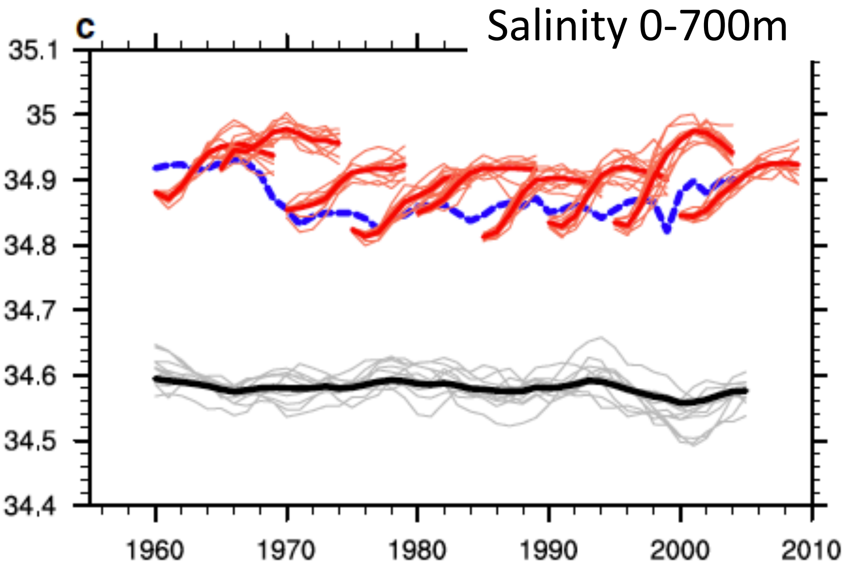
Slackening of the SPG circulation:

- **The east SPG strengthens from Yr11-12 to reach barely the attractor after 30 years.**

Subpolar Gyre: T and S







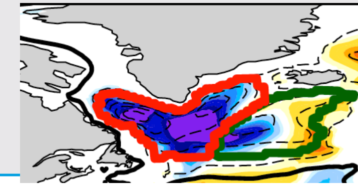
Temperature:

- Until Yr4-5: strong warming
- After Yr5: Strong cooling

Salinity:

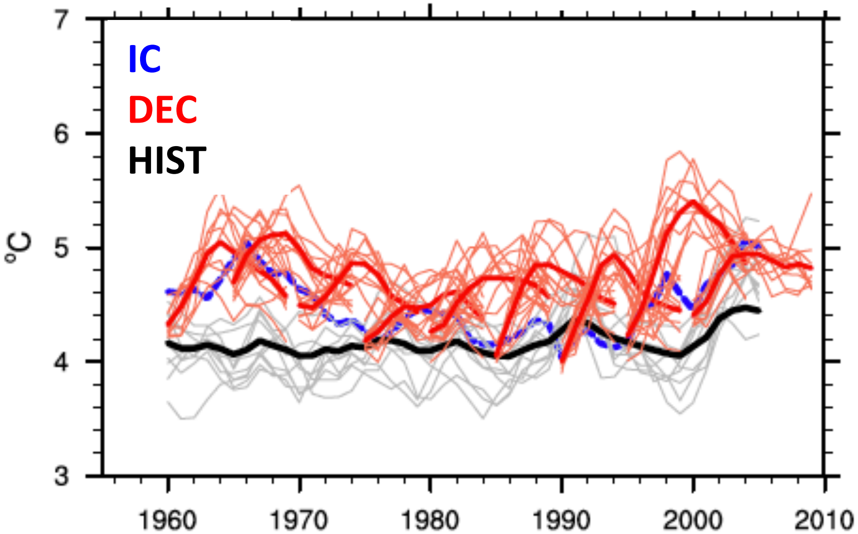
- Yr1: systematic decrease
- Until Yr4-Yr5: salinity increase
- After Yr5: slight salinity decrease

