HIGH ARCTIC PONDS, SOMERSET ISLAND, NUNAVUT: SPATIAL AND TEMPORAL VARIATION IN SNOWCOVER AND SNOWMELT

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ABSTRACT: Extensive low-gradient wetlands in the Canadian High Arctic have been the focus of recent studies. These wetlands typically are composed of a variety of wetland types; for example, wet meadow patches, ponds and riparian zones. Brown and Young's (2004, submitted) study indicated that within one large wetland system near Creswell Bay (72°43'N, 94°15'W), a variety of ponds existed; some located in a moraine area, others in bedrock, while others could be classified as coastal and associated with isostatic rebound. The amount of snow together with the timing and duration of snowmelt are important factors in defining the amount of water available for ponds at the start of the summer season and also signaling the point where runoff and vertical water losses (e.g. seepage, evaporation) start to dominate. These processes can influence the sustainability of ponds or trigger their demise through desiccation. In 2004 detailed snow surveys and snow pits were conducted of selected ponds representing these distinct geomorphological areas. The snowmelt pattern was defined using a physically-based surface energy balance model. Snowcover and melt varied between pond types located in similar ground (e.g. moraine, bedrock) as well as contrasting landscape settings (e.g. moraine vs. coastal). An examination of mid- to late summer conditions of the ponds (e.g. water table, frost table) suggest that the survival of ponds depends on more than just an initial deep snowcover.

Keywords: arctic wetlands, climate variability, snowcover, snowmelt model.

INTRODUCTION

Wetlands are important ecological sites in the High Arctic. They are often the only zones where sufficient grasses and sedges exist to supply northern ungulates such as Muskox and Caribou with sufficient grazing grounds. They also provide food and water for migratory birds and help to cleanse and store water. Despite their ecological importance, a limited understanding of their hydrology remains, hindering our ability to assess their response to climate variability and change. Recent warming in Alaska has resulted in the disappearance and drainage of ponds in both the discontinuous and continuous permafrost zones (Fitzgerald and Riordan, 2003; Yoshikawa and Hinzman, 2003).

Some progress has been made in understanding small patchy wetlands in high arctic landscapes (Woo and Young, 2003; Young and Woo, 2000, 2003a, 2003b). These wetlands often exist below late-lying snowbeds, breaks-of slopes, in topographic depressions where water seeps or settles, in valley floors and surrounding the periphery of lakes and rivers or small pond locations. Snowmelt is the most important input and shallow thaw together with water inputs from the surrounding basin; e.g. contributions from ground ice melt and meltwaters from late-lying snowbeds help to maintain water levels especially during warm, dry summers. Less information exists about the hydrological status of extensive wetlands in the Canadian High Arctic. In one study, Rydèn (1977) examined a large wetland area located at Truelove Lowland, Devon Island (76°N, 85°W). Snowmelt runoff showed a high degree of irregularity with the pattern changing from day to day in response to fluctuations in solar radiation and air temperature. Snowmelt caused large parts of the lowland to flood, with the floods accentuated by snow and ice that blocked lateral drainage. Surface flow was poorly integrated and subsurface flow was minimal due to the presence of frozen ground. After the snowmelt peak there was a steady depletion in runoff only interrupted by a few rains. Evaporation was higher in wetland areas than non-wetland zones. To date, relatively little hydrological information exists for large low-gradient wetlands at Eastwind Lake, Ellesmere Island (80°07'N, 84°40'W), Polar Bear Pass, Bathurst Island (75°44'N, 98°N, 25'W) and near Creswell Bay, Somerset Island (72°43'N, 94°15'W) despite their ecological importance in the High Arctic. Recent studies indicate seasonal soil moisture and water storage in ponds, lakes and streams draining wetlands influence the emission of trace gases. However, the seasonality and magnitude of these exchanges are not well documented for arctic environments (Callaghan *et al.,* 2004). The transition period from snowcover to snow-fee also influences the warming of the atmosphere with a dramatic drop in surface albedo (from ~0.8 to 0.15) leading to enhanced radiation absorption and recycling of water. Hence, any increase in the duration of snow-free conditions results in a strong positive feedback to the regional climate (e.g. Callaghan *et al.,* 2004; Vorosmarty *et al.,* 2000)

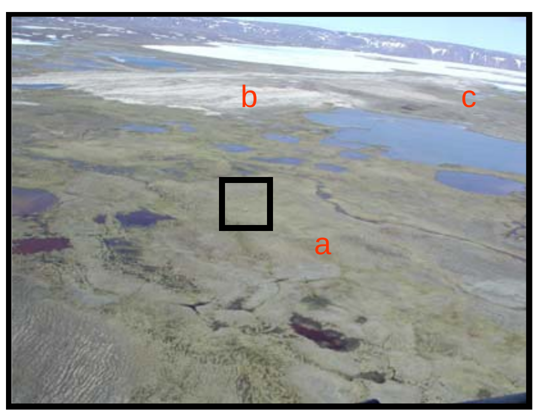
Brown and Young (submitted) using a combination of remote sensing imagery, maps and air photos were able to map an extensive wetland area located near Creswell Bay, Somerset Island. They noted that there were numerous ponds (>200) located in various geomorphological settings: bedrock, moraine, coastal areas, along with thermokarst ponds and ponds sustained by late-lying snowbeds. Limited fieldwork in 2003 (a warm, dry summer) also indicated that several ponds in certain areas of this extensive wetland-complex were drying up (e.g. coastal-type ponds). Since, snowmelt is considered to be the most important input of water into northern wetlands, a critical objective of this present study is to examine the snowcover (amount, distribution) and snowmelt patterns (rates, duration) of typical ponds which characterize a large part of this area. Ultimately, we are interested in assessing whether this initial influx of water is sufficient in sustaining a positive water surplus in these ponds or whether other mechanisms or strategies for pond survival are required.

