Interhemispheric climate variability: A bipolar see-saw?

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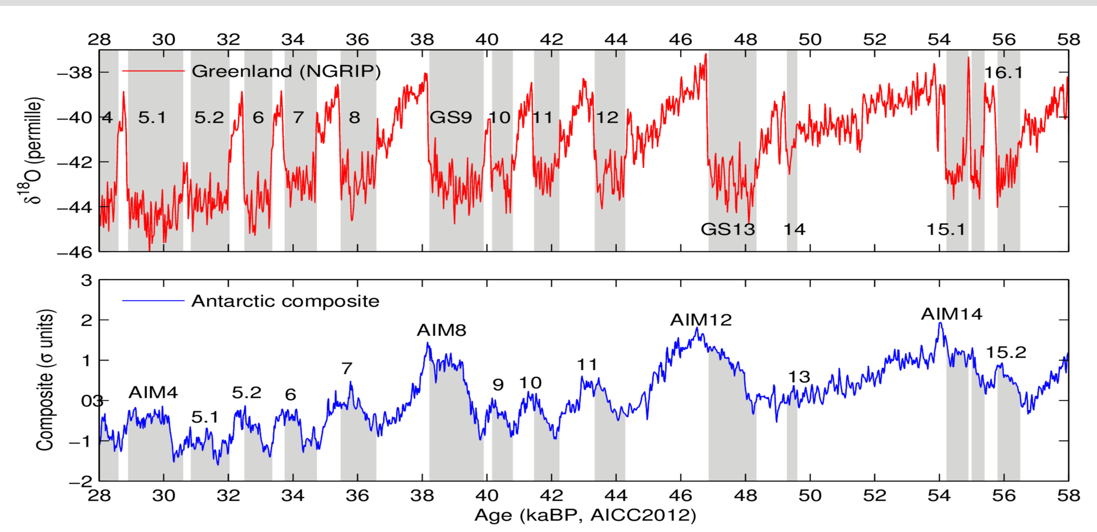
Motivation

Climate reconstructions from ice core records in Greenland have revealed a series of abrupt climate transitions during the last glacial period known as D-O events. In Antarctica, ice core records have shown a similar but opposite signal called AIM events, thus illustrating a distinct relationship between the northern and southern hemisphere during glacial times.
It is generally believed that changes in the AMOC are responsible for this interhemispheric connection, but the dynamics of this **bipolar see-saw** are still heavily debated.



The bipolar see-saw Composite of Antarctic temperature proxies compared with Greenland δ18O from NGRIP. [Pedro et al., in review]

Abrupt climate transitions in an unforced climate model

In a pre-industrial control simulation of CCSM4, a series of spontaneous and **unforced** climate transitions in the North Atlantic is found. In the 1000-year long integration we identify two different phases of North Atlantic climate mimicing the stadial-interstadial transitions during the last glacial.

We pursue two hypotheses to explain the north-south climate coupling and the connection between D-O and AIM events

