Investigation of the Impact of a Heinrich-Event-like Abrupt Event Superimposed Onto the RCP 8.5 Scenario

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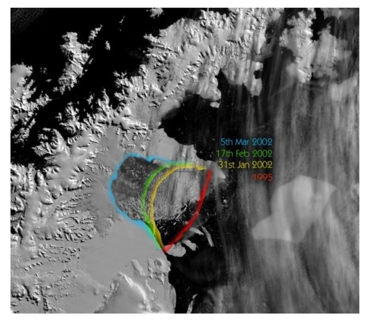
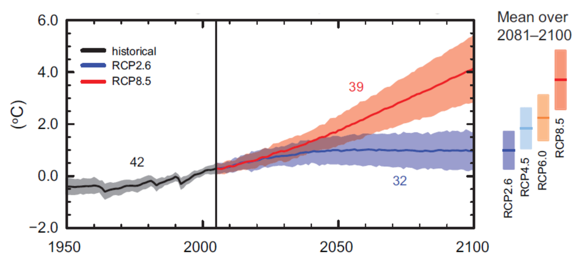
1/ Context

- Recent collapse of the Larsen B ice-shelf illustrates that a non-linear response of the cryosphere may occur in a warming world[1,2].
- In glacial periods, ice sheets have been unstable: huge surges of icebergs occurred and deeply modified the climate: Asian monsoon, drought in Sahara[3,4].
- The CMIP5/IPCC (AR5) projections of climate change showed that the temperatures should increase by 1.3 °C to 4.4 °C by 2100 according to the different scenarios[5].



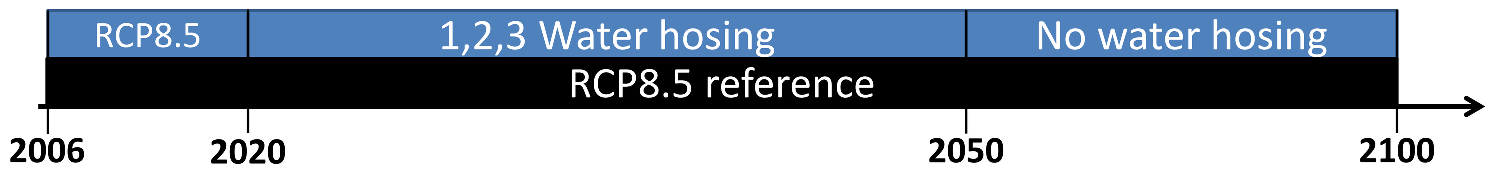
Collapse of the Larsen B ice-shelf[1].



Temperature evolution for RCP2.6 and RCP 8.5 scenario [5].

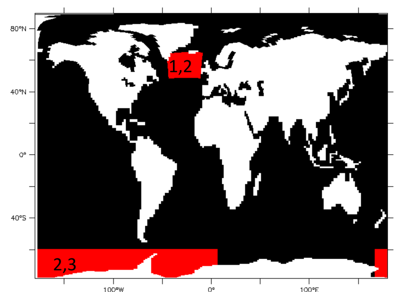
Goal of this study : Investigate for the first time the climatic effects of an abrupt ice sheet surge superimposed onto the RCP 8.5 scenario.

