Decrease in the Atlantic overturning does not significantly impact oceanic CO2 uptake over century timescale

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Background

- **A positive climate feedback** is associated with the carbon cycle (Klepper and deHaan, 1995) due to a different response of ocean and land CO2 uptake when the climate warms
- A **large uncertainty** exists about the rate of this feedback (20 to 200 ppm among CGCM, Friedlingstein et al., 2006)
- Oceanic uptake reduction in warmer condition is due to the decrease of CO2 solubility related with SST increase and modification in mixed layer depth as from changes in circulation
- **Thermohaline circulation (THC)** weakening will participate to the reduction in oceanic carbon uptake via the reduction in deep ocean ventilation

Aim of this work

- Investigate if changes in THC can effectively affect CO2 uptake under global warming conditions in a coupled GCM
- **Quantify the effect** of various modifications of ocean due to THC weakening

1. **Overturning circulation and biology production decrease** due to THC weakening tend to reduce the oceanic CO2 uptake
2. **SST decrease, SSS decrease and sea-ice cover increase** due to a THC weakening tend to increase the oceanic CO2 uptake

Experimental design

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)

Monthly mean output of the climate simulation are then used to force « off line » the global ocean carbon model **PISCES**

The model **succeed in reproducing** the main feature of **observed** anthropogenic CO2 uptake

We consider scenarios of **quadrupling CO2 in 140 years**, one with land-ice melting (GW1), the other without (GW2) (See Swingedouw et al.. 2006).

We integrate PISCES with these two simulations, one with a **THC reduction of 47%** (GW1), the other with **a THC reduction of 21%** (GW2)

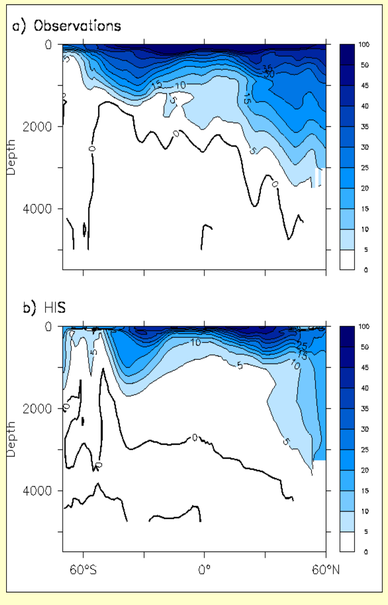

Fig.1: Zonal means of anthropogenic Dissolved Inorganic Carbon (DIC) in the Atlantic basin a) estimated form observations (Sabine et al., 2004), b) modelled in HIS.

Influence of THC changes on CO2 uptake

Global warming tend to diminish the CO2 uptake by 70.5 PgC after 140 years

Various weakening of THC and the land-ice melting does not significantly affect the CO2 uptake globally

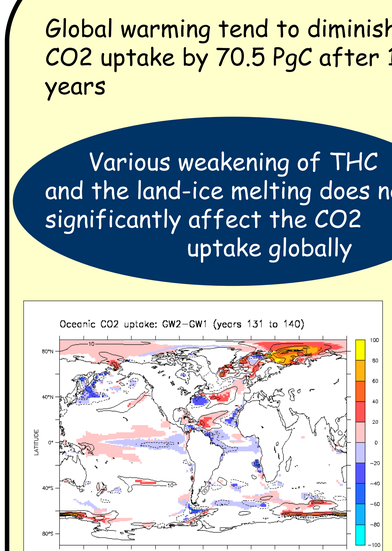

Fig. 2: Time evolution of: a) Global mean surface temperature, b) AMOC index, c) projected CO2 uptake, d) cumulative ocean CO2 uptake.

Fig. 3: Difference GW2-GW1 of oceanic uptake (in molC/m2) averaged on year 131 to 140. The shaded line correspond to the 99% significant difference (student test)

There is however a small but significant difference in the North Atlantic CO2 uptake

Sensitivity experiments

To dissociate the effect due to **circulation changes** from the one due to **temperature and salinity changes** associated with land-ice melting and THC modifications, we have performed different sensitivity experiments.

