EGU23-1752, updated on 15 Apr 2024
https://doi.org/10.5194/egusphere-egu23-1752
EGU General Assembly 2023
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The influence of North Atlantic Oscillation on oxygen and hydrogen stable isotopes in precipitation of the Late Cenozoic: implications on paleoenvironment reconstructions

Daniel Boateng, Sebastian G. Mutz, and Todd A. Ehlers
University of Tübingen, Department of Geosciences, Tübingen, Germany (daniel.boateng@uni-tuebingen.de)

Stable isotope ratios of oxygen ($\delta^{18}O_p$) and hydrogen (δD_p) record information about the hydrological cycle. These signals are preserved in natural archives, such as speleothems, stalagmites, ice cores, and pedogenic carbonates. Recent studies have used these proxy records of water isotopologues to reconstruct the evolution of paleoclimates, paleoenvironments, and even tectonic-related changes in surface elevations. However, such reconstructions require information about the atmospheric dynamics that drive the spatial variability of isotopic ratios. $\delta^{18}O_p$ and δD_p are known to reflect the history of air masses, surface temperature, precipitation, and synoptic-scale atmospheric teleconnection patterns like the North Atlantic Oscillation (NAO). Climate-driven variations in these data can complicate their interpretation of geologic processes. The NAO is the predominant mode of inter-annual and seasonal variability that controls the weather and climate system across the North Atlantic region and continental Europe. The influence of the NAO on the Global Network of Isotopes in Precipitation (GNIP) stations records of $\delta^{18}O_p$ and δD_p across Europe was previously studied in the winter season when the NAO impacts are well defined.

Here we build upon previous work by (1) investigating the present-day NAO-$\delta^{18}O_p$ and -δD_p relationships and their associated atmospheric dynamics and causal mechanism in all seasons, and (2) studying the NAO's influence on the $\delta^{18}O$ and δD in precipitation in the late Cenozoic. We focus on the latter since many $\delta^{18}O_p$- and δD_p-based studies tackle problems in the Late Cenozoic. In addition, important characteristics of such pressure systems (e.g., the location of the centers of maximum and minimum pressures and axis of polarity) may change over longer (centennial to geological) time scales in response to different forcings such as atmospheric CO_2, paleogeography, orbital changes, and land-surface cover. To achieve the study's first goal, we explore the NAO-$\delta^{18}O_p$ and -δD_p link by tracking the NAO in the ERA5 reanalysis data and relating its variability with GNIP observational data across Europe. For the second goal, we use the isotope-enabled Atmospheric General Circulation Model ECHAM5-wiso to perform time-specific, high spatial resolution (paleo)climate simulations with (paleo)environmental conditions of the middle Miocene (~14 Ma), the mid-Pliocene (~3 Ma), the Last Glacial Maximum (~21 ka), the mid-Holocene (~6.5 ka), the pre-industrial (the reference year 1850) and the present-day (1979-2000). We then transfer the analyses from the first step to our paleoclimate simulation output, using the present-day simulation for calibration. Our results help reconstruct the NAO from proxy archives and provide

context for more refined interpretations of the isotopic ratios of rainwater in proxy archives.