2/ Experimental setup



Experiment design

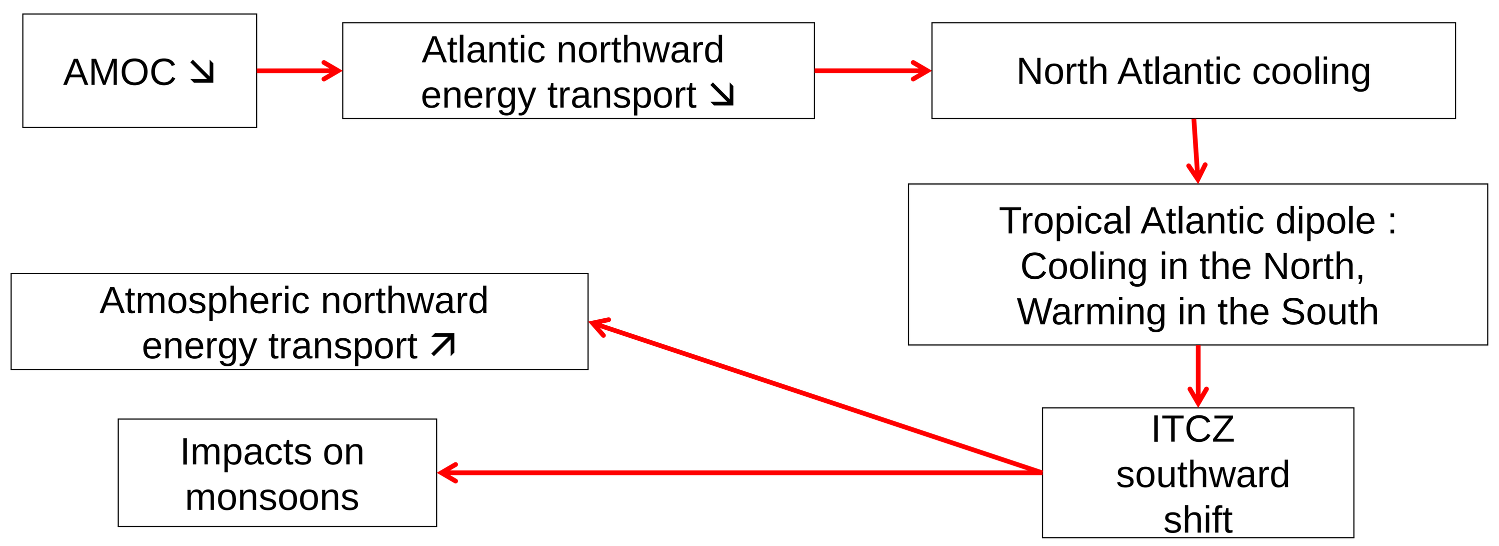
- Using an atmosphere-ocean general circulation model (OAGCM) : IPSL-CM5A-LR [6]
- RCP 8.5 IPPC reference scenario
- Freshwater input of 0.68 Sv (10^6 m^3/s) during 50 years (Water hosing), corresponding to a sealevel rise of 3 meters.
- 30 years without water until 2100.
- 3 scenarios with 3 different freshwater locations (in figure)
- 1 corresponds to a contribution from Greenland only;
- 2 from both ice sheets ;
- 3 from West-Antarctica only;

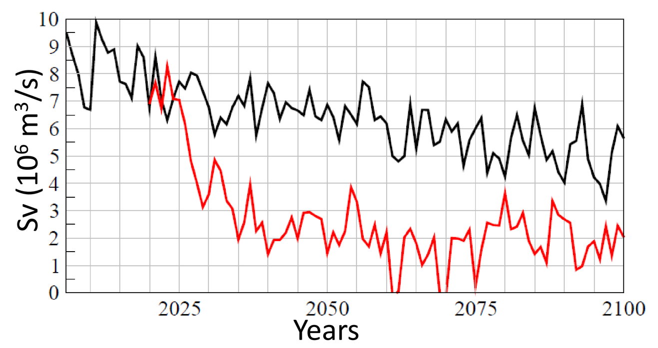


Freshwater locations (red)

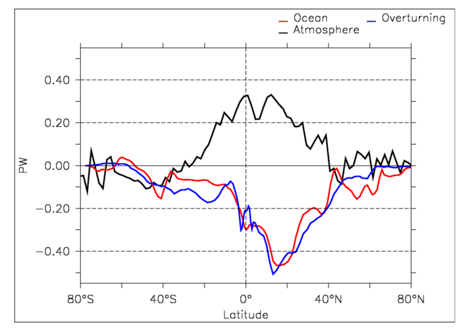
4/ Mechanisms: illustration for Greenland experiment

Heat transport





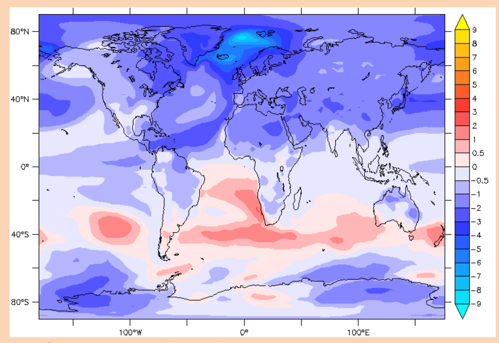
NADW @30N. Black = RCP 8.5, Red = Greenland