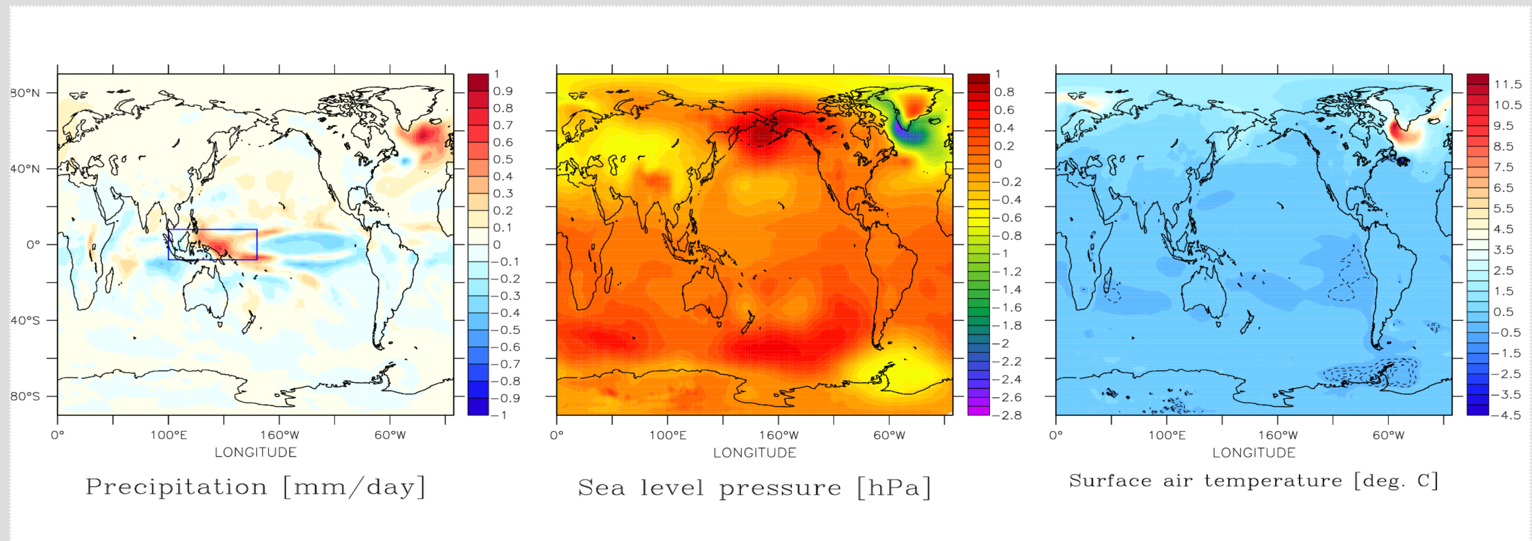
1) D-O and AIM events are correlated because they are both triggered by precipitation events in the tropics
2) D-O events cause AIM events through the **bipolar ocean see-saw**

Part I: An atmospheric teleconnection

1.1 Global atmospheric response to NA warming

The precipitation pattern in the tropical Pacific resembles the signature of a negative ENSO-phase with positive precipitation anomalies centered over the western equatorial Pacific and negative precipitation anomalies over the central and eastern part of the tropical Pacific. Precipitation events, associated with ENSO variability, trigger SLP changes simultaneously in the northern and southern high latitudes. The associated temperature response is characterized by strong warming over the subpolar gyre and weak cooling over the Antarctic Peninsula.

Figure 1.1 - Global atmospheric response in the CCSM4 control run - Precipitation, SLP and temperature anomalies following the abrupt climate transition from a cold to a warm climate.



