APPENDIX 1: Methods

Data Methods:

Jumbo piston core 11JPC was collected by the R/V Knorr on cruise 166, leg 14, from 2707m water depth on Gardar Drift (56°14’N, 27°39’W), in the eastern North Atlantic (Fig. 1). The top 222cm of core 11JPC was sampled at 1cm intervals to study changes in surface water hydrography during the Younger Dryas. From each sample, up to 15 tests of each of the planktonic foraminifera species *N. pachyderma* (s) and *G. bulloides* were selected using a binocular microscope from the 250–350µm size fraction of each sample and analyzed for stable isotopic composition on an Optima Mass Spectrometer at Rutgers University (1-σ laboratory precision of an internal lab standard is 0.08‰ for δ18O and 0.05‰ for δ13C). The difference (Δδ18O) between the δ18O values of the surface-dwelling *G. bulloides* and thermocline-dwelling *N. pachyderma* (s) was also calculated by subtracting the *G. bulloides* δ18O value from *N. pachyderma* (s) δ18O values for each sample to determine the differences in environment of calcification. The Δδ18O values can reflect temperature due to seasonal biases or vertical stratification due to fresh water inputs (Backstrom et al., 2001).

The number of lithic grains (>150µm) per gram of sediment was counted as a proxy for ice-rafted detritus (IRD; Fig. 3; Bond and Lotti, 1995). The location of 11JPC is too far from terrestrial sources to have a large quantity of lithic grains transported to the site by means other than ice rafting (Bond and Lotti, 1995).

Deepwater variations were reconstructed by measuring downcore benthic foraminiferal δ13C values. Up to 5 tests of the benthic foraminifera *Planulina wuellerstorfi* were selected from the 25 –350µm size fraction and analyzed for stable oxygen and carbon isotopic composition. Differences between the δ13C value of bottom waters in the North Atlantic and the South Atlantic (~1‰ and ~0.4‰, respectively in the modern oceans; Kroopnick, 1980), which are recorded in benthic foraminifera, allow for the use of benthic foraminiferal δ13C as a water mass tracer. Only *P. wuellerstorfi* tests were chosen for analysis since some *Cibicidoides* taxa (e.g., *C. robertsoniensis*) do not record equilibrium values and may be up to 1‰ lower in δ13C values (Elmore and Wright, unpublished data).
Age Model:

For each AMS $^{14}$C analysis, 4-6mg of planktonic foraminifera *Globigerina bulloides* were selected using a binocular microscope and sonified in deionized water. Samples were then analyzed at the Keck Center for Accelerator Mass Spectrometry at the University of California, Irvine. The resulting radiocarbon ages were converted to calendar ages according to the Fairbanks0805 calibration, after a 400-year reservoir correction was applied (Figure 1; Table S1; Fairbanks et al., 2005). The Younger Dryas termination at 183cm, as recorded in % *N. pachyderma* (s) and in $\delta^{18}$O of *N. pachyderma* (s), was used as additional chrono-stratigraphic tie point (11.5ka; Alley et al, 1995; Ellison et al, 2006). AMS dates at 145 and 149cm were not included in the age model because they produced slight age reversals (Fig. 1; Table S1). The resulting age model produces a nearly linear age vs. depth relationship, indicating that continuous sedimentation has occurred at the site since 13.6ka (Fig. 1). The mean sedimentation rate is 16cm/kyr throughout the Holocene and Younger Dryas sections.

The resulting age model revealed an ~19kyr hiatus between 220 and 227cm, from 13.6 to 33ka; this is consistent with a sediment color change at 222cm in the core, abrupt increase in sand-sized grains, and change in magnetic susceptibility values, indicating an unconformity at this depth. Continental sedimentation has been suggested on Gardar Drift since the early- to middle- Miocene on million-year time-scales (Huizhong and McCave, 1990; Wold, 1994). However, at 11JPC, erosion removed sediments that were deposited during Marine Isotope Chron 2 and late MIC 3. This erosion is concomitant with the reinvigoration of NCW during the early Bolling/Allerod observed on the Blake Outer Ridge (Keigwin and Schlegel, 2002). The age model for the Younger Dryas and Holocene sections of core 11JPC, indicates that continual accumulation immediately followed this erosional event (Fig. 1).

