# Impact of transient freshwater releases in the Southern Ocean on the AMOC and climate

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## Background and motivations

- There is an intriguing relationship between the reconstructed temperatures in Greenland and Antarctica (Blunier and Brooke 2001 [1]).
- The bipolar ocean seesaw, an image of the balance between the North Atlantic deep Water (NADW) and the Antarctic Bottom Water (AABW), can explain this type of relationship.
- In that picture, a decrease in AABW production leads to an increase in NADW production and conversely (Stocker et al. 1992 [2]).
- Nonetheless, Stouffer et al. (2007 [3]) show, using an ocean-atmosphere GCM, that putting freshwater in the Southern Ocean (SO) decreases the NADW production.

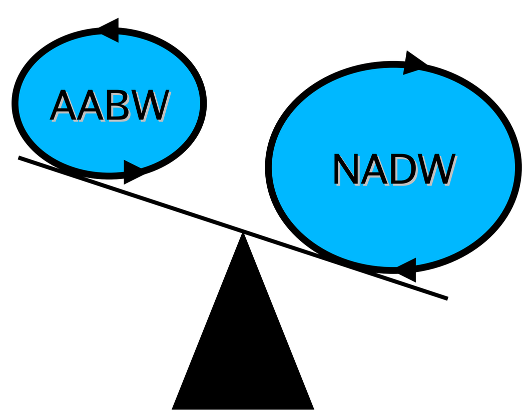


FIGURE 1: Simplified scheme of the concept of the oceanic bipolar seesaw.

**What are the large scale mechanisms excited by a freshwater input in the Southern Ocean?**

## Experimental design

**Tool: LOVECLIM, a climate model of intermediate complexity [4].**
In this study we only need and activate the following components:

- ECBilt: Quasi-geostrophic atmospheric model (prescribed cloudiness; T21, L3).
- CLIO: Ocean general circulation model coupled to a thermodynamic-dynamic sea ice model (3°×3°, L20).
- VECODE: Reduced-form model of the vegetation dynamics.

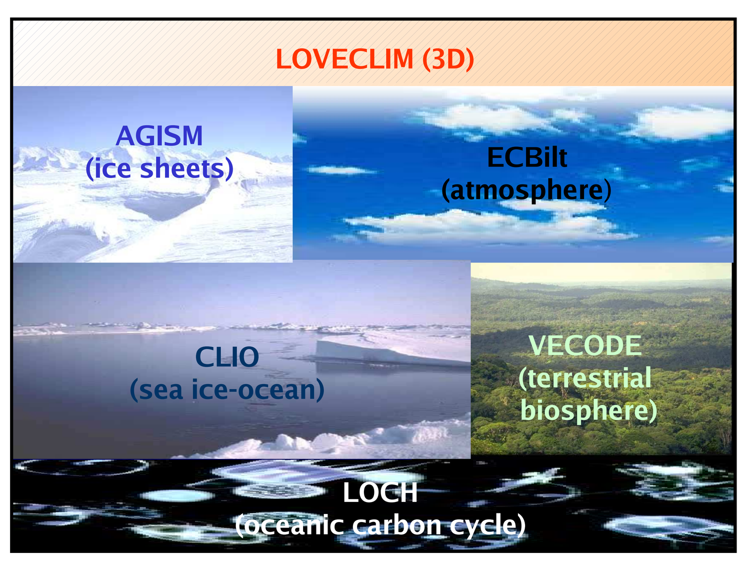


FIGURE 2: Components of the climate model LOVECLIM

**Numerical experiments performed with LOVECLIM [5]:**

| Name of the experiment | Description |
|---|---|
| CTRL | 1500-yr long control simulation under preindustrial conditions. |
| Hos1 | Sensitivity experiments where a 1 Sv freshwater input is added south of 60°S in the SO for 100 years, without any salt compensation in remote areas. |
| HosWind | Same experimental design as Hos1, except that the wind stress computed interactively by the atmospheric model to force the ocean is replaced at each time step by the daily varying values coming from the first 100 years of CTRL experiment. |
| Hos0*i* | Sensitivity experiments where 0.*i* Sv freshwater input is added south of 60°S in the SO ($i \in \mathbb{N}$). The duration of the freshwater input is calculated as $1000/i$ years. |

The total amount of freshwater added is the same in every experiment and equals 100 Sv.yr.

## Oceanic and climatic response in Hos1

In Hos1, by the end of the freshwater perturbation:

- The AABW cell is weakened by around 15 Sv.
- The NADW cell is weakened north of 30°N, and is is enhanced south of 30°N.
- The freshwater input in the southern Ocean cools the Southern Hemisphere (SH) which enhances the zonal wind around the Drake Passage.

