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Model Reconstruction of Solid Precipitation in the Arctic

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1. INTRODUCTION

Why are estimates of freshwater fluxes in the Arctic important? The Arctic ocean has a thin layer of cold, fresh water, overlying relatively warm, salty water of mainly Atlantic origin. Long-term changes in freshwater fluxes into the Arctic Ocean will affect the stability of the water column, vertical fluxes of heat, and the state of sea ice cover (Weatherly and Walsh 1996). Freshwater fluxes from the Arctic to the northern North Atlantic affect the formation of deep waters in this region and thus the heat transport by the ocean (Dickson and Brown 1994). The Arctic is also a place where considerable changes in climate have been observed over the last century, prompting questions about how global climate changes may be amplified in the Arctic (Serreze et al 2000).

Much of the uncertainty in land-based Arctic freshwater estimates relates to the difficulty of measuring solid precipitation (Goodison et al. 1998). Precipitation gauges that work well for liquid precipitation perform poorly for mixed and solid precipitation because the gauge itself disrupts the boundary layer wind flow and causes snow to preferentially fall downwind from the gauge (Sevruk 1998). Another problem in the Arctic is the paucity of gauges (compared to mid-latitudes) which is compounded by creating gridded products for use in climate studies when there are only a few points of observation (Bowling et al. 2000). Such products are even more misleading when different countries and regions use different kinds of gauges, each kind with a unique bias toward undercatch.

The goal of this proposal is to reconstruct a century-long record of solid precipitation in the Arctic by running the NASA Seasonal to Interannual Prediction Project (NSIPP) land surface hydrology model in an inverse mode (Ducharne et al. 2000, Koster et al. 2000). To this end, the model is run using observations of snow depth and surface air temperature to reconstruct the precipitation that must have fallen to produce the observed snow depth. Transport of snow by wind on the Arctic prairies may be as much as 75% (Pomeroy and Gray, 1995) and sublimation induced by strong winds may account for losses to the atmosphere of nearly 30% (Pomeroy et al. 1997). For these reasons, the model includes compaction, surface sublimation, and blowing snow. This reconstruction is based on simple snow depth measurements using a ruler, with minimal instrumental error and little or no destructive influence on the snowpack. The snow depth record is quite long (back to 1890 in some stations) and adds thousands of stations to the small number of precipitation gauges in the Arctic (over 400 new stations in the Mackenzie catchment alone). By estimating the historical land-based solid precipitation in the Arctic, uncertainty in the Arctic freshwater budget associated with precipitation gauges is significantly reduced.

2. PROCEDURE

The Reynolds Mountain station at Reynolds Creek Experimental Watershed (RCEW) in southwestern Idaho was chosen to calibrate and evaluate the method because there are relatively few rain-on-snow events, (Marks et al. 2000) which are also rare in the Arctic. Hourly measurements of all the relevant climate and hydrological variables for this study have been taken at RCEW since 1984. Snow depth and snow water equivalent (SWE) are measured on several permanent snowcourses, twice monthly, and SWE is measured on an automatic snowpillow (pressure-based measurement of the weight of overlying snow) once hourly. RCEW was one site of the World Meteorological Organization's Solid Precipitation Intercomparison Project from 1987-1994, a time during which instrumental biases associated with several solid precipitation gauges were carefully evaluated against the double fenced intercomparison reference (DFIR), considered the least biased snow gauge available. Transfer functions were then developed to adjust the gauge data for known biases. These adjustments are applied to the precipitation observations for the present study.

Known biases in snowcourse and snowpillow measurements are also considered. Wetting of the Rosen sampler used to take a core of snow to measure SWE has been shown to under sample the pack by 2.9% (Work et al. 1965) which makes such a small difference in the density that the effects on the model physics are not significant. The type of snowpillow used at RCEW is a large diameter (3m) automatic snowpillow which is thought to minimize biases caused by bridging, that is snow outside the pillow supporting snow on the pillow (Goodison et al. 1981). Johnson and Shaefer (2002) have identified other biases in snowpillows related to melting and subsequent water loss caused by heat fluxes between the pillow and the underlying soil. These are most significant during the spring transition when temperatures are hovering near freezing and can lead to both over- and under-measurement of SWE. Results for the winter-spring transition period at RCEW are interpreted cautiously for this reason, but also because this is when rain-on-snow events are most likely to occur. However, the wetting and bridging biases do not apply to the ruler-based snow depth observations in the Arctic.

First, the model is forced with corrected observed precipitation, surface temperature, surface pressure, vapor pressure, wind, incoming shortwave and longwave radiation. The simulated snow depth is then compared to observed snow depth (from cumulative corrected gauges, pillows, and courses) to demonstrate the ability of the model to reproduce the observed snowpack. Then the model is run in an inverse mode to reconstruct precipitation. In this way, snowdepth observations and modeled snowpack physics are used to calculate how much precipitation must have occurred to produce the observed snow depth. Results from a pilot run show excellent agreement (< 3% yearly SWE) between NSIPP reconstructed precipitation and adjusted observed precipitation. Error estimates on the observations are essential for validating this method. Note that the error in the unadjusted solid precipitation gauge is on the order of 40% (Goodison et al, 1998).

In the Canadian and Eurasian sectors of the Arctic, there exist long records of daily snow depth and surface air temperatures available to force the model (Armstrong 2001, MSC 2000). This makes it possible to study the climatology of solid precipitation in the Arctic, as well as its spatial and temporal variability and relationship to large-scale modes of climate variability. The method outlined here will be used to reconstruct solid precipitation in the Arctic, which would be a significant contribution to our understanding of the Arctic freshwater budget.

3. PROPOSED STUDY

Support from the LDEO Climate Center would be used to finish the RCEW pilot study and to prepare a proposal for the NSF Arctic Freshwater Initiative. Travel to RCEW is necessary to meet field engineers and observe siting of snow gauges and other instruments. The purpose is to better quantify measurement errors of these instruments, as well as to obtain radiation data from the Agriculture Research Station in Boise, ID. Travel to Fairbanks, Alaska would be necessary to meet with collaborators and experts on the Arctic application of the method developed at RCEW. Collaborators include Vladimir Alexeev and Pavel Groisman. Experts include Daqing Yang and John Walsh. Remaining data for the pan-Arctic region will be obtained from the National Snow and Ice Data Center (NSIDC) for a nominal handling fee.

4. REFERENCES

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5. Budget

Computing resources (Apple Powerbook G4 notebook):	$2,400.00
Travel to Reynolds Creek, Idaho to meet with field engineers and observe site and instruments:	
Flight	$400.00
Hotel	$200.00
Rental car	$173.00
Meals	$200.00
Travel to Fairbanks, Alaska for to meet with collaborators:	
Flight	$700.00
Hotel	$500.00
Rental car	$215.00
Meals	$200.00
Data handling fees from NSIDC:	$200.00
Total	$5188.00