STUDY AREA

The study area (~23 km^2, elevation range of 50 m a.s.l) is located in an extensive low-gradient wetland system located on the southern shore of Creswell Bay, Somerset Island, Nunavut (72^{o}43'N, 94^{o}15'W) (Figure 1a). The area is underlain by continuous permafrost and the active layer reaches about 0.40 m in boggy areas and about 1.0 m in sandy and gravelly zones. There are no continuous climate records from Somerset Island but the area is considered similar to Resolute Bay, Cornwallis Island (200 km to the north) with its long cold dry winters and brief cool, damp summers (de March *et al.*, 1978; Dyke, 1984). Resolute Bay has an annual temperature of -16^{o}C, with only July and August reaching mean temperatures above 0^{o}C. Annual precipitation is 150 mm with 69 mm falling as rain (MSC, 2002). Earlier research by Woo *et al.,* (1983) and Woo and Marsh (1977) indicates that station precipitation generally under represents precipitation in the surrounding basins, particularly snow. Figure 1b shows an aerial overview of the area with the automatic weather station (AWS) identified. Letters indicate ponds located in the different geomorphological areas. The site contains two contrasting landscapes, the northern part being modified by beach and coastal processes, and the southern section showing more evidence of glacial and periglacial influence (M-K. Woo, *pers. comm*. 2002). In the area of Creswell Bay, Dyke (1984) reports that the bedrock is a limestone and dolostone of Silurian Read Bay and Cape Storm formations and Ordovician Allen Bay, Irene Bay and Land River formations (i.e., continental shelf deposits). Surfacial material is characterized by beach sediments (1 to 5 m thick) in the northern sector and a till veneer (0.5 to 2 m thick) in the southern zone. Beach sediments form a ridge-swale topography, while the till area is wetter and has greater plant coverage (30 to 60%) (Dyke, 1984). Vegetation here includes *Cassiope tetragona*, *Dryas integrifolia, Oxyria digyna, Pedicularis arctica, Saxifraga oppositifolia* and *Salix arctica* and a variety of wet meadow grasses, sedges and mosses.

Figure 1: (a) Location of the study area indicated by "X" and; (b) aerial overview of the study site. Letters indicate studied ponds in different areas: a) moraine; b) west bedrock; c) coastal. East bedrock zone not shown. The AWS is identified with a square.

a



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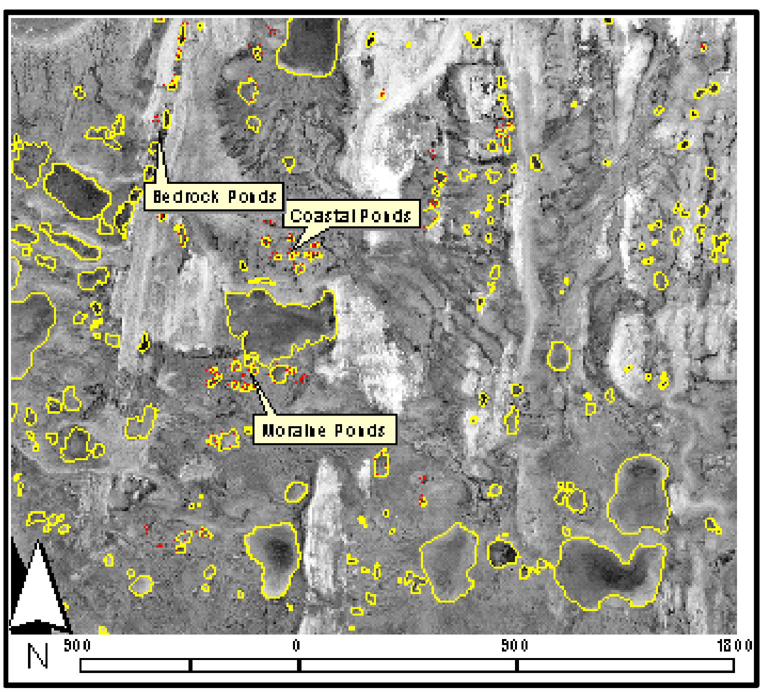
METHODOLOGY