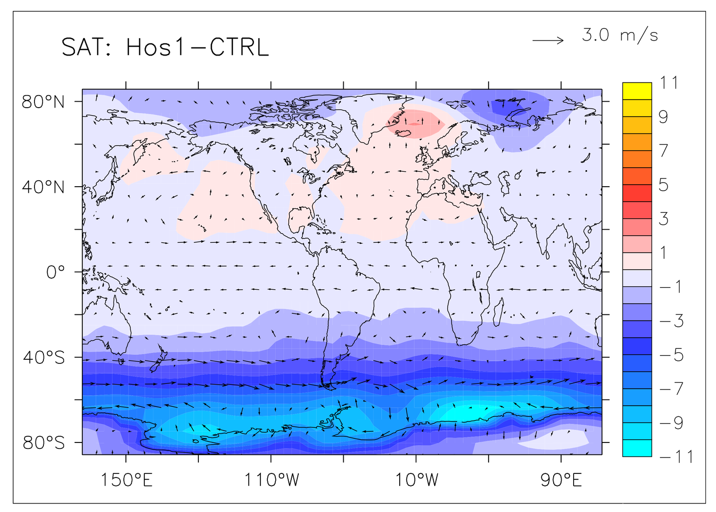


FIGURE 3: Difference in Surface Air Temperature (SAT) averaged over the last 20 years of the experiments Hos1 and CTRL. The wind speed (in m/s) differences are also represented in overlay.

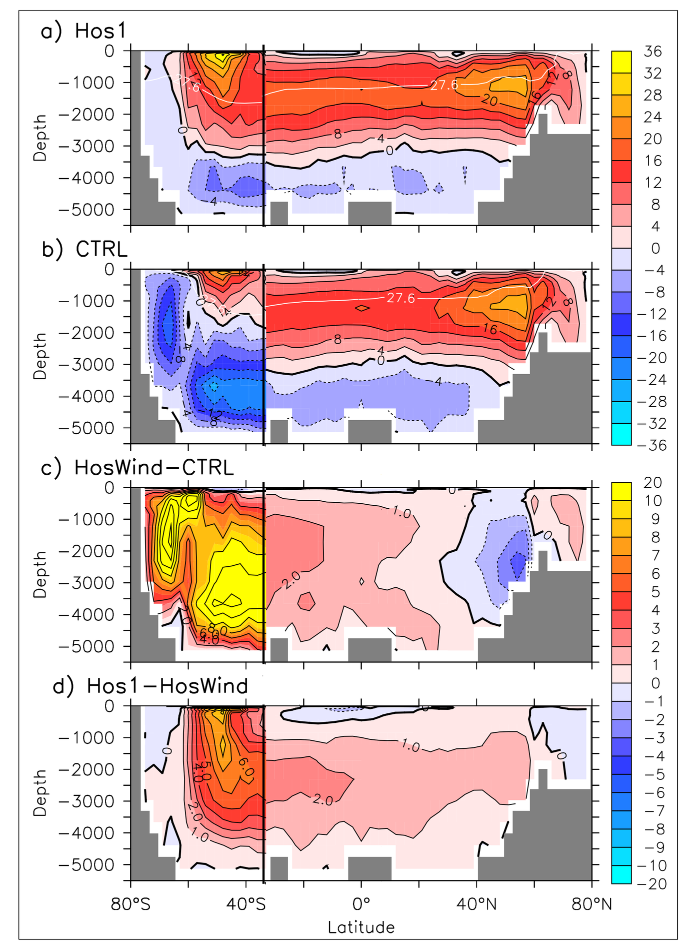


FIGURE 4: Latitude-depth section of the meridional overturning streamfunction in the Atlantic Ocean and in the Southern Ocean. Are represented the first 100-yr annual mean time average from a) Hos1 and b) CTRL; c) HosWind- CTRL and d) Hos1-HosWind. The 27.6 $kg/m^3$ isopycnal is superimposed in white.

## Amplitude and time scale of the mechanisms excited

Three main processes are excited and affect the NADW cell:

1. deep water adjustment;
2. salinity anomalies propagation;
3. southern wind increase.

