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Decoupling between the carbon cycle and climate during Pleistocene glaciations

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Abstract

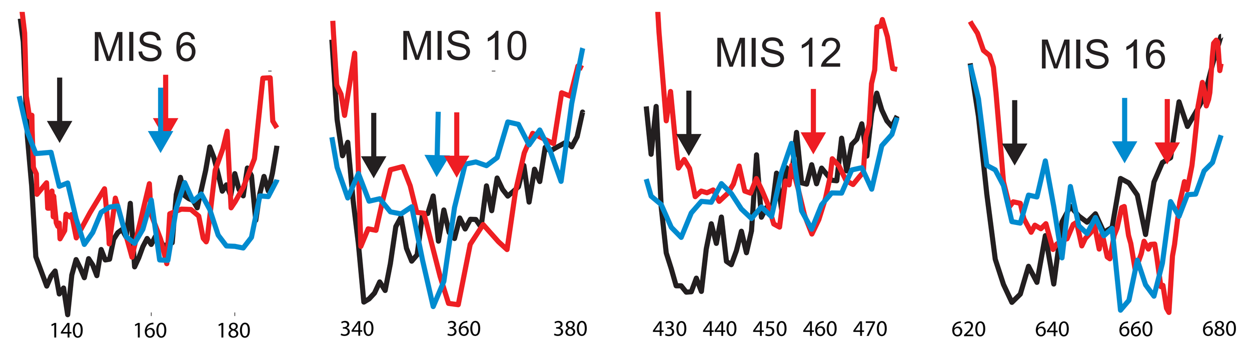
We present a Pacific $\delta^{13}C$ stack (3300-3850 m water depth) of the last 800 kyr and compare it to atmospheric CO_2 concentration [1, 2, 3], Antarctic temperature [4], and benthic $\delta^{18}O$ [5]. We find that the carbon cycle proxies $\delta^{13}C$ and CO_2 share some features which differ from records of Antarctic temperature and benthic $\delta^{18}O$. For example, the carbon cycle proxies reach their most extreme glacial values 10-30 kyr before the glacial maximum during five of the last eight glacial cycles. We suggest that 30-50% of glacial-interglacial change in the Pacific $\delta^{13}C$ stack may derive from changes in the ventilation of the deep Pacific, providing a link between $\delta^{13}C$ and CO_2. Additionally, the agreement of benthic $\delta^{13}C$ and CO_2 during Termination 6 and MIS 18 suggest that these apparent discrepancies between the EDC3 [6] and LR04 [5] chronologies represent real carbon cycle lags rather than age model errors.

Methods

Benthic $\delta^{18}O$ is a proxy for high-latitude climate, which records changes in global ice volume and deep water temperature. Mean ocean $\delta^{13}C$ records changes in terrestrial organic carbon storage during glacial cycles [7]. Deep Pacific $\delta^{13}C$ may also contain a circulation signal, reflecting reduced ventilation of these waters during glaciations [8, 9]. We construct a Pacific benthic $\delta^{13}C$ stack by averaging the benthic $\delta^{13}C$ records from ODP sites 677 [10], 846 [11], and 849 [12] (3300-3850 m). Age models are based on the alignment of benthic $\delta^{18}O$ from each site to the LR04 benthic $\delta^{18}O$ stack [5], which is orbitally tuned and constrained by global mean sedimentation rates. Atmospheric CO_2 concentrations [1, 2, 3] and ice δD (Antarctic temperature) [4] are on the EDC3 age model [6] based on 1) a snow accumulation and mechanical flow model, and 2) a large set of absolute and orbitally tuned age estimates.

