Investigating the elevation dependence of atmospheric water isotope ratios in the coastal North Pacific

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Scientific problem and Goal

The application of research in $\delta^{18}O$ distribution within areas of high relief span farther than developing a more complete understanding of stable oxygen isotope fractionation in the water cycle, as it contains related implications in ice core paleoclimate studies when reconstructing past climate (Holdsworth 2008) and also in paleoelevation research in discerning past topographical and elevation layouts (Galewsky 2009). These reconstructions that center around collected $\delta^{18}O$ data can then be related to current climate situations. Ice core paleoclimate and paleoelevation studies that work off of $\delta^{18}O$ distribution data recognize a break from simple Rayleigh models as $\delta^{18}O$ data are collected with regard to altitude (Galewsky 2009; Holdsworth 2008). The evaporation and condensation of water fractionates stable oxygen isotopes within that water, creating a situation where weather systems preferentially precipitate out $\delta^{18}O$ (Bradley 1999). This means that the $\delta^{18}O$ ratio in the precipitate decreases at a fairly constant rate over a flat distance, predicted by Rayleigh models (Bradley 1999; Galewsky 2009). The pattern in this ratio, however, seems to become distorted when analyzing measurements transecting certain altitudes (Holdsworth 2001) and also under certain weather conditions, latitudes, and surface terrain (Galewsky 2009). Data collected in Holdsworth (2008) displays a stepping trend at altitudes of 5-7km that are not consistent with flat level fractionation research, and a nonlinear atmospheric model implemented in Galewsky (2009) shows variation and anomalies of stratified atmospheric flows effect on precipitation isotopic ratios (with elevation considered) (Fig 1). In order to use $\delta^{18}O$ ratio levels in an isotopic paleothermometer that relates the $\delta^{18}O$ measurements to a prescribed temperature, as well as in paleoelevation investigations, the relationship between altitude and $\delta^{18}O$ data/anomalies needs to be understood (Galewsky 2009; Holdsworth 2008).

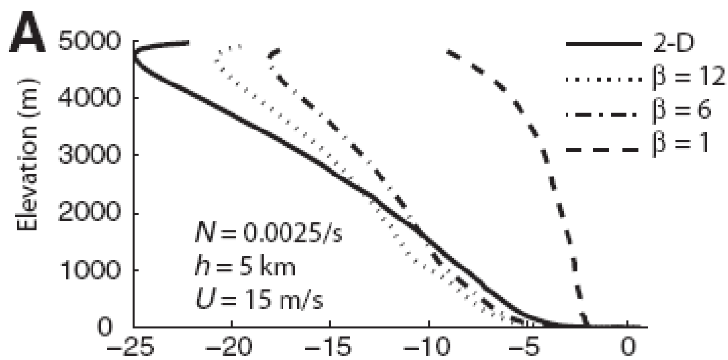


Figure 1: Figure developed in Galewsky (2009) from Weather Research and Forecast Model showing elevation vs. $\delta^{18}O$ values where N is the Brunt-Väisälä frequency of atmospheric stratification, h is the large scale terrain relief, and U is the wind speed upstream of the topography. (β) is the horizontal aspect ratio. Notice how $\delta^{18}O$ values around an elevation of 5000m break the distillation trend.

Objectives

The steep glaciated coastal topography boarding the Eastern North Pacific provides a useful natural laboratory to investigate the vertical atmospheric $\delta^{18}O$ distribution. The ability to access samples that span both mean annual precipitation (snowpits) and event-based (fresh snow) timescales across an elevation transect is an ideal test of the relationship between $\delta^{18}O$ values and altitude. The Juneau Icefield Research Program provides a logistical opportunity to observe and understand this phenomenon in that the Juneau Icefield (Fig 2) provides an area of high relief where samples can be gathered over a large distance and elevation transect.

