Emergence of North Atlantic Deep Water during the Cenozoic: A Tale of Geological and Climatic Forcings

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CONTEXT

- The **Cenozoic era** saw substantial shifts in global ocean circulation, including the initiation of the **Atlantic Meridional Overturning Circulation** (**AMOC**).
- There is no agreement on the **timing** of the **initiation** of **AMOC**, nor on the specific **processes** that **instigated** this circulation.
- This study aims to **analyze** how **ocean circulation responds** to **atmospheric** and **geological influences**, with the goal of **understanding** the **mechanisms** underlying the **destabilization** of the **North Atlantic water column**.

METHODOLOGY

Global Climate Model : IPSLCM5A2 [3] is composed by the LMDZ atmospheric model with 96 x 96 horizontal (longitude/latitude) and 39 vertical layers, NEMOv3.6 oceanic model with 182 x 149 horizontal and 31 vertical layers, PISCES biochemical model and ORCHIDE land surface model.

Simulations [2, 4] :

Name	Epoch	pCO_2 (ppm)	Antarctic Ice Sheet
40Ma_4X	40 Ma	1,120	No
40Ma_2X_ICE	40 Ma	1,120	Yes
20Ma_Tet120	20 Ma	560	Yes

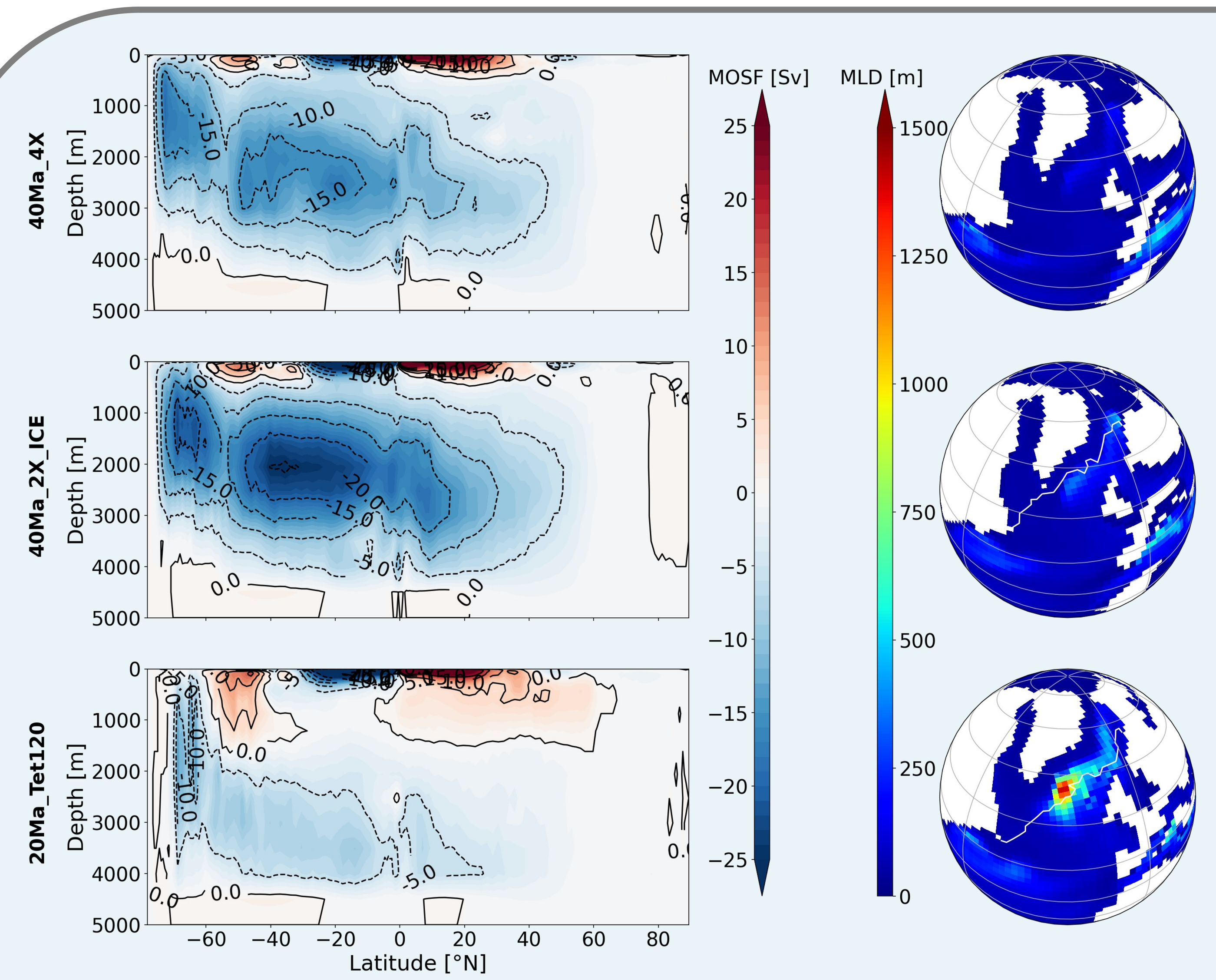

Figure 1: Global meridional overturning stream function averaged over the year (left), the maximum of the mixed layer depth during the winter for the "40Ma_4X" (top), "40Ma_2X_ICE" (middle) and the "20Ma_Tet120" (bottom) simulations. The white lines represent the maximum of sea ice extent.