Subpolar Gyre: T and S



WEST

Temperature 0-700m



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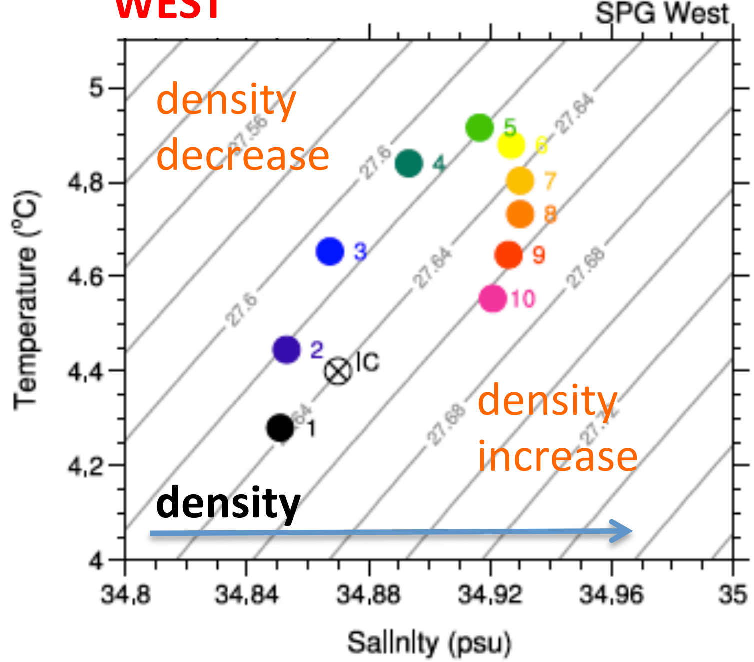
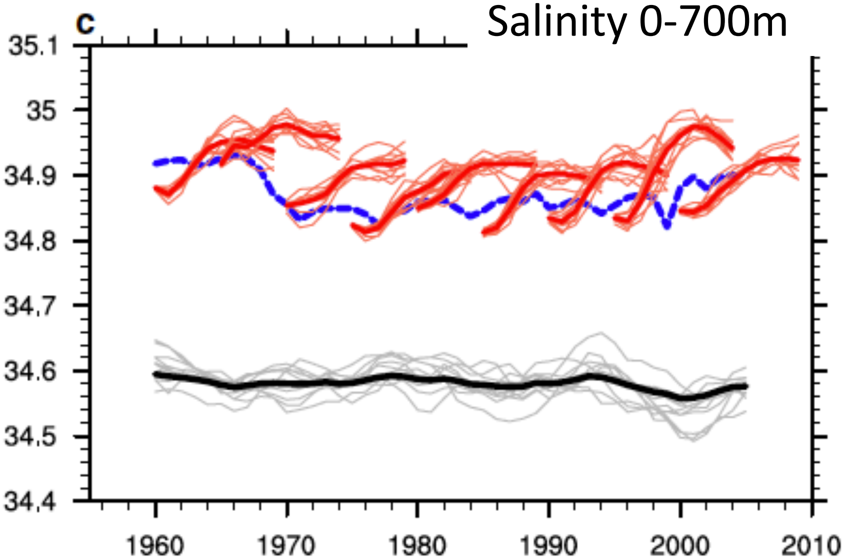


Salinity 0-700m



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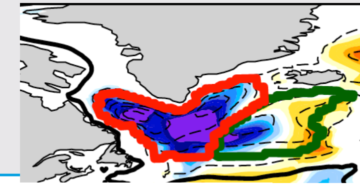
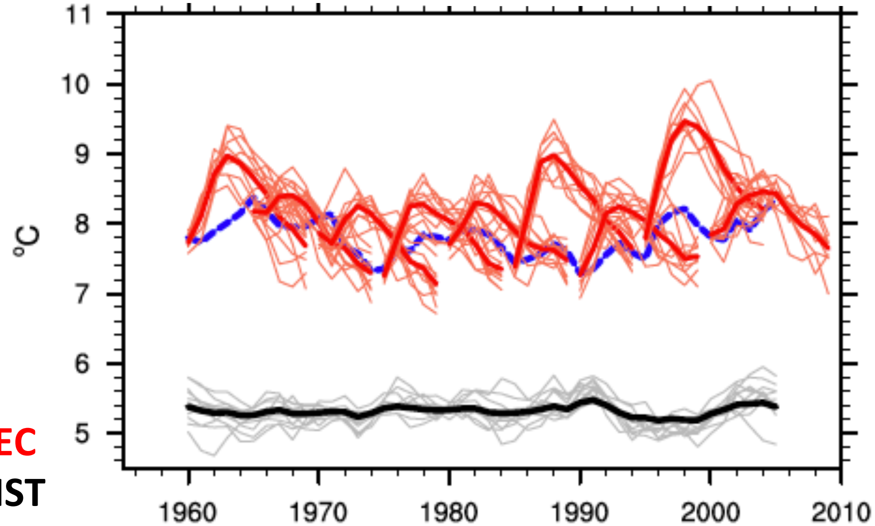