The adjustment due to these processes is very fast (years to decades)

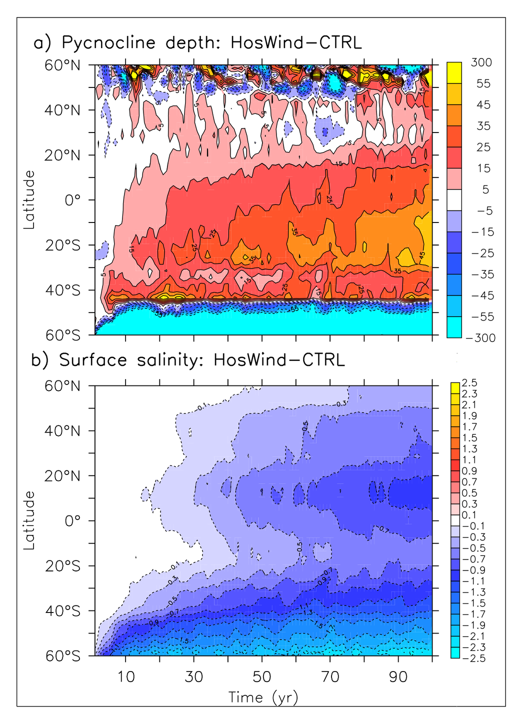


FIGURE 5: HosWind-CTRL averaged zonally in the Atlantic for a) the pycnocline depth (m); b) SSS (PSU).

To quantify the effect of these processes, we use the water mass "binning" diagnosis:

$$\Psi^{Atl} = -\partial_t \mathcal{V}^N + \mathcal{F}^N + \mathcal{D}^N \quad (1)$$

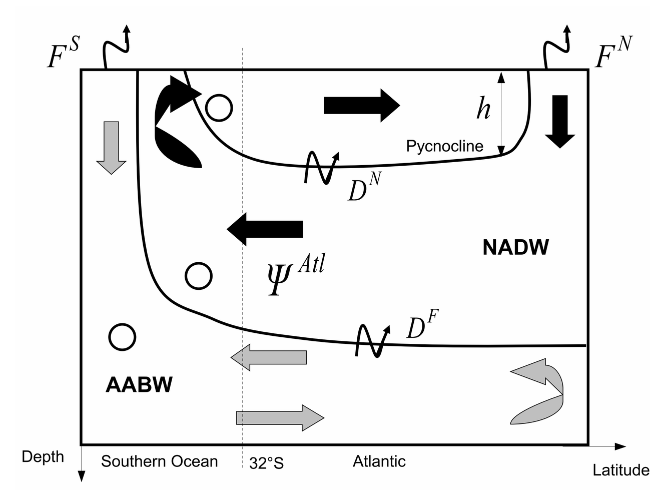


FIGURE 6: Schematic view of a zonal mean of the Atlantic and Southern Oceans.

**"Binning" in the Atlantic** ($\sigma_0 > 27.6 kg/m^3$, in Sv):

| | $\Psi^{Atl}$ | $-\partial_t \mathcal{V}^N$ | $\mathcal{F}^N$ | $\mathcal{D}^N$ |
|---|---|---|---|---|
| CTRL | 14.6 | 0.6 | 22.3 | -8.6 |
| HosWind-CTRL | 2.4 | 4.1 | -2.6 | 0.9 |
| Hos1-HosWind | 1.3 | -0.1 | 1.3 | 0.1 |

## Phase space diagram

- The AABW cell weakens linearly with freshwater perturbation duration (called $\tau$ hereafter).
- The NADW cell export increases as a logarithm with $\tau$.
- The NADW cell maximum decreases as a logarithm with $\tau$.