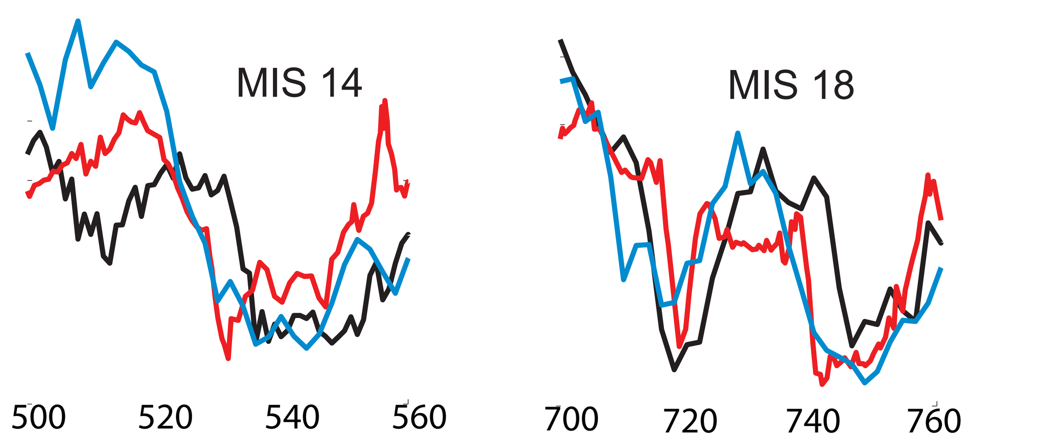
Glacial Maxima

The carbon cycle proxies $\delta^{13}C$ and CO_2 reach their most extreme glacial values 10-30 kyr before the glacial maximum in benthic $\delta^{18}O$ during MIS 6, 8, 10, 16 and 18. Antarctic temperature (δD) is intermediate between CO_2 and benthic $\delta^{18}O$ during MIS 10, 12, and 16.



Terminations

During the warming trends of Termination 6 and MIS 18, $\delta^{13}C$ and CO_2 lag benthic $\delta^{18}O$ by ~10 kyr. This suggests that the difference between benthic $\delta^{18}O$ and CO_2 is not an artifact of comparing different age models. These asynchronous warming trends differ from typical terminations in that full interglacial levels are not reached.



Interpretation

Our Pacific benthic $\delta^{13}C$ stack has a LGM-Holocene difference of -0.45‰, compared to a mean ocean $\delta^{13}C$ change of 0.3‰ [13, 14]. This suggests that 30% of Pacific $\delta^{13}C$ change at 3300-3800 m depth may be due to circulation change (perhaps 50% for earlier cycles with greater $\delta^{13}C$ amplitudes). Box models [8] and GCM simulations [9] demonstrate that reduced ventilation of the deep Southern Ocean can draw down CO_2, decrease Pacific $\delta^{13}C$ below ~3000 m, and increase Pacific $\delta^{13}C$ above ~3000 m.

Pacific $\delta^{13}C$ has a better correlation with CO_2 (r=0.66) than deep South Atlantic $\delta^{13}C$ does (r=0.56), presumably because the deep Pacific represents a larger CO_2 reservoir than the deep South Atlantic. If the 500-kyr cycle in benthic $\delta^{13}C$ [15] is removed, the Pacific correlation improves to 0.75. The correlation between benthic $\delta^{18}O$ and CO_2 is slightly higher (0.83) perhaps due to greater noise in the $\delta^{13}C$ stack based on only three sites.

Coupling between terrestrial organic carbon storage and atmospheric CO_2 provides another possible link between Pacific $\delta^{13}C$ and CO_2.

Conclusions

- Deep Pacific $\delta^{13}C$ and CO_2 share some features which differ from benthic $\delta^{18}O$. Most notably, the carbon cycle proxies tend reach their most extreme glacial values 10-30 kyr before the glacial maximum in benthic $\delta^{18}O$.
- Additionally, $\delta^{13}C$ and CO_2 lag benthic $\delta^{18}O$ by ~10 kyr at ~530 ka and ~740 ka. The agreement between $\delta^{13}C$ and CO_2 suggests that these are real lags between climate and the carbon cycle rather than differences between the marine and ice core age models.
- 30-50% of change in the Pacific benthic $\delta^{13}C$ stack may derive from changes in deep

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