Proximal trigger for late glacial Antarctic circulation and CO_2 changes

Thomas J. Crowley
Braeheads Institute, Maryfield, Scotland, UK; tcrowley111@googlemail.com

The Brazil Current may have played a key role in shunting heat towards the Antarctic during the meridional overturning shutdown at the end of the last ice age.

The remarkable relationship between late Pleistocene carbon dioxide variations and Antarctic temperatures has been as inscrutable as the faint smile of a stone Buddha. Recently, a string of papers provide promise of unlocking the secrets of that relationship by shedding light on ocean circulation/carbon dynamics involving the key first phase of carbon dioxide rise at the end of the last glacial period. During an interval that has long been termed the "Late Glacial", and is broadly correlative with Heinrich Event 1 (H1, ~17.8-14.6 cal ka), significant carbon reservoir changes at the time of the first major CO_2 rise have been related to Antarctic ocean circulation changes (Marchitto et al., 2007; Anderson et al., 2009; Rose et al., 2010). In turn, these changes link to variations in North Atlantic Deep Water (NADW) overturning rate (Anderson et al., 2009; Toggweiler and Lea, 2009), which cause a see-saw in sea surface temperature (SST) patterns between the North and South Atlantic (Crowley, 1992; Toggweiler and Lea, 2009).

In this note, I point out that an overlooked feature of the NADW see-saw provides additional insight into the nature of the "bolt of warmth" that characterized Antarctic temperature change at this time. As noted in Crowley (1992), shutdown of NADW production "banks" about 1 petawatt (PW) of heat in the South Atlantic, which would otherwise be exported north of the equator to compensate for southward outflow of NADW across the equator. An early modeling study indicates that adjustment of the South Atlantic to this shutdown involves an enormous 1 PW increase in heat transport (Maier-Reimer et al., 1990; Fig. 1A), which is shunted southward into higher latitudes via the Brazil Current, i.e., the western boundary surface current of the South Atlantic (Fig. 1B).

It is remarkable that the South Atlantic model heat transport for the perturbation run is greater than for the Gulf Stream in the control run (Fig. 1A). In a sense the deglacial Brazil Current vertical section and transport is dynamically similar to the Gulf Stream at present—the strong flow is required to compensate for both the increased northward transport of Antarctic Bottom Water and the decreased southward transport of both NADW and North Atlantic Intermediate Water. Enhanced Southern Ocean inflow into Atlantic Basins is supported by geochemical assays (Negre et al., 2010).

