Noble Gases Record Widespread Six Degrees Celsius Low-Latitude Land Cooling During the Last Glacial Maximum

Jessica Ng[1], Alan Seltzer[2], Werner Aeschbach[3], Rolf Kipfer[4], Justin Kulongoski[5], Jeffrey Severinghaus[1], and Martin Stute[6]

[1]Scripps Institution of Oceanography
[2]Woods Hole Oceanographic Institution
[3]Heidelberg University
[4]EAWAG Swiss Federal Institute of Aquatic Science and Technology
[5]Univ California San Diego
[6]Barnard College

November 22, 2022

Abstract

Estimates of climate sensitivity rely in part on the magnitude of global cooling during the Last Glacial Maximum (LGM). While ice cores provide reliable LGM temperatures in high-latitude regions, proxy records of sea-surface temperature (SST) disagree substantially in the low latitudes (1-3), and quantitative low-elevation paleotemperature records on land are scarce. Filling this gap, noble gases in groundwater record land surface temperatures via their temperature-dependent solubility in water (4), a direct physical relationship uncomplicated by biological and chemical processes (5-6). Individual groundwater noble gas studies (e.g. 7-8) have shown 5-7 °C LGM cooling, in line with some proxy data (e.g. tropical snowline reconstructions) but larger than notable low-latitude SST reconstructions considering land-sea cooling ratios. To date, limited spatial coverage and the use of different physical frameworks to determine temperature from noble gas data has prevented a comprehensive estimate of low-latitude LGM cooling from noble gases in groundwater. Here we compile four decades of groundwater noble gas data from six continents, all interpreted using a consistent physical framework (9). We evaluate the accuracy of the "noble gas paleothermometer" by comparing noble gas derived temperatures in late Holocene groundwater with modern observations. From LGM noble gas data, we find that the low-elevation, low-to-mid-latitude land surface cooled by 5.8 $\pm$ 0.6 °C during the LGM (9). The ratio of our land cooling estimate to a recent SST reconstruction (1) that found 4.0 °C cooling over the same low latitude band is consistent with the inter-model mean land-sea cooling ratio of 1.45 °C from PMIP4 simulations (10). Together, these recent land- and sea-surface LGM temperature reconstructions indicate greater low-latitude cooling and thus climate sensitivity than prior studies, with implications for projections of future climate. 1) Tierney et al. (2020). *Nature.* 2) CLIMAP Project Members (1976). *Science.* 3) MARGO Project Members (2009). *Nat. Geosci.* 4) Jenkins et al. (2019). *Mar. Chem.* 5) Aeschbach et al. (2000). *Nature.* 6) Kipfer et al. (2002). *Rev. Mineral. Geochem.* 7) Stute et al. (1995). *Science.* 8) Weyhenmeyer et al. (2000). *Science.* 9) Seltzer et al. (2021). *Nature.* 10) Kageyama et al. (2021). *Clim. Past.*

Title: Noble Gases Record Widespread Six Degrees Celsius Low-Latitude Land Cooling During the Last Glacial Maximum

Authors: Jessica Ng, Alan M. Seltzer, Werner Aeschbach, Rolf Kipfer, Justin T. Kulongoski, Jeffrey P. Severinghaus, Martin Stute

Estimates of climate sensitivity rely in part on the magnitude of global cooling during the Last Glacial Maximum (LGM). While ice cores provide reliable LGM temperatures in high-latitude regions, proxy records of sea-surface temperature (SST) disagree substantially in the low latitudes (1-3), and quantitative low-elevation paleotemperature records on land are scarce.

Filling this gap, noble gases in groundwater record land surface temperatures via their temperature-dependent solubility in water (4), a direct physical relationship uncomplicated by biological and chemical processes (5-6). Individual groundwater noble gas studies (e.g. 7-8) have shown 5-7 °C LGM cooling, in line with some proxy data (e.g. tropical snowline reconstructions) but larger than notable low-latitude SST reconstructions considering land-sea cooling ratios. To date, limited spatial coverage and the use of different physical frameworks to determine temperature from noble gas data has prevented a comprehensive estimate of low-latitude LGM cooling from noble gases in groundwater.

Here we compile four decades of groundwater noble gas data from six continents, all interpreted using a consistent physical framework (9). We evaluate the accuracy of the “noble gas paleothermometer” by comparing noble gas derived temperatures in late Holocene groundwater with modern observations. From LGM noble gas data, we find that the low-elevation, low-to-mid-latitude land surface cooled by 5.8 ± 0.6 °C during the LGM (9). The ratio of our land cooling estimate to a recent SST reconstruction (1) that found 4.0 °C cooling over the same low latitude band is consistent with the inter-model mean land-sea cooling ratio of 1.45 °C from PMIP4 simulations (10). Together, these recent land- and sea-surface LGM temperature reconstructions indicate greater low-latitude cooling and thus climate sensitivity than prior studies, with implications for projections of future climate.

1) Tierney et al. (2020). *Nature*. 2) CLIMAP Project Members (1976). *Science*. 3) MARGO Project Members (2009). *Nat. Geosci*. 4) Jenkins et al. (2019). *Mar. Chem*. 5) Aeschbach et al. (2000). *Nature.* 6) Kipfer et al. (2002). *Rev. Mineral. Geochem*. 7) Stute et al. (1995). *Science*. 8) Weyhenmeyer et al. (2000). *Science*. 9) Seltzer et al. (2021). *Nature*. 10) Kageyama et al. (2021). *Clim. Past.*