Supporting Information

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SI Materials and Methods

Core Locations. The locations of cores MD99-2334K and MD07-3076 are shown in Fig. S1. The site of MD99-2334K (37°48′N; 10°10′W; 3,146 m), on the Iberian Margin in the Northeast Atlantic, is currently bathed in northward recirculating Northeast Atlantic Deep Water, a modified form of North Atlantic Deep Water that includes ~47% Lower Deep Water (derived from Antarctic Bottom Water) (1). The site of MD07-3076 (44° 4.46′S; 14°12.47′W; 3,770 m), on the eastern flank of the mid-Atlantic Ridge in the sub-Antarctic South Atlantic, is currently bathed in a predominantly southward-flowing mixture of modified North Atlantic Deep Water and Lower Circumpolar Deep Water, which feeds into the core of eastward flowing Circumpolar Deep Water. Fig. S1 illustrates the locations of these cores within the field of modern (prebomb) seawater radiocarbon concentrations, as well as the estimated proportion of water that is currently derived from the surface North Atlantic (>40°N) versus the surface Southern Ocean (>40°S), based on the methods of ref. 2.

Planktonic Stable Carbon Isotopes. Planktonic stable carbon isotopes were measured on samples of *Globigerina bulloides*, using ~30 individuals handpicked from the 250–300-μm size-fraction of core MD07-3076. Stable isotope analyses were carried out using a VG SIRA mass spectrometer at the Godwin Laboratory, Cambridge, United Kingdom, reacted sequentially using an ISOCARB preparation system. Measurements of $\delta^{13}C$ were determined relative to the Vienna Peedee Belemnite standard; analytical precision is better than 0.06‰.

Radiocarbon Dates and Chronology. Radiocarbon dates from core MD99-2334K are listed in Datasets S1 and S2. Here we have supplemented radiocarbon dates previously reported in ref. 3. Where planktonic dates are not available from precisely the same depth interval as the benthic dates, interpolated planktonic dates have been used to calculate benthic–planktonic (B-P) offsets.

To obtain a record of surface- and deep-water reservoir age variability (i.e., the evolving offset between marine and atmosphere radiocarbon concentrations), radiocarbon dates from core MD99-2334K must first be placed on an independent calendar age-scale. It has been shown that past changes in Greenland temperatures, as recorded by ice-core precipitation isotope records, have been closely tracked by surface temperature changes on the Iberian Margin, as recorded by planktonic $\delta^{18}O$ (4, 5) and Mg/Ca (6), as well as pollen transported from the Iberian Peninsula (7). This close coupling (which is also conceptually supported) provides a basis for aligning marine records from the Iberian Margin to the Greenland ice-core event stratigraphy.

A similar alignment may also be performed with the event stratigraphy of the east Asian speleothem records (8–11). The advantage of this alignment is that it permits the transferral of the relatively precise and accurate radiometric speleothem age-scale (12, 13). In the context of this study, a further advantage of adopting the speleothem chronostratigraphy is that it directly incorporates atmospheric radiocarbon measurements that have been performed in the Hulu speleothem H82 (11).

If the Greenland and Asian speleothem event stratigraphies are indeed coupled, and if the independent chronologies associated with each of these stratigraphies are indeed correct, then an alignment of marine records to each of these event stratigraphies should be equivalent and should be consistent with further independent calendar age constraints [including uranium-series dated atmospheric radiocarbon estimates from corals, for example, (13)]. Despite small discrepancies between Asian speleothem ages and the most recent Greenland NGRIP-GICC05 ice-core chronology (14), it does appear that the two chronologies are very close indeed (15).

The Greenland/Asian speleothem link is robust for the clearly identifiable Greenland Isotope Stages 1–4, for example, but it appears to break down in the interval comprising Heinrich Stadial 1 (HS1) and the Last Glacial Maximum (LGM), where the Greenland event stratigraphy itself becomes ambiguous, and the link between Greenland and Asian speleothem event stratigraphies is no longer clear. For this reason, we adopt what might be an "optimum" calendar chronology for core MD99-2334K, based on an alignment to the most highly resolved Asian speleothem records, using all possible tie-points (i.e., including within the HS1/LGM interval), while also considering an alternative chronology that ignores tie-points that cannot be clearly identified in both the speleothem and Greenland ice-core stratigraphies within the HS1/LGM interval. The two possible stratigraphic alignments are illustrated in Fig. S2.

