Land-ice melting causes strong multi-century slowdown of Atlantic circulation even under 2xCO2 stabilisation

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Background

- IPCC 2001: **None of the GCM climate models** includes melting of land-ice (Greenland, Antarctic and mountain glaciers)

- Large uncertainty on the speed of the Greenland melting
  - Possible amplification processes (lubrication effect)
  - 0.12 Sv during the Younger Dryas (Bard et al., 1996)
  - Actual observations of the melting: faster than previously thought (Rignot and Kanagaratnam, 2006)
- Fichefet et al. (2003) and Swingedouw et al. (2006): melting of Greenland could be an important term for the AMOC response to global warming on a century time scale

Aim of this work

- **Estimate the impact of land ice melting** in scenario on 500 years time scale
- Analyze the **mechanisms of the response** of the AMOC **to global warming**

Land-ice melting impact on the AMOC

We use the **IPSL-CM4** coupled model (Ocean ORCA2: 2°x(0.5-2°) resolution, Sea-ice LIM: dynamic-thermodynamic, Atmophere LMDz: (2°x3.75°) resolution,Land model ORCHIDEE)

We include a **parameterization of land-ice melting** that only considers thermodynamics processes for the melting, no dynamics processes for the ice-sheet are included.

Two scenarios:

- With Ice-Sheet melting (WIS2)
- No Ice-Sheet melting (NIS2)

It leads to a melting of about **0.13 Sv** stabilized after 200 years (more than half of Greenland has melted after 500 years)

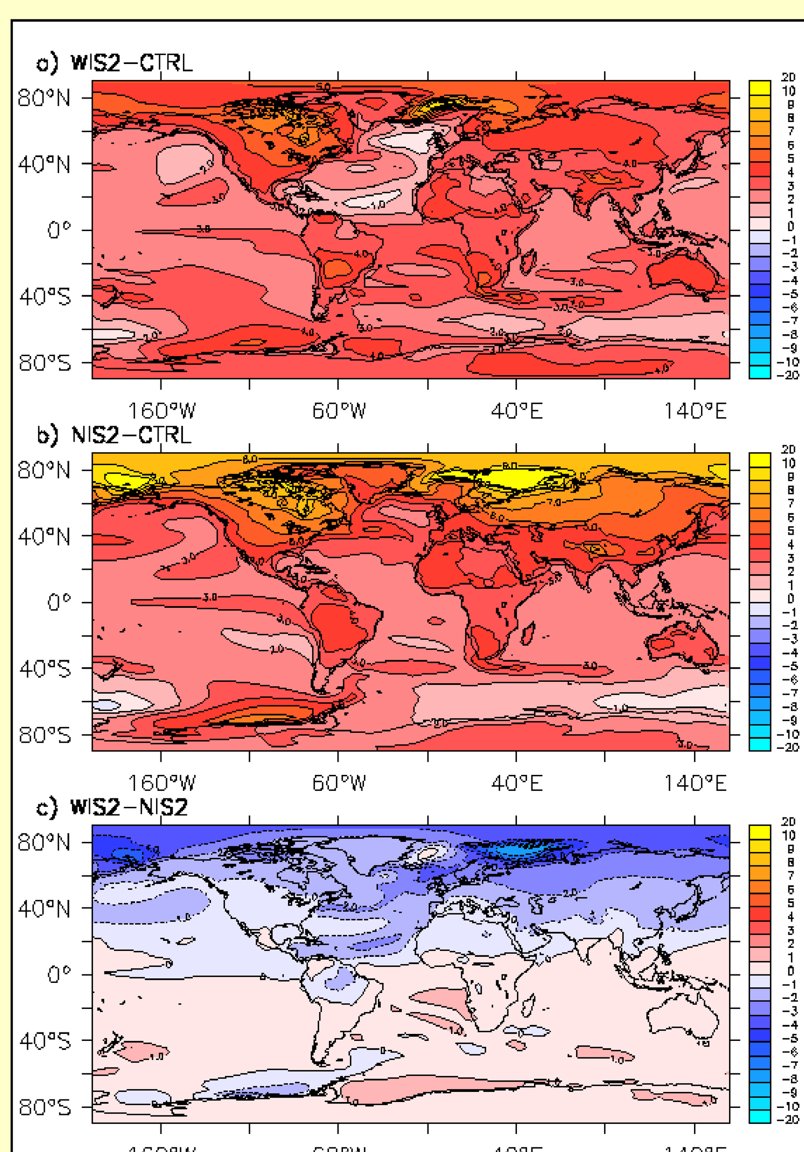


Fig.1: Difference in surface atmospheric temperature in K for the last 30 years of simulation between a) WIS2-CTRL, b) NIS2-CTRL, c) WIS2-NIS2