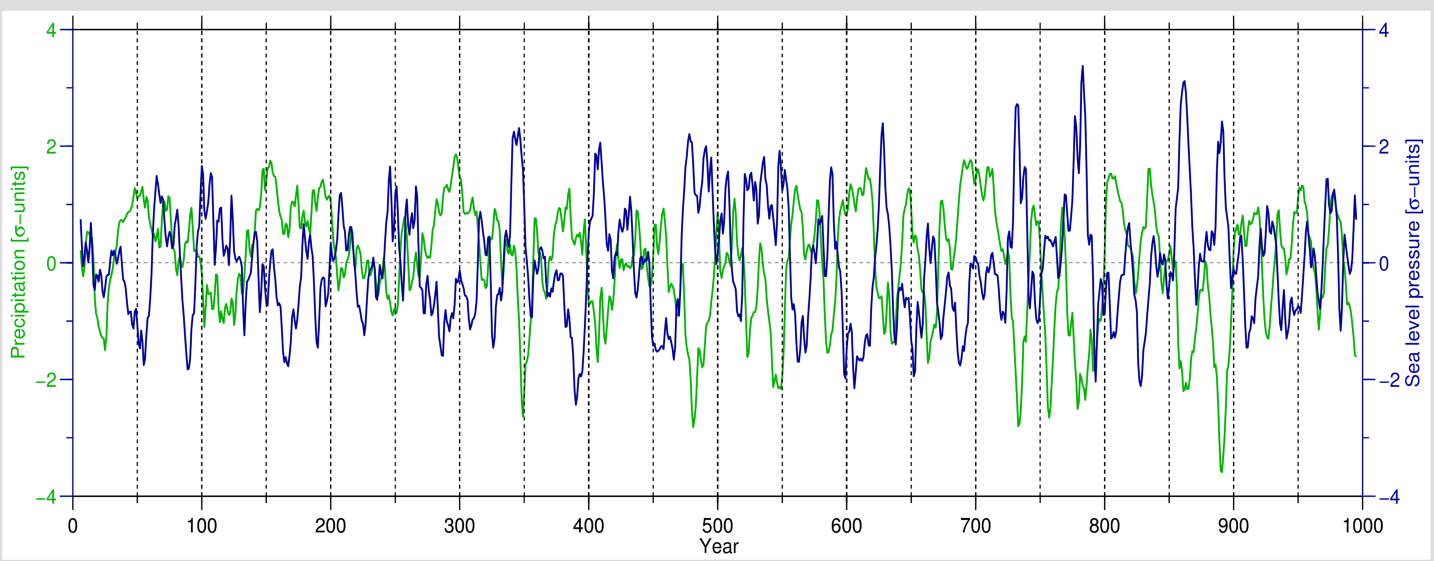


Figure 1.2 – A fast atmospheric teleconnection out-of-phase relationship between precipitation anomalies (green) in the western tropical Pacific and SLP anomalies (blue) averaged over the Antarctic Peninsula.

1.2 Tropical-high latitude teleconnection

Precipitation events in the tropical Pacific trigger SLP anomalies in the southern high latitudes and influence the atmospheric circulation over West Antarctica.
This tropical-polar teleconnection allows for a virtually instantaneous response to tropical forcing and is identified as a wave-like pattern of SLP anomalies extending from the tropical Pacific to West Antarctica. This is indicative of a classic atmospheric **Rossby wave response**. [Trenberth et al., 1998]

1.3 ENSO variability as a potential trigger for Antarctic climate change

Open-ocean deep convection in the Weddell Sea is a key feature of bottom water formation in the Southern Ocean and presents a potential mechanism for the north-south coupling. (Crowley [1992], Broecker [1998])
Deep convection is closely linked to changes in the atmospheric circulation over the Weddell Sea triggered by stochastic climate variability in the tropics. This influences the stratification in the Weddell Sea region, consequently leading to a break-down of the pycnocline. Upwelling of warm sub-surface water facilitates polynya formation which further sustains deep convection.

