The Bipolar Seesaw

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Introduction

The thermohaline circulation (THC) in the Atlantic exports cold water beyond the equator, thereby effectively drawing heat from the Southern Ocean. The combination of warm northward surface currents and cold deepwater currents results in a coupling of the hemispheres (fig. 2), where warming in the northern hemisphere (NH) can be linked to cooling in the southern hemisphere (SH). A weakening of the Atlantic THC may result in a cooling of the NH and a warming of the SH. This behaviour is described as the bipolar seesaw, which may be mediated by different mechanisms over a large range of different timescales.

Occurances of Seesaw Events from Paleo Data

- On 100,000-year timescale in-phase climate changes of NH and SH dominate
- During last ice age (14-110 ka BP) millenial-scale rapid warming events on NH and damped antiphase responses on SH are inferred from analysing GRIP isotope data of Greenland and Byrd isotope data of the Antarctic [4]
- Radiocarbon records for atmospheric CO_2 suggest antiphase millenial duration modulations during last period of deglaciation (fig. 1) [1]

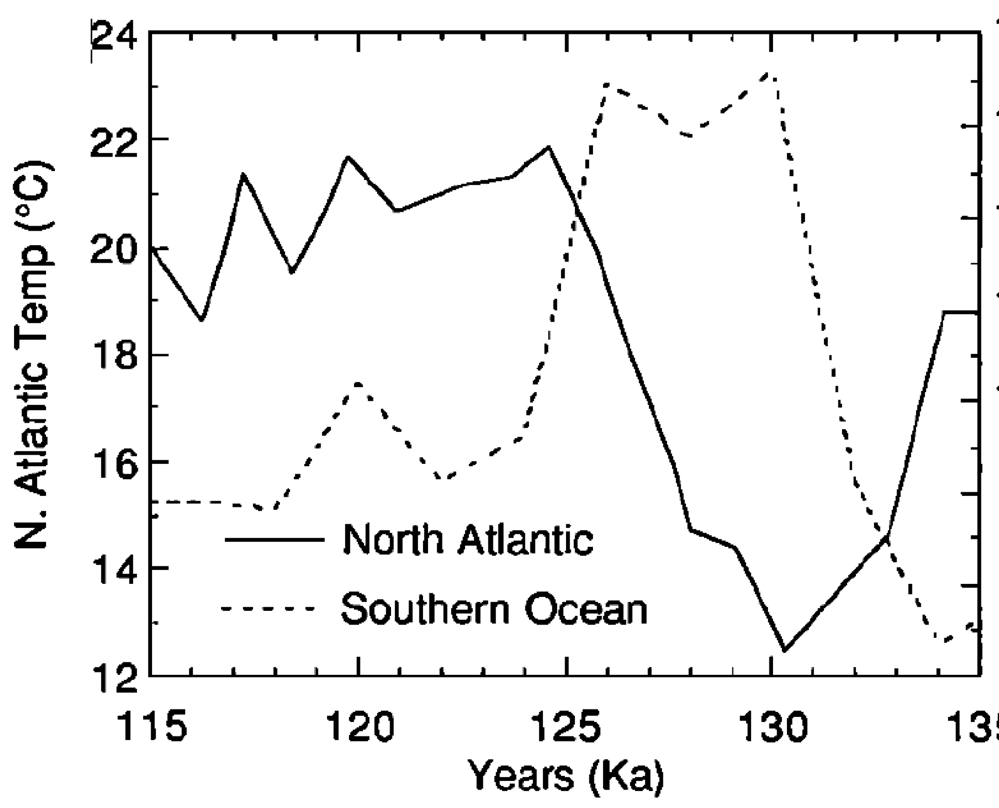

Figure 1: The antiphase relation of North Atlantic and Southern Ocean temperatures exhibits an example of an out of phase seesaw.

A Minimum Thermodynamic Model for the Bipolar Seesaw

- Simple thermodynamic model shall reproduce Byrd from GRIP data
- Classical bipolar seesaw: bad reproduction
- Model hypothesis: classical seesaw coupled with southern heat reservoir (fig. 3) results in dampening and integration in time of NH climate signals
- Heat storage responds according to characteristic time-scale τ (fig. 3):
$$\frac{dT_S(t)}{dt} = \frac{1}{\tau}[-T_N(t) - T_S(t)]$$
- Advanced model succeeds in reproduction of large parts of Antarctic Byrd isotope data with characteristic timescale of $\tau = 1120$ years