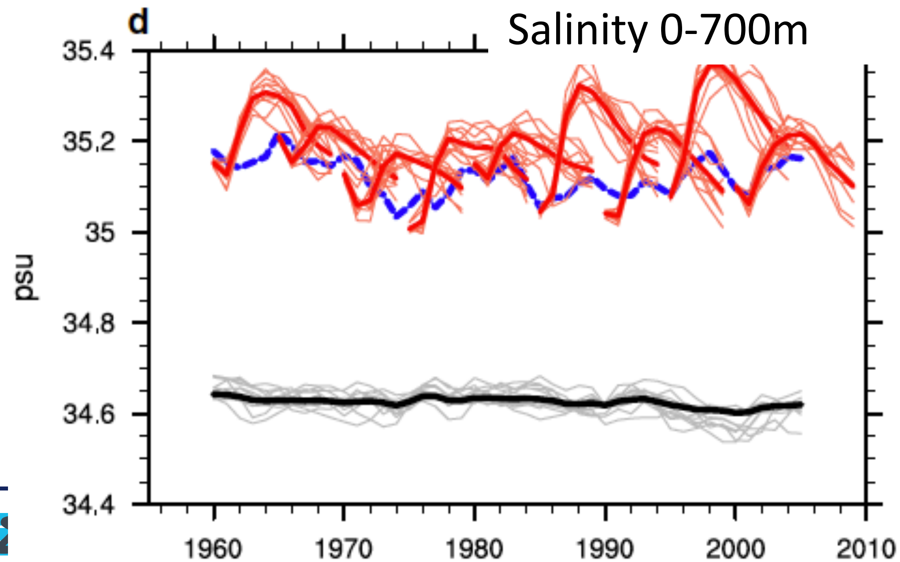
EAST

Temperature 0-700m



IC
DEC
HIST

Salinity 0-700m



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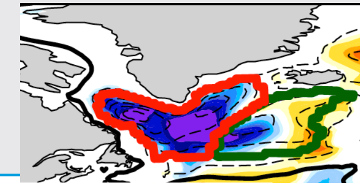

