Forum

Rapid climate change and Arctic Ocean freshening: COMMENT and REPLY

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The Research Focus article by Peltier (2007), which is a distillation of Peltier et al. (2006), discusses the possible effects of Arctic freshwater forcing on the strength of Atlantic meridional overturning circulation (AMOC), with emphasis on the Younger Dryas cold event (YD). The cause of the YD was originally associated with northward retreat of the Laurentide Ice Sheet out of Lake Superior, rerouting continental drainage from the Mississippi to the St. Lawrence River, with the attendant increase in eastward-flowing freshwater perturbing North Atlantic climate (Johnson and McClure, 1976; Rooth, 1982). More recent work emphasizes the opening of the eastward outlet through Lake Superior that caused much of Lake Agassiz to drain rapidly, with a 1 yr flood triggering reduced AMOC (Teller et al., 2002). Lowell et al. (2005) argued that the lack of an identifiable spillway called the YD flood-trigger hypothesis into question. Peltier cites this work as the motivation for Tarasov and Peltier (2005), who concluded that freshwater routing occurred from the south to the north into the Arctic Ocean. Peltier fails to cite two recent studies that shed additional light on this question.

Meissner and Clark (2006) used the University of Victoria Climate Model to evaluate the response of AMOC to a 1 yr freshwater flood of 0.3 Sv (1 Sv = 10^6 m^3 s^{-1}), a 0.074 Sv base discharge increase from the eastward freshwater routing for the duration of the YD, and the combination of the two. The modeled AMOC response to the 1 yr flood was negligible; only with inclusion of the base discharge increase did the model simulate a reduced AMOC for the duration of the YD. Thus, any flood that Lake Agassiz may have generated at the start of the YD was incapable of affecting AMOC, and the lack of evidence for a flood does not preclude the routing of western Canada freshwater to the St. Lawrence River.

Carlson et al. (2007) demonstrated that there is a clear low-salinity signal present in planktonic $\delta^{18}O$ during the YD in the St. Lawrence Estuary after accounting for decreased sea-surface temperature. Four independent geochemical tracers showed that this freshening was from an increased freshwater flux of 0.06 ± 0.02 Sv from western Canada to the St. Lawrence Estuary at the start of the YD.

Peltier refers to "direct paleoceanographic evidence" in support of Arctic freshwater forcing. Though he provides no references for that evidence, they are presumably listed in Peltier et al. (2006). These do not show an Arctic source of freshwater at the start of the YD ~11.0 ^{14}C k.y. B.P. Light planktonic $\delta^{18}O$ anomalies are observed in the Arctic Ocean ~12.5-11.8 ^{14}C k.y. B.P. and ~10 ^{14}C k.y. B.P. (Poore et al., 1999; Andrews and Dunhill, 2004; Hall and Chan, 2004) with heavier planktonic $\delta^{18}O$ during the YD arguing against an Arctic freshwater forcing (Hillaire-Marcel et al., 2004). A light planktonic $\delta^{18}O$ anomaly in the Laptev Sea off of northeastern Russia may or may not have occurred at the start of the YD (Spielhagen et al., 2005). During the last deglaciation, the largest light planktonic $\delta^{18}O$ anomaly in Fram Strait occurred ~14.5 ^{14}C k.y. B.P. due to the disintegration of the Barents ice sheet (Koç and Jansen, 1994).

Peltier's model uses Arctic freshwater forcings of 0.3 and 1.0 Sv for 100 yr rather than the Tarasov and Peltier (2005) values of 0.12–0.22 Sv for 100 yr. The 1.0 Sv × 100 yr forcing is equivalent to a rise in eustatic sea level of 8.7 m at the start of the YD, which did not occur (Tarasov and Peltier, 2005). In neither case is the 100-yr forcing sufficient to explain the duration of the YD. The subsequent decrease in the Arctic freshwater flux to 0.05–0.07 Sv of Tarasov and Peltier (2005) continues well beyond the YD, and thus cannot explain the duration of the YD.

We conclude that there are no existing paleoceanographic records that suggest an increase in Mackenzie River discharge or an Arctic freshwater source at the start of the YD. Rather, the available paleoceanographic evidence indicates that freshwater was routed from the Mississippi River to the St. Lawrence River at the start of the YD with a base flow discharge increase sufficient to have reduced AMOC.

