Quantifying Snow Water Equivalence in High Arctic Watersheds

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Introduction

The accumulation patterns, redistribution, and melting of snow are often the most prominent hydrological considerations in the Arctic. Therefore, accurate quantification of the spatial distribution of snow at the end of winter is essential to inventory water available for runoff and soil moisture recharge.

The majority of studies that investigate small watersheds measure depth and density at multiple points along a given distance to obtain an estimate of mean snow water equivalence (SWE) along a transect. However, the difficulty lies in determining where the snow transects should be located to best represent the terrain, and how to spatially distribute the measurements to obtain an accurate estimate of watershed SWE.

The objective of this project is to establish the optimal locations for the measurement of snow properties, and to obtain an approximation of watershed SWE by applying a terrain classification to account for topographic controls on snow accumulation and redistribution.

Study Area

The research site is Cape Bounty (74°54N, 109°35W), Melville Island, Nunavut (Figure 1). The study area contains two watersheds of interest (West and East; Figure 2). Elevation ranges from 5m (West and East Lake) to approximately 165m a.s.l. Upland regions may be classified as polar desert with little soil development, whereas the wetter lowland areas contain a minimal vegetation cover. The primary streams within each catchment are incised into the surrounding terrain and the area is underlain by continuous permafrost.

Figure 1: Location of Cape Bounty, Melville Island, Nunavut

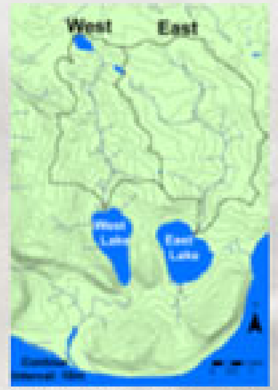

Figure 2: Watershed Locations

Methodology

The snowcover at Cape Bounty was characterized in early June 2005. Eleven depth and three density measurements were taken along 42, 100m transects distributed throughout the two watersheds. The locations of 30 sites were established in 2003/2004, 12 sites were added in 2005 to account for specific areas of terrain.

A 10m cell-size, digital elevation model (DEM) was generated from a 1:50 000 scale NTS map sheet (78 F/15) using an iterative finite difference interpolation method (Figure 3). Stream channels and watershed boundaries were delineated from the DEM, along with surface characteristics such as slope (Figure 4), aspect (Figure 5) and land surface curvature (Figure 6).

A terrain classification based equally on slope, aspect and curvature was produced using an ISODATA unsupervised classification scheme (Figure 7).

Results

Five terrain classes were selected to represent the topography at Cape Bounty. However, an additional class was required to represent the incised channels. A 30m buffer (15m on each side of the primary streams) is shown as Class 6.

Figures 3-6: Surface characteristics of Cape Bounty. 3: Elevation (m), 4: Slope (°), 5: Aspect (° from N), 6: Curvature (Negative=Concave, Positive=Convex)

