

## El Niño during the last glacial maximum

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Reconstructions of the El Niño-Southern Oscillation (ENSO) in the geologic past are arguably the most promising avenue for understanding its long-term dynamics and its sensitivity to climate change. While much effort has focused on ENSO variability during the Holocene, insights from other climatic periods are essential for a broader understanding of ENSO dynamics over a wide spectrum of background climate conditions. Here we report the first paleoceanographic evidence for significant amplification of ENSO variability during the Last Glacial Maximum (LGM), based on oxygen isotopic analyses of individual foraminifera from core V21-30 in the Galapagos Islands. Over 1200 isotopic analyses on individual *G. ruber* were carried out in the Holocene and glacial sections of the core, documenting changes in ENSO variance during the middle-late Holocene and the LGM. Compared with the Late Holocene, oxygen isotopic results indicate a mid-Holocene decrease in total variance by 40% and an LGM increase of 30%. After accounting for the contribution of the annual cycle to the total reconstructed variance, we estimate that interannual ENSO variance was nearly zero in the mid-Holocene (absent ENSO), while in the LGM it was higher by 30-50%. What do these results imply about long-term ENSO dynamics? We show that the amplification of ENSO during the LGM is linked to a dampening of the equatorial annual cycle of SST, which was tied to a relaxation of the cross-equatorial cold tongue/ITCZ frontal complex, itself tied to a southward-displaced ITCZ. The results have implications for the future evolution of ENSO under a warming climate, and can further help evaluate which model predictions of the future ENSO response have greater validity.

## O-H absorption coefficients of four common mechanisms for water substitution in olivine

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There are four ways by which OH<sup>-</sup> commonly substitutes into olivine: associated with Si or Mg vacancies, or with Ti or trivalent cations [1, 2]. The four mechanisms, which we label [Si], [Mg], [Ti] and [triv] respectively, may each be fingerprinted by their characteristic absorption peaks associated with O-H stretching modes in the infra-red spectrum. We show by comparing the integrated intensity of absorption of these characteristic IR peaks against total water analysed by SIMS, obtained for a suite of synthetic olivines plus one natural olivine, that the different substitution mechanisms require different absorption coefficients (*k*). For [Ti], we find  $k = 0.182 \pm 0.067$ , identical to the value previously obtained from natural olivines in which the water was mainly present associated with [Ti] defects [3]. Values of *k* for [Si] and [triv] are  $0.572 \pm 0.041$  and  $0.178 \pm 0.049$  respectively; that for [Mg] is too small to be accurately determined ( $0.03 \pm 0.03$ ). This significant variation in absorption coefficients emphasises the importance of distinguishing the substitution mechanism if meaningful quantitative results are to be obtained from infra-red spectroscopy.

[1] Berry *et al.* (2005) *Geology* **33**, 869-872. [2] Berry *et al.* (2007) *Earth Planet. Sci. Let.* **216**, 134-142. [3] Bell *et al.* (2003) *J. Geophys. Res.* **108**, 2105-2113.