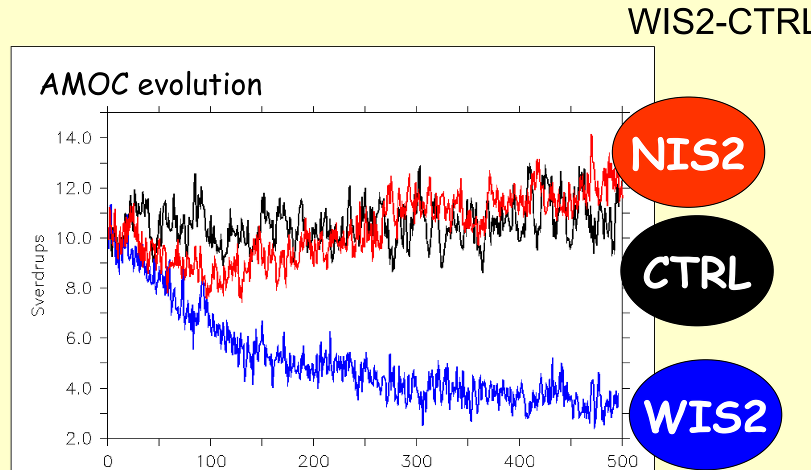


Fig. 2: Time series of AMOC index in Sverdrup, defined as the maximum of the meridional overturning circulation in the Atlantic.

AMOC and convection sites density

We define a large convection sites region in the model:

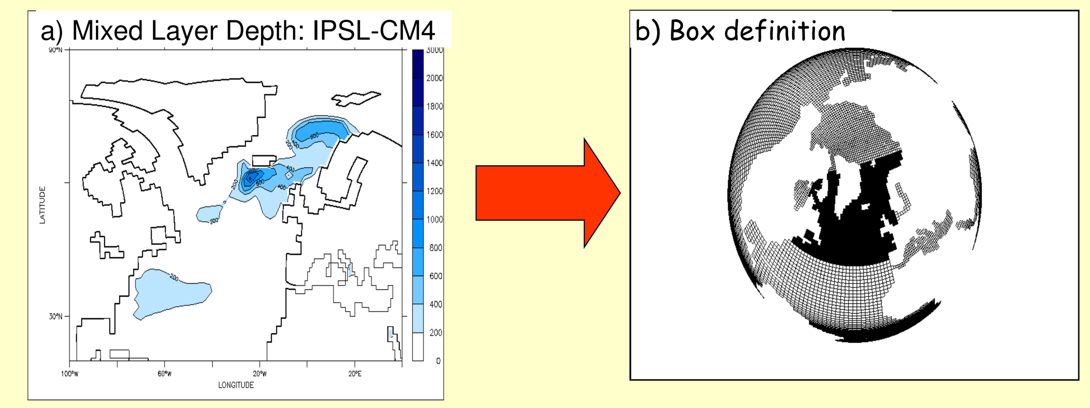


Fig. 3: a) Mixed layer depth in March in CTRL and b) convection sites region definition (in black)

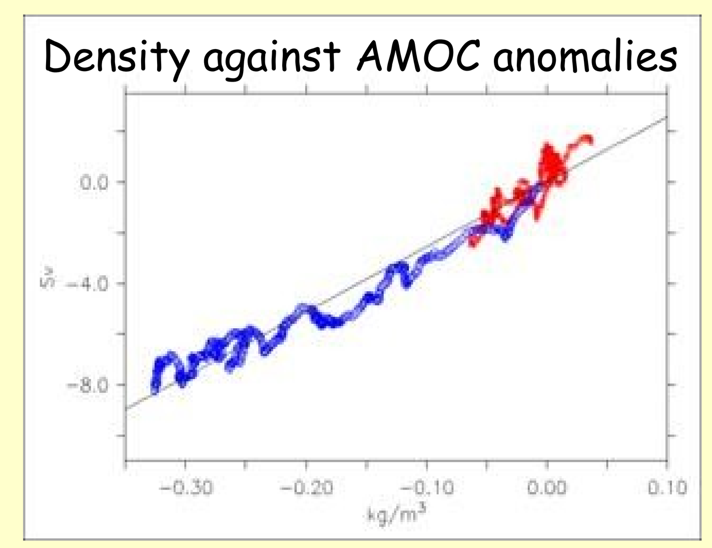


Fig. 4: Anomalies of buoyancy in the convection sites in the scenarios compared to CTRL against anomalies of AMOC index. Each point correspond to a year.

