

High Resolution Arctic Snow Observations: Snow-Net

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INTRODUCTION

Snow's importance has become especially prominent in the terrestrial Arctic, where snow dominates the landscape most of the year and changes in snow arrival, depth, and melt meet substantial energy budget and biota consequences (e.g., Chapin et al. 2005; Sturm et al. 2007; Euskirchen et al. 2007). Yet, the Arctic presents formidable challenges to accurate snow measurements because snow depths can vary greatly over relatively short distances (< 10 m). Snow distribution patterns in windy environments, such as the Arctic, arise from interactions among wind, snow, vegetation, and topography. In this environment, snow is transported easily and is retained in topographic depressions, near taller vegetation, and deposited on the lee sides of hills. Reliable observations of where snow exists in the Arctic landscape can be difficult to obtain, and estimates vary depending on where snow is sampled. Measurements tend to be widely distributed and sparse. In addition, observed changes in Arctic vegetation (e.g., increasing shrubs) and land surfaces (e.g., thermokarst) complicate matters further.

Study Areas

Three study areas have been installed in Alaska and Canada's Northwest Territories (Fig. 1). Barrow (est. 2007) is representative of the Arctic Coastal Plain and is dominated by tundra polygons. Innvait Creek (est. 2008) is a relatively high elevation site in the Arctic typical of Brooks Range foothill environments. Inuvik is our most recent site, installed in fall 2009, and is partially forested.

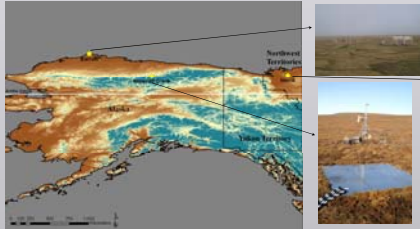


Fig. 1. Our first study sites are in the Alaskan and Canadian Arctic.

OUR OBJECTIVES WERE TO:

- Develop a prototype observational network (SnowNet) employing standard and emergent meteorological observations,
- a comprehensive spatially-intensive snow measurement program,
- and high resolution spatial (topographic and vegetation) data.
- Determine the water balance components for our sites (Fig. 2) following

$$G(x, y, z) = P - S - T - I$$



Fig. 2. A schematic illustrating the relationship between precipitation (P) and snow-on-ground (G) for the tundra (left) or the tundra and sea ice (right).

METHODS

Site Measurements

The site at Barrow (Fig. 3) is representative of our sites (Fig. 1) and features various meteorological instruments and data collections.



Site Measurements Continued

A snow fence outside of Barrow is used to approximate snow transport, T (Fig. 4). The 1 km long Cake Eater snow fence features a camera, anemometer, and sounding sensors downwind of the fence (Fig. 5). Measurements of snow depth and density are also collected.



Fig. 4. The 3 m tall, 1 km long Cake Eater snow fence.



Fig. 5. Sonic sounders continuously record drift height and a ski-mounted GPS is used to map drift profiles during field work.

Field Measurements

- Surveys gathered tens-of-thousands of snow measurements along transects using magnaprobes (Fig. 6).
- Barrow intensive snow surveys were performed in Dec. 2007; March, April, and May 2008; and March and April 2009.
- Innvait snow surveys occurred in Dec. 2007, Feb. 2008, and April 2009.
- Snow surveys also gather snow densities (Fig. 7).
- At drifts formed by snow fences, a ski-mounted DGPS (Fig. 5) was used to measure the surface elevation (snow depth).
- Ground-based LIDAR was used for snow surveys in 2008 at Barrow and in 2009 at Barrow and Innvait (Fig. 8).



Fig. 6. Magnaprobes enable researchers to rapidly observe many snow depths.



Fig. 7. A weighed snow core measures density.



Fig. 8. LIDAR was mounted on a sled for high-precision mobile snow surveys at Innvait and Barrow.