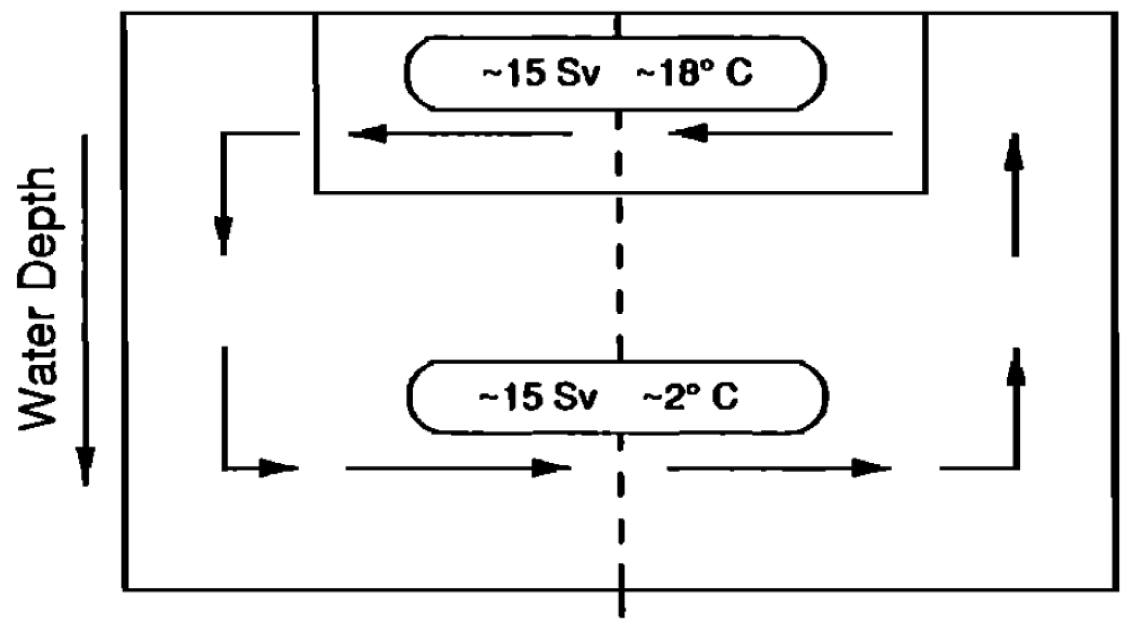

Figure 2: The transport of warm near surface water northwards (top, from right to left) and cold north atlantic deep water southwards (bottom, from left to right) across the equator (dotted line) due to the conservation of mass.

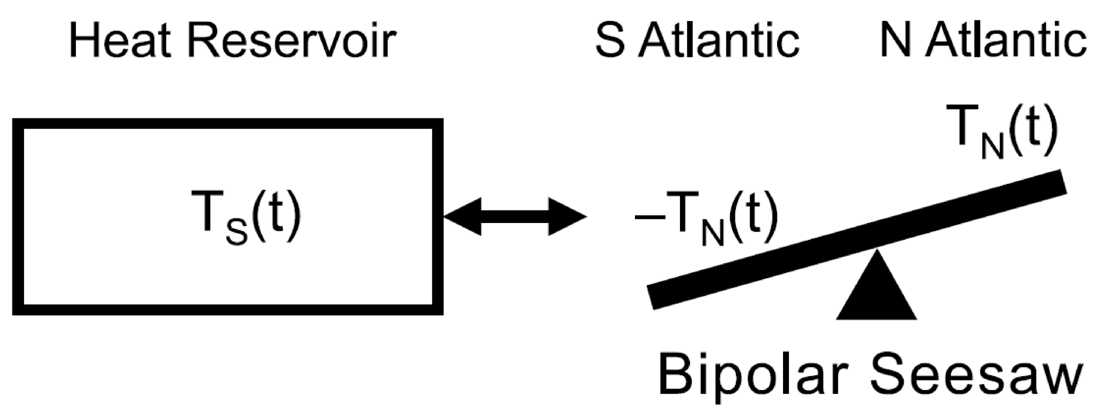

Figure 3: Schematic of the thermal bipolar seesaw model: The classical bipolar seesaw with the time-dependent temperature anomaly T_N is coupled to a heat reservoir T_S which slowly responds to the southern tip of the seesaw. This heat reservoir might be the Southern ocean.