Correlation of 0.98 between density anomalies in the convection sites and AMOC anomalies:

$$\Delta\, AMOC \approx \gamma \Delta\rho$$

where $\gamma = 23\ Sv/kg/m^3$

Surface buoyancy forcing

We linearize the buoyancy anomalies and decompose into a salinity and a temperature components:

$$\Delta\rho \approx \beta\Delta S - \alpha\Delta T$$

Main results

- NIS2: temperature (T) diminishes the AMOC, salinity (S) increases it
- WIS2: T et S decrease the AMOC

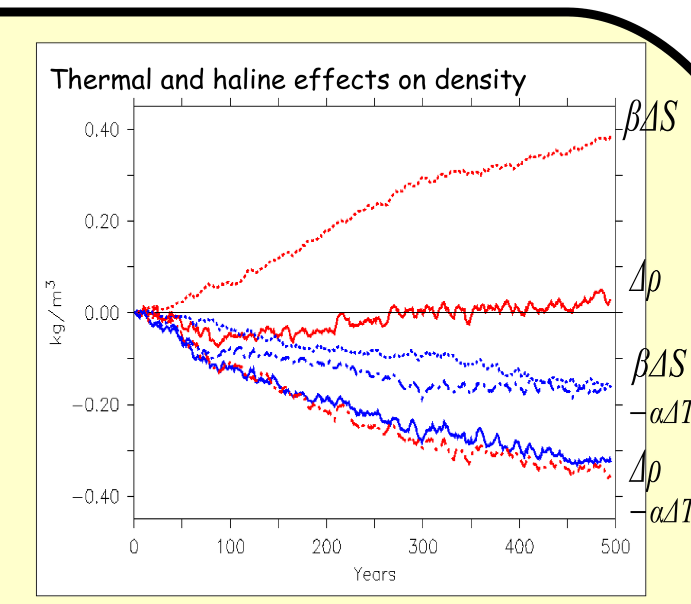


Fig. 5 Time series of buoyancy differences with CTRL averaged over the convection sites

We further decompose the buoyancy anomalies:

$$\Delta\rho \approx \Delta\rho^S_{Transport} + \Delta\rho^S_{surface} + \Delta\rho^S_{OT} + \Delta\rho^T_{Transport} + \Delta\rho^T_{surface} + \Delta\rho^T_{OT}$$

Main contributor to AMOC recovery in NIS2:

2. **Salinity anomaly from the tropics** transported by gyre (32% of the recovery mechanisms)

3. **Decrease in sea-ice transport** through Fram Strait (15% of the recovery mechanisms)

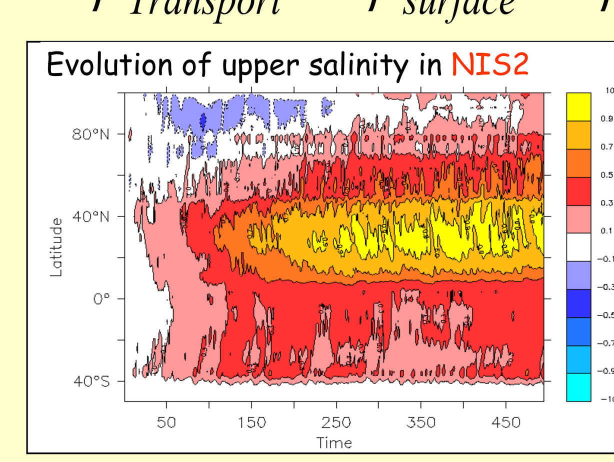


Fig. 8: Time-latitude of salinity anomalies in surface Atlantic between NIS2 and WI2.