We use these two possible stratigraphic alignments, and their likely uncertainties (consisting of a uniform 50-y dating uncertainty plus a uniform 300-y correlation uncertainty), to derive "best guess," "maximum," and "minimum" age-scales for MD99-2334K. These age-scales (illustrated in Fig. S3) then provide the basis for calculating a range of surface reservoir ages in MD99-2334K. This is done by determining the difference between radiocarbon ages in MD99-2334K (placed on the best guess, maximum, and minimum chronologies) versus concurrent atmospheric radiocarbon ages from the *Intcal09* radiocarbon calibration curve (16) (0–10,670 y BP) and the Hulu H82 speleothem (11) (10,674–26,850 y BP).

For surface reservoir ages, we take the most conservative approach of only inferring reservoir ages at tie-points (using interpolated planktonic radiocarbon dates where necessary). These reservoir-age constraints are used to correct down-core planktonic radiocarbon dates (interpolating where necessary), which are then used to derive a *Bchron* (17) age-depth model that is consistent with both the structure in the down-core radiocarbon dates and the calendar age constraints from the two alternative speleothem chronostratigraphies. Deep-water reservoir ages [i.e., benthic versus atmosphere radiocarbon age offsets, or benthic–atmosphere (B-Atm)] are determined as the sum of the known down-core B-P offsets and interpolated surface reservoir ages, consistent with the best guess and bounding *Bchron* chronologies.

It is important to stress that this approach is preferable to simply placing the sediment core on two alternative stratigraphic age-models, based on linear interpolation between very sparse depth-age constraints, and then deriving offsets between planktonic and benthic radiocarbon dates versus atmospheric ages from the Hulu H82 speleothem (the resultant B-Atm ventilation age records are illustrated in Fig. S3 for comparison). The reason for this is that the latter approach ignores additional information on the structure of the age–depth relationship in MD99-2334K (i.e., from the succession of planktonic radiocarbon dates) in the intervals where there is no information on the likely age–depth relationship from chronostratigraphic tie-points (e.g., when tie-points in the HS1/LGM interval are ignored for the minimum age-model, as discussed earlier). Our approach essentially follows the premise that it is more reasonable to assume smooth/minimal changes in surface reservoir ages between exceedingly sparse chronostratigraphic constraints than to assume completely invariant sedimentation rates between exceedingly sparse chronostratigraphic constraints. Accordingly, the difference between the two approaches is maximized when the number of available chronostratigraphic tie-points is minimized.

Finally, by plotting optimum reservoir age estimates within a possible range, we underline the proposition that the likelihood distribution of possible reservoir/ventilation ages within the maximum/minimum range is probably not uniform. This proposition will be correct to the extent that the "best guess" speleothem chronology is also closest to being correct. It is notable that the radiocarbon age versus depth relationship in MD99-2334K has a similar shape to the calendar age versus depth relationship defined by the best guess chronology (Fig. S3). This is not the case for the age scale that would derive from a linear interpolation that ignores the possible age constraints in the LGM/HS1 interval. This would suggest that the best guess chronology is indeed more likely to be correct than one that ignores age constraints during the HS1/LGM interval.

Revised Ventilation Ages in MD07-3076. For consistency, it is important the two radiocarbon records we compare are both referenced to the same atmospheric radiocarbon dataset. For MD99-2334K, placed on the "speleothem age scale," we adopt the *Intcal09* and Hulu Cave radiocarbon records (11, 16), whereas the reservoir ages, chronology, and radiocarbon ventilation estimates from core MD07-3076 were originally derived using a splice of the *Intcal04* (18) (0–26,000 y BP) and Cariaco Basin (>26,045 y BP) (12) datasets. Using the same calendar age constraints on core MD07-3076 as originally published, we have reassessed the reservoir ages, the calibrated radiocarbon-age *Bchron* chronology, and the inferred B-Atm ventilation ages for MD07-3076, using the same *Intcal09*/Hulu atmospheric radiocarbon splice as used here for MD99-2334K. As shown in Fig. S4, this results in almost no change at all, except before ~20,000 y BP, where the revised ventilation ages in MD07-3076 are slightly older, yet still within the originally estimated uncertainty range (19).