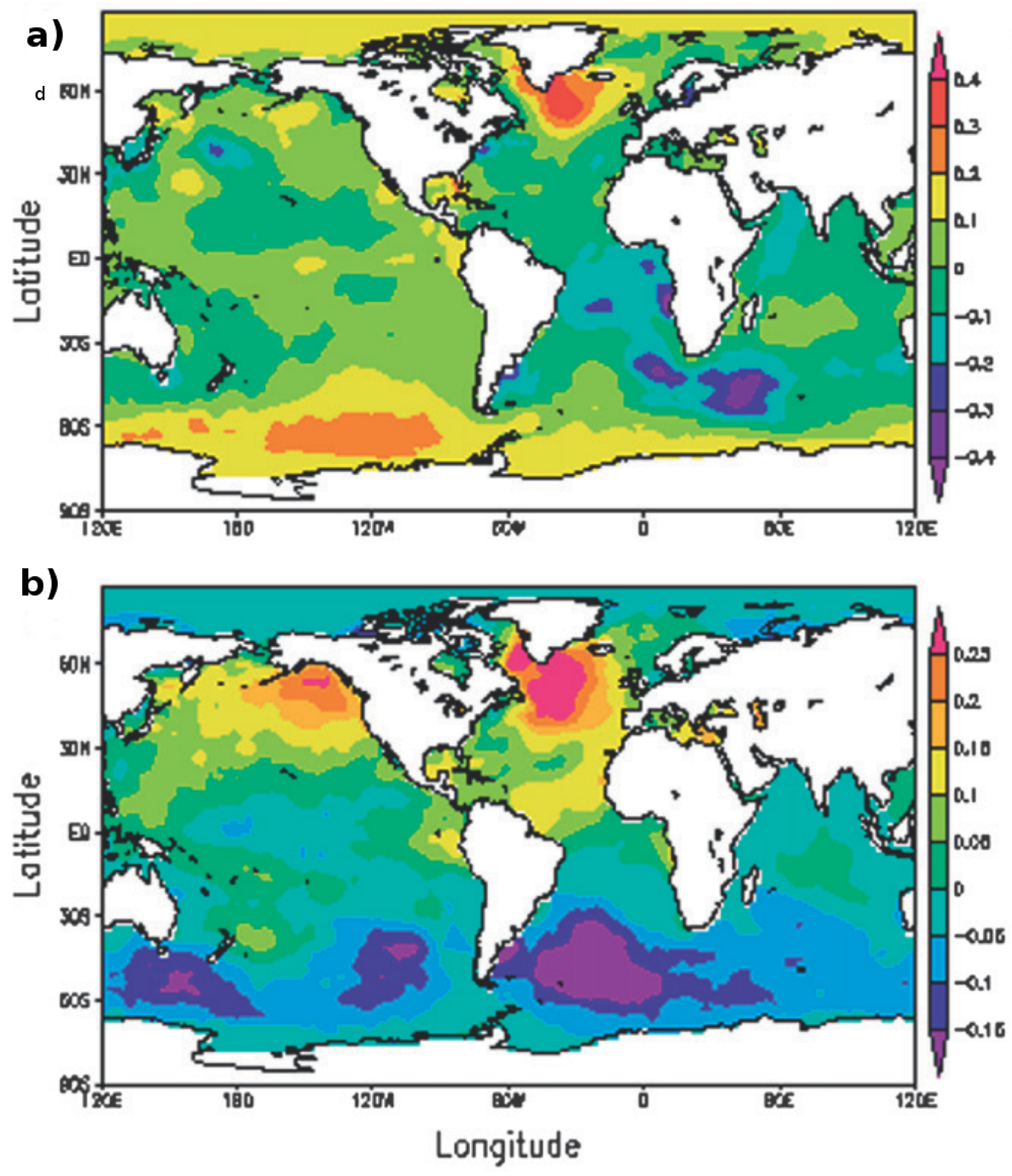

Figure 4: Annual SST anomaly fields of both modes. a) Mode G is dominated by prominent localized centers of temperature anomalies near Greenland and Antarctica clearly showing an interhemispherically quasi-symmetric in-phase structure. b) Mode A is characterized by an asymmetric distribution of anomalies in both hemispheres effectively representing the seesaw structure.