Pond snow survey

Using a GIS-derived map of the area as a template (Figure 2) eight ponds from various areas were selected for intensive study: 3 moraine ponds from the lowland; 1 moraine pond from the upland, 2 coastal ponds, 1 pond site located in the eastern bedrock area and 1 pond from the western bedrock region. Ponds were selected according to type and size (Table 1). Initially, we aimed to survey more ponds for the snowmelt period but this was not logistically feasible given the distance between sites. Intensive snow surveys (snow depth and density) of these sites were conducted June 5, 2004 (JD 156) and followed the methods described by Woo (1998). For small and medium-sized ponds, transects were set around the periphery of the pond and across it in an "X-shape". Snow depth measurements were every 2 m and snow density measurements with a MSC snow tube were taken at the start, middle and end of each transect. For larger ponds, a large "X" across the pond area extending out into the surrounding basin was defined and snow depths were every 5 m. Similarly, snow density determinations with a MSC snow tube were made at the beginning, middle and end of each transect. These measurements allowed an average snow water equivalent (SWE) to be determined for each study pond (see Table 1). Snow depth and density measurements were also made near the Automatic Weather Station-a wet meadow area located in the moraine ground type. Hourly meteorological information measured here is used as both input and validation data in a physically-based surface energy-balance type snowmelt model (Woo and Young (2004). This model was previously used to model both snow accumulation and melt for various terrain areas (slopes, valleys, plateau) on Cornwallis Island. Its utility at the local scale and over rolling arctic landscapes (16 x 13 km^2) was assessed with observed data and Landsat-TM imagery and it was shown to provide realistic results at both scales.

Figure 2: GIS-derived map of the study area.



Snowmelt

Snow indicies for the ponds (as required by the model-see Figure 3) were determined as a ratio to SWE measured at the AWS site (Table 1). Initially, we anticipated that we would be able to monitor melt at the site but a late spring and a prolonged cold spell prevented this as we had to leave the field site for about six weeks. Subsequently, snow pits were dug and snow properties surveyed (snow grain size, thickness of layers) at each site on June 12 (JD 163). A Stowaway tidbit temperature sensor ± 0.1^{o}C was placed at the snow/ground interface of the snowpit and then pits were backfilled with snow. All sensors indicated that snowpacks were still far from melting with temperatures well below -8^{o}C. (Table 1). Given that we would be out of the field during the main melt period, it was anticipated that these temperature sensors might provide a good indication of the start (T= 0^{o}C) and end of melt (T> 0^{o}C). Initial SWE measurements used to derive the snow indicies in the model were not adjusted from JD 156 since daily surface ablation measurements at all sites indicated that little melt/condensation had occurred to sufficiently change the SWE values on JD 163 and this was also confirmed by our snowpit measurements. Albedo decay in the model follows the empirical function of Woo and Dubreuil (1985). Woo and Young (2004) used an initial value of α=0.8 in their study but here, α=0.75 to reflect the surface snow conditions by JD 161 at the AWS when the model was initiated. Daily albedo measurements at the other sites confirmed a similar pattern and no significant differences existed at this time. While snow pits were dug on JD 163, the model was started a few days earlier because surface melt, while low was occurring with more consistency by this date. An initial snow temperature of -10^{o}C was defined for the AWS (control) site based on measured values (Table 1). Within the model the cold content of the snowpack at each site is adjusted on a daily basis and ablation of the snowpack (SWE-mm) only occurs once the cold content is eliminated. No adjustment was made for wind speed in the model because there was no data to verify differences in the wind regimes at each site. Woo and Young (2004) showed that winds tend to be higher on plateau areas and can be reduced in valley terrain. It is likely that this omission did introduce some error into the snowmelt estimates especially for two sites which were more sheltered than others (SP1, SP9). Meteorological data inputs required for the model were obtained from the AWS and consisted of hourly values of precipitation (mm), air temperature (^{o}C), relative humidity (%), wind speed (m/s) and incoming solar radiation (W/m^{2}). Air pressure (Pa) was provided by the government weather station at Resolute Bay, Cornwallis Island (74^{o} 45'N, 94^{o}50'W; elevation 67.4 m a.s.l) since none was available at the AWS (~30 m a.s.l). Incoming short-wave measured at the AWS is assumed to be transferable to all sites in the study. This is a reasonable assumption since all ponds were considered to be level and are all within a small region. The model does have the ability to adjust for sloping terrain if required. Surface temperature is modelled after Woo *et al.* (1999). Longwave radiation outgoing is modelled using ε_s = 0.97, modelled T_s and incoming L↓ is determined with air temperature and ε_a, the emissivity from the sky according to Idso and Jackson (1969) using air temperature (^{o}C). Radiation melt attributed to net radiation (Q*) is composed of two components: the shortwave part calculated using snow albedo (α) and the longwave calculated as the balance between incoming L↓ and outgoing L↑. Measured net radiation (Q* -W/m^{2}) and albedo values (K↑/K↓-dimensionless) from the AWS were used to confirm the reliability of model results (modelled albedo and net shortwave radiation+ net longwave radiation) (Woo and Young, 2004). All measured data were recorded by a Campbell Scientific CR10 datalogger and instruments were approximately 1 m above the snow surface.

Table 1: Physical characteristics of the study sites and initial snow conditions. Snow indices used in the snowmelt model are also shown.