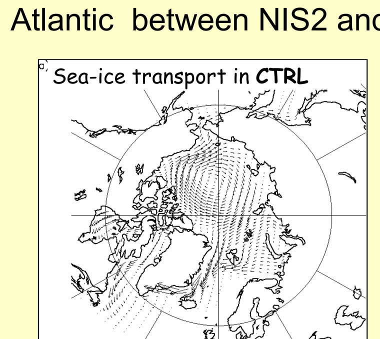


Fig. 7: Sea-ice transport in CTRL. 0.15 Sv crosses the Fram Strait each year

AMOC internal feedbacks quantification

Following an analogy with electronic (Hansen et al. 1984), we define linear feedbacks by:

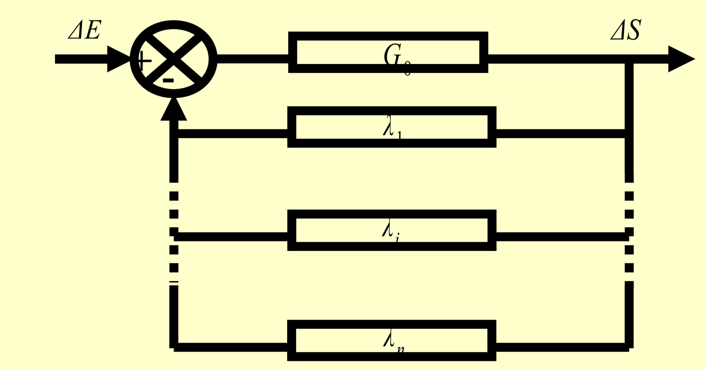


Fig.8 : Scheme of a system with linear feedback

We consider now the difference between the scenarios.

We write the equation for buoyancy as:

$$\Delta\rho \approx \Delta\rho_0 + \sum_i \Delta\rho_i$$

where $\Delta\rho_0$ is the buoyancy anomaly due to land-ice melting

$$\Rightarrow \Delta\rho = \frac{1}{1-\sum_i \lambda_i}\Delta\rho_0$$

where $\forall i \quad \lambda_i = \frac{\Delta\rho_i}{\Delta\rho}$ is the feedback factor

We define a dynamical gain for the system which stands for the amplification of a perturbation:

$$G = \frac{\Delta\rho}{\Delta\rho_0} = \left(\frac{1}{1-(\lambda_S+\lambda_T)}\right) = 2.5$$

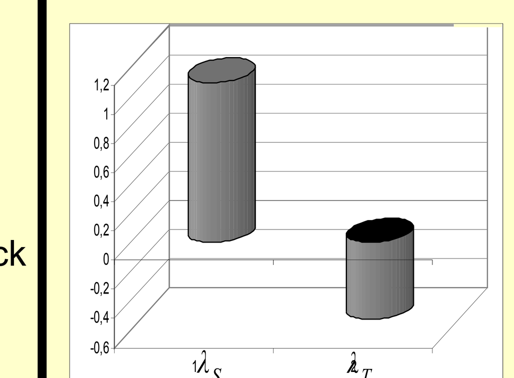


Fig.9 : Magnitude of temperature and salinity related feedback factors

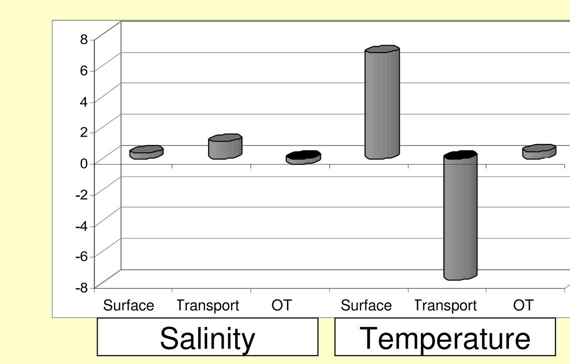
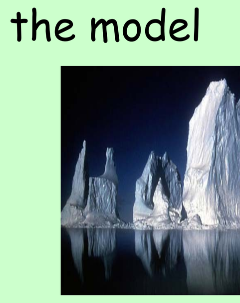


Fig.10 : Further decomposition of the magnitude of feedback factors

Heat flux damping is a strong positive feedback that limits heat transport negative feedback

Discussions and conclusions

- Land ice melting can lead to a **collapse of the AMOC** in IPSL-CM4
- **Extreme melting scenario** but not impossible due to the huge uncertainties concerning the Greenland discharge in the future
- Weak AMOC in IPSL-CM4 can lead to an important sensitivity of the model
- Main processes that help the AMOC to recover:
  - Transport of salinity anomalies from the tropics
  - Decrease of sea-ice melting in the convection site



- Salinity positive feedback dominates negative temperature feedback which gives a **dynamical gain of 2.5**

Outlooks

- Include an ice-sheet model to refine land-ice melting
- Apply feedbacks quantification methodology to **Hosing experiments** (Stouffer et al., 2006) to identify the origin of uncertainty among GCMs
- Compare land-ice melting effect in different GCMs: intercomparison of **scenarios with artificial additional 0.1Sv**

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