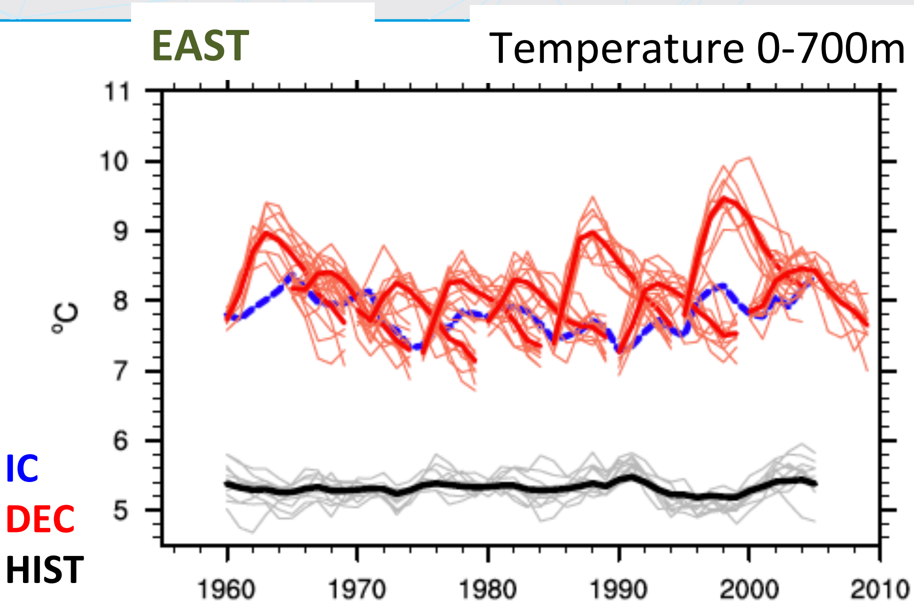

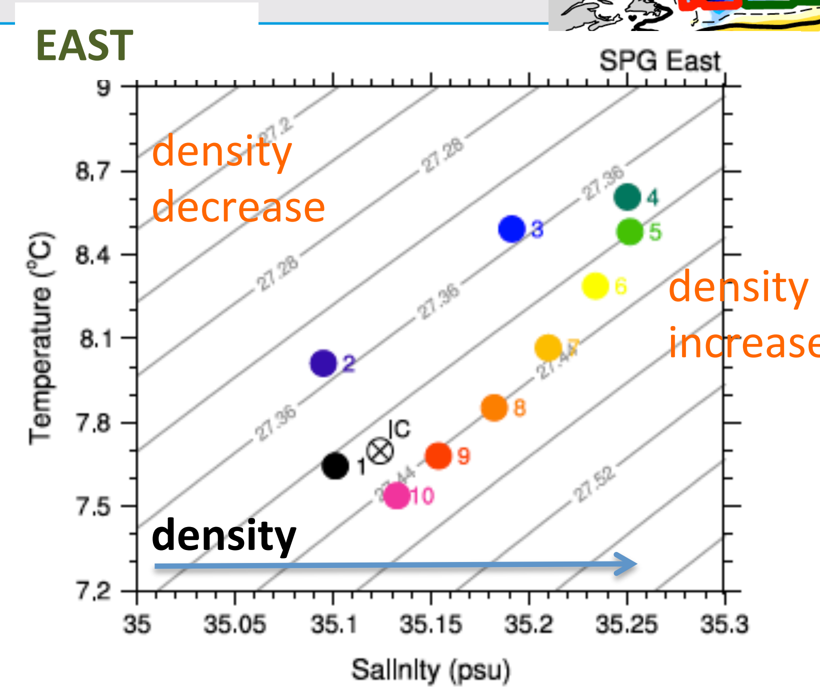

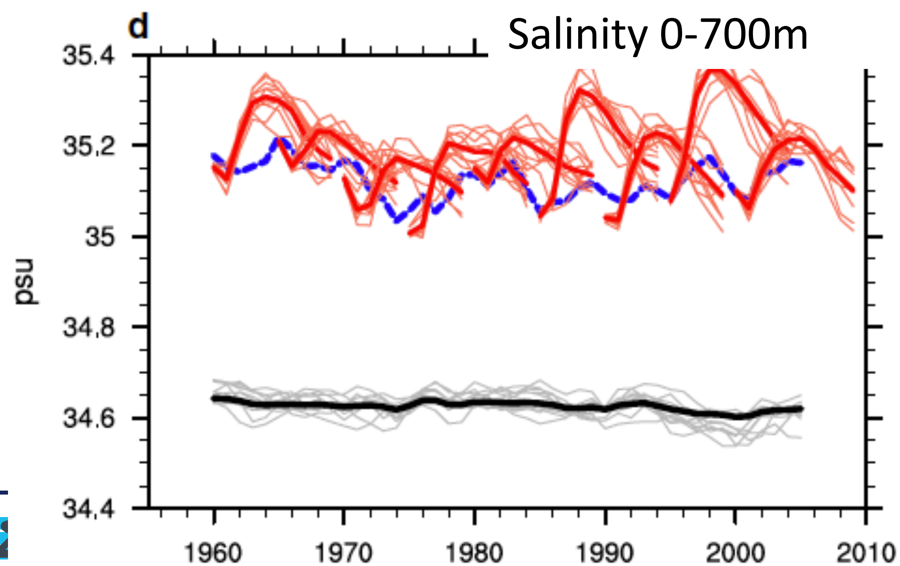

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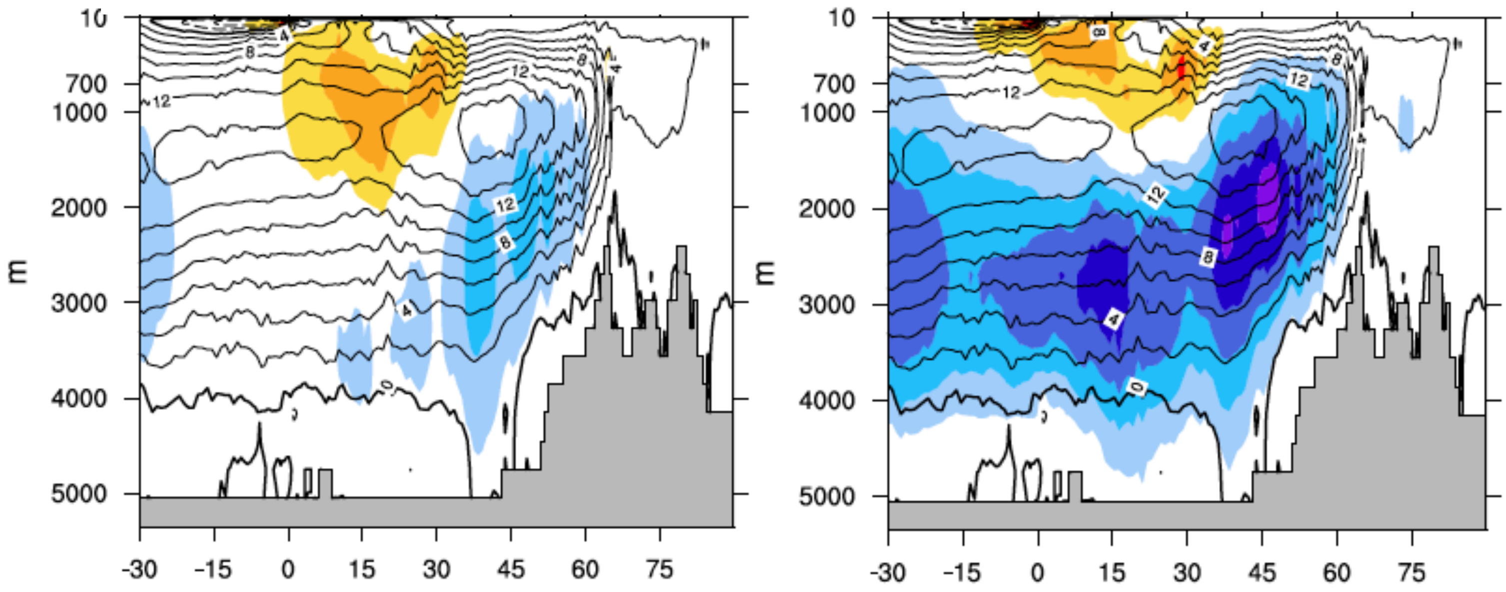
- After Yr5: strong salinity decrease