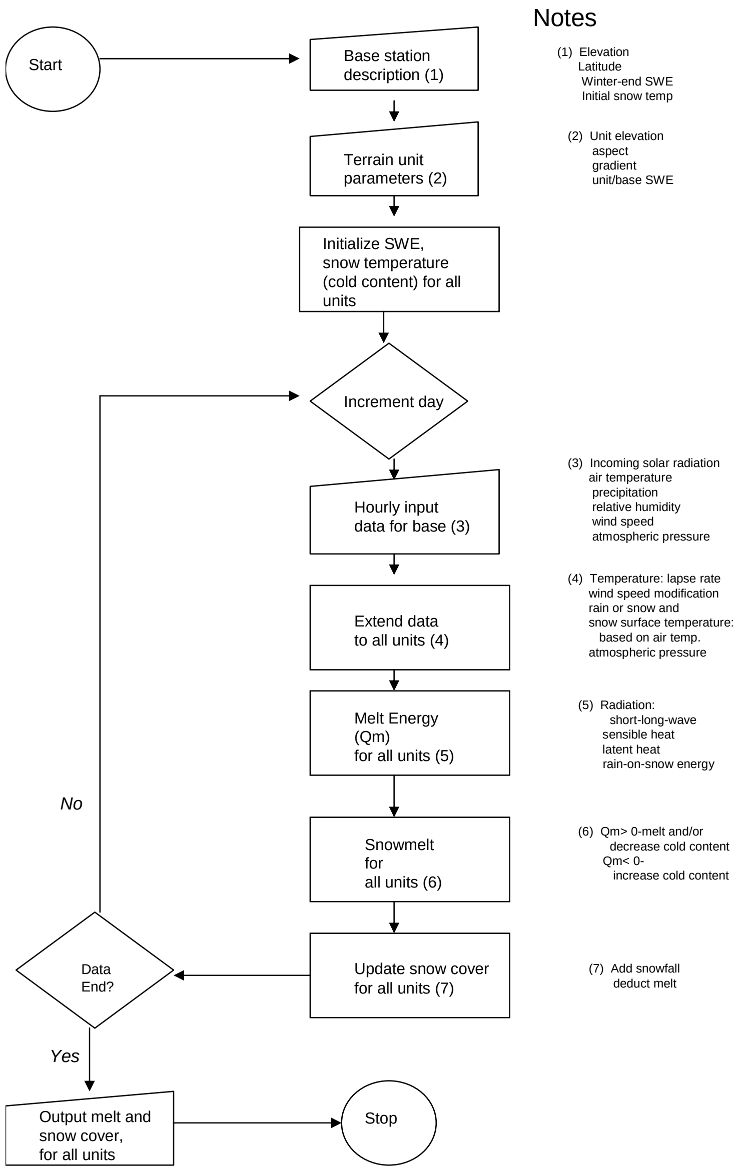
Study Site	Elevation and Setting	Area (m^{2})	Snow Conditions (JD 156)	Snow Index (ratio of pond SWE to AWS SWE)
SP1	28 m moraine	525		1.61
snow depth (mm)			747±88[1]	
sample size			86	
snow density (kg/m^{3})			346±41	
sample size			10	
SWE			258	

SP2 snow depth (mm) *sample size* snow density (kg/m^3) *sample size* SWE	30 m moraine	4386	 312±84 72 247±41 9 77	0.48
SP5 snow depth (mm) *sample size* snow density (kg/m^3) *sample size* SWE	30 m moraine	4680	 436±167 37 300±25 5 131	0.82
SP6 snow depth (mm) *sample size* snow density (kg/m^3) *sample size* SWE	42 m moraine	682	 405±44 56 275±19 9 111	0.69
SP8 snow depth (mm) *sample size* snow density (kg/m^3) *sample size* SWE	20 m coastal	1710	 389±125 36 277±30 5 108	0.68
SP10 (original)[2] snow depth (mm) *sample size* snow density (kg/m^3) *sample size* SWE	20 m coastal		 332±69 71 305±34 9 101	0.63
new SP10 (selected JD 199)	20 m coastal	615	-	-
SP9 snow depth (mm) *sample size* snow density (kg/m^3) *sample size* SWE	17 m east bedrock	345	 405±137 69 305±34 9 124	0.78
SP12 snow depth (mm) *sample size* snow density (kg/m^3) *sample size* SWE	22m west bedrock	460	 262±60 74 222±45 9 58	0.36
AWS snow depth (mm) *sample size* snow density (kg/m^3) *sample size* SWE	28 m moraine	-	 480 1 (snow pit) 333 2 160	1

[1] Standard Deviation

[2] by JD 199, this site was dried up and a nearby pond was selected for further analysis
Note: AWS snow depth is determined from snowpit information (480 mm on JD 163) and the snow density values (n=2) from the snow corer on JD 159.

Figure 3: Flow chart of Energy Balance Snowmelt Model (*after* Woo and Young, 2004)



Post-Snowmelt

In July a survey of about 71 ponds over this area was carried out. A range of environmental measurements were made including frost and water tables, water chemistry and soil conditions. Frost table was probed with a rod until frozen ground was encountered at three points in each pond. Water table was measured with a metric ruler or measuring tape at the same location as frost table measurements. Near shore soil cores were also obtained for volumetric soil moisture determination, organic content, soil size grain analysis and colour. Ponds in this study were measured initially on JD 199 and again on JD215. Some of this information is used here to assess the sustainability of ponds past the snowmelt period.