Experiences	Description	CO2 uptake
CTL	Control simulation	638.4
GW1	Transient simulation with ice sheet melting	567.9
GW2	Transient simulation without ice sheet melting	571.3
Exp1	Sensitivity experiment similar to GW2 but with GW1 temperature	580.7
Exp2	Sensitivity experiment similar to GW2 but with GW1 salinity	587.3
Exp3	Sensitivity experiment similar to GW2 but with GW1 sea-ice cover	572.4

Table 1: Simulation description and cumulative CO2 uptake ater 140 years in PgC

Changes in the THC have strong **compensating effects**:

- the weakening of the THC is associated with a diminution the circulation that **diminishes the export production** and thus the CO2 uptake
- the diminution of salinity and temperature due to THC weakening and land-ice melting enhance the uptake and **counteract by 89% the circulation and biology effect**

Effect	ΔCO_2 uptake	Ratio /(CTL-GW1)
«All»=GW1-GW2	-3.4	-5.2%
«SST»=Exp1-GW2	+9.4	+14.4%
«SSS»=Exp2-GW2	+16.0	+24.6%
«Sea-ice»=Exp3-GW3	+1.1	+1.7%
«Circu+bio»	-29.9	-45.9%

Table 2.: Effect of changes in SST, SSS, sea-ice cover and circulation+biology due to THC reduction

Redistribution of oceanic CO2 content

- The storage of oceanic carbon follows the global ocean circulation
- The small difference in North Atlantic uptake lead to a small difference in DIC storage
- The weakening of the AMOC limits the depth of CO2 storage

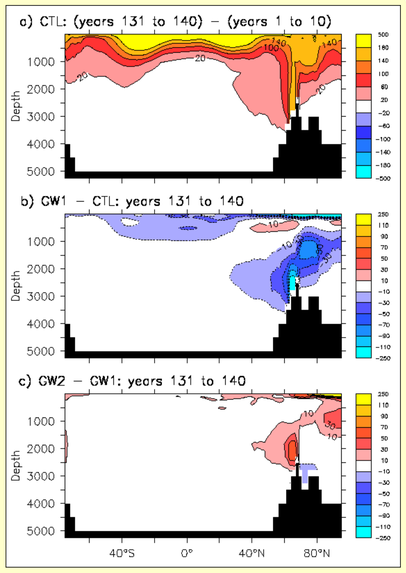

Fig. 3: Zonal mean of anthropogenic DIC for the Atlantic basin (years 131-140). a) CTL, b) GW1-CTL, c) GW2-GW1

Discussions and conclusions

- Global warming in a 4xCO2 experiment limits the carbon uptake by 11% in 140 years
- The effect of the THC is here isolated through the difference between two experiments at 4xCO2 with various THC weakening due to the account of land-ice melting or not
- Globally the effect of land-ice melting and THC weakening is small (-5.2%) because:
  - **Salinity and Temperature relative decrease** associated with land-ice melting and THC weakening **intensifies the CO2 uptake by 25.4 pgC** through surface dissolution improvement
  - **Circulation weakening and modification of biology** through change in export production tend to **decrease the oceanic CO2 upatke by 29.9PgC**
- Locally the difference in CO2 uptake is concentrated in the North Atlantic where a larger DIC storage appears when the THC remains active.

Outlooks

- The small impact of THC weaknening on cumulative CO2 uptake on century time scale can **accumulate on millenium time scale** and lead to a globally significant difference in oceanic carbon storage
- The depth of the storage could modify the time scale of release of this CO2 on millenial time scale **affecting the residence time of carbon in the ocean**

References:

Klepper O and Dehaan BJ. A sensitivity study of the effect of global change on ocean carbon uptake. Tellus 47, 490-500 (1995)

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