The Response of the Atlantic Meridional Overturn Circulation During the Middle Pleistocene Transition.

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Abstract

The MPT marked a period in Earth’s history when the climate shifted from responding to the 41 ky orbital periodicity to 100 ky periodicity. The LR04 stack is used to analyze the onset of high amplitude benthic δ¹⁸O shifts associated with the transition from 41ky to 100ky cycles and to reconstruct the climate and volume of glacial ice prior to and during the MPT. Changes in δ¹⁸O and δ¹³C were used to reconstruct the flow rate of the AMOC before, and during the MPT. The AMOC flow rate leading up to and during the MPT is indicative of dramatic changes in the Earth’s climate. Leading up to the MPT the AMOC flowed at a rate that was greater than any time during the MPT. The ventilation of the thermocline in different areas demonstrates the global impact of the increased flow rate of the AMOC leading up to the MPT. SST and SSS recorded in planktonic foraminifera and δ¹⁸O are used to analyze the shifts in and the impact on gyre circulation feeding the return leg of the AMOC during the MPT. The heat transport the gyres are responsible for are major contributors to the global heat budget. Changes in the meridional heat transport contributed to the cooling the Earth experienced during the MPT.

Introduction

The Pleistocene was a period of global cooling marked by the Middle Pleistocene Transition (MPT), when a shift in the Earth’s response to orbital periodicity was accompanied by enhanced glaciation in the Northern Hemisphere (Bell et al., 2015). A major contributor to the global heat budget is the Atlantic meridional ocean circulation (AMOC). The AMOC is responsible for equatorial and polar exchange of heat through the movement of water masses. Water heated along the Equator in the Atlantic is transported by the Gulf Stream up the eastern coast of the United States. The extension of the Gulf Stream then directs the flow of water out to sea and further north approaching the subduction zones in the North Atlantic. Heat is transferred from the warm sea water to the cold atmosphere at higher latitudes. In addition, the water salinity increases when sea water is frozen and salt is excluded from ice crystals. Both the cooling and increased salinity increase the density of the water, and this denser water then subducts and flows south toward the Equator at depth. The loss of heat to the atmosphere from sea water in high latitudes where deep water formation occurs is a major contributor latitudinal heat transport. During the MPT the AMOC flow rate decreased and the meridional heat transport also decreased (Hernandez-Almeida et al., 2012). The decrease in meridional heat transport during the MPT contributed to the cooling during the MPT (Bell et al., 2015).

Early Pleistocene

The early Pleistocene was a period of glacial cycles dominated by a 41 kyr glacial/interglacial periodicity (Lisieki and Raymo 2005). The LR04 stack of benthic foraminifera δ¹⁸O was used to identify marine isotope stages (MIS) during the Pleistocene (Lisieki and Raymo 2005). MIS are identifiable oscillations in ice volume that are determined with the use of benthic climate proxies (Figure 1). The MIS are sequentially numbered to identify the changes in the individual events (figure 2). The MIS stages leading up to the MPT imply that during interglacials the climate of Earth was relatively steady (McClymont et al., 2013). During the glacial periods the Earth’s climate cooled, remained cooled during the steady interglacial, and further cooled during the next glacial period (McClymont et al., 2013). The Earth was in a long term cooling trend leading up to the MPT (McClymont et al., 2013).

The AMOC reached a maximum flow rate during the early Pleistocene prior to the MPT (Bell et al., 2015). The increase of the AMOC flow rate enhanced the subduction of North Atlantic deep water (NADW) into the Eastern Atlantic (Bell et al., 2015). The warm return flow of the AMOC compensated for the enhanced subduction and drew heat from the Southern Atlantic (Bell et al., 2015). The heat piracy resulted in limited regional warming in the North Atlantic and a cooling of the South Atlantic SST (Bell et al., 2015). The enhanced AMOC flow rate had global effects by shoaling the thermocline in both the South Atlantic and the North Pacific (Bell et al., 2015). The changes in δ¹⁸O and δ¹³C at multiple sites in the Atlantic suggest that there were large scale changes to the AMOC leading up to and during the MPT (Bell
et al., 2015). The equatorial Pacific cold tongue emerged, and the intensity of the Walker and Hadley Cell increased in the Pacific (Bell et al., 2015).