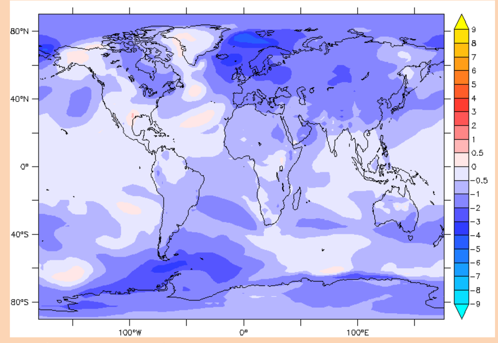
Difference of heat transport between Greenland experiment and RCP 8.5 (annual mean: 2036-2040)

3-1/ Annual temperature between scenarios and RCP8.5

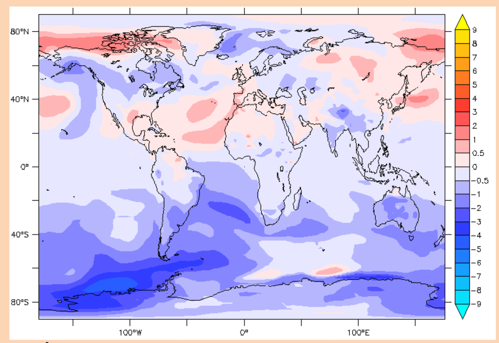
Situation in 2045- 2049



1) Greenland scenario



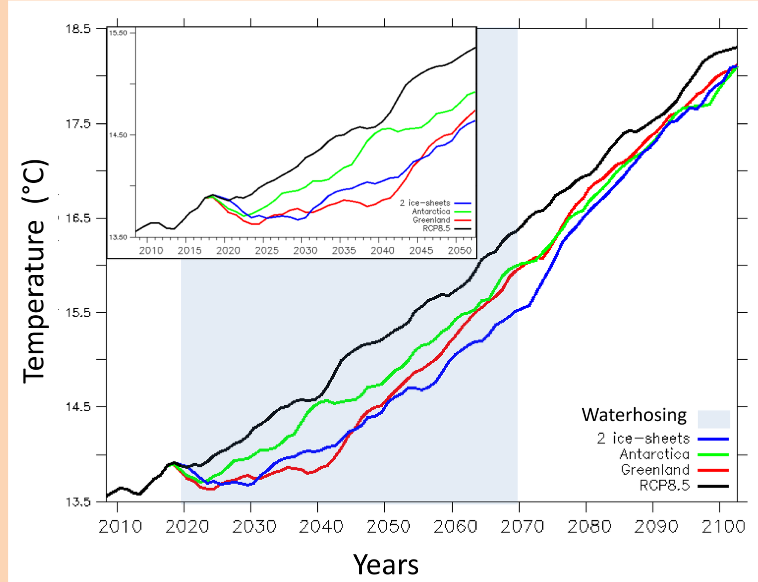
2) 2 ice-sheet scenario



3) Antarctica scenario

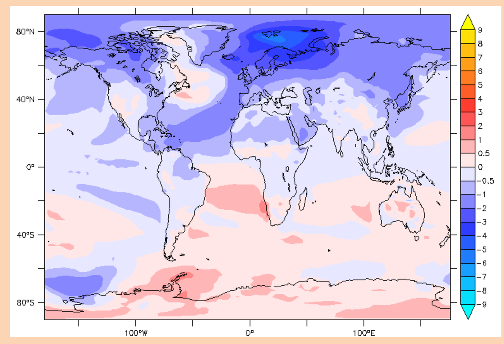
For 1, 2, 3:
Red: RCP85 < scenario
Blue: RCP85 > scenario