The drift of the AMOC

DEC – IC in Yr1 to Yr4 | **DEC – IC in Yr5 to Yr10**

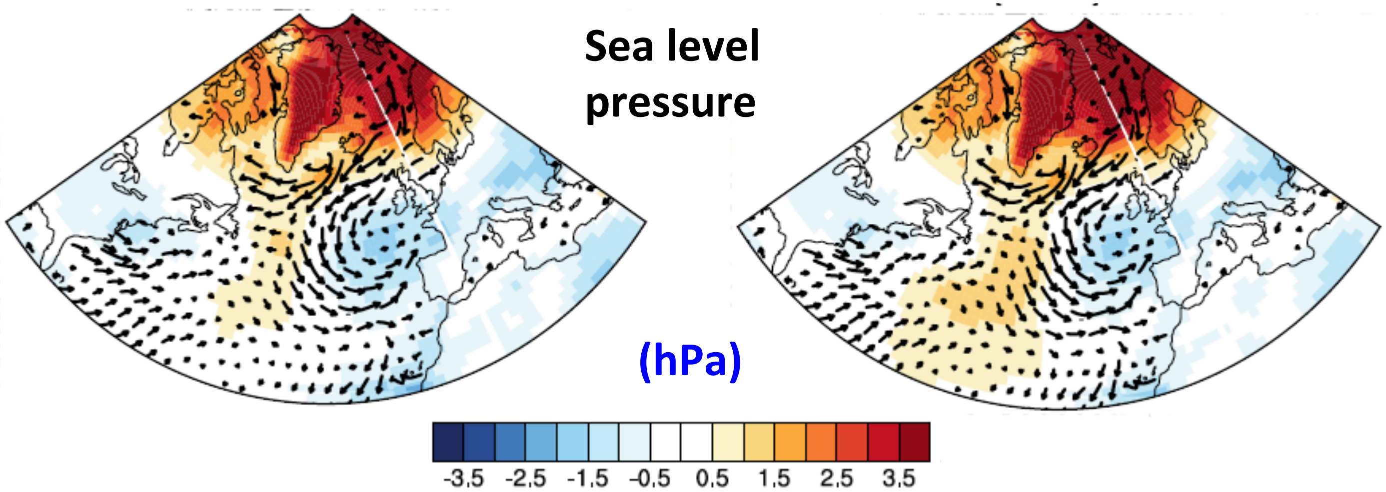


Black contour: IC climatology

AMOC slowdown (~6 Sv), leading to a reduction of heat and salt poleward transport
(coherent with cooling and desalinisation of SPG after Yr5)

