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Summer hydroclimatology of an extensive low-gradient wetland: Polar Bear Pass, Bathurst Island, Nunavut, Canada

Kathy L. Young and Claude Labine

ABSTRACT

Polar Bear Pass (PBP) (75°40′N, 98°30′W) is considered a critical wetland area for migratory birds, caribou and muskox. Little is known of its climatology and hydrology. Here we evaluate both the short-term and long-term summer climatic record for this wetland. A 10 m high automatic weather station (AWS) was established here 27 years ago, and in 2007 this centrally located AWS was supplemented by three more weather stations placed across the wetland pass. The long-term climate record here indicates little significant departure when compared to the long-term climate means (1971–2005) at Resolute Bay, a government weather station lying 90 km to the southwest (74°43′N, 94°59′W). Exceptions exist for July minimum air temperature (PBP > Resolute) and number of days in June, July and August < 0°C (PBP < Resolute). Climate variability from year to year remains the norm. Radiation receipt, air temperature, humidity and wind speed vary little across the wetland pass, while terrain-modified fluxes do. The precipitation regime is similar to Resolute Bay but local site conditions modify the amounts. In 2007, July evaporation levels were twice as high as that of 2008; more akin to Low Arctic sites. As yet, no clear trend in long-term climatic signals can be established.

Key words | Arctic wetlands, climate variability, evaporation, hydroclimatology, northern wetlands

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INTRODUCTION

Wetlands are central to northern ecosystems as they are lush areas which cleanse and store water. But recent evidence shows that they are vulnerable and are disappearing in some locations while expanding in others in response to climate warming (e.g. Yoshikawa & Hinzman 2003; ACIA 2005; Smith *et al.* 2005; Smol & Douglas 2007). Recently, Abnizova & Young (2008, 2009) demonstrated that the sustainability of wetland ponds can be tied to their landscape setting. Ponds in a polar desert setting remain resilient to triggers of climate variability (e.g. warm/dry conditions) if they can maintain a suite of linkages to additional water sources (e.g. water spillage from ponds/lakes, meltwater/ground water from nearby late-lying snowbeds) during the post-snowmelt season. Ponds located in ice-rich, fine-textured or organic soils also fair well. Here, frost tables are shallow, water tables remain elevated and ground ice melt can augment water availability in the absence of rain (Edlund *et al.* 1990; Abnizova & Young 2008, 2009). Conversely, ponds in ice-poor, coarse-textured soils generally dry out after snowmelt or rainfall owing to rapid and deep ground thaw which promotes vertical water seepage. These latter ponds can be considered to be more vulnerable to future warmer and drier conditions.

Hydrologic processes in northern wetlands (e.g. snowmelt, ground thaw and evaporation) are intimately tied to climate (Young & Woo 2006*a*,*b*). Net radiation and air temperature generally define the timing and magnitude of snowmelt, and evaporation from ponds, lakes and meadows

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is modified by energy availability, humidity gradients and turbulence. Ground thaw occurs when a strong thermal gradient exists and sufficient heat is available to both melt *in situ* ground ice, and warm the ground.

Polar Bear Pass (PBP) can be described as an extensive low-gradient wetland. It has been designated a wildlife sanctuary, so is considered a critical wetland area for migratory birds, caribou and muskox (Nettleship & Smith 1975). While much work has been done on the ecology of this area, less is known about its climatology and hydrology. We have little understanding of how this wetland might respond to future shifts in precipitation (type or magnitude), timing of snowmelt and evaporation rates if the thaw season is extended. In this study, we evaluate both the short-term and long-term climatic record for this wetland, targeting the months June, July and August, the active hydrologic period, which generally spans snowmelt to freeze-back. Emphasis is placed on average climatic conditions, trends and spatial variations across the wetland. Finally, the environmental response of PBP in terms of pond temperatures and evaporation rates is considered.