Global temperature (running mean: 5 year) during the 21st century

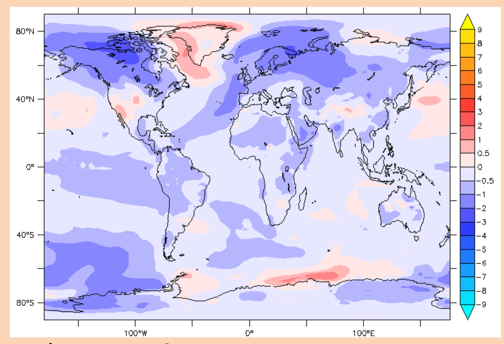


- Globally, for the three scenarios, there is a rapid damping of the temperature increase during the water hosing **BUT** at the end of the simulation, all scenarios have the same average temperature.
- For the Greenland experiment (1) the temperature decrease is the highest during the freshwater input. A dipole appears: the northern hemisphere is cooler than with the RCP8.5 scenario (-6°C) and the southern hemisphere is warmer (2°C). In 2100 the difference are reduced but are still visible.
- For the Antarctica scenario (3) the response is less pronounced but a dipole is present with a cooler southern hemisphere and a warmer northern hemisphere until 2100.

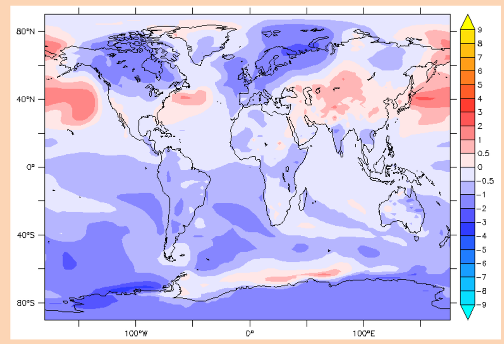
Situation in 2095- 2099



1) Greenland scenario



2) 2 ice-sheet scenario

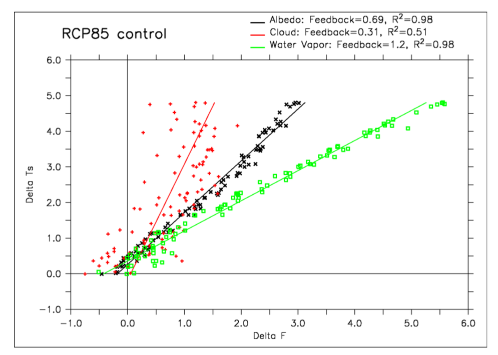


3) Antarctica scenario

For 1, 2, 3:
Red: RCP85 < scenario
Blue: RCP85 > scenario

Radiative Balance

The permanent damping of the AMOC causes a new heat partial redistribution by the atmosphere (Bjerknes) and some feedbacks on the climate. To show the impact of the freshwater on the feedback mechanisms, we define the relation between the radiative balance and the temperature difference with the pre-industrial climate. For each experiment and the RCP 8.5 scenario, three feedbacks are arbitrarily defined : the « albedo clear sky » calculated by the radiative net balance (eq 1) linked with the surface albedo; the « water vapor » increasing in the atmosphere with the temperature increase (Clausius-Clapeyron) and in response to the increase the greenhouse gases concentration (eq 2) ; and the « cloud effect » defined by the cloudiness variation which influences albedo (low-level cloud) and the greenhouse effect (high-level cloud) (eq 3). The figure RCP85 control gives the R2 and the importance of the feedback on the IPSL-CM5A-LR model.



$$\lambda_1 = \frac{\Delta SW_0}{\Delta T_s} \quad \text{(Eq 1)}$$

$$\lambda_2 = \frac{4\sigma T_e{}^3 \Delta T_s - \Delta LW_0 - \Delta Q}{\Delta T_s} \quad \text{(Eq 2)}$$

$$\lambda_3 = \frac{\Delta N - \Delta N_0}{\Delta T_s} \quad \text{(Eq 3)}$$

λ = feedback factor, Δ is the difference between RCP8.5 or Greenland scenario and the pre-industrial data. T_s = ground temperature, Q = radiative forcing, N = radiative balance at the atmosphere top, N_0 = radiative balance with clear sky at the atmosphere top, SW_0 = clear sky short wave, LW_0 = clear sky long wave, T_e = 253.9K

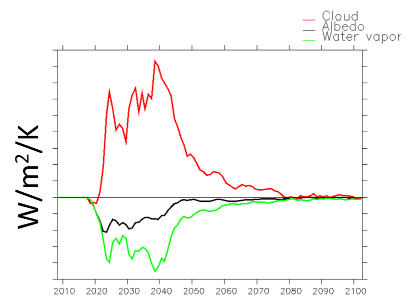


Fig a: Feedback factor ($\lambda_{1,2,3}$)