RESULTS AND DISCUSSION

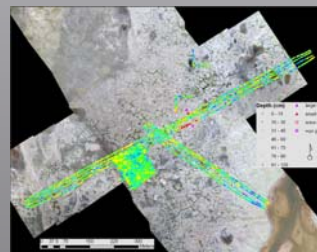


Fig. 9. Snow depths collected during May 2008 are overlaid on our high-resolution aerial photo mosaic for Barrow. There are two transect sets and a 1 ha area that was intensively sampled.
 N = 10,461 mean = 48.3 cm



Fig. 10. Kriged snow depths from May 2008's 1 ha survey were made transparent and were overlaid on our aerial photo mosaic. Clearly topography and vegetation are tied to observed snow depths and seasonal distribution of water. In Barrow and other areas with polygonal ground, topographic variability at fine scales (<5 m) controls overall snow depth.

Cross Validation
 RMSE = 8.67; SE = 11.08
 $r^2 = 0.78$

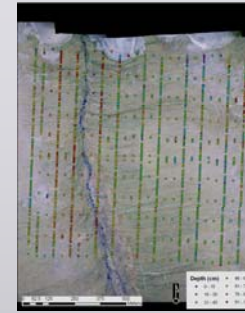


Fig. 11. At Innvait, snow depths are collected on an existing 1km² transect system (broken into 100 m intervals). Data collected during April 2009 are overlaid on our high-resolution aerial photo mosaic.
 N = 16,983 mean = 61.0 cm

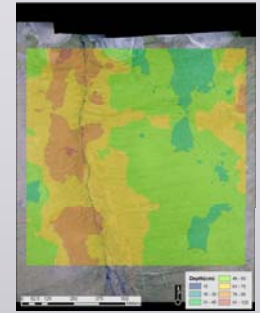


Fig. 12. Innvait snow depths were kriged to produce a snow map. Deeper snows at Innvait are associated with the creek bottom (runs south to north) and east-facing ridges. Analyses of spatial snow patterns is ongoing.
 Cross Validation (RMSE = 8.68; SE = 10.17; $r^2 = 0.85$)

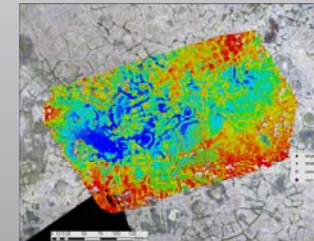


Fig. 13. In summer 2008 ground-based LIDAR was used to develop a snow-free bare earth scan for a portion of our site. Warm colors are higher than cool colors. Innvait was surveyed in September 2009.

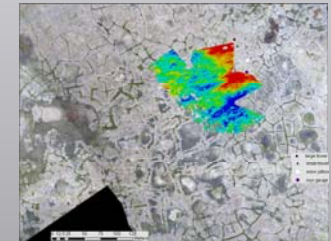


Fig. 14. In May 2008 ground-based LIDAR scanned the snow surface at Barrow (blue is low and red is high). Processing the extensive LIDAR scans from the April 2009 Barrow and Innvait field campaigns is progressing. Once completed, the bare earth layer will be subtracted from snow surface scans to yield snow depths.

COMMENTS AND LESSONS

- Measuring G (Fig. 2) is what we do best (Figs. 9-12) and we need to capitalize on that strength for future efforts.
- These data will yield a number of benefits tied to common snow measurements, snow statistical modeling, snow-vegetation-topography effects, and physical snow modeling.
- We are growing our user community and promoting our network through presentations, outreach, and the Internet.

FUTURE TASKS

- Snow Data Analyses and producing papers on snow patterns and snow-vegetation-topography interactions
- Working with LIDAR datasets and a paper detailing our methods and SnowNet Data.
- Developing better methods for robust measurements of Arctic snow.
- Integrate MicroMet and SnowModel into our project to calculate poorly measured components (S and P) of water balance (Fig. 2).

MicroMet – Micro-Meteorological Distribution Model (Liston and Elder 2006a)

SnowModel – A Spatially Distributed Snow-Evolution Modeling System (Liston and Elder 2006b)

EnBal – Surface Energy Balance/Melt Model (Liston et al. 1999)

SnowPack – 1-D, Single-Layer Snowpack Model (Liston and Hall 1995)

SnowTran-3D – Blowing and Drifting Snow Model (Liston and Sturm 1998; Liston et al. 2007)

SnowAssim – Snow Data Assimilation Model (Liston and Hiemstra 2008)



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