Current Modes of Large-Scale Ocean Circulation Changes

- Two THC-related modes can be inferred from global sea surface temperatures (SST) from the last century (fig. 4 and fig. 5)
- Global mode (G) results from variations in the vertical oceanic heat transfer
- Atlantic mode (A) corresponds to changes in the horizontal heat advection by surface currents of the North Atlantic THC

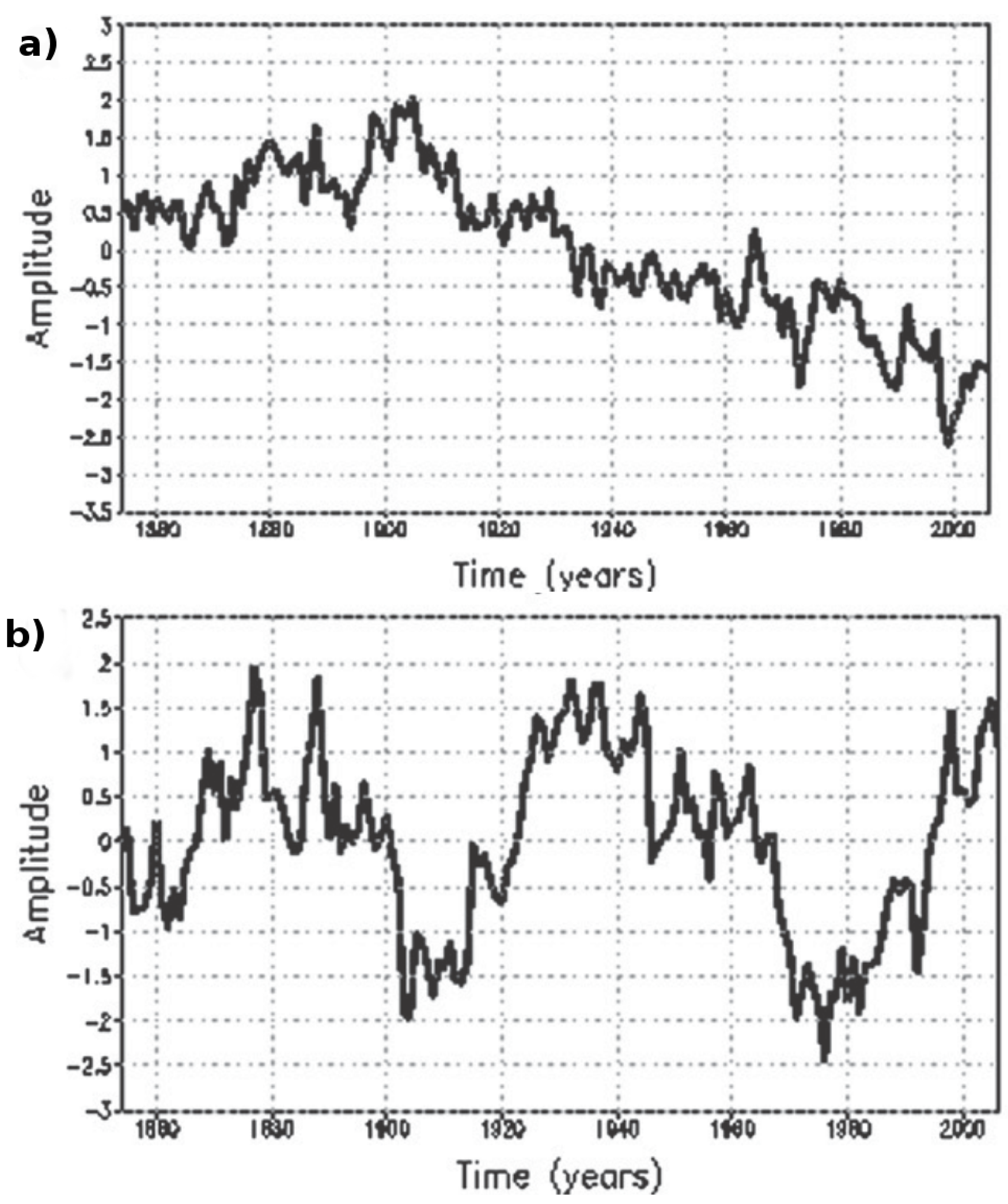

Figure 5: Times series of annual SST anomalies. a) Mode G has a relatively long response time of the order of decades and longer. It also shows a decreasing trend since the late 1930s. b) Mode A exhibits pronounced multidecadal variability ending with an increasing trend since 1980. It reflects the Atlantic multidecadal oscillation (AMO).

References

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[2] Thomas J. Crowley. "North Atlantic Deep Water cools the southern hemisphere". In: *Paleoceanography* 7.4 (1992), pp. 489–497.

[3] Mihai Dima and Gerrit Lohmann. "Evidence for Two Distinct Modes of Large-Scale Ocean Circulation Changes over the Last Century". In: *J. Climate* 23.1 (2010), pp. 5–16.

[4] Thomas F. Stocker and Sigfus J. Johnsen. "A minimum thermodynamic model for the bipolar seesaw: THERMAL BIPOLAR SEESAW". In: *Paleoceanography* 18.4 (2003), pp. 1–9.