Drift in the atmospheric circulation

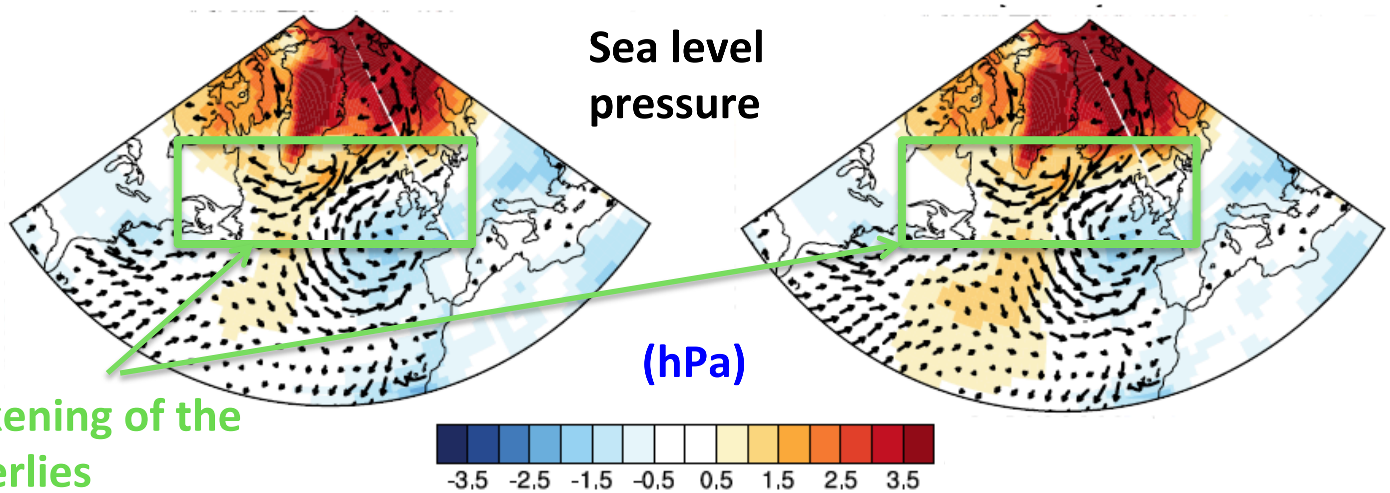
DEC – NCEP in Yr1 to Yr4 **DEC – NCEP in Yr5 to Yr10**



The atmosphere reaches quickly the attractor. The coupled model bias projects **onto a negative NAO.**

