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McCall Glacier record of Arctic climate change: Interpreting a northern Alaska ice core with regional water isotopes

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ABSTRACT

We explored modern precipitation and ice core isotope ratios to better understand both modern and paleo climate in the Arctic. Paleoclimate reconstructions require an understanding of how modern synoptic climate influences proxies used in those reconstructions, such as water isotopes. Therefore we measured periodic precipitation samples at Toolik Lake Field Station (Toolik) in the northern foothills of the Brooks Range in the Alaskan Arctic to determine $\delta^{18}O$ and $\delta^{2}H$. We applied this multi-decadal local precipitation $\delta^{18}O$/temperature regression to ~65 years of McCall Glacier (also in the Brooks Range) ice core isotope measurements and found an increase in reconstructed temperatures over the late-20th and early-21st centuries. We also show that the McCall Glacier $\delta^{18}O$ isotope record is negatively correlated with the winter bidecadal North Pacific Index (NPI) climate oscillation. McCall Glacier *deuterium excess* (*d-excess*, $\delta^{2}H - 8^{*}\delta^{18}O$) values display a bidecadal periodicity coherent with the NPI and suggest shifts from more southwestern Bering Sea moisture sources with less sea ice (lower *d-excess* values) to more northern Arctic Ocean moisture sources with more sea ice (higher *d-excess* values). Northern ice covered Arctic Ocean McCall Glacier moisture sources are associated with weak Aleutian Low (AL) circulation patterns and the southern moisture sources with strong AL patterns. Ice core *d-excess* values significantly decrease over the record, coincident with warmer temperatures and a significant reduction in Alaska sea ice concentration, which suggests that ice free northern ocean waters are increasingly serving as terrestrial precipitation moisture sources; a concept recently proposed by modeling studies and also present in Greenland ice core *d-excess* values during previous transitions to warm periods. This study also shows the efficacy and importance of using ice cores from Arctic valley glaciers in paleoclimate reconstructions.

1. Introduction

Many paleoclimatic reconstructions rely on understanding the modern relationships between climate and water isotopes (Steinman et al., 2012). Of particular importance to climatologic studies is the relationship between $\delta^{18}O$ of precipitation and air temperature (Dansgaard, 1964), which can be used as a paleothermometer to reconstruct temperatures from past isotope values collected from ice cores or other sediment records. However, as the global relationship between $\delta^{18}O$ of precipitation and air temperature across many locations is different (i.e., spatial) than repeated measurements in the same region (i.e., temporal), the most accurate climate reconstructions require the application of local modern precipitation isotope-temperature relationships to regionally similar climate proxy records (Jouzel et al., 1997). Although, even with a local isotope-temperature relationship, some of the variability in $\delta^{18}O$ values is not accounted for by temperature, as other processes such as moisture source characteristics also influence isotope fractionation (Klein et al., 2015; Rozanski et al., 1992).

Climate modes of variability such as the North Atlantic Oscillation (NAO), Pacific North American (PNA) teleconnection, and Southern Oscillation Index (SOI) are increasingly recognized for their ability to influence the spatial and temporal patterns of precipitation isotopes throughout the globe (Liu et al., 2013, 2014). These alterations in atmospheric circulation can also dramatically

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impact isotopes in regional precipitation because they often shift the moisture sources and trajectories that deliver water vapor and precipitation (Liu et al., 2014; Vachon et al., 2010). As shifting modes of climatic variability may alter the spatial and temporal patterns of precipitation isotope values, and thus isotope-temperature transfer functions (Birks and Edwards, 2009), it is important to use modern precipitation isotope-climate records that extend over multiple years, and preferably decades. For example, modern precipitation isotope-temperature records (Welker, 2000) helped understand how shifting PNA phases throughout the Holocene influenced North American lake sediment and speleothem isotope records (Liu et al., 2014).

Arctic systems also are impacted by periodic phase changes in climate patterns, such as the North Pacific Index (NPI), because the atmospheric pressure gradients associated with these patterns influence storm tracks and moisture source regions (Minobe and Nakanowatari, 2002). In addition to these climate phase changes, overall atmospheric warming in Arctic Alaska is leading to pronounced Earth system changes, such as thawing permafrost (Schuur, 2013), shrub expansion (Sturm et al., 2001), and shifts in carbon and nitrogen cycling (McGuire et al., 2009; Pattison and Welker, 2014). The coupling of two regionally specific records is necessary to better understand how these changes might be recorded in Arctic region paleoclimate archives: a modern precipitation isotope record and a paleo-isotope record. The only such Arctic Alaska paleo-isotope ice core record currently available is from McCall Glacier, a valley glacier in the northeastern Brooks Range (Fig. 1). McCall Glacier is one of the most studied glaciers in the Arctic with a history of research dating back to the third International Polar Year (IPY3, also known as IGY) in 1957–58 (Weller et al., 2007). In 2008, as part of IPY4, a 152 m ice core was extracted for paleoclimate analysis and as part of a subsequent project the oxygen and hydrogen isotopes over the upper 37 m were measured continuously in a melter-system. Here we compare these ice core-derived isotope records with a multiyear Arctic Alaska-derived relationship between precipitation isotopes and modern climate. Therefore, this study has three research goals: 1) develop an Arctic Alaska specific paleothermometer from event based precipitation $\delta^{18}O$ and air temperature measurements; 2) apply this Arctic Alaska specific paleothermometer to isotope water ratios collected from a McCall Glacier valley glacier ice core to reconstruct air temperatures in the Brooks Range region of northern Alaska; and 3) investigate changes in moisture source inputs to the McCall Glacier.