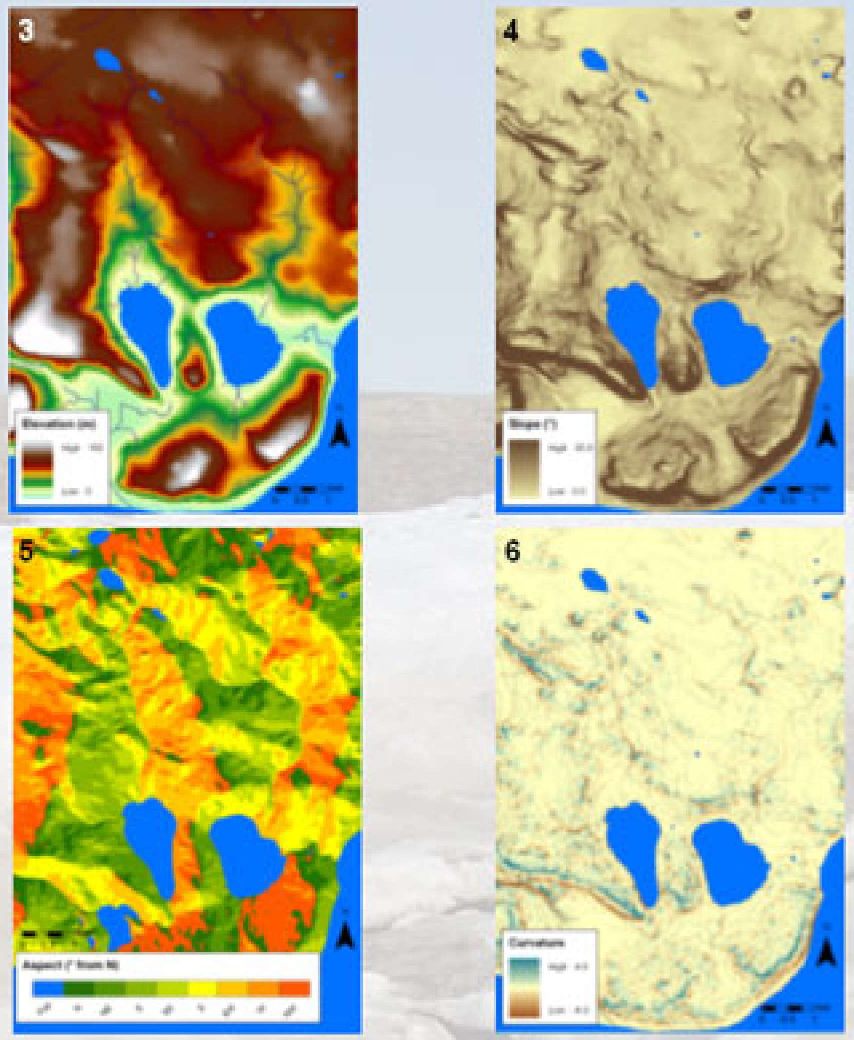

Table 1: Mean SWE of Terrain Classes: Total SWE is the mean SWE of the classes, using all transect locations (n=42). The West and East Watershed class SWEs are based only on the transects in the classes within the respective watersheds (West n=21, East n=21).

Terrain Class	Total SWE (mm)				West Watershed SWE (mm)				East Watershed SWE (mm)			
	SWE	n	S.D.	Range	SWE	n	S.D.	Range	SWE	n	S.D.	Range
1	0	2	0	0	0	1	N/A	N/A	0	1	N/A	N/A
2*	89 (10)	14 (9)	133 (18)	0-396 (0-52)	94 (17)	7 (4)	140 (25)	0-396 (0-52)	84 (5)	7 (5)	136 (12)	0-303 (0-27)
3	56	15	81	0-277	68	5	84	0-161	50	10	84	0-277
4	140	8	161	0-360	161	6	178	0-360	80	2	114	0-162
5	225	3	64	152-271	202	2	71	152-252	271	1	N/A	N/A
6	231	5	132	85-396	173	3	122	85-396	282	2	30	261-303

*Note: 1. Class 2 differences result when Class 6 is accounted for, these values are in brackets.
2. Values of n refer to number of transects for each class.

Table 2: Methods for Estimating Mean Areal SWE: SWE from Both Watersheds is based on all the transect locations from both watersheds. SWE from Individual Watersheds was estimated from transect locations within each watershed boundary.

	Terrain Classification				SWE (mm) Using 2003/2004 Sites*
	Excluding River Buffer		Including River Buffer		
	SWE (mm) Both Watersheds	SWE (mm) Individual Watersheds	SWE (mm) Both Watersheds	SWE (mm) Individual Watersheds	
West Watershed (7.46 km²)	81	91	60	70	50
East Watershed (11.56 km²)	73	63	49	41	26
Total Area (19.02 km²)	76	74	53	52	37

*Note: SWE from 2003/2004 sites are based on areal weighted averages (no terrain classification,) using only 2003/2004 sites (n=30), West Watershed Area=9.46km² East Watershed Area=11.46km²