- During the Eocene epoch, conditions inhibited deep convection in the Northern Hemisphere. Consequently, the global ocean circulation was regulated by a solitary counterclockwise cell, primarily propelled by the formation of deep water in the Southern Ocean (Fig. 1).
- In our Miocene simulation, North Atlantic Deep Water formation begins, reaching depths of 1,500 meters near Southeast Greenland (Fig. 1). This leads to a shift in global circulation to a bipolar mode, where the Southern Ocean cell is overlaid with the AMOC cell.

How can we explain these differences of global ocean circulations between Eocene and Miocene ?

RESULTS

Oceanic dynamics

Eocene:

- Weak subpolar and subtropical gyres, slight strenghtening observed upon halving pCO2 levels.
- Robust eastward current transports water to the Pacific through the Central American Seaway (CAS) (Fig. 2).

Miocene:

- Strong subpolar and subtropical gyres.
- The constrained CAS at 20 Ma restricts the leakage of water into the Pacific Ocean (Fig 2).

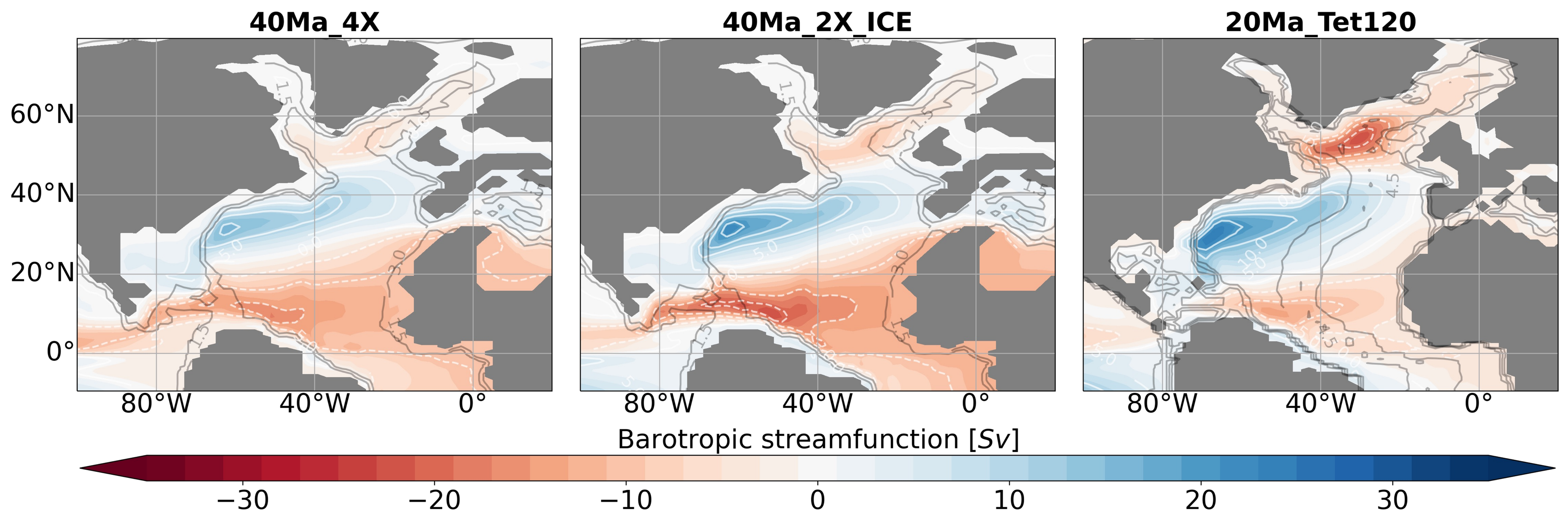

Figure 2: Barotropic streamfunction of the North Atlantic for the "40Ma_4X", "40Ma_2X_ICE" and "20Ma_Tet120" simulations are expressed in Sv and are average annually for the last 100 years. The white (black) lines correspond to the isolines of the barotropic streamfunction (bathymetry), the step is 5 Sv (1.5 km).