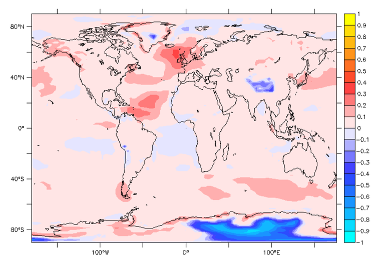


Fig b: Low-level cloudness: Greenland – RCP 8.5

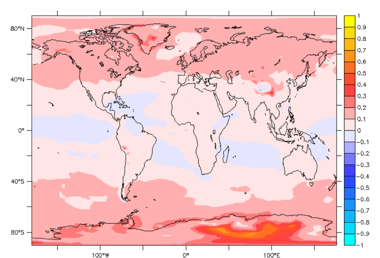


Fig c: Medium-level cloudness: Greenland – RCP 8.5

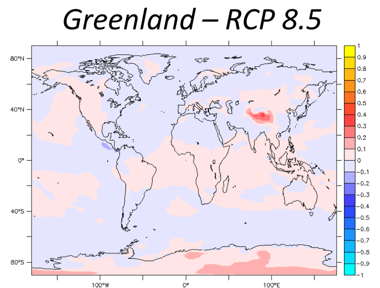


Fig d: High-level cloudness: Greenland – RCP 8.5

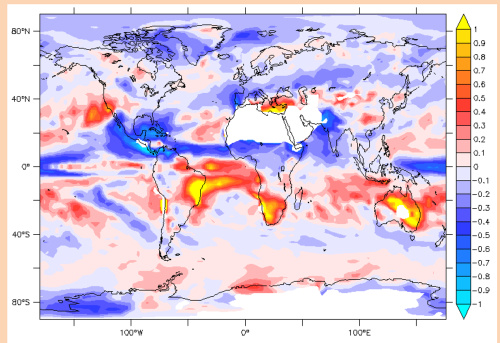
The comparaison between Greenland and the RCP8.5 scenario show that the water hosing changes the feedback factors (λ 1,2,3). The main difference is for the cloud feedback (red on figure a). The analysis (Greenland – RCP8.5) of the cloudiness type exhibits that the low-level clouds (fig b) are more abundant in the North Atlantic and the medium-level clouds (fig c) in Antarctica. They promote the albedo feedback and are responsible for the temporarily temperature decrease. The high-level clouds (fig d) vary little.

3-2/ Annual precipitation between scenarios and RCP8.5

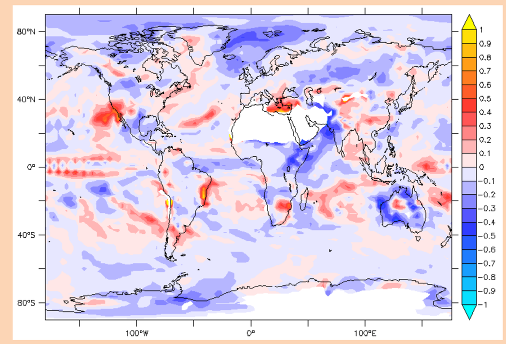
The freswater perturbations change the areal precipitation with an ITCZ shift. There are impacts on the monsoon cycle but also in North America and Europe. For the maximum difference between experiments and RCP8.5 scenario (in 2045-2049), we have:

1) an southward ITCZ shift (Greenland);
2) No shift (2 ice sheets);
3) A northward ITCZ shift (Antarctica).

