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GLACIAL INCEPTION IN NORTH-EAST CANADA: THE ROLE OF TOPOGRAPHY AND CLOUDS

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1. Introduction

Over the past 2.5 million years, ice ages have dominated Earth's climate. Interglacials, like our current climate, were brief, sometimes lasting only a few thousand years (Peltier 1999). Mountain glaciers in the Canadian Arctic Archipelago are the last remnants of the Laurentide Ice Sheet, and likely sites of glacial inception (Clark 1993). Currently, state-of-the-art global climate models (GCMs) have trouble simulating the transition of Earth's climate from interglacial to glaciated, which questions the validity of future predictions. Otieno and Bromwich (2009) emphasized the difficulties in simulating glacial inception and the importance of cold summers and wet winters, which we use in our study. A more recent study on glacial inception by Jochum (2012) found increased glacial susceptibility when the horizontal resolution was increased. We decide to investigate glacial inception by focusing on two aspects of GCMs: their coarse spatial resolution, which smooths topography, and their parameterized representation of clouds and convection.

2. Method

To better understand the small scale topographic and cloud processes mis-represented by GCMs, we run the Weather Research and Forecasting (WRF) atmosphere-land model (Skamarock 2008) in a regional, cloud-resolving configuration over the Penny Ice Cap of Baffin Island. We run 6 experiments, as detailed in Table 1, exploring the roles of Milankovitch forcing, meteorology, and topography. Using integrated insolation (Huybers 2006), we identify 115kya as an insolation minimum (our control), 128kya as a maximum, and present day as mean insolation. We use boundary data from ECMWF (Dee et. al. 2011), choosing years that are anomalously average, cold, and warm. Finally, we examine the role of topography by lowering the domain to that of most GCMs, which smooths Baffin Island by over 1000m.

3. Results

Our results show the possibility of ice cap growth with realistic topography, insolation values from the last glacial inception, and cold summer combined with wet winters (Figure 1). Whereas, smoothed low topography, as seen in GCMs, loses almost 1000kg/m2 of snow water equivalent, even with the relevant 115kya orbital parameter configuration. The low topography snow depth is similar to that of the warm scenarios (warm boundary conditions and increased insolation).

In diagnosing how the ice cap grows, we find that the low topography experiment has increased melting, but also decreased precipitation. Therefore, we posit that the precipitation in this area is largely orographic, and the spatial pattern of accumulation for the 115kya control run reveals large variations within the domain in Figure 2a. In contrast, the pattern of precipitation for low topography is mostly uniform (Figure 2b) with almost 600mm less snowfall over the Penny Ice Cap. We calculate the CAPE, finding that convection only occurs during August, and we decide to examine precipitation rates by month in Figure 3. Most of the precipitation is frozen, but during the summer there is some liquid rain, which mostly freezes and contributes to snow depth. The low topography experiment precipitation differs greatly by month from the realistic topography with the same boundary conditions. There is no snowfall during the summer with low topography. Thus, orography in this region is important to both the amount and type of precipitation.

We also analyze the change in snow depth over three years and cloud radiative forcing by domain height. As seen in Figure 4a, we partition the height in the domain by percentage bins. In Figure 4b, we can effectively see where the ice cap transitions from melting to accumulation. 115Kya and cold meteorology causes the lowest ice cap edge. Milankovitch forcing causes only slight changes in ice cap extent, while the various boundary conditions cause much larger changes in the ice cap. Most importantly the low topography experiment has net melting, so the ice cap will likely disappear completely, even with 115kya insolation. We confirm that clouds are a negative feedback (Jochum 2012), and less insolation causes less radiation to be reflected (Figure 4c). Low topography has more negative cloud forcing , but it is more significant in the upper part of the domain. The lower parts of the domain more closely resemble the low topography experiment because they both have similar types

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of low clouds and fog. Thus, the low topography experiment has such strong cloud forcing because the entire domain has lower clouds.

Melting, precipitation, and clouds are all changed substantially when topography is lowered. Our results indicate that increased topographic resolution is paramount to accurate modeling of the Canadian Arctic Archipelago, past and present.

4. References

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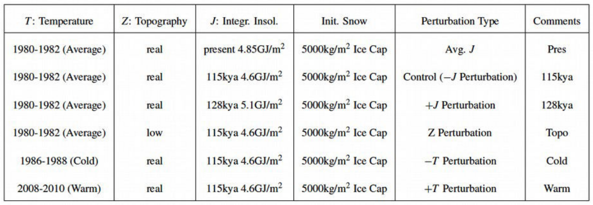
5. Figures and Tables



T: Temperature	Z: Topography	J: Integr. Insol.	Init. Snow	Perturbation Type	Comments
1980-1982 (Average)	real	present 4.85GJ/m^2	5000kg/m^2 Ice Cap	Avg. J	Pres
1980-1982 (Average)	real	115kya 4.6GJ/m^2	5000kg/m^2 Ice Cap	Control ($-J$ Perturbation)	115kya
1980-1982 (Average)	real	128kya 5.1GJ/m^2	5000kg/m^2 Ice Cap	$+J$ Perturbation	128kya
1980-1982 (Average)	low	115kya 4.6GJ/m^2	5000kg/m^2 Ice Cap	Z Perturbation	Topo
1986-1988 (Cold)	real	115kya 4.6GJ/m^2	5000kg/m^2 Ice Cap	$-T$ Perturbation	Cold
2008-2010 (Warm)	real	115kya 4.6GJ/m^2	5000kg/m^2 Ice Cap	$+T$ Perturbation	Warm

Table 1: Summary of WRF Experiments with Perturbations to Temperature, Topography, and Insolation.