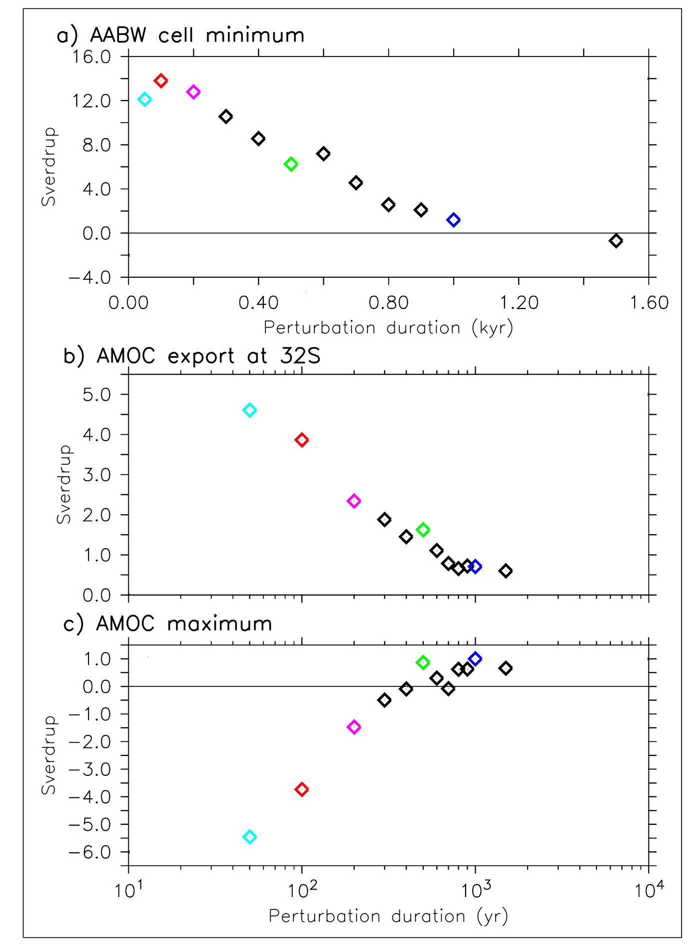


FIGURE 7: Diagram of different ocean circulation index differences with 100-yr average of CTRL (in Sv) against the freshwater perturbation duration.

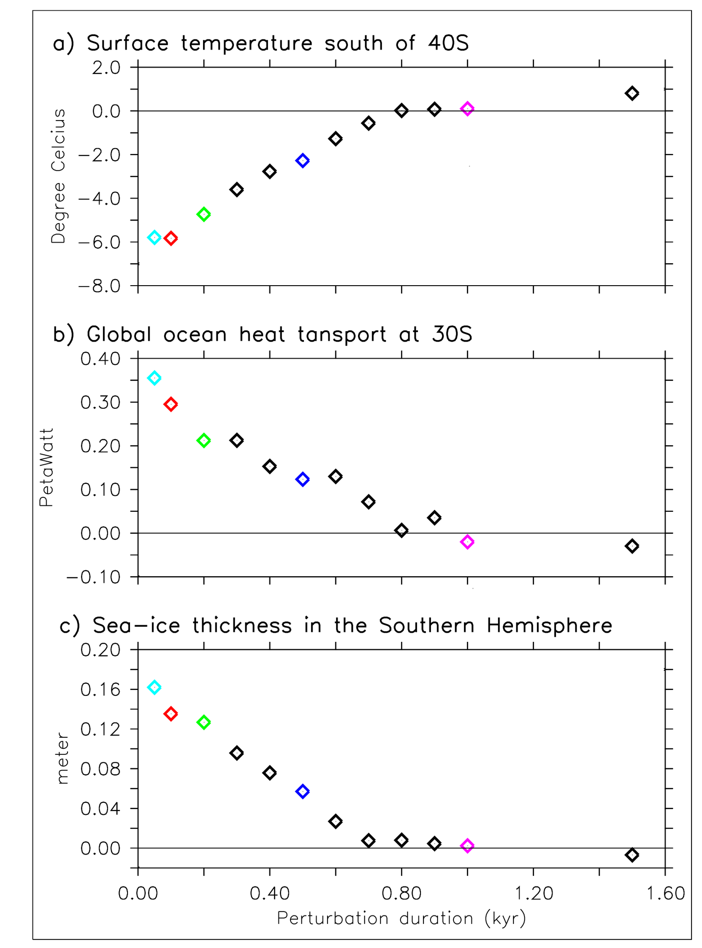


FIGURE 8: Diagram of different climate index differences against the freshwater perturbation duration.

- The cooling south of 40°S diminishes linearly with $\tau$.
- This behavior is associated with a decrease both in the Southern Hemisphere sea-ice cover and in the southward oceanic heat transport.

## Conclusions

Three main processes affect the Atlantic Meridional Overturning Circulation (AMOC) response to a SO freshwater input:

1. The deep water adjustment tends to enhance the NADW cell through the pycnocline deepening in the Atlantic in response to the AABW production decrease.
2. The spread of salinity anomalies from the SO up to the North Atlantic (NA) weakens the AMOC because it decreases the NADW production in the NA convection sites.
3. The SH wind increase, in response to the cooling in the SH that increases the SH meridional SAT gradient, tends to enhance the AMOC, through the "Drake Passage effect" [6].

As a result of the influence of these different processes, for freshwater input rate in the Southern Ocean larger (lower) than 0.2 Sv the AMOC is weakened (enhanced).

**The "hosing" rate in the Southern Ocean strongly influences the AMOC response**

### References

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