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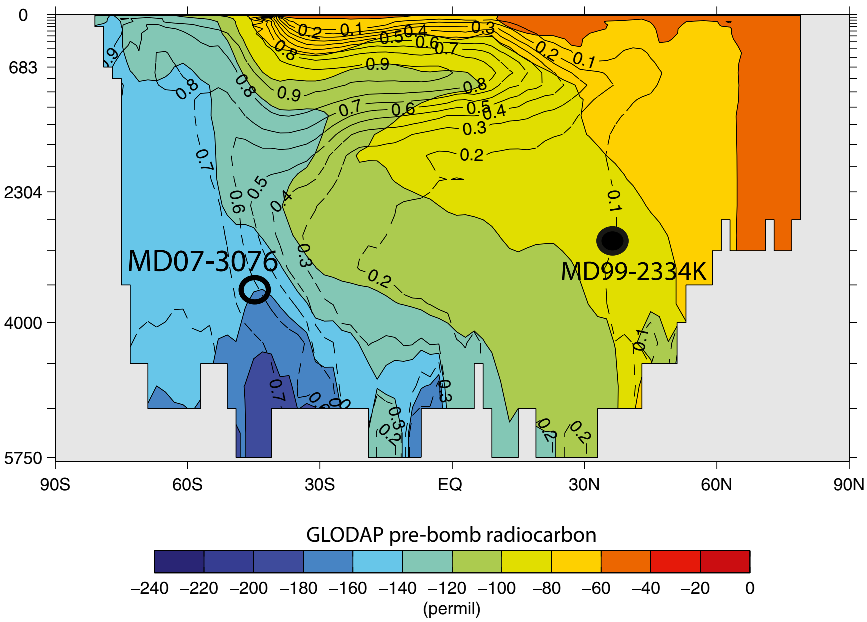

Fig. S1. Location of cores discussed in the text; MD99-2334K (37°48′N, 10°10′W; 3,146 m) and MD07-3076 (44° 4.46′S; 14°12.47′W, 3,770 m) are indicated by solid and open circles, respectively. Color shading indicates modern Global Data Analysis Project prebomb radiocarbon concentrations (20), and dashed contours indicate the proportion of water that last made contact with the surface Southern Ocean >40°S, based on the methods in ref. 2, courtesy of Primeau.

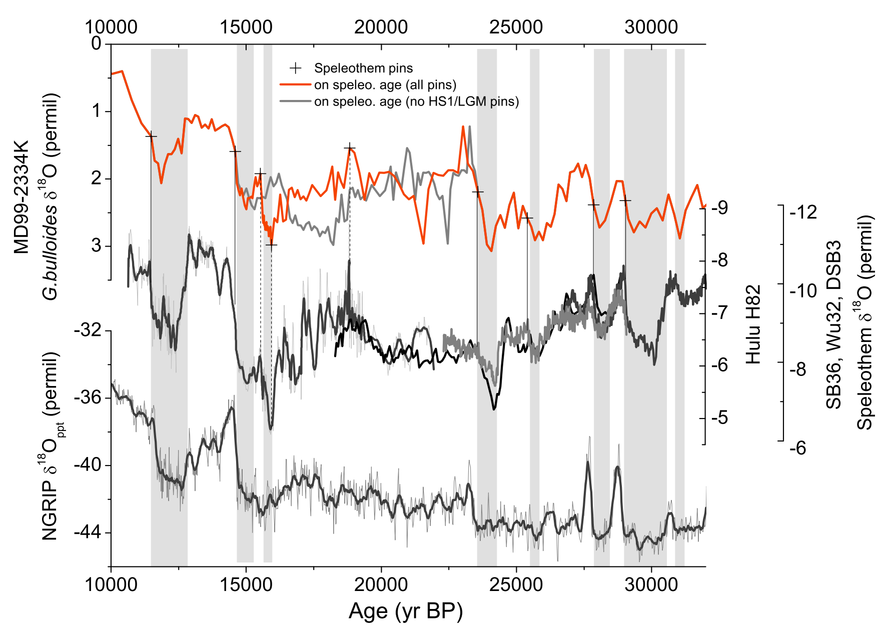

Fig. S2. Alignment of planktonic $\delta^{18}O$ measured in core MD99-2334K (6), with the Asian speleothem event stratigraphy (10, 11, 15). The Greenland (NGRIP) event stratigraphy on the GICC05 age scale is essentially identical (14), although it is difficult to identify the same tie-points as in the speleothem records within the HS1-LGM interval (crosses with dashed vertical drop-lines). Two bounding age scales are therefore considered in this study, one using all tie-points to the speleothem event stratigraphy (red line in top plot) and one that avoids using tie-points within the HS1-LGM interval (gray line in top plot).