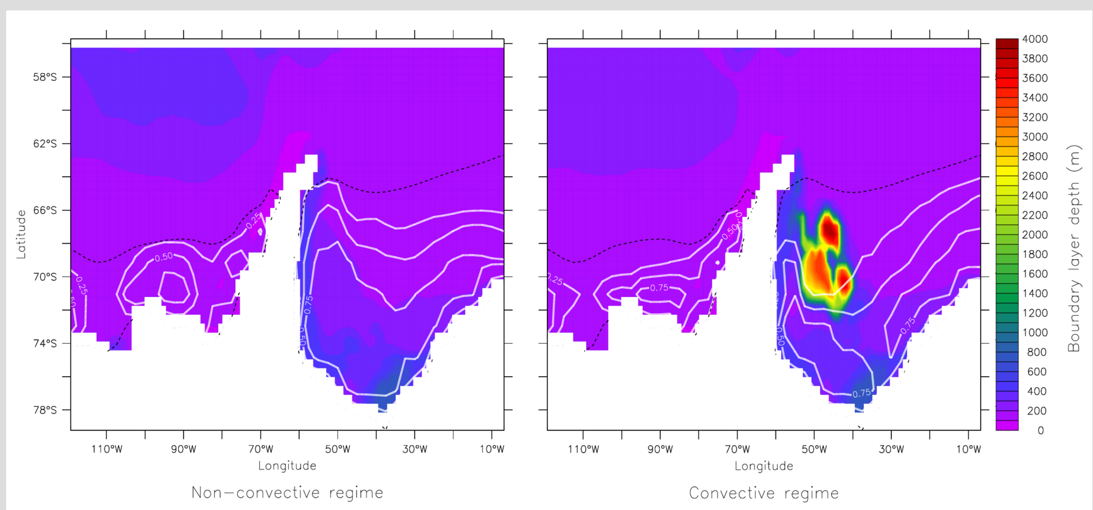
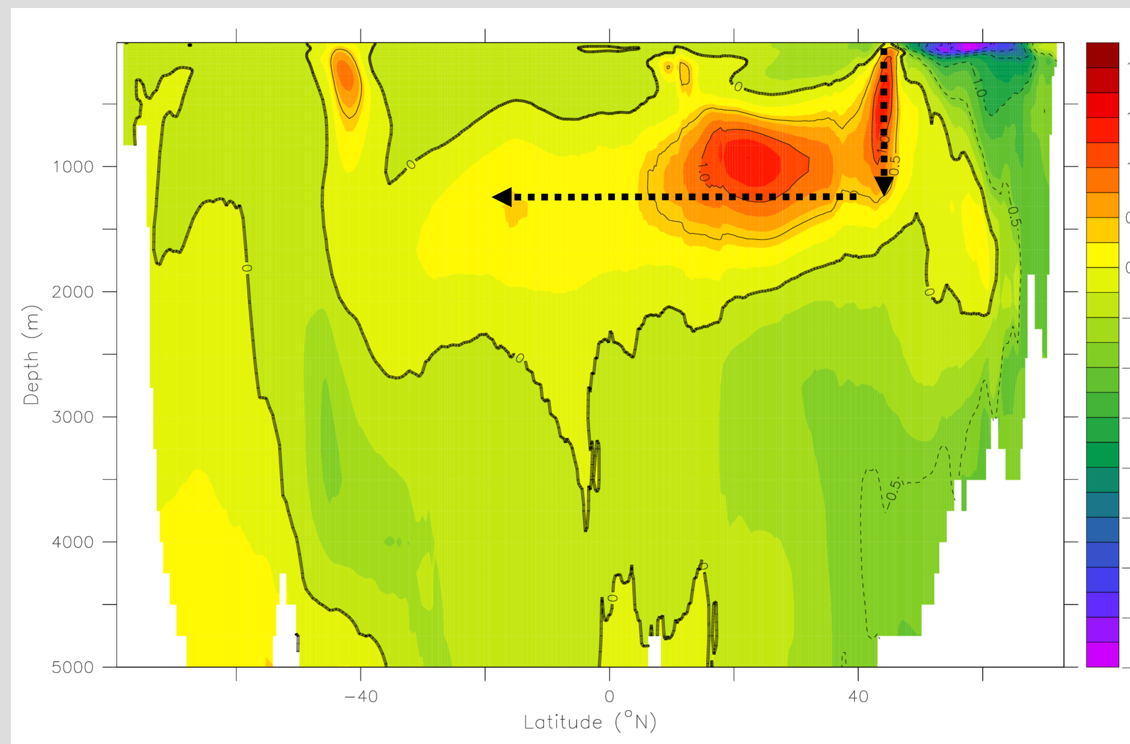


Figure 1.3 – Deep convection in the Weddell Sea Open-ocean deep convection in the Weddell Sea expressed as the maximum mixed layer depth.

Part II: Signal propagation in the Atlantic Ocean

Figure 2.1 - Atlantic temperature anomalies Depth-latitude cross section of the Atlantic Ocean showing warming at mid-depth associated with the North Atlantic cooling event.



2.1 Ocean circulation response to North Atlantic cooling

The mid-depth warming anomaly is caused by a slowdown of the subpolar gyre circulation due to a persistent atmospheric circulation anomaly causing a strong surface cooling in the North Atlantic and weakening of the AMOC.
Consequently, there is a build-up of heat in the subtropical gyre, which spreads throughout the subtropics and into the South Atlantic.

Southward propagation of the warming signal is confined to the deep western boundary current and characterized by slow advective time-scales. After ~45 years the anomaly reaches 20˚S where the magnitude of the signal is significantly reduced.

Further southward propagation is inhibited by the presence of the Antarctic Circumpolar Current (**ACC**), suggesting that the Southern Ocean is a limiting factor in setting the time-scale of the bipolar see-saw response.

