PALAEOCLIMATE

A glacial zephyr

The hydrology of the North American west looked very different at the Last Glacial Maximum to today. A model–data comparison suggests the observed precipitation patterns are best explained if the storm track was squeezed and steered by high-pressure systems.

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During the peak of the last glacial period, when Earth's largest ice sheet — the Laurentide — covered much of northern North America, the Great Basin of western North America was transformed into a vast lake district. Ancient shorelines etched into mountain flanks from Utah to California bear witness to the extraordinary hydrological change that accompanied peak glacial conditions. More than a century has passed since these high-water marks were identified[1,2], and yet our understanding of the underlying climate dynamics is still incomplete. Writing in *Nature Geoscience*, Oster *et al.*[3] present a comprehensive data–model comparison for glacial western North America that identifies a southwest–northeast precipitation dipole. They suggest that this pattern can be explained as steering of the westerly storm track by glacial high- and low-pressure systems, rather than a simple latitudinal displacement as previously suggested.

About 21,000 years ago, the southwestern Great Basin was wetter than it is now, whereas the areas to the northeast of the Great Basin — closer to the southwestern margin of the Laurentide Ice Sheet — were drier. Various hypotheses have been invoked to explain why today's drylands were wet and prairies were dry, including incursions of moist tropical Pacific air masses to the interior Great Basin[4], latitudinal shifts of the polar jet stream[5], and the influence of the Laurentide Ice Sheet on atmospheric circulation[6]. Each of these hypotheses would require a different pattern of atmospheric circulation.

To sift between theories, Oster *et al.*[3] compared an ensemble of model simulations from the Palaeoclimate Modelling Intercomparison Project with a compilation of hydrologic data from the end of the last glacial period. The precipitation reconstruction is compiled from data from lakes, speleothems, groundwater deposits, packrat middens and glaciers from the western and southwestern US. The pattern identified from these records is matched best by models that simulate the squeezing of the westerly storm track over glacial western North America. This steering is due to the combined effects of a stationary anticyclone over the Laurentide Ice Sheet, a high-pressure system in the North Pacific, and a weaker and southward-displaced Aleutian Low (Fig. 1). Overall, the results presented by Oster and colleagues favour hypotheses suggesting that moisture delivery into the glacial Great Basin was stimulated by an invigoration or southward shift of the westerlies, in part due to the atmospheric influence of the massive Laurentide Ice Sheet lurking in the northeast.

The mechanism for moisture delivery to the Great Basin described by Oster *et al.* seems to have an analogue in today's climate. Over the course of the modern seasonal cycle, precipitation reaches its maximum during the winter in most of the Great Basin[3,7]. This winter pattern occurs when a strengthened North Pacific subtropical jet guides the storm track over the American west[7]. Although there is no longer a great ice sheet covering much of Canada and the northern United States, the variations of the westerly storm track proposed by Oster *et al.* for glacial times do resemble the dynamics observed now.

The study of Oster *et al.* is an important step forward in understanding the glacial North American hydroclimate. However, there is still a puzzle that has yet to be solved. Although the peak of the last glacial period in the southwestern United States was indeed wetter than today, the largest rise in lake levels in the Great Basin actually occurred early in deglaciation, coincident with the onset of Heinrich Stadial 1 in the North Atlantic region[5]. Heinrich Stadial 1, which lasted from 17,800 to 14,700 years ago, featured a major reorganization of the ocean–atmosphere system, and is thought to have been a key factor in bringing the glacial cycle to an end[8].

The precipitation dipole between the southwestern and northeastern regions of the American west further intensified during this cool interval[7,9]. And, much like the hydrological dipole that existed across

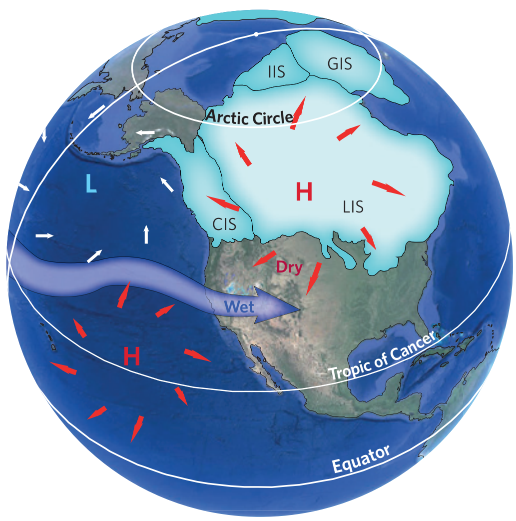

Figure 1 | Glacial atmospheric circulation. During the last glacial period, the Laurentide (LIS), Cordilleran (CIS), Innuitian (IIS) and Greenland (GIS) ice sheets covered much of northern North America. Oster *et al.*[3] compiled reconstructions of precipitation over the Great Basin from 21,000 years ago, and identified wetter conditions than today to the southwest of the basin and drier conditions to the northeast. Numerical climate simulations that best capture this precipitation dipole also simulate stronger high pressure systems (H) over the North American ice sheets and in the North Pacific, along with a weakened Aleutian low pressure system (L). Together, these pressure systems steered the westerly storm track (blue arrow) over the southwestern Great Basin. Modern coastlines are shown for reference.

the Great Basin during the Last Glacial Maximum, the southern sectors of North American ice sheets also expressed a west-to-east dipole behaviour of advance and retreat at the time of Heinrich Stadial 1. The southeastern margin of the Laurentide Ice Sheet receded, whereas the southwestern margin reached the maximum extent of the last glacial cycle[10]. The southern margin of the Cordilleran Ice Sheet (Fig. 1) also underwent a significant advance during this time[11]. Therefore in light of modelling results[3], a question emerges: was this dipole in ice-sheet behaviour a response to, a cause of, or a feedback on the precipitation changes documented across the western United States at the onset of the last glacial termination?

Lake levels in the western US may have risen during Heinrich Stadial 1 as a result of a southward shift of the intertropical convergence zone[7]. This would have caused the Pacific subtropical jet to intensify, which in turn could guide the winter storm track toward the southwestern Great Basin, boosting winter precipitation[7]. If this hypothesis and that of Oster *et al.* hold water, then continued warming of the northern continents and weakening of the boreal westerlies could act in the opposite sense and intensify drought in the American West.

Oster *et al.*[3] have established an important approach that unites robust observations with sophisticated climate modelling to show how water was delivered to western America during the last glacial period, and provides a blueprint for assessing changes to the planet's drylands. The key to resolving the interplay of atmospheric dynamics and hydrology now lies in the collection of more primary geologic data that document past hydrologic change. They will need to be underpinned by secure chronologies to be useful as benchmarks for testing state-of-the-art atmospheric models.

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