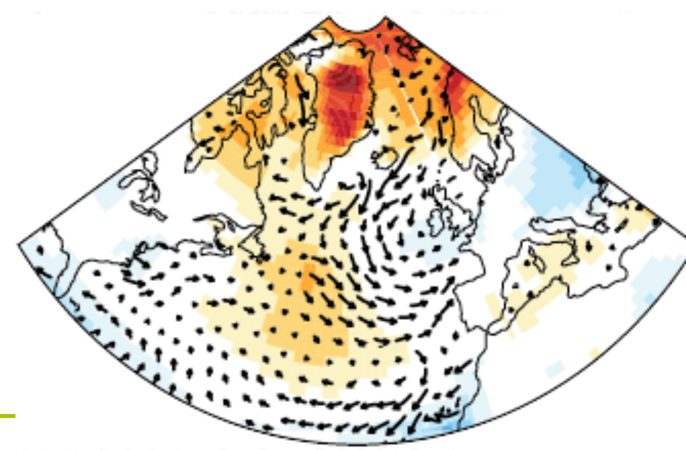
Drift in the atmospheric circulation

DEC – NCEP in Yr1 to Yr4 **DEC – NCEP in Yr5 to Yr10**



Weakening of the westerlies

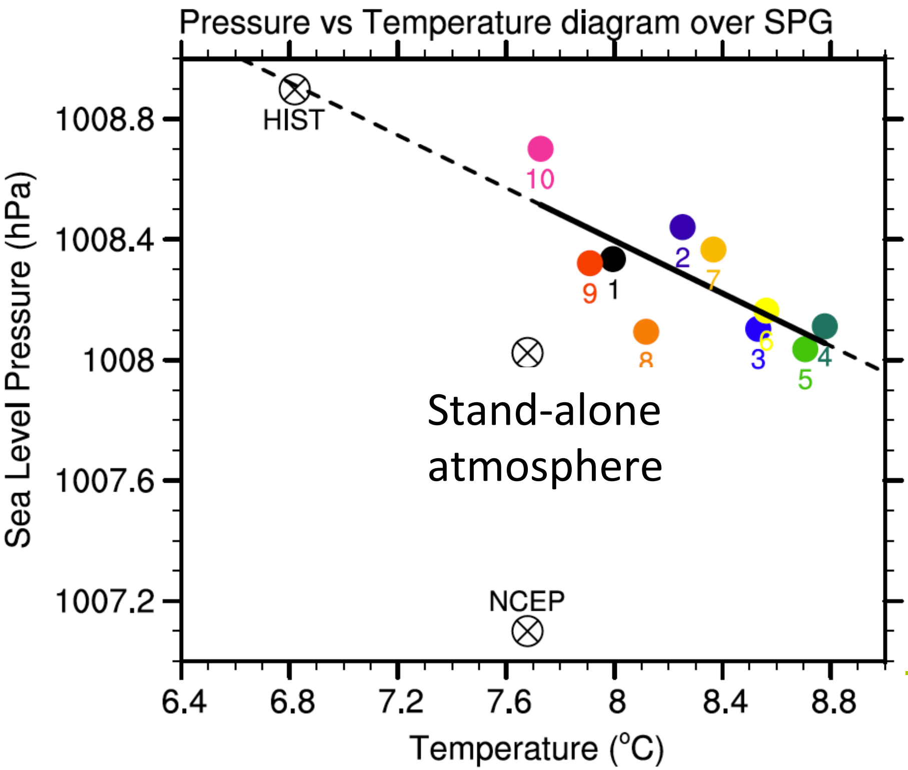
Stand-alone atmosphere - NCEP



- The stand-alone atmospheric component bias projects onto the **NAO-**.
- The intrinsic **atmospheric bias is amplified in DEC**

Drift in the atmospheric circulation

The **NAO-** →
weakening of westerlies → initial warming of the SPG → reduction of deep-water formation → slackening of the AMOC → decrease of the poleward heat and salt transport → cooling and desalinisation of the SPG *(Lohman et al. 2009, Barrier et al. 2013)*



Slope=-0.44 hPa/°C
Correlation = -0.75

A weak SLP/SST feedback is establised

Summary and conclusions

- **In the North Atlantic, the coupled model biases projects onto a NAO-pattern, which is present from the beginning of the forecasts and can act like a forcing for the ocean.**

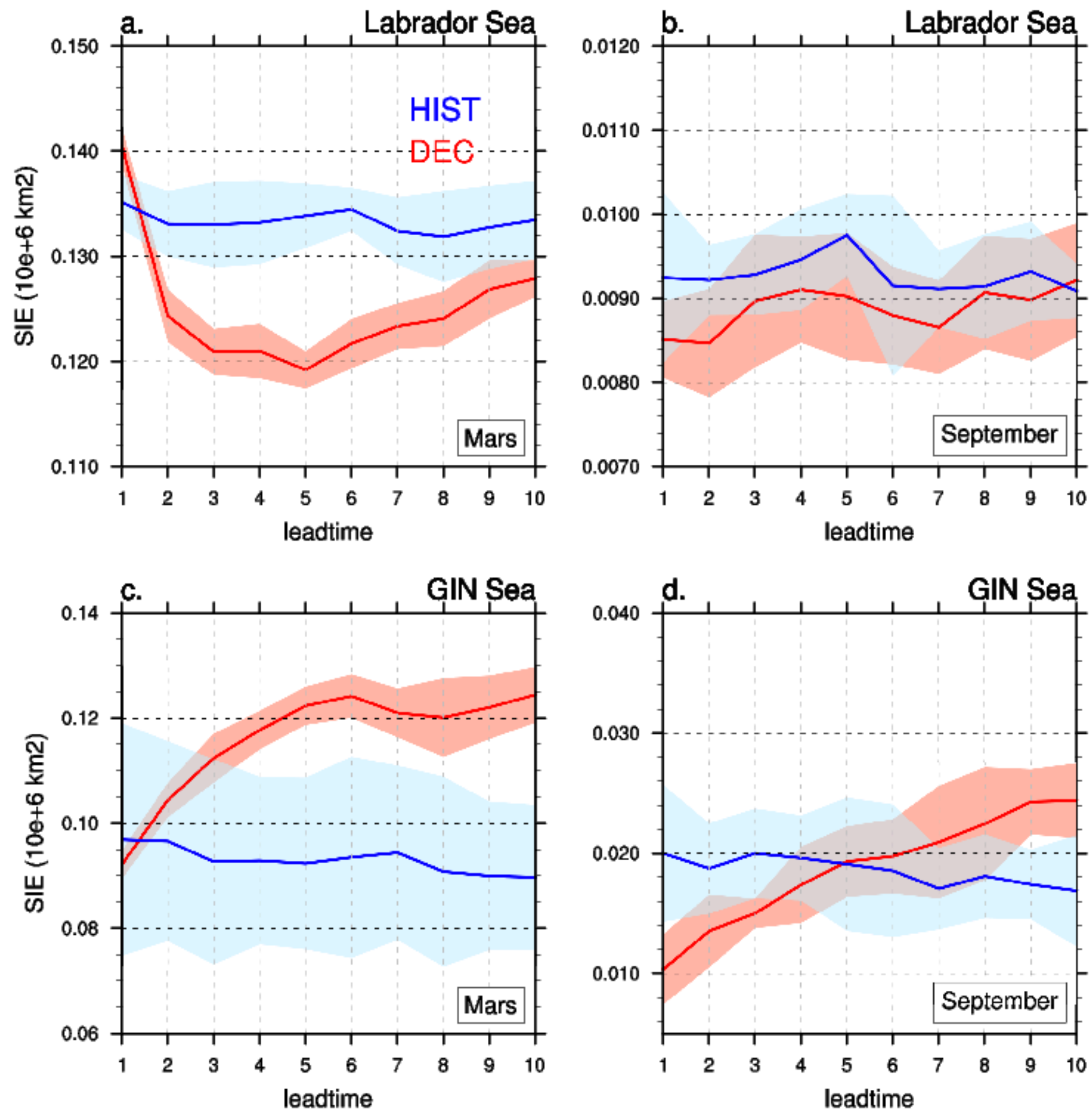
- **These atmosphere circulation biases can be partially attributed to the biases of stand-alone atmospheric component.**