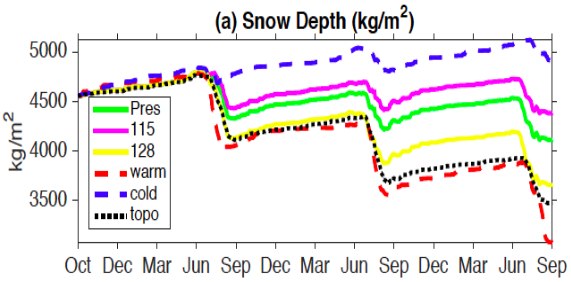


Figure 1: Times Series of Snow Depth Over the Penny Ice Cap.

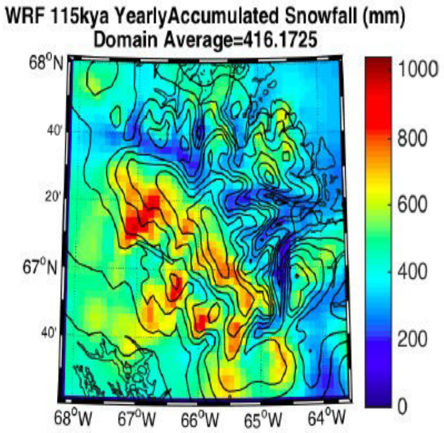


Figure 2a: Map of Accumulated Snowfall for Control Experiment

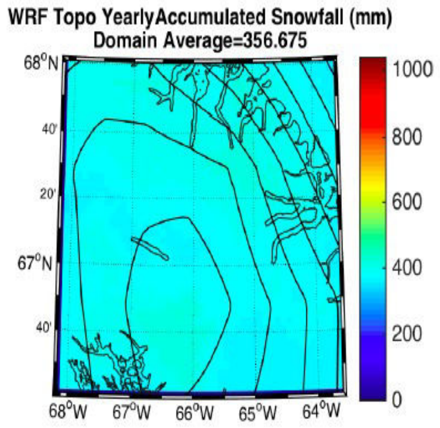


Figure 2b: Map of Accumulated Snowfall for Low Topography Experiment

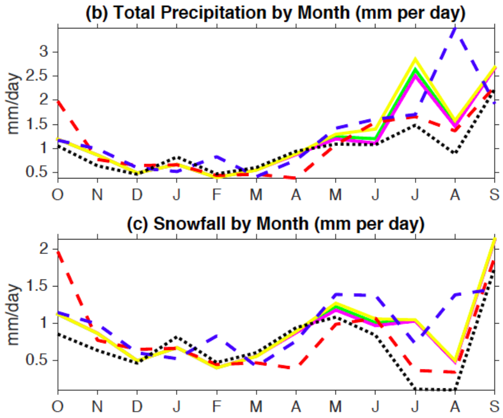


Figure 3: Average Precipitation Rates by Month

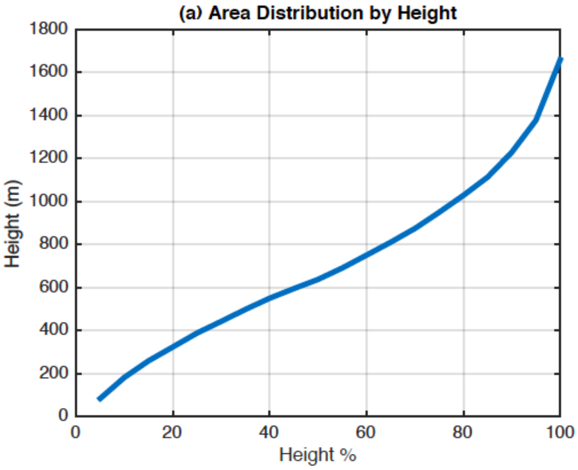


Figure 4a: Height within Domain distributed into Height Bins by Percentage

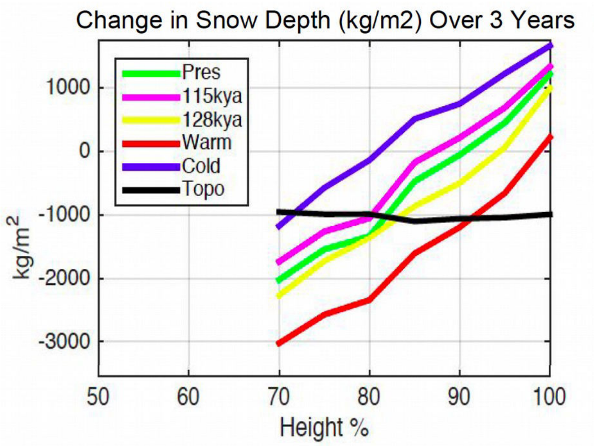


Figure 4b: Change in Snow Depth on Ice Cap by Height Bin Percentage

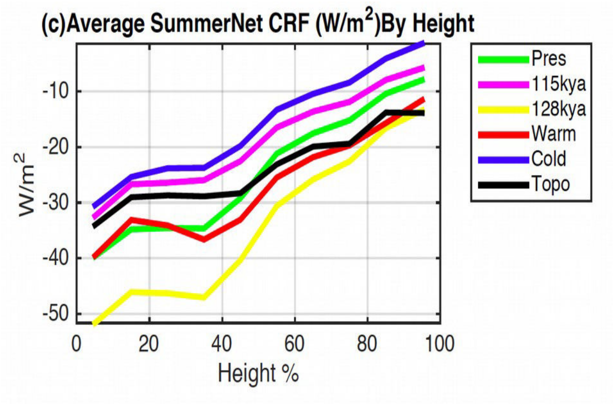


Figure 4c: Summer Net Cloud Radiative Forcing by Percentage Height Bins