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REPLY: doi: 10.1130/G24971Y.1

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The primary goal of the Comment by Carlson and Clark (2008) appears to be to draw attention to the Carlson et al. (2007) paper, which disputes the findings of de Vernal et al. (1996). A joint reply focusing on significant issues with the Carlson and Clark (2008) paper therefore appears appropriate.

De Vernal et al. (1996) applied the modern analogue technique to dinocysts to estimate sea-surface salinity (SSS) at the mouth of the St. Lawrence River at the onset of and during the Younger-Dryas (YD) event. Their data did not support the idea of enhanced freshening during the YD. Subsequently, Lowell et al. (2005) reported on an unsuccessful search for a viable route that could have been the spillway via which Lake Agassiz water made its way through the Great Lakes–St. Lawrence River system into the North Atlantic. This is consistent with de Vernal and others' conclusions.

Carlson et al. (2007) write "We corrected the Mg/Ca record in *Globigerina bulloides* [Gb] for sea surface temperature (SST) and salinity effects using an existing SST record (from de Vernal et al., 1996)." The idea that one may employ the results of one proxy to correct another is naïve. Dinocysts represent conditions in the photic zone where August SSS ranged from 30 psu to 31 psu (de Vernal et al., 1996). Planktic foraminifera such as *G. bulloides* could not have developed with such a low salinity. *G. bulloides* shells were either carried into the area by a saltier subsurface layer, as in the modern Gulf of St. Lawrence, or developed sporadically when suitable conditions prevailed.

Carlson et al. (2007) apply a dinocyst-inferred summer SST shift from ~8 °C to ~16 °C to the isotopic paleotemperature equation using an ^{18}O-record from *Neogloboquadrina pachyderma*, thus artificially producing a 2.75‰ drop in surface-water ^{18}O content and a salinity drop of more than 3 psu. Firstly, *N. pachyderma* requirements are incompatible with a 8–16 °C temperature range (they develop with T <<8 °C and S >34 or 34.5 psu; e.g., Kucera, 2007; Spindler, 1996). At high latitudes, *N. pachyderma* represents conditions toward the deeper portion of the pycnocline between the surface layer and the underlying water mass (the Labrador Sea Water in the modern North Atlantic, the North Atlantic Water Mass in the modern Arctic) (Hillaire-Marcel and Bilodeau, 2000; Hillaire-Marcel et al., 2004). It follows that the reconstruction of a salinity drop during the YD advocated by Carlson et al. (2007) is an artifact of (mis)interpretation.

The use by Carlson et al. (2007) of U/Ca ratios to label "a signal from the western Canadian plains" is odd. The data depicts a single brief excursion in the middle of the YD, not at its inception, inconsistent with the notion of a trigger from the west. Moreover, the modern St. Lawrence River system carries a U/Ca molar ratio of ~2 × 10^{-6} (Durand, 2000), compared with ~1.3 × 10^{-6} in seawater. There is no reason to believe that carbonate erosion was inactive in the St. Lawrence River area during the YD. It thus seems a stretch to argue that significant freshwater was being flushed through the system from the west based on this argument. The use of Sr isotope data in Carlson et al. (2007) is similarly questionable in view of the large array of Sr sources in regional rocks.

Carlson et al. (2007) conclude "the dinoflagellate-cyst salinity reconstruction for the St. Lawrence River is in error during the YD." If this were true, one would have thought that they might have been more cautious in using temperatures reconstructed with the same dinocyst transfer function, as assumed in their paper.

Carlson et al. (2007) contest the assumption that the meltwater flux through the McKenzie River outlet to the Arctic Ocean computed in Tarasov and Peltier (2005) could have caused the YD event, based upon the reference to Peltier et al. (2006). However, modern coupled atmosphere-ocean global climate models such as the NCAR (National Center for Atmospheric Research) CSM1.4 model used in Peltier et al. (2006) are heavily damped. Thus the magnitude of the freshwater forcing needed to cause a significant slowdown of the Atlantic meridional overturning circulation may be an overestimate. Their concerns regarding the carbon dating of freshening events in the Arctic also fails to recognize the issue of reservoir age for this interval of time.

Further support for Peltier (2007) and Tarasov and Peltier (2005) is provided by Darby et al. (2002), Moore (2005), Stokes et al. (2005), and Hillaire-Marcel and de Vernal (2008).

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