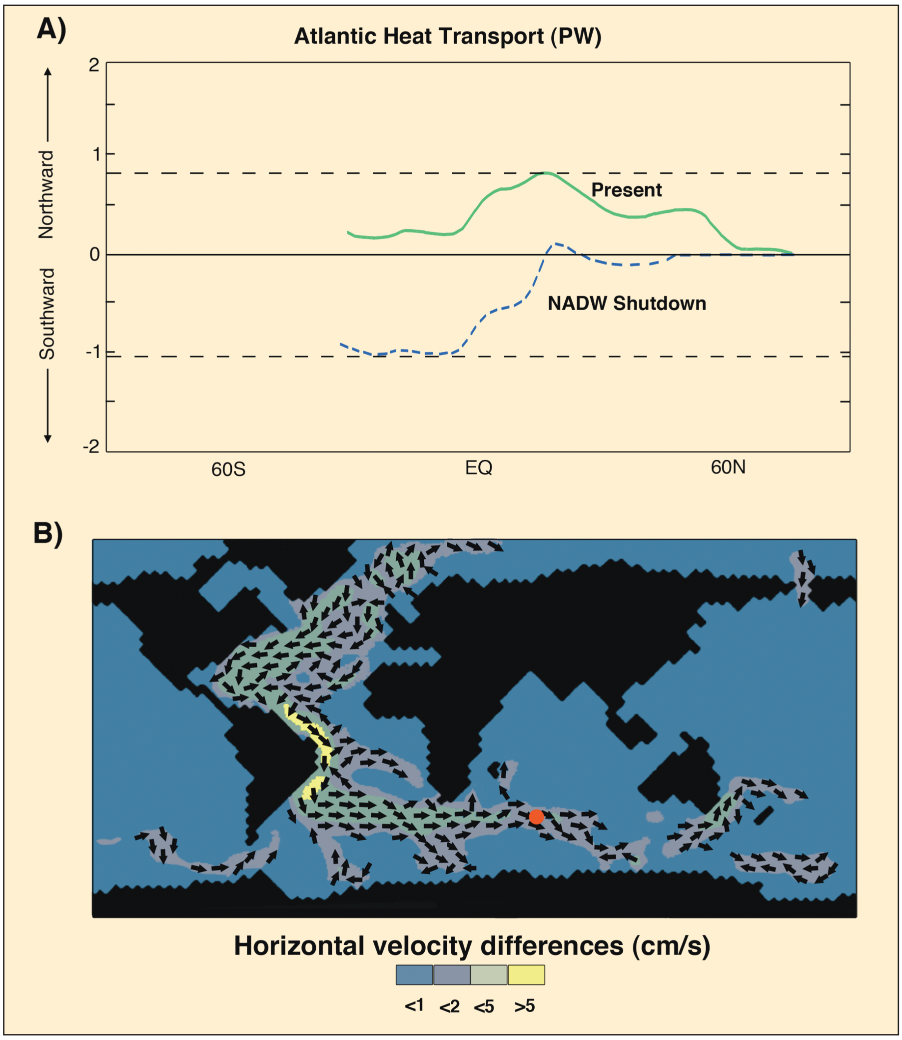

*Figure 1: **A**) Comparison of zonal poleward ocean heat transport (1 PW = 10^{15} Watts) in the Atlantic sector for the model runs illustrated in Figure 2. Figure from Maier-Reimer et al., 1996. **B**) Difference of surface current (25 m) between the control and perturbed run, illustrating the effects of an NADW shutdown (in this case due to an open central American isthmus) on global ocean circulation (Figure from Maier-Reimer et al., 1990). Red dot refers to location of sub-Antarctic core illustrated in Figure 2.*

In the illustrated model example, convergence of the stronger Brazil Current with sub-Antarctic waters leads to stronger currents (Fig. 1B) and presumably enhanced convergence in the frontal zone (cf., Marchitto et al., 2007), with changes extending zonally downstream at least as far as the eastern Indian Ocean. These changes are likely responsible for the observed zonal changes in the Antarctic Circumpolar Current (cf., Anderson et al., 2009). The heat injection, along with a sea-ice melt feedback, likely explains the long-known (Hays et al., 1976) rising temperatures in the sub-Antarctic at the time of H1 (e.g., Fig. 2), and the parallel rise recorded in Antarctic ice cores. Additional adjustments can be expected from the warming effects of surface warming on the Antarctic overturning circulation, with potential implications for possible tapping of the deeper ocean glacial carbon reservoir in the Southern Ocean (Toggweiler and Samuels, 1995; Rose et al., 2010). It is conceivable that warmer surface waters could have prevented recharge of very cold and saline deep Antarctic waters, leading to a transient enhanced vertical stratification (tidal mixing would probably break down