RESULTS AND DISCUSSION

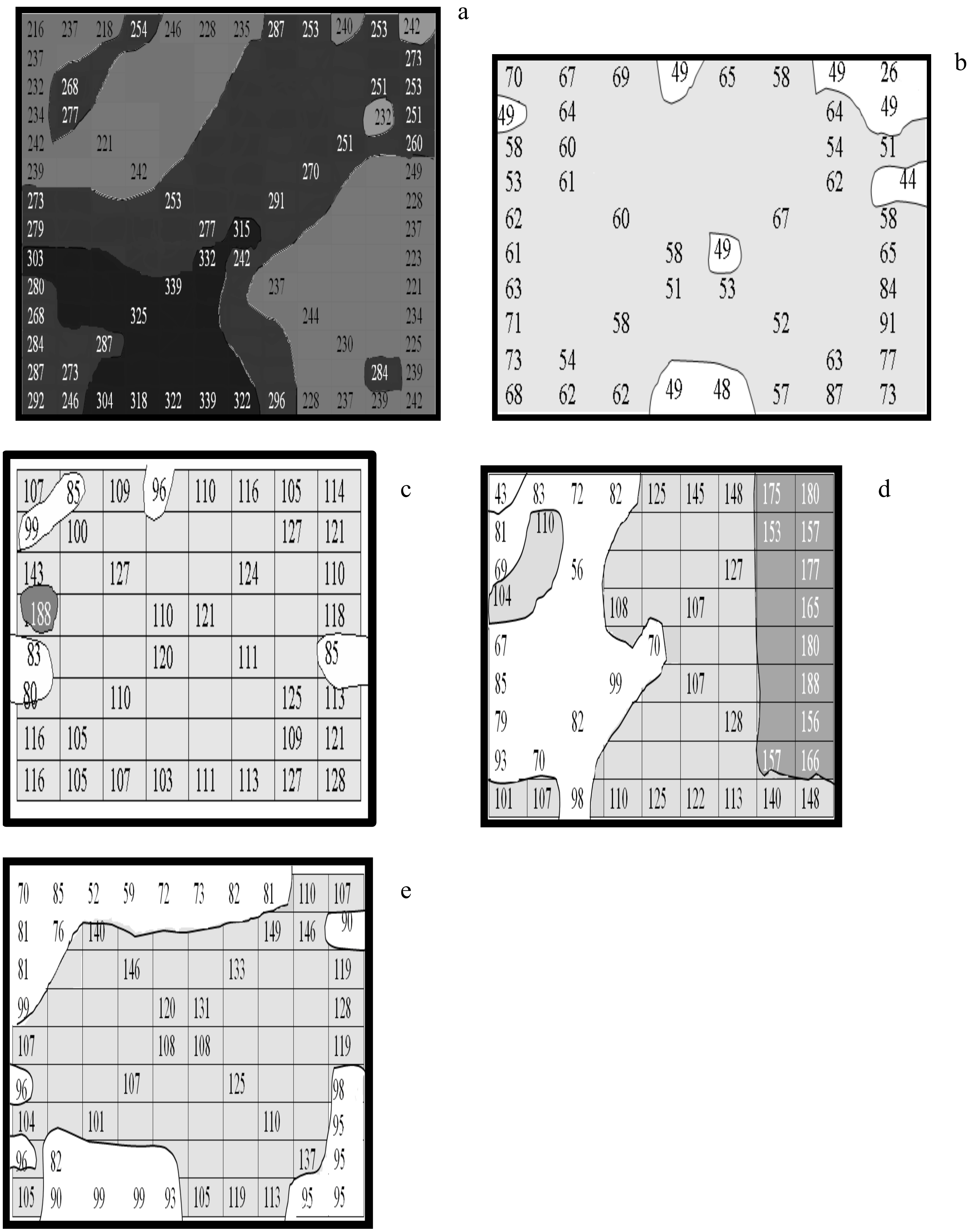
Snowcover

Snow is considered to be most important water input into northern hydrological systems and this environment is no exception. Snowfall occurs from about September till May and in June melt proceeds. The snowfree period is short with only July and August considered being the snowfree period though snow can fall in any month. Table 1 indicates the initial snow depths, snow densities and snow water equivalents (SWE) for the study ponds. Snow amount varies amongst the different pond types. SP1 with deep snow (i.e. 747 mm) lies at the foot of a southwest-facing slope which shelters it from strong winds. The upslope area also supports a large snowdrift which provides meltwater to the pond once the main snowmelt season is completed. More exposed locales tend to have shallower snow amounts (e.g. SP2-312 mm and SP10-332 mm). Snow density tends to be less variable than snow depth, with snow densities ranging between 222 kg/m^3 (SP12) to 346 kg/m^3 (SP1). Accordingly, snow water equivalent values (SWE, mm) differ amongst the sites; in particular, variations exist for ponds within the same geomorphological unit and across zones. For example, SP2 contained 77 mm while the SP5 pond site, a short distance away had about twice as much (SWE=131 mm). However, these two ponds still had much less than SP1. While the two coastal ponds (SP8 and SP10) have similar SWE (108 vs. 101 mm) the two bedrock ponds have quite different accumulations. The east bedrock pond, SP9 had an average coverage of 124 mm but the western bedrock pond site, SP12 contained much less (58 mm). The western pond is located near a rocky ridge, is more exposed to the dominant northwesterly winds (blew~40% of the time) while the eastern bedrock pond (SP9) is located in a slight depression sheltered from winds.