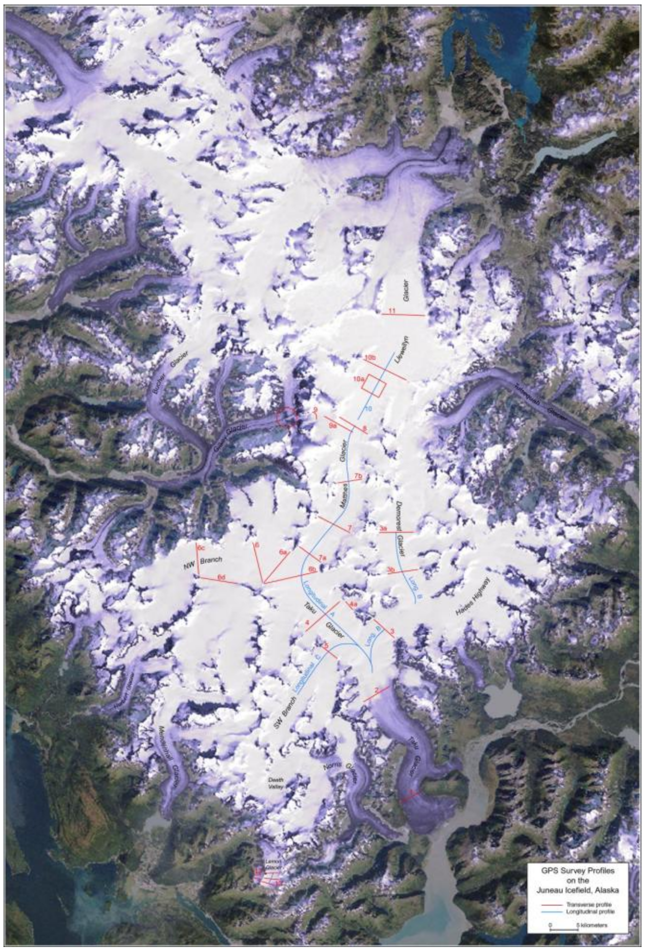


Figure 2: Image of the Juneau Icefield, showing the area of research for the Juneau Icefield research

Over this past summer, I collected snow samples over an elevation of 4400ft to 5800ft, transecting a branch of the Taku Glacier, spanning over 3 horizontal miles. Snow pits were dug 1 meter deep every 100 meter rise in elevation (elevation measured by GPS). Snow samples were taken every 10cm within the 1 meter deep pit, accounting for 10 samples per pit. 15 individual snow pits were dug in accordance to this rise in elevation, creating a total of 150 samples in all. These samples were later analyzed in the University of Maine Stable Isotope Laboratory for $\delta^{18}O/\delta D$ values in order to observe a relationship between these values and their respective altitudes (Figure 3). Data collected from the Juneau Icefield will be compared with data sets from different locations using the GNIP database and simple Rayleigh models, as well as fit in with Holdsworth's and Galewsky's research on high-altitude anomalies. In recognizing prior research (Galewsky 2009; Holdsworth 2008), I predict that at this limited altitude (a maximum of 2.6km) there will be a linear decrease in $\delta^{18}O$ in regard to elevation on the Juneau Icefield. There may, however, be a difference when analyzing the $\delta^{18}O$ distillation values of mean-annual (snowpits) and single system events, suggesting a more complex model that is non-adherent to simpler Rayleigh models.

Rationale

The Juneau Icefield Research Program, geared towards interdisciplinary studies of earth systems science in arctic and mountainous regions, provided an ideal logistical opportunity for both training in expeditionary and field/lab work skills that allows for interactions with faculty and other students in the field, and also encouraged independent research to be carried out by the participants. I am planning to use this program to satisfy my capstone field experience, and am currently devising an honors thesis that utilizes the data collected on the expedition.

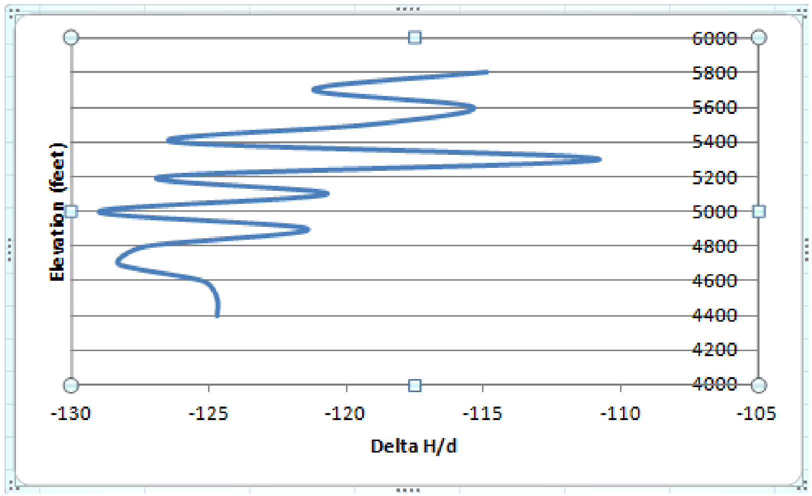


Figure 3: Figure developed from Juneau Icefield pit dataset based on pit averages. Shows δD graphed with respect to elevation. Notice the trend of increasing δD values (moving closer to 0) that corresponds with the increase in elevation. Keep in mind that the pits were dug every 100ft starting at 4400ft in elevation.