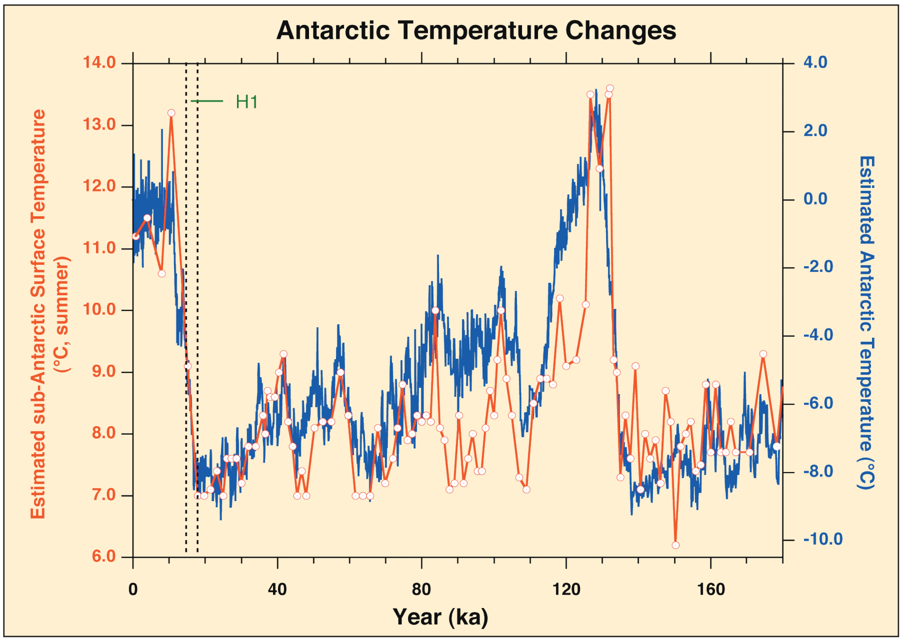

Figure 2: Comparison of the sub-Antarctic record (core RC11-120; Hays et al., 1976), using higher-resolution sampling from Martinson et al. (1987) and converted to an updated marine chronology (Lisiecki and Raymo, 2005), with the Vostok deuterium isotope record and ice core GT4 chronology (Petit et al., 1999). H1 interval is Heinrich Event 1.

this barrier after a few hundred years; R.-X. Huang, pers. comm.).

It therefore appears that the Brazil/ Malvinas-Falkland Convergence (where the southerly vectors of the Brazil Current merge with the easterly flow of the Sub-antarctic in Figure 1B) may be the pressure point where the heat accumulated in response to stalled Atlantic overturning circulation is injected into southern high latitudes, thereby driving the planet into deglaciation through positive feedbacks from ocean-circulation releasing carbon stored in the deep ocean around Antarctica. Closer inspection of data from the Malvinas/Falkland region might provide enhanced insight into kinematics of this process. The postulated response should also be testable with the present generation of coupled climate/carbon models and would be much more realistic if started from a glacial base state. The transient model response would be especially intriguing to examine, for it could provide fascinating insight into the time-space evolution of the heat package injected into the sub-Antarctic region and the partitioning of the heat between the ocean and the atmosphere (Seager et al., 2002).

Even though the model results invoked herein represent an uncoupled run from twenty years ago, I suggest that the system response is so constrained by conservation of volume arguments—overturning shutdown in the north blocking heat export from the South Atlantic—that newer model simulations are likely to respond in the same manner. Elements of this argument can even be traced back to (or at least anticipated in) Henry Stommel's classic explanation for differences in strength of the Gulf Stream and Brazil Current (Stommel, 1965). His interpretation was certainly supported by the 1990 simulation (Maier-Reimer et al., 1990).

Data

Data for Fig. 2 from Martinson et al. (1986) and NOAA/NGDC Paleoclimatology website.

References

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For full references please consult:
http://www.pages-igbp.org/products/newsletters/ref2011_2.pdf

Paleoclimate Reconstruction Challenge: Available for participation

Nicholas Graham[1] and Eugene Wahl[2]

[1]Hydrologic Research Center, and Scripps Institution of Oceanography, USA; ngraham@hrc-lab.org
[2]NOAA, National Climatic Data Center, Paleoclimatology Branch/World Data Center for Paleoclimatology, Boulder, USA

The last millennia Paleoclimate Reconstruction (PR) Challenge is a model-based venue for experimenting with climate reconstruction methods. The overall idea has been described before (Ammann, 2008) and a modified version of the Challenge is now "live" and available for participation. It is designed to engage the scientific paleoclimate community in examining its methods in a common framework for the purpose of evaluating their relative strengths and weaknesses. A key design element of the Challenge is to allow true "apples to apples" comparison of reconstruction methods across identical experimental platforms. The ultimate goal is to improve last two millennia PR methods so that paleoclimate science can offer the best possible information to help understand both natural and anthropogenic climate change.

The Challenge is organized around 4 themes. In each theme, a set of long (1,000+ yrs) forced global climate model (GCM) integrations is used to formulate simulated paleoclimate proxy data (pseudo-proxies) and to provide pseudo-instrumental climate data for calibration and examination of reconstruction fidelity. Several different GCM runs provide a range of simulated climate evolutions that present different reconstruction scenarios. In each Theme, the reconstruction method used is at the prerogative of the participants.

Theme 1: Reconstruction of Northern Hemisphere temperature with strongly limited proxy data set (implemented)

This theme focuses on the capacity of a very limited set of proxy data sites to enable reconstruction of hemispheric (20-90° N) mean annual temperature. The pseudo-proxy data-set consists of 14 extratropical tree-ring-chronology sites in the Northern Hemisphere (Fig. 1). It is designed to mimic the dataset used by Esper et al. (2002).

Theme 2: Reconstruction of Northern Hemisphere temperature and spatial patterns with a richer, but still somewhat limited proxy data set (in process of implementation)