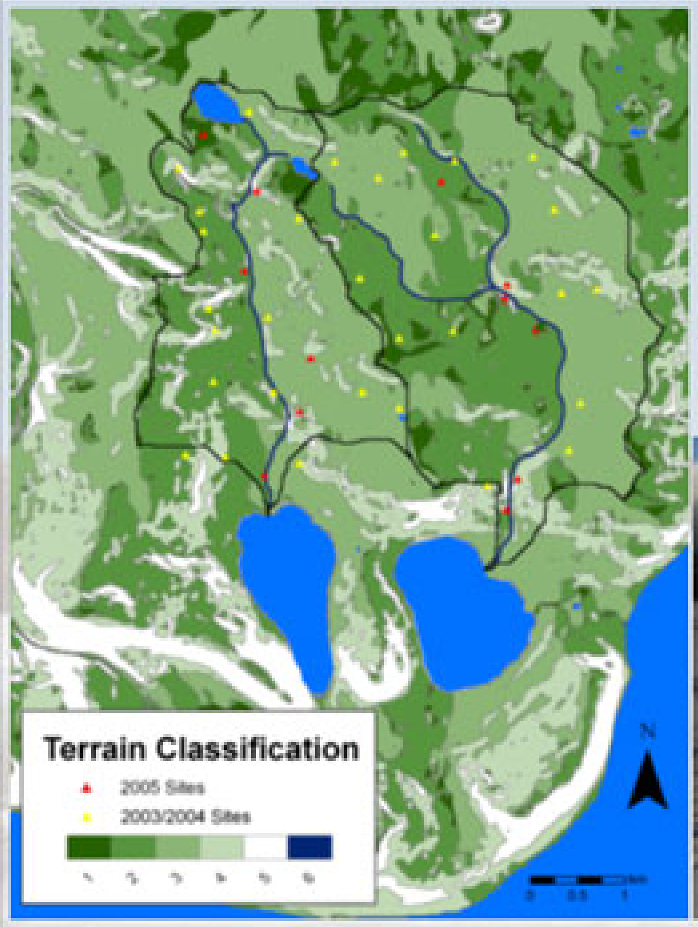

Figure 7: Terrain Classification
Class 1: Flat (<1°) plateau,
Class 2: East facing slope (1-5°)
Class 3: West facing slope (1-5°)
Class 4: Moderate slope (5-12°)
Class 5: High slope (>12°)
Class 6: 30m wide concave stream buffer

Figure 8: West Watershed Channel Snowcover

Discussion

Effects of Terrain on SWE

This study confirms that terrain exerts a significant control on High Arctic snow distribution. Flat windswept plateaus contain very little SWE and act as areas of redistribution for sheltered areas such as stream valleys and gullies. East and west facing slopes contain shallow snowcovers, but contribute significantly to watershed SWE due to their large areal coverage. Areas of moderate to high slope are sheltered and contain drifts high in SWE, whereas valley bottoms accumulate substantial quantities from surrounding slopes (Figure 8).

Estimates of Mean Areal SWE

The addition of the river buffer significantly lowers watershed SWE because Class 2 no longer includes the valley bottom transects. This is significant because the high SWE associated with the relatively small Class 6 is not attributed to the relatively large Class 2, resulting in decreased Class 2 SWE. The estimates of watershed SWE based on transects from each individual watershed result in increased SWE within the West Watershed and decreased SWE within the East Watershed. This occurs because measured SWE is greater within Class 2,3 and 4 (large areas) in the West Watershed. In theory, the best method includes the river buffer and is based on SWE calculated from individual watersheds. However, this method likely underestimates watershed SWE.

Sources of Error

The majority of SWE measurements may be underestimated due to the inability to quantify the ice layer located at the snowpack base (possible underestimation of 20-30% SWE). In addition, there is likely an underestimation of SWE for Classes 4 and 5. This is because survey transects normally run parallel to the direction of greatest slope, but the areas of Classes 4 and 5 are typically elongated features orientated perpendicular to the slope. Therefore, the transects often included areas of relatively flat and barren terrain (e.g. Class 1, 2, or 3) along with portions of the deep snowdrifts in the concave slopes.

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