STUDY AREA

The study area, Polar Bear Pass (PBP), is centrally located on Bathurst Island (75°40′N, 98°30′W) (Figure 1). It spans 100 km^2 (20 km × 5 km) and extends from one end of the island to the other. The geological structure of Polar Bear Pass is characterized by an east–west thrust fault with limestone and dolomite forming the dominant bedrock (Blake 1964). Hills to the north of Polar Bear Pass are formed from long, regular east–west folds of limestone and shale, most under 180 m in height. Hills to the south of the pass are lower, and rise much more gradually from the valley floor. Many v-shaped valleys dissect the hills and deliver snowmelt and rainwater into the pass. Bathurst Island was covered by ice from about 35,000 to 10,000 years ago. Parallel terraced ridges of beach gravel are left in the pass, marking the changing location of the shoreline and the marine limit is estimated to be 90 m above sea level. PBP is covered by two large lakes, several smaller lakes and many small ponds often surrounded by lush, wet meadows of sedges and grasses. This landscape is modified by frost cracks, frost mounds, polygons and other expressions of patterned ground (Blake 1964). Edlund & Alt (1989) suggest that PBP is part of a zone 3-Prostrate shrub zone. Here, vascular plants are dominated by prostrate and matted shrubs on mesic sites and in wet areas by sedges. According to their definition, PBP can be considered to be a “biological oasis” typical of other High Arctic wetland sites (e.g. Truelove Lowland, Devon Island (Rydén 1977) or Bylot Island (Ellis & Rochfort 2006)). The PBP cabin is centrally located on a polar desert hilltop above the wetland, and is sparsely vegetated (lichens, *Saxifraga oppositifolia*, *Papaver radicatum*). The main Automatic Weather Station (MAWS) (installed in the early 1980s, 60 m a.s.l.) sits about 30 m northwest of the cabin. One roving automatic weather station (CAWS) is centrally located below the camp in a lush, wet meadow zone (sedges, moss) near several studied ponds ca. 25 m a.s.l.. The east roving weather station (EAWS) is situated at 75°44.1′N, 98°05.4′W, at 5 m a.s.l.. Ground cover here is sparser but plant diversity is higher. The west roving weather station (WAWS) is located at 75°42.3′N, 98°45.2′W and 20 m a.s.l.. It has a ground cover similar to EAWS.

METHODS

Since the early 1980s, climate data such as incoming solar radiation, air temperature, relative humidity, wind speed and direction have been collected at the main PBP AWS (MAWS). Occasionally, additional variables (e.g. ground temperatures) were monitored, depending on the particular aim of the project for that year. Unfortunately, data has gone missing, notably when the site was not visited on a regular basis. Roving weather stations were installed in early June 2007 and equipped with standard sensors to measure incoming and outgoing radiation, net radiation, air temperature, relative humidity, wind speed and direction, and ground heat flux. Precipitation in 2007 and 2008 was measured at all meteorological stations with both manual and recording rain gauges. All instruments were calibrated before going into the field and accuracy in the field is ca. ± 5% (Table 1). Only climate data, screened and quality checked, have been employed here to examine trends, to allow comparisons with the Resolute Bay weather station data (66 m a.s.l., 74°43′N, 94°59′W), and to assess spatial differences across the wetland. While year-round