Given a typical bioturbation depth for the region of 10cm (Thomson et al, 2000), it is reasonable to expect that the AMS $^{14}$C date at 220cm, immediately above this unconformity, may be contaminated by bioturbation of some older material from below the hiatus; AMS $^{14}$C dates at 213 and 198cm could also be contaminated. To estimate the degree of contamination at 220cm from older sub-hiatus material, the $^{14}$C activity of older material ($A_{\text{pre-hiatus}}$), was calculated by (Rutherford, 1905):

$$A_{\text{pre-hiatus}} = A_0 \times \exp(-\lambda t)$$

Where $A_0$ is the initial activity of $^{14}$C (13.56dpm/g; Karlen et al., 1966), $\lambda$ is the decay constant for $^{14}$C (1.209 *$10^{-4}$ y$^{-1}$; Libby, 1955; Godwin, 1962), and $t$ is the age of the sub-hiatus material (~ 33,000y). Solving equation 1 yields $A_{\text{pre-hiatus}} = 0.2509$. The excess $^{14}$C activity above the hiatus due to bioturbation of the pre-hiatus material ($A_{\text{post-hiatus}}$) was calculated by the following equation from Berger and Heath (1986):

$$A_{\text{post-hiatus}} = A_{\text{pre-hiatus}} (1 - \exp(-T/m)) \times \exp\left(-\left(L_e + m\right)/m\right)$$

where $T$ is the thickness of older sediment (1m; Bard et al, 1988), $m$ is the thickness of the layer that was mixed due to bioturbation (10cm; Thomson et al., 2000), $L_e$ is the depth above the hiatus (2cm at 220cm). Solving equation 2 yields and activity at 220cm of $A_{220\text{cm}} = 0.07558$. 

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The effect of bioturbation on the sediment at 220cm can be deconvolved by:

\[ A_{220\text{cm}} = A_{\text{measured}} + A_{\text{post-hiatus}} \]

where \( A_{\text{measured}} \) at 220cm (13.62ka) = 2.5878, this yields an activity at 220cm of 2.6634, which is equivalent to an AMS \(^{14}\text{C} \) age of 13.46ka. This indicates that the foraminifera are recording an age 160 years older than the sediment age due to the bioturbation of older material. Doubling the bioturbation distance results in a corrected age of 13.44ka at 220cm, which is not significantly different than the original estimate. By following the same method, the bioturbation corrected ages at 213 cm is 13.22ka, which is 120 years younger than the measured AMS \(^{14}\text{C} \) date of 13.34ka, demonstrating that the bioturbation of older material has a small effect on the age at this depth. Also, by the same method, the bioturbation corrected age at 198 cm is 11.97ka, which is within the error of the measured AMS \(^{14}\text{C} \) date of 11.99ka, indicating that bioturbation of older material is not affecting the age at this depth.

The age model for core 11JPC is complicated by some uncertainties due to the relatively long hiatus, AMS \(^{14}\text{C} \) dating, and the AMS \(^{14}\text{C} \) reservoir correction. These issues are addressed by first mathematically modeling the effects of the bioturbation across the hiatus, which introduces an age uncertainty of \( \sim 200 \) years for the sediments immediately above the unconformity. Second, while it is conventional to pick the most common planktonic foraminifera for AMS \(^{14}\text{C} \) dating to minimize the effects of bioturbation (Broecker et al., 1988), \textit{G. bulloides} were selected for AMS \(^{14}\text{C} \) dates throughout core 11JPC, so as not to introduce species offsets. AMS \(^{14}\text{C} \) dates on different species from the same level yielded differences of \( \sim 500 \) y in some LGM sediments (Brocker et al., 1988; Berger, 1987; Bard et al., 1988; Backstrom et al., 2001). \textit{Globigerina bulloides} was chosen for dating because it still makes up nearly 30\% of the planktonic foraminiferal species assemblage in the Younger Dryas section (Elmore, 2009). Finally, a large degree of uncertainty surrounds the appropriate reservoir correction for the Younger Dryas, which range from 400 (Fairbanks et al., 2005; Stuiver and Polach, 1977) to 500 (deMenocal et al., 2000) to 800 years (Bard et al, 1994; Haflidason et al, 1995). A reservoir correction of 400y was applied to all AMS \(^{14}\text{C} \) dates for core 11JPC, which probably represents the minimum reservoir correction; applying a larger reservoir correction would yield a younger age for the onset of the Younger Dryas by as much as a few hundred years (Figure 1).
Table DR1: Age model for the top of core 11JPC including AMS $^{14}$C dates and 1 chronostratigraphic tie point (blue). AMS $^{14}$C dates in red were not included in the age model as they caused slight age reversals. AMS $^{14}$C dates were corrected by 400y to account for the reservoir correction and calibrated to calendar years using the Fairbanks 0805 calibration (Fairbanks et al, 2005). Activity of $^{14}$C, bioturbated activity, corrected activity (Corr. Act.), and final calendar ages were determined according to the methods outlined above. All ages are given in years.

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Supplemental References:


Bard, E., et al.. 1988. Sea-level estimates during the last deglaciation based on $\delta^{18}$O and accelerator mass spectrometry $^{14}$C-ages measured in *Globigerina bulloides*. *Quaternary Research*.


Keigwin, L.D. and M.A. Schlegel. 2002. Ocean ventilation and sedimentation since the glacial maximum at 3 km in the western North Atlantic. *Geochemistry, Geophysics, Geosystems.* 3(6); 1-14.


