SIMULATING HYDROCLIMATE CHANGE IN SOUTHWEST NORTH AMERICA AT 21,000 YEARS AGO

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EXECUTIVE SUMMARY

How the hydroclimate in Southwest North America will change in the future remains an open question. Although models generally predict an increase in climate extremes in this region with both more severe droughts and more intense precipitation events, large uncertainties remain. By studying the past, we can improve our understanding of the mechanisms driving current and future hydroclimate change in the area.

Records suggest that the hydroclimate of this region was drastically different during much of the last glacial cycle. However, the various mechanisms that produced these signals are difficult to deconvolve and continue to be debated. In this project, the research team employed a high-resolution, water isotope-enabled Earth system model for simulations of the last glacial maximum and preindustrial climates. The combination of water isotope tracers and high resolution allows for more direct comparison of the model outputs with the proxy records.

RESEARCH CHALLENGE

Southwest North America has proven to be climatically sensitive over the observational record. However, confidence in model projections of that region's climate is limited by an incomplete understanding of the complex interactions driving regional climate variability and the unprecedented nature of future climate perturbation [1,2]. To better understand the range of possible climates in Southwest North America and provide additional sources of model validation, researchers can look to the past. Fortunately, this region has been particularly well surveyed, with some of the densest and most diverse coverage of paleoclimate proxy records available in the mid-latitudes. Of the many proxy archives gathered in Southwest North America, measurements of $\delta^{18}O$ (a measure of the ratio of stable isotopes oxygen-18 and oxygen-16) in cave records, known as speleothems, have proven to be particularly valuable. These records suggest that in contrast to today, the hydroclimate of Southwest North America was cold and wet during much of the last glacial cycle [3,4]. However, the various mechanisms that produced these $\delta^{18}O$ signals are difficult to deconvolve and continue to be debated.

Comparisons between climate model outputs and cave records are difficult. One common limitation relates to the heterogeneity of the land surface. Many proxy sites, especially those located in Southwest North America, are found in topographically diverse regions that create drastically different microclimates within a few hundred kilometers. In contrast, climate models typically do not resolve such fine spatial scales (Fig. 1), which limits the utility of models for mechanistically understanding this unique climate proxy. Another limitation comes from the indirect comparison of model variables such as temperature and precipitation with the $\delta^{18}O$ values found in the cave records. To overcome these common limitations of model–proxy comparison, the research team used a high-resolution, water isotope-enabled Earth system model to simulate the last glacial maximum (21,000 years ago) and preindustrial climates. These experiments shed light on the driving mechanisms behind the dynamic hydroclimatic changes that have been suggested in Southwest North America from more than a century of paleoclimate research.

METHODS & CODES

For this project, the team used the Community Earth System Model (CESM) with prognostic water isotopologue tracking. CESM is a widely employed, Intergovernmental Panel on Climate Change-class Earth-system model with the ability to accurately simulate preindustrial and present-day climates [5]. This version of CESM, known as iCESM, can track $\delta^{18}O$ and $\delta^{2}H$ in atmosphere, ocean, land, and sea ice components. Previous studies demonstrated that the $\delta^{18}O$ and $\delta^{2}H$ distributions within this version of CESM compare favorably with other isotope-enabled models of similar complexity [6]. Further, this version of CESM can track the transport of water in the atmosphere, allowing for a precise understanding of the mechanisms responsible for changes in isotopic composition of precipitation [7]. Given the topographic heterogeneity of Southwest North America, the team will perform isotope-enabled atmosphere and land-only simulations at approximately 0.25° resolution using prescribed sea surface temperatures.

