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Last Glacial Period hydrology of Lake Peten Itza (Guatemala) constrained with triple oxygen and hydrogen isotopes

Thomas Bauska (1), Fernando Gázquez (1,4), Anna-Lena Grauel (2), Daniel Herwartz (3), and David Hodell (1)

(1) University of Cambridge, Earth Sciences, Cambridge, United Kingdom (tkb28@cam.ac.uk), (2) Technische Universität Graz, 2210 Institut für Angewandte Geowissenschaften 8010 Graz, Rechbauerstraße 12, (3) Institute für Geology und Mineralogy. Universität zu Köln. Greinstrasse. 4-6, 50939, Köln, Germany. , (4) School of Earth and Environmental Sciences. University of St. Andrews. St Andrews, KY16 9AL, Scotland, United Kingdom.

Robust reconstructions of changes in the hydrological cycles remain challenging in large part due to the qualitative nature of most proxy systems. Here we utilize gypsum hydration water, a unique archive that records past changes in the complete isotopic composition of lake water (^{16}O, ^{17}O, ^{18}O, D, H). In Lake Peten Itza (16.55N, 89.50W), located in the lowland Neotropics of Guatemala, intervals of gypsum deposition are limited to the coldest intervals (stadials) of the last glacial cycle and last deglaciation, thus providing snapshots of the lake water δ^{17}O, δ^{18}O and δD (and derived parameters d-excess and ^{17}O-excess) during periods of abrupt climate change. As shown previously, these direct estimates of lake water δ^{18}O with coeval histories of carbonate δ^{18}O provide powerful constraints on lake temperature (Hodell et al., 2012; Grauel et al., 2016). Beyond temperature, derived parameters d-excess and ^{17}O-excess, which are sensitive to kinetic fractionation during evaporation, offer the possibility of reconstructing changes in ratio of evaporation to inflow and the relative humidity over the lake surface.

To provide quantitative climatic and hydrologic histories of the lake over the last $\sim$40,000 years we employ two novel modelling techniques. First we use a steady-state model of lake water isotopes in a Monte Carlo framework to explore the range of solutions for temperature, relatively humidity and lake connectivity (evaporation to inflow) that simultaneous satisfy all isotopes data constraints. Assuming the lake remained near the present day connectivity but allowing for shifts in the isotopic composition of the precipitation, the data suggest that the extreme cold events of the last glacial period are accompanied by reductions in relative humidity (possibly of 10%). We then drive a forward model of the lake that incorporates realistic bathymetry and climate variables such as temperature, relative humidity and precipitation from reanalysis data and model output. The model produces histories of lake level, the complete suite of water isotopes, calcium, sulphate, other ionic species and gypsum precipitation that can be subsequently reduced to set of plausible scenarios. These quantitative estimates of past temperature, relative humidity, evaporation to inflow, can be compared to numerical climate model simulations, which have had difficulty simulating the magnitude of the cold, dry conditions implied by the paleoclimate data from the lowland Neotropics.