Snow accumulation and its re-distribution results in a heterogeneous system. Snow pit information collected on June 12 (JD 163) (not shown here) indicated that all sites shared similar snow characteristics though differences exist in terms of the depth of occurrence and thickness of the layers. Most pond sites possessed depth hoar and had layers of wind slab or ice layers along with fresh or recent snow. Snow diameters ranged from 1 to 2 mm. These patterns reflect the local wind regime and treeless topography (Young and Woo 2004) and are characteristic of other exposed arctic environments (Sturm *et al.*, 2002).

The spatial pattern of snow at the end-of winter is highly variable (see Figure 4). Ponds with deep snow tend to show a higher degree of spatial variability (SP1) in SWE than ponds with shallower snow (SP12). Detailed snow cover was not plotted for the large ponds (SP8 and SP5) since it was felt that the sampling for spatial coverage was insufficient. Spatial snow coverage ultimately influences the melt pattern and initiation of ground thaw in the study ponds.

Figure 4: Spatial snowcover pattern (SWE-mm) for selected ponds, JD 156. (a) moraine pond (SP1); (b) west bedrock pond (SP12); (c) moraine pond (SP6); (d) coastal (SP10); (e) east bedrock (SP9). Grids are 2 m^2 and contour interval is 50 mm.



Snowmelt-Performance of Surface Energy Balance Model

Woo and Young (2004) showed the reliability of their physically-based surface energy model at a point and over space (13 x 16 km^2 grid). For this study we similarly explore the performance of the model at the point scale (modelled albedo and net radiation is compared to measured values at the AWS). The model's performance over space was also assessed with the Stowaway temperature sensors, which were originally placed in snow pits at each pond site to provide an indication of the initiation and duration of snowmelt (see Table 2). The model reproduces the albedo pattern quite well (figure not shown), though tends to overestimate measured albedo later in the melt season, as the albedo quickly drops down to 0.2. However, snowmelt is generally over for all sites before this point is reached. The daily rhythm and seasonal pattern of net radiation through the melt pattern has a good agreement (Figure 5).

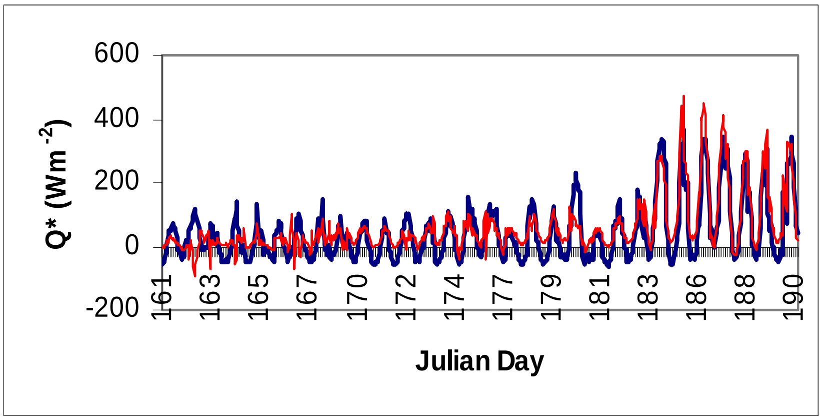


Figure 4: Comparison of modelled (thin line) and measured (thick line) net radiation (Q*) at the AWS

As indicated earlier, ablation of the pack does not occur until the cold content of the snow pack has been depleted. In the model it is determined as negative melt. At the AWS, there is good agreement between the start of consistent melt (cold content=0) as defined by the model and that as indicated by the Stowaway temperature sensor. The termination of melt is also modelled well. The greatest discrepancies occur for SP2 (start of melt is off by 3 days and the end of melt differs by 5 days). At this time, the reasons for these discrepancies are not clear. Owing to the initial spatial variability of SWE at all pond sites, the reliance of only one temperature sensor at each pond site to indicate the start and duration of melt is probably inadequate and more temperature sensors should have been deployed. However, in 2004, this was not possible. Overall, the Stowaway temperature sensors did provide a cost-effective and reasonable approximation of snowmelt duration for this low-gradient wetland area.