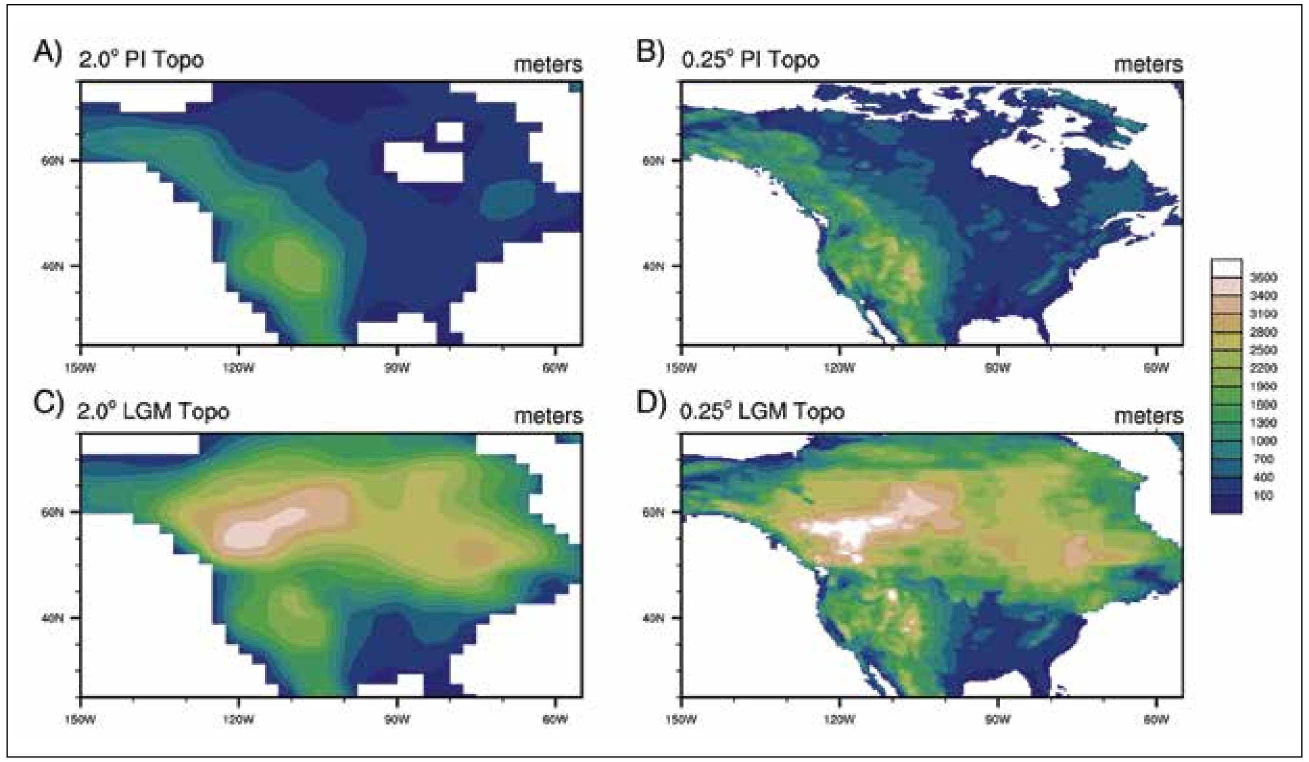

Figure 1: North American topography used in preindustrial and last glacial maximum (21 kiloannum) model simulations. (A) and (B) show preindustrial topography using the standard- (1.9 x 2.5°) and high- (0.23 x 0.31°) resolution model configuration, respectively. (C) and (D) show last glacial maximum topography using the standard- (1.9 x 2.5°) and high- (0.23 x 0.31°) resolution model configuration, respectively.

RESULTS & IMPACT

It is clear that further investigation is necessary to determine the most important mechanisms for driving the pattern of hydroclimatic change at the last glacial maximum. The combination of water isotope-enabled model experiments with speleothem records will allow the team to disentangle the influences of moisture source and transport, temperature, and precipitation amount on speleothem proxy records, an understanding that can be applied broadly to improve proxy interpretations across the region. From the results, the research group will be able to distinguish between several long-standing hypotheses of hydroclimate change in Southwest North America at the last glacial maximum, including: (1) a southward-displaced Pacific jet stream [8]; (2) a strengthening and meridional compression of the storm track [4]; (3) a thermodynamic control arising from a steepened humidity gradient [9]; and (4) an increase in moisture from a southwesterly, subtropical source [10] perhaps owing to increased contributions from atmospheric rivers [11]. These global simulations will also prove valuable for a wide range of paleoclimate questions. As the highest-resolution global simulations of the last glacial maximum ever performed, these outputs will be a valuable resource for the paleoclimate community and of particular interest to the paleoclimate model intercomparison project [12].

WHY BLUE WATERS

The large number of compute nodes on Blue Waters is ideal for these simulations. The combination of water isotope tracers and high resolution in CESM requires significant computing resources. Fortunately, CESM throughput scales well with a large number of processors. The research team expects high efficiency when employing well over 1,000 processors simultaneously per simulation. This research would not be possible without the computing power provided by Blue Waters.