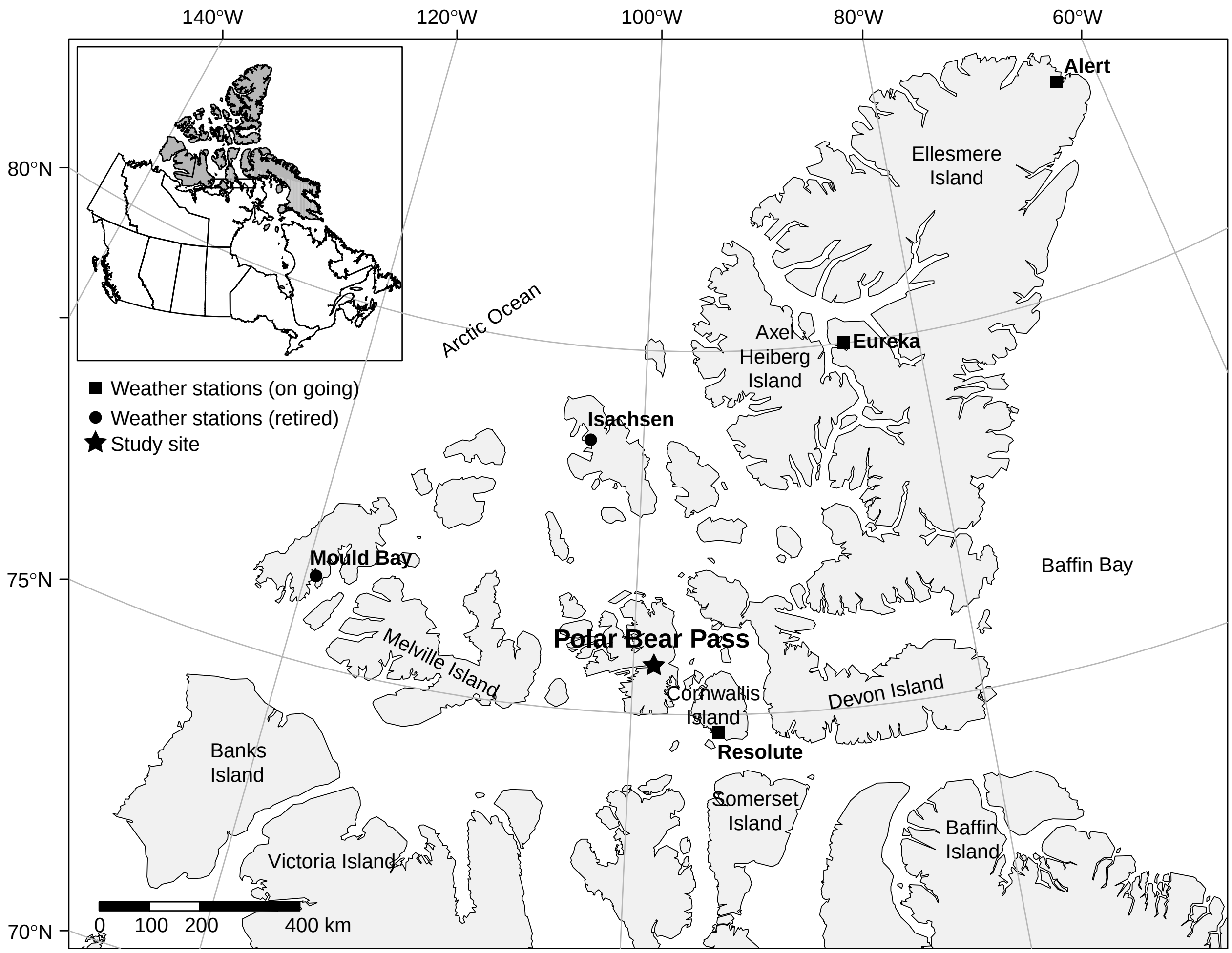

Figure 1 | Site map showing location of study site, Polar Bear Pass, Bathurst Island, Nunavut. Government weather stations are also indicated, including ones that have been retired (Mould Bay, Isachsen).

climate data does exist for PBP, uncertainty in AWS data can grow in the winter months, especially when the instruments and sensors become inoperable when coated with snow or rime (Woo *et al.* 2008). Hence, our focus here is on the summer season (June, July and August), since this time period is generally considered to be the most hydrologically dynamic. Moreover, climate data are often the most reliable as field scientists tend to be in the field concurrently and are able to check on AWSs. The number of thaw days was determined using the approach outlined by Woo & Young (1997) and a Student *t*-test ($\alpha = 0.05$) allowed differences of means to be evaluated for a suite of climatic variables (e.g. Davis 2002).

The wetland's response to climate (e.g. pond temperatures, evaporation) is also explored. Temperature is an important physical property because of its enormous significance to all freshwater organisms and water quality (Webb *et al.* 2008). Here we examine the variation in pond temperature (see Table 1) of linked and isolated ponds across the wetland and compare the signal to an earlier benthic pond study at PBP in 1969 (Danks 1971). In 2007 and 2008, pond temperatures were monitored continuously by small Stowaway Tidbit temperature probes (± 0.2°C), HOBO pressure transducers (± 0.1°C) and occasionally with a YS1 conductivity probe (± 0.1°C). Evaporation was assessed using the Priestley–Taylor approach for wet meadows and ponds with $\alpha = 1.26$ (Woo & Guan 2006; Abnizova & Young 2008; Wright *et al.* 2008). Rosenberry *et al.* (2004) have demonstrated that this method compares well to other approaches.