Atmospheric dynamics

Eocene:

- Vigorous African monsoon → intense precipitation over the central-West Africa and the Gulf of Guinea → all the freshwater flows into the Atlantic Ocean (Fig 3).

Miocene:

- Dimished African monsoon → maximum of precipitation over the Central-East Africa → A notable portion of freshwater flowing into the Indian Ocean (Fig. 3).

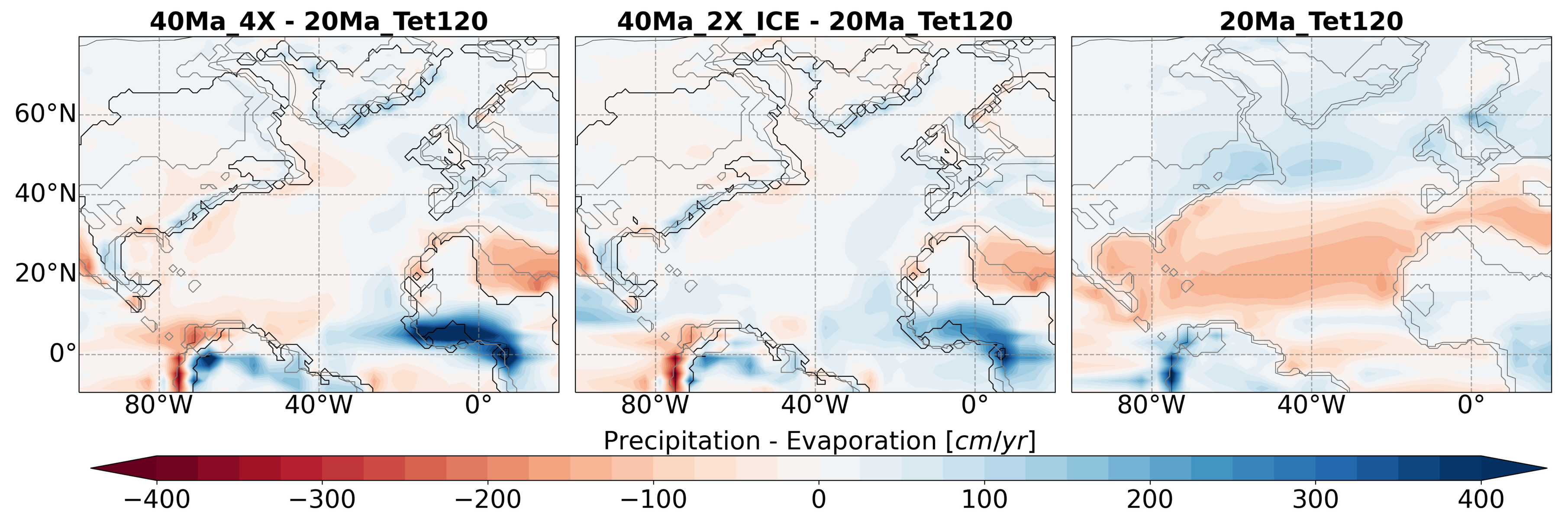

Figure 3: Hydrological cycle, precipitation minus evaporation for the "20M_Tet120" (right) and P-E anomalies between "40Ma_4X" and "20M_Tet120" (left), and between "40Ma_2X_ICE" and "20M_Tet120" (center) expressed in cm/yr.

CONCLUSION

- The **vigorous subpolar gyre** at **20 Ma uplifts isopycnals** and **reduces** the **local stratification** [1].
- The increase of exchanges between the supolar and subtropical gyres results in an **increase** of the **sea surface salinity** and consequently the **sea surface density** in the **North Atlantic Ocean** at **20 Ma**.
- **North** and **Tropical Atlantic** basins experience **reduced freshwater input** at **20 Ma**, resulting in a **saltier North Atlantic basin**.

During the **Eocene,** the **stability** of the **North Atlantic** appears unaffected by the **global cooling**, indicating that the **paleography** of this period **prevent deep convection** to occur into the North Atlantic through **oceanic** and **atmospheric processes**.

References

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