The Middle Pleistocene Transition

The MPT marks the transition in the Earth’s glacial/interglacial periodicity from 41 kyr to 100 kyr (Hernandez-Almeida et al., 2012). MIS 35-34 show an intensification of cooling in SST beginning at approximately 1.2 Ma (McClymont et al. 2013). Massive ice sheets accumulation in the Northern Hemisphere coincided with the decrease in SSTs (Hernandez-Almeida et al., 2012). Sea levels dropped globally, by as much as 50 m in some areas (Clark et al., 2006). The drastic changes in ice volume, SSTs, and sea level at approximately 1.2 Ma imply the beginning of the transition.

The shift in orbital periodicity is highlighted by the 900 kya event, when the 100 kyr cycle took control of the glacial-interglacial periods (Clark et al., 2006). A step-like increase in benthic foraminifera δ¹⁸O approximately 900 kya marked the shift in the orbital periodicity, contributing to expansion of the ice sheets in the Northern Hemisphere (Figure 3; McClymont et al. 2013). There was an abrupt increase in δ¹⁸O during the 900 Ka event, suggesting more ice volume globally and changes in the temperature of the ocean (both at the surface and at depth) (McClymont et al., 2013). The 900 Ka event coincides with MIS 22 & 24 (Hernandez-Almeida et al., 2012). The LR04 δ¹⁸O stack indicates the 900 Ka event was the first of the longer period glaciations lasting approximately 80 kyr (Clark et al., 2006).

The cooling during the MPT and the increase in ice volume cause a shift in the areas where NADW was subducted (Hernandez-Almeida et al., 2012). The subduction zones in the Greenland, Iceland, and Norwegian seas shifted south as a result of the moving arctic front (Hernandez-Almeida et al., 2012). The regional shifts in planktonic foraminifera species abundance, δ¹³C and δ¹⁸O describe the shifts in the deep water formation sites (Hernandez-Almeida et al., 2012).

The reconfiguration of the global ice budget associated with the 900 Ka event initiated a shift in the subduction of NADW to Glacial North Atlantic intermediate water (GNAIW) (Hernandez-Almeida et al., 2012). The southern limit of the arctic front reached between 32-37° N during the MIS 28-26 approximately 1000-900 Ka (Figure 4; Hernandez-Almeida et al., 2012). The change in the boundary condition of the deep water subduction zones contributed to the cooling by reducing northern heat transport of equatorial water and enhancing cooling of the intermediate and deep waters of the North Atlantic (Bell et al., 2015). The changes in the deep water formation areas and the enhanced cooling coincided with a decreased flow in the AMOC (Bell et al., 2015). The diminished flow of the AMOC became a positive feedback for the cooling as the equatorial heat transport was also diminished (Bell et al., 2015).

Conclusion

The transition from 41 kyr to 100 kyr periodicity pushed an already cooling planet to increase ice volume in the Northern Hemisphere (Bell et al., 2015). The cooling trend that began approximately 2 Ma intensified approximately at 1.2 Ma (Bell et al., 2015). The intensification of cooling coincided with the beginning of the transition from 41 kyr to 100 kyr orbital periodicity. The 900 Ka event signaled the transition between orbital periodicity with a glacial period that lasted for approximately 80 Ka (Clark et al., 2006). The LR04 stack of benthic δ¹⁸O record details the shift in the periodicity from the 41 kyr cycle to the 100 kyr cycle (Lisiecki and Raymo, 2005). The culmination of the multiple changes in atmospheric and ocean temperatures, heat transports, and circulation provided positive feedback for the cooling during the transition into the 100 kyr periodicity (Hernandez-Almeida et al., 2012). The glacial periods on Earth remain in the 100 kyr cycle to the present.
Figure 1. A plot of the LR04 stack of Benthic $\delta^{18}O$ demonstrating the shift in periodicity from 41 kyr to 100 kyr, note the difference of y axis scale. (Lisiki and Raymo, 2005).
Figure 2. Marine isotope stages recorded during the MPT. Each of the different stages during the MPT is denoted by the numbers on top of the graph. Item A is the change in $\delta^{18}$O during the MPT. Item B is the percent of change in a species of foraminifera during the MPT. (Hernandez-Almeida et al., 2012).
Figure 3. The top panel is the change in $\delta^{18}O$ over the last 2 million years. The rest of the panels are changes in temperature from multiple sites in the Atlantic spanning the last 2 million years. The highlighted area is the MPT. (McClymont et al., 2013)
Figure 4. The average shifts in the arctic front during the listed MIS. The arrows indicate the formation areas and flow of intermediate waters at each time series, the North Atlantic current (NAC) shown in red and the East Greenland Current shown in blue (Hernandez-Almeida et al., 2012).
Figure 5. The flow of different water regimes during the MPT (Pena and Goldstein 2014).