- **The coupled model drifts can be mostly interpreted as the integration by the ocean of these intrinsic atmospheric biases :** the NAO- forcing leads to a weakening of westerlies, an initial warming in the SPG and a reduction of deep-water formation yielding to a slackening of the AMOC, that in turns will reduce the poleward heat and salt transport, yielding to a cooling and desalinisation of the SPG area.

Sanchez-Gomez et al., Clim.Dyn. 2015

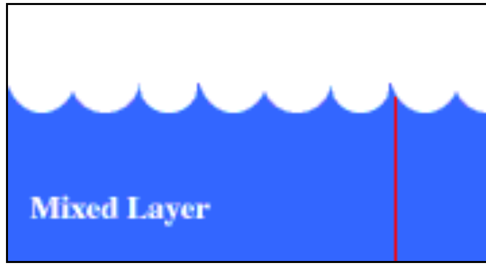
Model drift in Arctic Sea Ice

Drift averaged over the Labrador Sea area (top) and GIN seas area (botton). Only for DEC and for th Sea ice extent.



Initialisation method

Sea surface restoring



Sea Surface restoring

Heat flux:

$$Q_{ns} = Q_{ns}^{o} + \frac{dQ}{dT}(T_{k=1} - SST_{NEMOVAR})$$

Heat flux at the surface

feedback term

$\frac{dQ}{dT}$ *Feedback coefficient = -40W/m2/K*

Fresh water flux:

$$EMP = EMP_o + \gamma^{-1} e_{3t} \frac{(S_{k=1} - SSS_{NEMOVAR})}{S_{k=1}}$$

Fresh water budget at the surface

feedback term

γ_s *Feedback parameter = -167 mm/day*

Initialisation method

3D Newtonian damping

$$\frac{\partial T}{\partial t} = \cdots - \frac{1}{\beta}(T - T_{NEMOVAR})$$

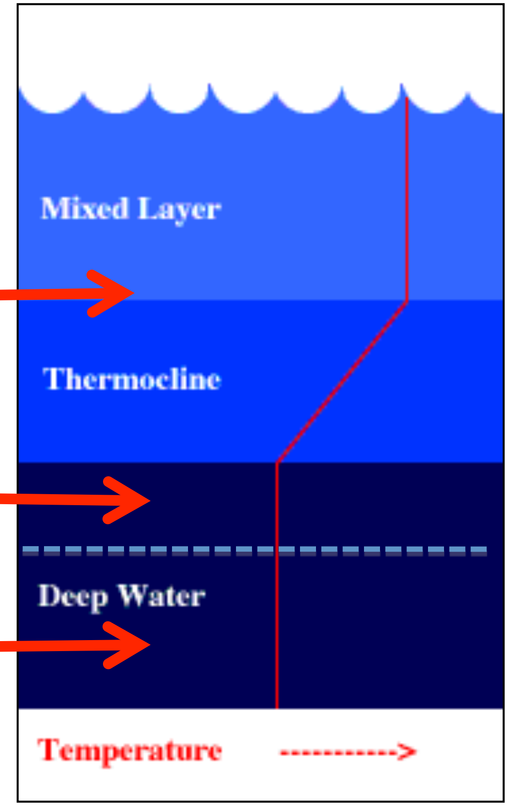
$$\frac{\partial S}{\partial t} = \cdots - \frac{1}{\beta}(S - S_{NEMOVAR})$$

β = f(depth, space)

In the thermocline
$(1/\beta) = 0$

Below thermocline
β = 10 days

Deep Ocean
β = 360 days



No nudging within the Equatorial band (1^{o}N-1^{o}S) and Near the coast (300km)
$(1/\beta) = 0$