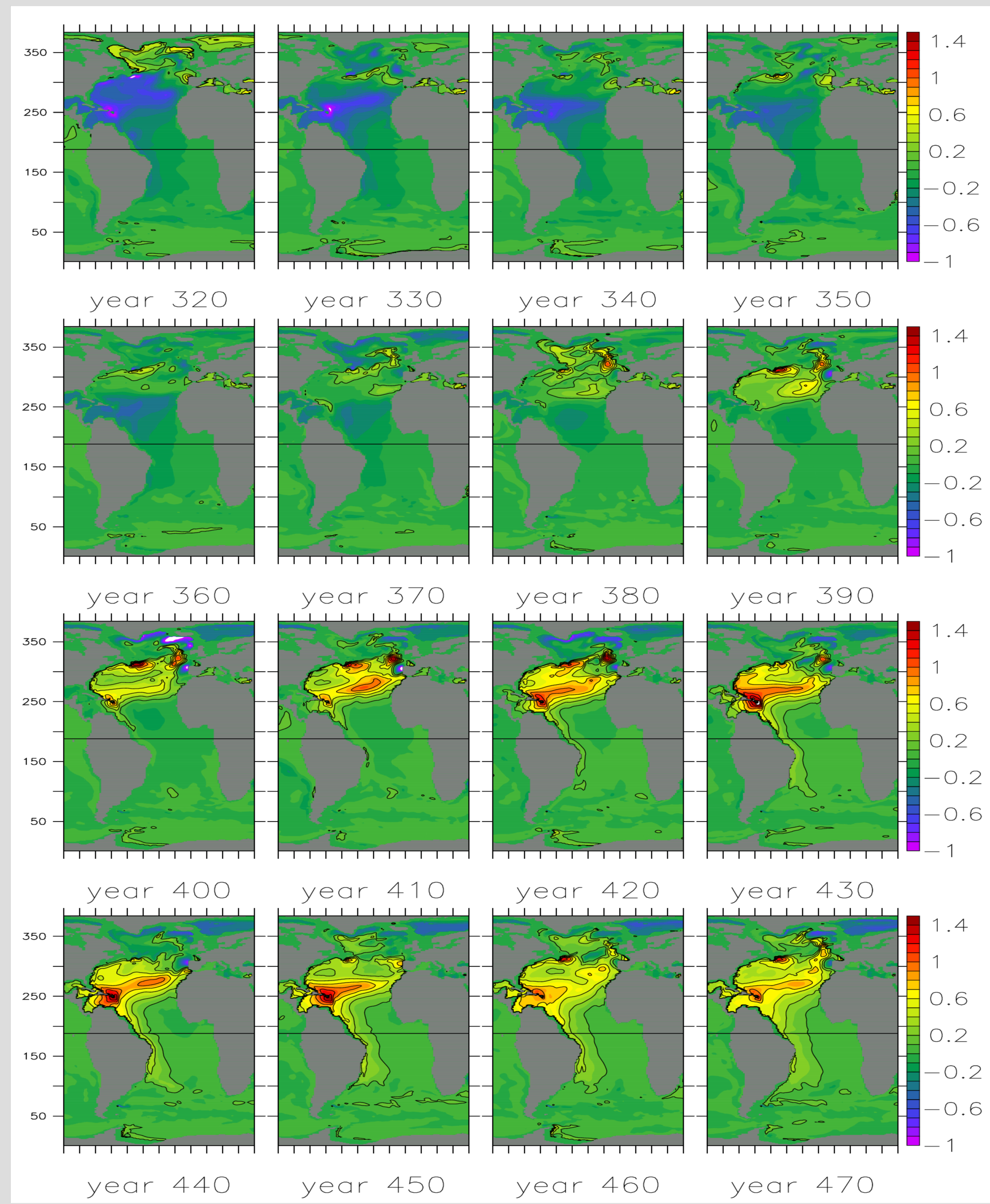
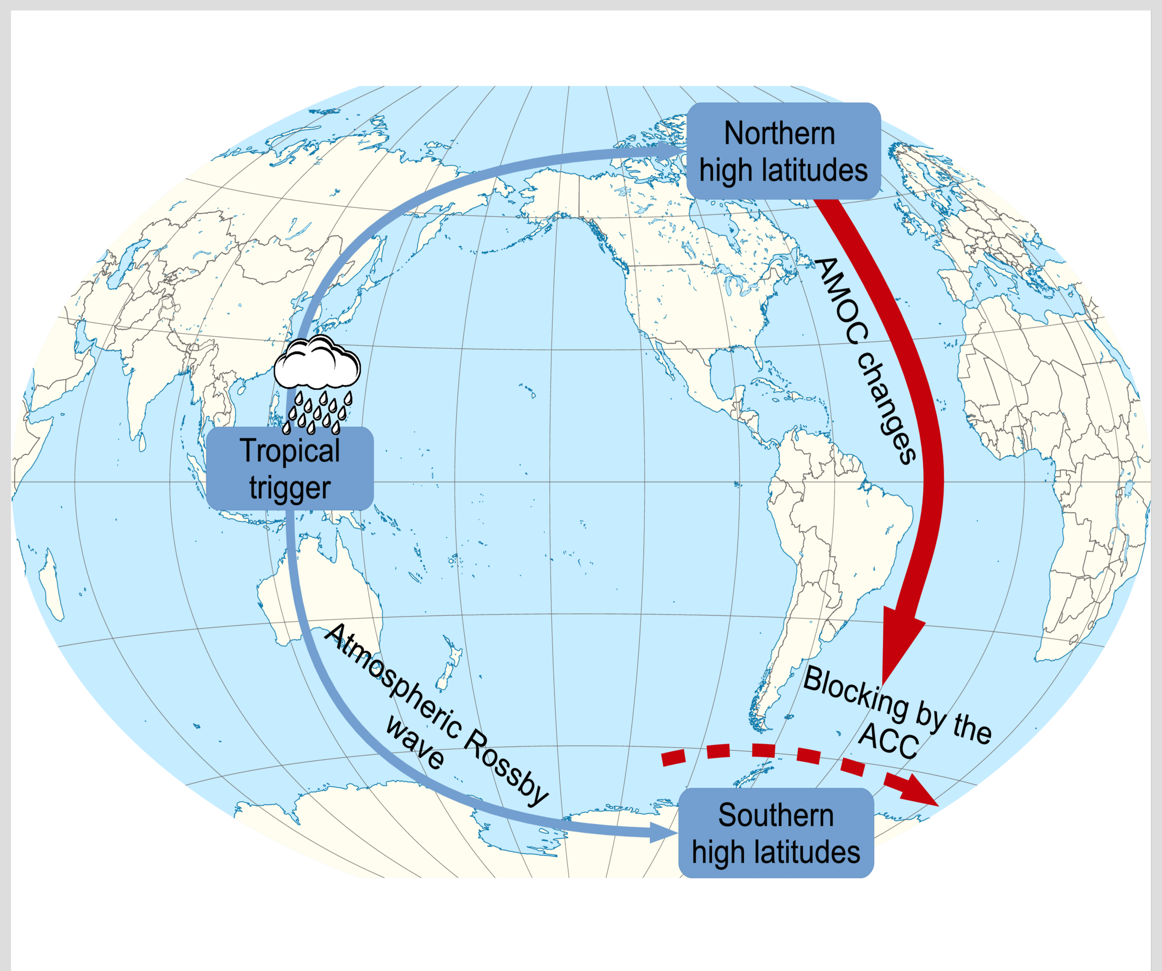


Figure 2.2 - Propagation of warming anomaly at mid-depth A cross-section of the Atlantic Ocean at 1,000 m depth showing the southward propagation of a warming anomaly associated with a strong surface cooling in the northern North Atlantic and weakened subpolar gyre circulation. The timescales suggest an advective process rather than the much faster wave adjustment processes.

Conclusions



Part I

- Both northern and southern high latitudes are triggered by stochastic precipitation anomalies in the tropics through atmospheric **Rossby waves**
- The tropical-polar teleconnection provides a trigger mechanism for deep convection in the Weddell Sea – and could potentially drive long term climate variability

Part II

- Mid-depth warming in the subtropical Atlantic is a response to North Atlantic surface cooling and AMOC weakening
- Southward propagation of the warming signal along the deep western boundary current suggesting slow advective timescales
- Warming anomaly does not reach past 40˚S - the ACC acts as a barrier against meridional flow