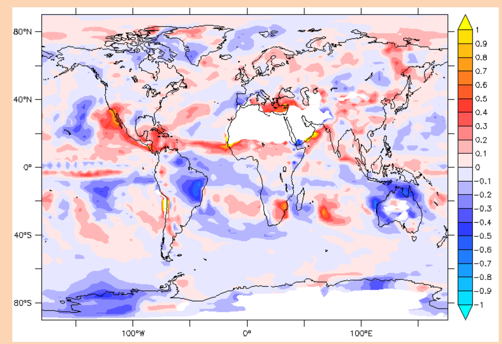
Situation in 2045- 2049



1) Greenland scenario



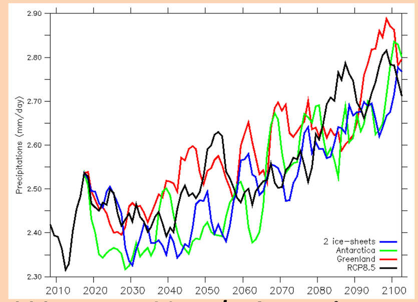
2) 2 ice-sheet scenario



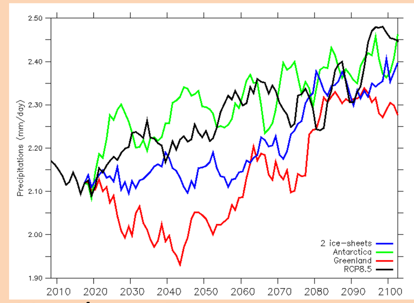
3) Antarctica scenario

Red/yellow: RCP85 < perturbation: 1 = doubled precipitation ; Blue/cyan: RCP85 > Perturbation: -1 = no more precipitation ; White: precipitation < 0.2 mm/day

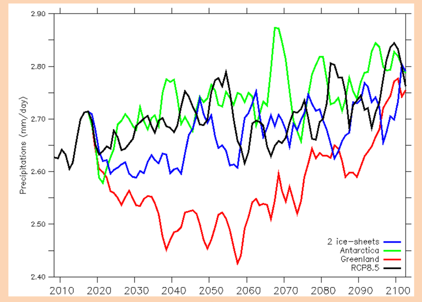
America | Europe



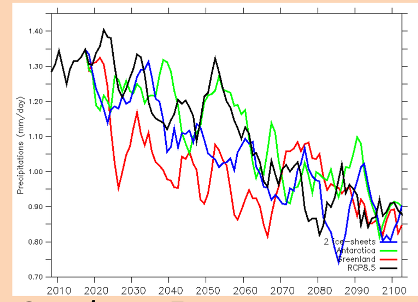
Western North America



Northern Europe



Eastern North America

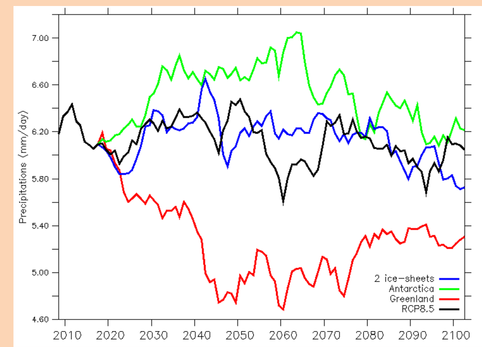


Southern Europe

- In the Western North America there is little difference about the annual precipitation between the 3 water hosing scenarios and the RCP8.5.
- In the Eastern North America, during the freshwater introduction in the Greenland area (red and blue scenarios), the precipitation decrease. At the end of the simulation there is no difference.
- In Europe, both northern and southern parts are impacted by the input of freswater from Greenland (red and blue). The precipitation decrease with respect to the RCP 8.5 scenario during the water hosing.

3-3/ West-African Monsoon (JJAS)

If the West-African monsoon is slightly weakened with the RCP8.5 scenario, it is involved by the different perturbations because of the ITCZ shift. For the Greenland experiment (red), the JJAS precipitation remain about 30% and is lower than in the RCP8.5 scenario (black) until 2100. For Antarctica experiment the total precipitation increase by 10-20%. For the 2 ice-sheet experiment the results are similar to those of RCP 8.5 scenario.



JJAS precipitation (running 5-year mean) in West-Africa (20W:15E, 4N-15N)

5/ Conclusion of water hosing experiment

- **Zonal differences in relation with the water hosing location**
- **Greater effects with Greenland scenario**
- **Short term consequences: radiative balance**
  - **Strong effects only during the water hosing (2020 – 2070)**
  - **Hemisphere with freshwater cooler than the RCP8.5 scenario**
  - **Other hemisphere warmer**
- **Long term consequences: heat transport**
  - **NADW damping permanently**
  - **Change in heat transport ocean/atmospheric**
  - **ITCZ shifts**
  - **Precipitation of West-African monsoon decrease**

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