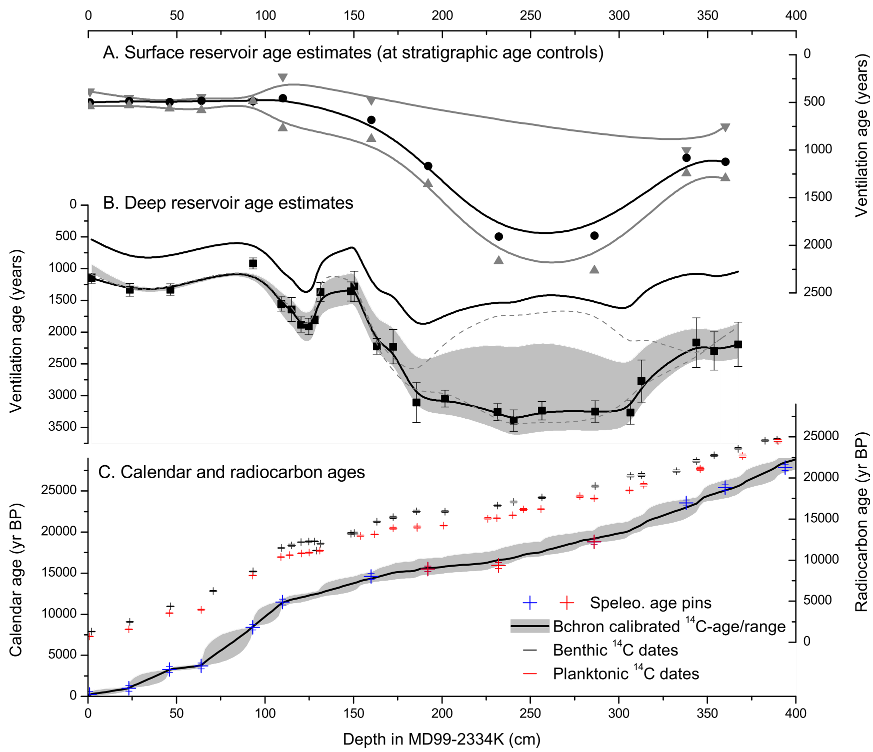

Fig. S3. (*A*) Best guess, maximum, and minimum likely surface reservoir ages in core MD99-2334K. (*B*) Deep ventilation ages (solid dark gray line indicates B-P offsets; solid black squares and line with 1σ radiocarbon dating uncertainties indicate best guess B-Atm offsets with maximum/minimum shaded range; dashed gray lines indicate alternative inferior ventilation histories as described in the text). (*C*) Benthic radiocarbon dates (black symbols) and planktonic radiocarbon dates (red symbols) compared with a range of *Bchron* calendar age–depth models (solid black line indicates the best guess or 50% cumulative probability age, and the shaded area indicates maximum/minimum or 2.5–97.5% cumulative probability age range), as well as the speleothem-based calendar age constraints on which these *Bchron* age-models are based (colored crosses). The maximum *Bchron* age-scale in *C* is derived from the minimum surface reservoir ages in *A*, which ignore the calendar age constraints within the HS1-LGM interval (red crosses in *C*). All error bars represent 1σ.

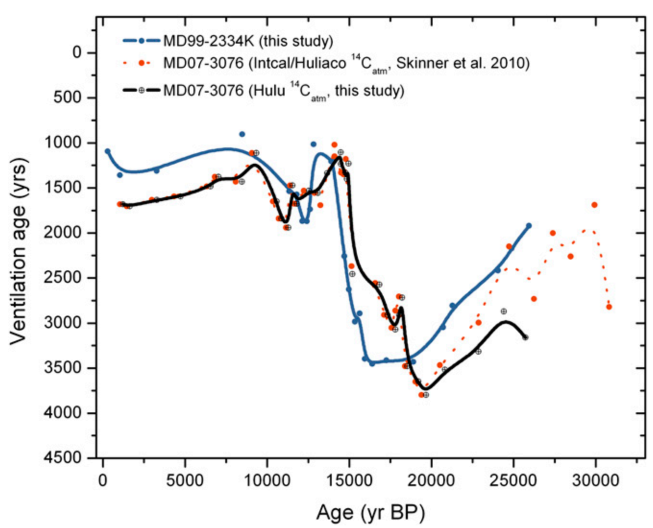

Fig. S4. Comparison of previously published ventilation age estimates from core MD07-3076 (19) [red circles and dotted line; referenced to the *Intcal04* and Cariaco Basin radiocarbon records (12, 18)], with the revised estimates presented in Fig. 2 [black crossed circles and solid line; referenced to the *Intcal09* and Hulu speleothem atmospheric radiocarbon records instead (11, 16)]. The Hulu speleothem record only extends to 25,850 y BP.

Other Supporting Information Files

Dataset S1 (TXT)
Dataset S2 (TXT)