Age differences between Atlantic and Pacific benthic δ¹⁸O at terminations

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Abstract

Benthic δ¹⁸O is often used as a stratigraphic tool to place marine records on a common age model and as a proxy for the timing of volume/ocean level change. However, Skinner & Shackleton (2005) found that the timing of benthic δ¹⁸O change at the last termination differed by 4000 years between two sites in the Atlantic and Pacific. Do these results imply that benthic δ¹⁸O change may not accurately record the timing of terminations? We compare benthic δ¹⁸O records from 34 sites in the Atlantic and Pacific to evaluate differences in the timing of terminations as recorded by benthic δ¹⁸O. Statistical analysis of sedimentation rates derived from the alignment of benthic δ¹⁸O suggests an Atlantic lead over Pacific benthic δ¹⁸O change during the last 6 terminations. We estimate an average termination age difference of 1300 years between the Atlantic and Pacific, approximately consistent with the delay expected due to ocean mixing rates, given that most glacial meltwater probably enters the North Atlantic. However, we also find evidence of brief 4000 yr lags during the middle of several terminations, suggesting that termination mid-points may make poor δ¹⁸O tie points.

Introduction

Because a large fraction of benthic δ¹⁸O change is due to glacial volume/sea level change, benthic δ¹⁸O is often used as a stratigraphic tool to place marine records on a common age model and as a proxy for the timing of volume/ocean level change. These applications require the assumptions that benthic δ¹⁸O change is rapidly transmitted throughout the deep ocean and that the effects of hydrographic changes are in phase with ice volume.

Recently, Skinner & Shackleton (2005) found that the timing of benthic δ¹⁸O change at the last termination differed by ~4000 years between two sites in the Atlantic and Pacific (Figure A). Based on Mg/Ca paleothermometry, they argued that these age discrepancies resulted from a signal lagging, with a time-scale dependent on the Pacific and millennial-scale circulation changes in the Atlantic. Such a large discrepancy in δ¹⁸O change would produce significant age model errors when the alignment of δ¹⁸O stratigraphy is based on termination mid-points. Additionally, this suggests that benthic δ¹⁸O change may not always be a reliable indicator of the timing of sea level change.

Here we compare benthic δ¹⁸O records from 34 sites in the Atlantic and Pacific to evaluate differences in the timing of terminations as recorded by benthic δ¹⁸O.

Methods

The age or duration of terminations (other than the most recent, T1) cannot be measured directly. Instead we compare sedimentation rates during terminations to examine whether the change in benthic δ¹⁸O at terminations may be delayed or slower in the Pacific than in the Atlantic. Aligning Pacific δ¹⁸O to Atlantic δ¹⁸O should produce a spike in Pacific sedimentation rates at the same time as the spikes in sedimentation rates in the Atlantic terminations. We align the benthic δ¹⁸O records of 20 Atlantic and 14 Pacific sites to the LR04 benthic δ¹⁸O stack (Lisiecki & Raymo, 2005) using an automated genetic combinatorial algorithm (Lisiecki & Shackleton, 2002) (Figure B). Figure C shows the sedimentation rates of each site and their geologic mean. Because uncertainty in our age model affects absolute sedimentation rates, we focus on the ratio of Pacific to Atlantic sedimentation rates (Figure D), which is independent of age model.

We must also address the fact that glacial cycles produce large sedimentation rate changes at many sites. This is particularly common for averaging the sedimentation rates of many globally distributed sites. However, glacial cyclicity remains in the ratio of Pacific to Atlantic mean sedimentation rate (Figure D) due to basin-wide sedimentation changes. In addition to 100-kyr cyclicity, the sed rate ratio also clearly shows rapid, large changes at some terminations (T1, T2, T4 and T7).

To test the statistical significance of the termination changes, we calculate the deviation of the sed rate ratio relative its 13-kyr running mean (Figure E). Over the last 550 kyr, deviations in the sed rate ratio above the 2σ limit are uniquely associated with terminations and the pseudo-termination preceding MIS 7. Integrating the area under each termination spike relative to pre- and post-termination sed rates provides an estimate of the average duration difference between Atlantic and Pacific δ¹⁸O change (Figure D).

Results

We create Atlantic and Pacific δ¹⁸O stacks for the last 5 terminations using 2σ points only at the start and end of each termination and averaging data in 2-kyr intervals (Figure F). We also adjust the duration of Pacific δ¹⁸O change by assuming that the duration differences calculated in Figure D result solely from lags in terminations. By simply adjusting the radiocarbon age all mid-termination, δ¹⁸O change appears to begin in nearly the same time in both oceans. Our sed rate results also suggest that a Pacific δ¹⁸O lag of the Atlantic by less than 1.2 kyr at the end of terminations.

Figure F shows the maximum lag between mean Pacific and Atlantic δ¹⁸O to be 2 kyr in T1.5, 2.5 kyr in T3, 4 kyr in T7, 4 kyr in T4 and 7.5 kyr in T5. The mean lag for all five terminations is only 1.3 kyr.

Discussion of Uncertainty

Age model uncertainty is ~4 kyr, but uncertainty in Pacific-Atlantic δ¹⁸O differences should be only ~2 kyr. Our results describe average differences between ocean basins. Lags may vary depending on the specific hydrological setting of a particular site.

Our analysis is based on the assumption that sed rate changes during terminations are small or randomly distributed. This assumption clearly fails at some study sites. Widespread, termination-specific changes in sed rates (e.g., due to RIR deposition, abyssal currents, or carbonate dissolution) would produce errors in our results. For example, RIR could lead to a longer termination stratigraphy in the North Atlantic and lead us to underestimate Pacific lags. Excluding the 5 North Atlantic sites with highly variable RIR content from our analyses results in changes in termination duration of only 0.2 kyr.

Conclusions

• For the last 5 terminations, Pacific benthic δ¹⁸O change lags the Atlantic by an average of 1.3 kyr.
• During some terminations this lag briefly increases to ~4 kyr, perhaps due to the hydrographic changes described by Skinner & Shackleton (2005).
• Because we find no evidence for large age offsets at the beginning or end of terminations, these points make better δ¹⁸O tie points than terminations midpoints.
• The timing of δ¹⁸O change at individual sites could vary significantly from the basin-wide averages presented here.

References


Original reference for benthic δ¹⁸O records can be found in Lisiecki & Raymo (2005).