Table 1 | Climatologic instrumentation employed at Polar Bear Pass

Location and variable	Instrument	Height	Accuracy
Main AWS			
Incoming solar radiation*	Kipp & Zonen	3.75 m	> ± 1% or 0.01 MJ/m^{2}h
Wind speed	R. M. Young 05103 Wind Monitor	4 m	± 0.2 m/s
Wind direction	R. M. Young 05013	4 m	> ± 3°
Air temperature and relative humidity	CSI Probe	2.50 m	± 0.2°C and 5% respectively
Central AWS			
Incoming solar radiation*	Kipp & Zonen	1.24 m	> ± 1% or 0.01 MJ/m^{2}h
Outgoing solar radiation*	Epply	0.81 m	> ± 1% or 0.01 MJ/m^{2}h
Net radiation*	Kipp & Zonen	1.24 m	> ± 1% or 0.01 MJ/m^{2}h
Ground heat flux	Middleton	0.025 m	± 3%
Wind speed	Davies	1.90 m	> 5%
Wind direction	Davies	1.90 m	± 7%
Air temperature and relative humidity	CSI Probe	1.10 m	
Precipitation	CS Tipping Bucket Raingauge	0.38 m above ground	± 0.25 mm per tip
	Manual Raingauge	0.15 m above ground	± 1 mm
Eastern AWS			
Incoming solar radiation*	Hollis	1.98 m	> ± 1% or 0.01 MJ/m^{2}h
Outgoing solar radiation*	Hollis	0.44 m	> ± 1% or 0.01 MJ/m^{2}h
Net radiation*	REBS	1.33 m	> ± 1% or 0.01 MJ/m^{2}h
Ground heat flux	Middleton	0.025 m	± 3%
Wind speed	Davies	1.88 m	> 5%
Wind direction	Davies	1.88 m	± 7%
Air temperature and relative humidity	CSI Probe	1.30 m	
Precipitation	HOBO Tipping Raingauge	0.29 m above ground	± 0.25 mm per tip
	Manual Raingauge	0.15 m above ground	± 1 mm
Western AWS			
Incoming solar radiation*	Licor	1.35 m	> ± 1% or 0.01 MJ/m^{2}h
Outgoing solar radiation*	Licor	1.20 m	> ± 1% or 0.01 MJ/m^{2}h
Net radiation*	REBS	1.42 m	> ± 1% or 0.01 MJ/m^{2}h
Ground heat flux	Middleton	0.025 m	± 3%
Wind speed	Davies	1.76 m	> 5%
Wind direction	Davies	1.76 m	± 7%
Air temperature and relative humidity	CSI Probe	1.43 m	
Precipitation	HOBO Tipping Raingauge	0.29 m above ground	± 0.25 mm per tip
	Manual Raingauge	0.15 m above ground	± 1 mm

*instruments are calibrated prior to going into the field; accuracy in field ± 5%.

RESULTS AND DISCUSSION

Long-term trends

Radiation

Figure 2 considers the monthly averages of available radiation, wind and air temperatures for PBP since the early 1980s as recorded at the main AWS (MAWS). Incoming solar radiation is typically highest in June (242.4 W/m^2), lower in July (189.8 W/m^2) and levels in August are generally 50% of that in June (ca. 113.1 W/m^2) (see Figure 2(a)). Monthly radiation levels are quite typical of environments having a polar-desert-type climatic regime (long cold winters, cool, moist summers (Woo & Young 1996)). The seasonal pattern can be attributed to a declining solar angle, increasing cloud cover and low cloud cover as the season progresses (Woo & Young 1996). Radiation levels are variable from year to year, but of particular note is July 2007. Incoming solar radiation (ca. 260 W/m^2) was much higher than June, reaching a level representative of regions possessing polar-oasis-type climatic regimes (e.g. Fosheim Peninsula, ca. 80°N). Here, due to the sheltering effect of nearby mountain systems, these areas have a greater amount of radiation receipt than lower latitudes in the High Arctic and snowmelt is often advanced by about a month (Woo & Young 1996).

Wind

Wind speeds at a height of 4 m typically vary from 4.7 m/s (June) to 5.5 m/s (July) and 5.4 m/s (August) (Figure 2(b)). Wind speeds at the MAWS for June and July are slightly lower than the long-term means (1971–2000) recorded at Resolute Bay ($\alpha = 0.05$; height of measurement is 10 m).