Program Log

The Juneau Icefield Program is not only a scientific program, but also an expeditionary experience like no other. The first week of the program starting June 28th was held in the Juneau area for orientation with local field trips in the surrounding area. Safety and emergency medical instruction as well as training in glacier travel and crevasse rescue was completed when arriving at the first camp on the Juneau Icefield. To get to this first camp meant a 12-14 hour trek through the Tongass national rain forest, ascending outlying peaks and ridges, and finally up the Ptarmigan Glacier. After this initial "orientation", we were divided into expedition teams and started to depart camp 17 for camp 10 in our groups, one group a day. Camp 10 is located in the middle of the Taku Glacier (and the icefield itself). This was a 2 day journey across fairly technical terrain. A mass balance pit up the Taku (based out of camp 10) is where my research was conducted, and I got a lot of help from all who were involved with that trip. After a couple of weeks there, we split back into expedition groups and made the 1 day journey to camp 18, located above the Gilkey Trench. After a couple weeks there of me assisting others with their projects, we moved on to the final camp on the British Columbia side of the icefield, and exited in Atlin where we gave oral presentations regarding our projects to the community.

Conclusion/Acknowledgement

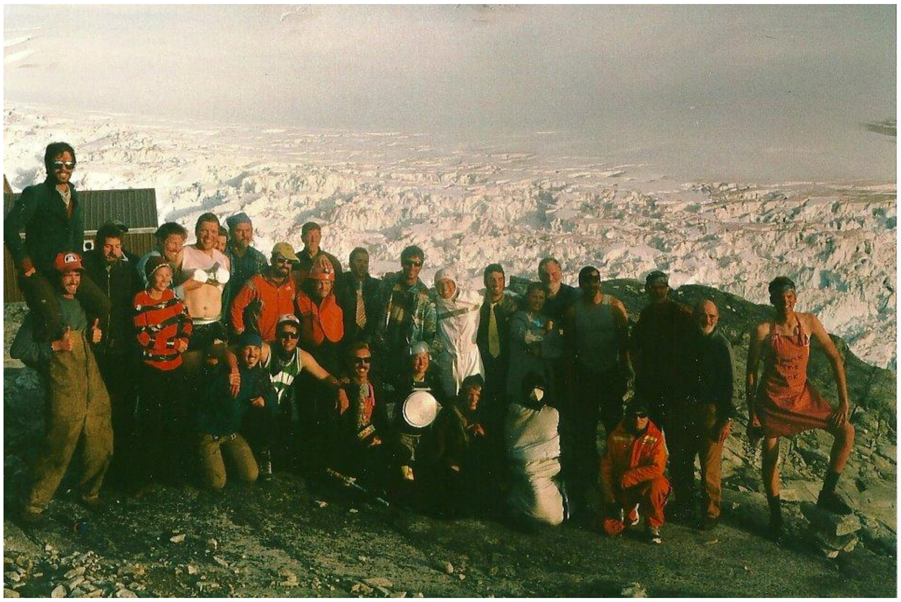
The data collected from this field work and expeditionary experience is currently being formed into an honors thesis. The research has evolved from its original state to include the great amount of data available, incorporating the concept of a systems model that can explain/predict fractionation phenomena. This is an exciting and active field within paleo-climate and paleo-elevation studies, and it is foreseeable that the project idea and data collected on this experience will contribute to the scientific community.

With this being said, none of this could have been possible without the aid and support of many benefactors. Firstly, the financial support received from the Dan and Betty Churchill Exploration Fund was imperative to getting started on this research. Without it, I would not have had this invaluable experience as well as the data to start an honors thesis that I am truly excited about. For this, I am very grateful. I would also like to thank Dr. Karl Kreutz (University of Maine) for his assistance in not only getting me involved in the field, but also in introducing me to the ideas and concepts that will be utilized in my thesis. His guidance is greatly appreciated. I would also like to thank Seth Campbell (University of Maine), Bradley Markle (University of Washington), and the fellow participants on the expedition for their assistance in project development, logistics, and physical labor in the field.

One of the test pits dug for my sample collection.


My fellow expedition participant helping with my project (on a beautiful day).


The Gilkey Trench from Camp 18. One of the most stunning locations on the icefield.


Expedition participants and leaders after a costume party (icefall in the background).

References:

- Galewsky, J. (2009), *Orographic precipitation isotopic ratios in stratified atmospheric flows: Implications for paleoelevation studies,* J. Geology 2009., 37; 791-794 doi: 10.1130/G30008A.1

- Holdsworth, G. (2008), *A composite isotopic thermometer for snow,* J. Geophys. Res., 113, D08102, doi:10.1029/2007JD008634.

- Holdsworth, G. (2008), *Interpreting H2O isotope variations in high-altitude ice cores using a cyclone model*, J. Geophys. Res., 113, D08103, doi:10.1029/2007JD008639.

- Holdsworth, G., H. R. Krouse. (2001), *Altitudinal variation of the stable isotopes of snow in regions of high relief*, J. Glaciology, Oct. 2001.