El Niño in the Eocene greenhouse recorded by fossil bivalves and wood from Antarctica

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[1] Quasi-periodic variation in sea-surface temperature, precipitation, and sea-level pressure in the equatorial Pacific known as the El Niño – Southern Oscillation (ENSO) is an important mode of interannual variability in global climate. A collapse of the tropical Pacific onto a state resembling a so-called 'permanent El Niño', with a preferentially warmed eastern equatorial Pacific, flatter thermocline, and reduced interannual variability, in a warmer world is predicted by prevailing ENSO theory. If correct, future warming will be accompanied by a shift toward persistent conditions resembling El Niño years today, with major implications for global hydrological cycles and consequent impacts on socioeconomic and ecological systems. However, much uncertainty remains about how interannual variability will be affected. Here, we present multi-annual records of climate derived from growth increment widths in fossil bivalves and co-occurring driftwood from the Antarctic peninsula that demonstrate significant variability in the quasi-biennial and 3–6 year bands consistent with ENSO, despite early Eocene (~50 Mya) greenhouse conditions with global average temperature ~10 degrees higher than today. A coupled climate model suggests an ENSO signal and teleconnections to this region during the Eocene, much like today. The presence of ENSO variation during this markedly warmer interval argues for the persistence of robust interannual variability in our future greenhouse world. **Citation:** Ivany, L. C., T. Brey, M. Huber, D. P. Buick, and B. R. Schöne (2011), El Niño in the Eocene greenhouse recorded by fossil bivalves and wood from Antarctica, *Geophys. Res. Lett.*, *38*, L16709, doi:10.1029/2011GL048635.

1. Introduction

[2] Will climate oscillations in the 2–7 year ENSO band persist as our planet warms, or will the Earth move toward a permanent El Niño or La Niña-like state? Short of waiting for the future to happen, answering this question relies on predictions drawn from dynamical theories and coupled climate models or on insights drawn from warm intervals in the Earth's past. Most models and theory favor progression toward one or the other end-member state, but some argue for no change, and observational data are equivocal [*Fedorov and Philander*, 2001; *Fedorov et al.*, 2006; *Vecchi et al.*, 2008; *Collins et al.*, 2010]. Therefore, there is significant disagreement about which of these is more likely [*Vecchi et al.*, 2008; *Karnauskas et al.*, 2009]. Given this uncertainty, paleoclimate data can provide key insights. Datasets from the early Pliocene warm period (~3–5 mya), for example, indicate a flatter thermocline and comparatively warm temperatures in the eastern equatorial Pacific [*Molnar and Cane*, 2002; *Wara et al.*, 2005; *Fedorov et al.*, 2006], indicating a shift toward more El Niño-like mean conditions. However climate models have not produced a reduction in this variation, and a recent dataset suggests instead the persistence of ENSO-scale variability [*Watanabe et al.*, 2011]. It therefore remains an open question whether a warmer world is characterized by a less variable tropical Pacific.

[3] Demonstrating interannual variability in warmer worlds of the past offers an approach to evaluating predictions for the future, but this is not a simple task. Long, continuous, annually-resolved records from times when the planet was significantly warmer than today and from a region where the ENSO signal is expected to be strong are required. Such proxy datasets from the rock record are rare, however, as sediment and ice cores generally do not retain annual resolution far enough back in time to reach markedly warmer climate conditions. Previous attempts to investigate this issue in the distant past rely on varved sediment records, which might be challenged as not reflecting true interannual variability [*Ripepe et al.*, 1991; *Huber and Caballero*, 2003; *Galeotti et al.*, 2010; *Lenz et al.*, 2010; *Davies et al.*, 2011].

2. Interannual Variation Derived From Growth Increments

[4] Life histories of long-lived organisms that grow by accretion and preserve well in the fossil record have the potential to offer an archive with which to evaluate predictions of ENSO-like behavior in the distant past. Changes in environmental conditions that occur seasonally generally lead to changes in skeletal growth rate that manifest as visible growth bands, such as those seen in the wood of trees. If the widths of annual growth increments correlate with environmental variables, then long records of consecutive increment widths can be used to test for interannual variation in the ENSO band. Many authors have explicitly tied variation in increment widths and shell chemistry of modern long-lived bivalves to observed variations in temperature and primary production (food supply) [*Kennish and Olsson*, 1975; *Jones et al.*, 1989; *Schöne et al.*, 2003; *Strom et al.*, 2004; *Schöne et al.*, 2005; *Ambrose et al.*, 2006; *Black et al.*, 2009; *Butler*

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