To address these goals we present a long-term dataset of $\delta^{18}O$ in precipitation and air temperature from individual events at Toolik Lake Field Station (hereafter Toolik) in Arctic Alaska (Fig. 1), which can serve as a localized paleothermometer for interpretation of isotope records in paleoclimate data collected in Arctic Alaska. This local, Arctic Alaska paleothermometer was applied to $\delta^{18}O$ isotope measurements from an ice core collected at McCall Glacier to reconstruct regional temperatures. Future studies will apply our results from the upper 37 m of ice core, which dates back ~65 years, to the full 152 m, which dates back over 200 years. This approximately 65 year record of water isotope ratios and reconstructed temperatures was compared to reanalysis temperature data from near the McCall Glacier. The McCall glacier core was one of the first collected from an Arctic valley glacier, as most previous ice core measurements have been from ice sheets (Dansgaard et al., 1993; Jouzel et al., 2005). In addition to $\delta^{18}O$, the values of δ^2H also were analyzed. The $\delta^{18}O$ and δ^2H values were combined to calculate

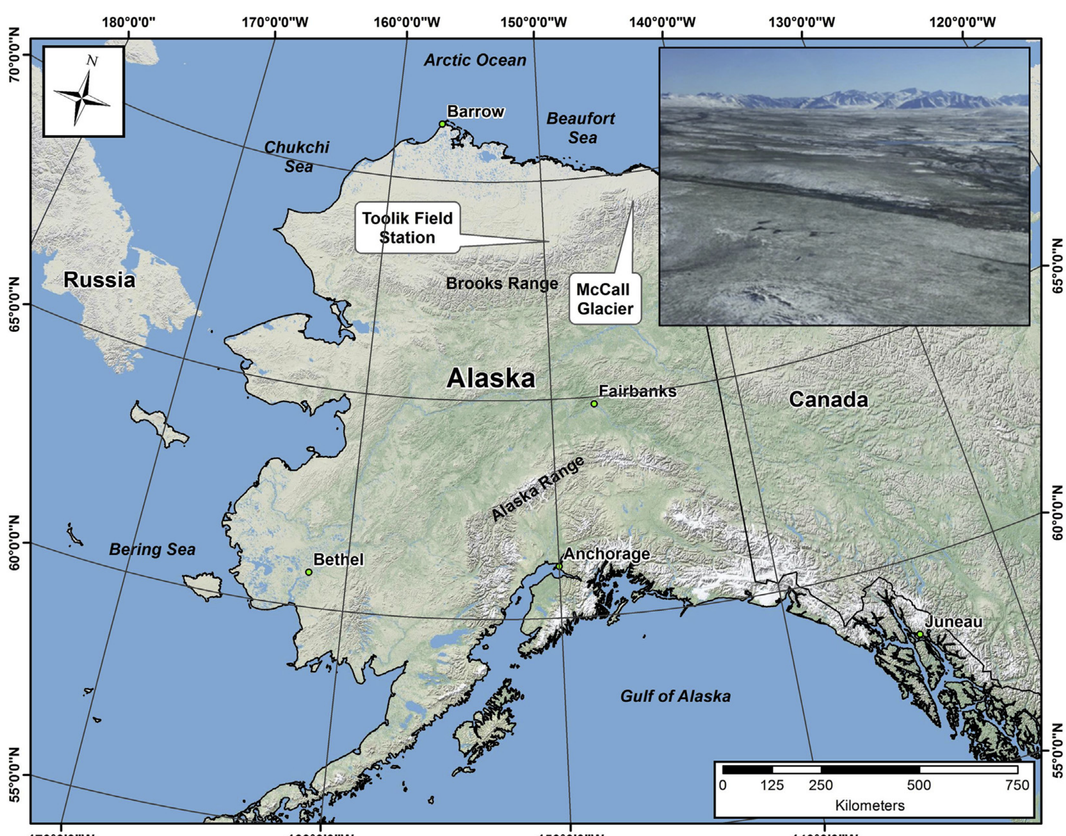

Fig. 1. Study site locations of Toolik Field Station and McCall Glacier in Arctic Alaska. Toolik is in the northern foothills of the Brooks Range about 185 km south of the Arctic Ocean at an elevation of about 760 m. McCall Glacier is located in the Romanzof Mountains in the eastern Brooks Range. Inset: Looking south toward the Brooks Range from near Toolik Field Station (photo: ESK).

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