Table 2: Initial Snow Pit Temperature and Modelled versus Observed Start and End Dates of Melt

Study Site	Snow Pit Temperature (^{o}C) (snow/ground interface) JD 163	Start of Continuous Melt (JD)		End of Melt (JD)	
		Modelled	Observed	Modelled	Observed
SP1	-9	175	173	185	182
SP2	-8.6	174	170	179	174
SP5	-10.7	174	172	182	182
SP6	-10.8	175	176	182	179

SP8	-10.7	173	173	180	181
SP10 (original)[1]	-11.8	173	173	180	182
SP9	-10.7	173	173	180	179
SP12	-9.7	167	170	172	173
AWS	-10.0	174	174	183	180

[1] Observed values obtained from Stowaway temperature sensors
[2] by JD 199, this site was dried up and a nearby pond was selected for further analysis

Snowmelt-Temporal and Spatial Patterns

Figure 6 indicates the depletion of the snowcover at each pond site. As indicated earlier, SP1 (a moraine-type) pond had the deepest snow and SP12 (west bedrock pond) had the shallowest snow cover. Subsequently, SP12 became isothermal sooner and melted out much earlier than the other sites. SP2 (moraine pond) had only 77 mm of snow but it melted out later than SP12 but still earlier than the other moraine ponds. The coastal ponds had comparable melt patterns attributed to their similar snow amounts and elevations. The two bedrock ponds SP9 and SP12 had variable snow amounts and this is reflected in the melt patterns with SP9 becoming isothermal later and taking longer to melt-out (6 days vs. 3 days for SP12).

Figure 7 provides an indication of the spatial pattern of melt at the pond sites during peak snowmelt (uniform melt is assumed for each pond site). By this day (JD 178), the snowpack is reduced for most pond sites in comparison to initial conditions (see Figure 4) and snow amounts are often less than 50 mm of SWE. SP12 has melted out by this date and SP2 is largely snowfree. Only at SP1, does a sizeable snowpack still occur. Spatial variation of snow coverage and its eventual disappearance is important in defining the pattern and timing of ground thaw, releasing water for runoff generation or providing waters for vertical water losses such as infiltration or evaporation.

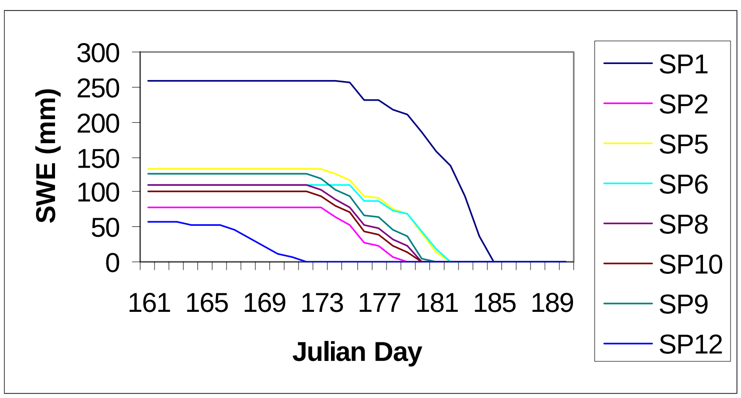
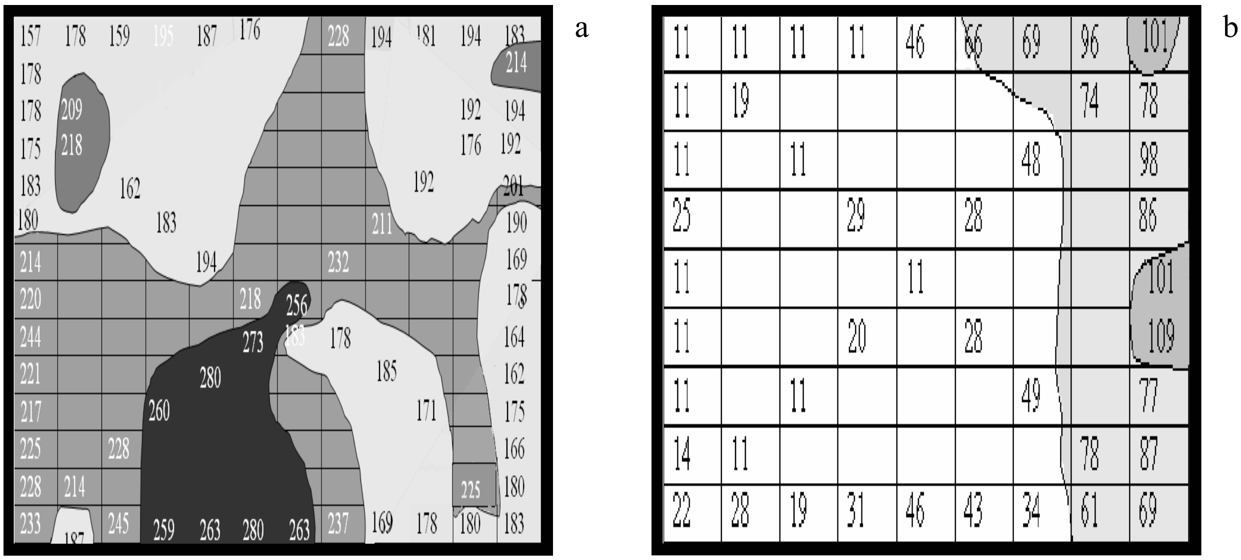


Figure 6: Depletion of snowcover (modeled) at the study ponds during the melt period, 2005.

Figure 7: Spatial snowcover pattern (SWE-mm) for selected ponds by JD 178. (a) moraine pond (SP1) and (b) east bedrock pond (SP9).



Degree of Sustainability

A deep snowpack often provides an indication that a positive water balance will be maintained in ponds. Deep snow generally takes longer to disappear, thus promoting a shallow frost table which sustains high water tables. This then allows surface conditions to remain saturated for an extended period and ensures the existence of hydrophillic plants. One of the goals of our research is to understand how different ponds are able to maintain positive water balances under varying climatic conditions. Table 3 provides an indication of the sustainability of the ponds by mid-summer. Sites which had a high degree of sustainability were SP1, SP2, SP5, SP8 and SP12. SP9 maintained a positive water balance, but shallow water over a black (2.5Y 2.5/1) (blue-green algae) crusted gravelly substrate by early August indicated that it could be vulnerable to desiccation either through evaporation or water loss through vertical seepage. SP6 and SP10 were intermittent. Both were dry when they were surveyed JD 199 and SP6 only became rejuvenated after ~21 mm of rain fell (JD 209-210). SP6 had initially deep snow but its sandy texture (46% fine sand-0.25 to 0.125 mm) provides good drainage and in the absence of a connection to other water sources (water spillage from ponds, streams) its chances for survival diminish. In the absence of sufficient rain, these types of ponds might cease to exist. This pattern is shared by SP10 in the coastal zone. SP8 does better than SP10 likely owing to its linkage to a nearby frost crack which channels melt water and rainwater from a distant slope. Initially, one would have suspected that SP12 and SP2 would be vulnerable to desiccation. Initial snow amounts were low and ground thaw and evaporation started earlier than the other sites. However, SP2 maintains a deep water level coupled with strong connections to other water sources (ponds, streams). At this point, it is not clear why SP12 is sustaining itself, since linkages to other water sources were not evident. Further research in 2005 may indicate the occurrence of a reliable groundwater source for this pond. Many ponds in this area are receiving meltwater draining from a series of late-lying snowbeds but SP12 was not one of them.

What is emerging from our research so far is that while the winter snowpack is still the most important input of water into pond systems, the survival of some ponds may also depend on how well connected they are hydrologically to nearby late-lying snowbeds, streams, lakes and frost cracks. These connections are critical in providing additional meltwater or for channeling and spilling water into their basins long after the seasonal snowpack has disappeared. This degree of connectivity might be the “make-or-break” trigger for the survival or demise of many small wetland ponds.

Table 3: Mid-summer Water and Frost Tables and Degree of Connectivity for Study Ponds

Study Site	Average Frost Table (m) (sample size=3)		Average Water Table (mm) (sample size=3)		Degree of Connectivity[1]
	JD 199-201	JD 215	JD 199-201	JD 215	
SP1	0.15	0.29	140	180	yes
SP2	0.23	0.40	330	460	yes
SP5	0.16	0.44	340	360	yes
SP6	0.38	0.61	dried out	10	no
SP8	0.37	0.62	150	200	yes
SP10 (original)[2]	-	-	dried out	20	no
new SP10 (selected JD 199)	0.56	0.66	50	80	no
SP9	too rocky to sample	too rocky to sample	130	40	no
SP12	0.24	too rocky to sample	110	140	no

[1]qualitative assessment in the field
[2] by JD 199, this site was dried up and a nearby pond was selected for further analysis
Note: Between JD 199 and JD 215 approximately 24 mm of rain fell over the area. The bulk of the rain (~21 mm) occurred over a two day period (JD 209 to 210).

CONCLUSIONS

This study has indicated the following:

1) Snow cover (SWE) and coverage in this low-gradient wetland system is variable among ponds occurring within similar geomorphological terrain (*e.g.* moraine) as well as for ponds which exist in different ground-types (moraine vs. bedrock). Snow coverage is a function of wind conditions and topography, with sheltered areas accumulating more snow while exposed ponds generally having less. High winds can re-distribute snow out of an area (Woo and Young, 2004).

2) Owing to the difference in snow coverage of the pond sites, timing of snowmelt and its duration varied amongst the sites. One pond in the bedrock zone with very shallow snow (58 mm) warmed up and melted out before a pond in the moraine area with 4x more snow initiated melt. For most sites though, the beginning and end of melt started within a few days of each other. Generally, melt started around June 22 (JD 173) and was finished in about 10 days. This snowmelt pattern also confirmed the applicability and reliability of a physically-based snowmelt model (Woo and Young, 2004). Previously, this model had been applied to the rolling landscape of Cornwallis Island.

3) Snowmelt inputs are important in maintaining the integrity of high arctic ponds but for some of the ponds at this extensive, low-gradient site, snowmelt inputs are not sufficient (SP6, SP9, SP10) and other inputs of water are required to maintain a positive water balance (WT>0). Clearly, consideration of hydrological connectivity and amount and frequency of summer precipitation (rain+snow) is required to assess how ponds will sustain themselves through both short- and long- term shifts in climate.

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