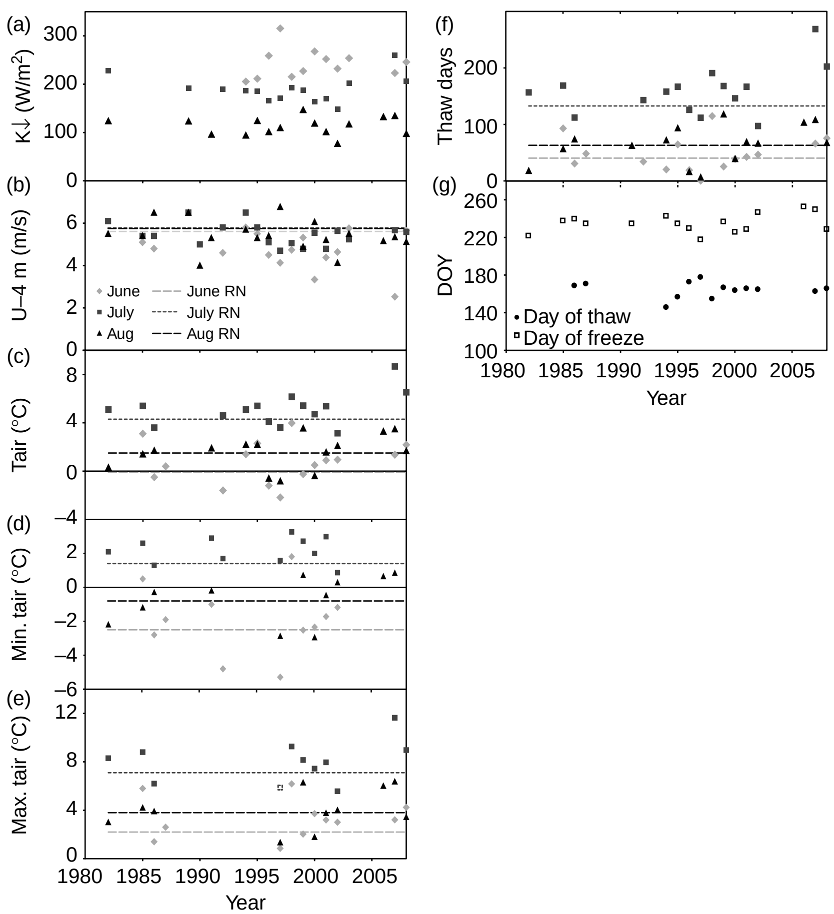

Figure 2 | Long-term summer climatic conditions (June, July, August) at Polar Bear Pass from 1982 to 2008. Note (a)–(e) are monthly averages. Climate normals (June, July, August) for Resolute Bay (1971–2005) are provided (RN).

Like radiation receipt, there is considerable variability in wind speed from year to year at Polar Bear Pass, though winds are typically >4 m/s, making it a moderately windy site (Figure 2(b)).

Air temperature

Air temperature plays a significant role in the timing and duration of snowmelt, active layer thaw (Rawlins & Willmott 2003) and plant growth and diversity (Walker *et al.* 2005). Mean air temperatures at MAWS (June = 0.8°C, August = 1.6°C) do not vary from Resolute's long-term mean (1971–2005), but July temperatures are higher (Figure 2(c)). Only in July are daily minimum temperatures higher at PBP than Resolute Bay (Figure 2(d)). Maximum temperatures in July and August are no different than long-term means for Resolute Bay, but June is significantly higher (Figure 2(e)). No long-term trend is evident in the temperature records. This is consistent with other studies across the circumpolar north where large year-to-year variations lead to low signal-to-noise ratios (e.g. Førland *et al.* 2004).

In terms of days >10°C and <0°C (data not shown here), PBP has a lower percentage of days than Resolute Bay ($\alpha = 0.05$). Given that the MAWS is centrally located and about 10 km from open water, one would have suspected that PBP should have experienced more days >10°C than Resolute which is located along the coast. Inland areas tend to be less cloudy, receive more radiation and are generally drier and warmer than coastal sites (Edlund & Alt 1989; Woo & Young 1997; Atkinson 2000): however, one explanation could be the limited climate record of good quality (about 10 years) for PBP. Nevertheless, in terms of thaw days at PBP, July shows significantly higher estimates than Resolute Bay (159 vs. 133 d) (see Figure 2(f)). To date, there is no evidence of an earlier start to thaw or a delay in the freeze-back date (see Figure 2(g)).

Typical summers (June, July, August)

Radiation

In Figure 3, we examine typical summers (2002–cool, 1994–average and 2007–warm) in more detail. Comparable to Figure 2(a), incoming radiation generally peaks in June,

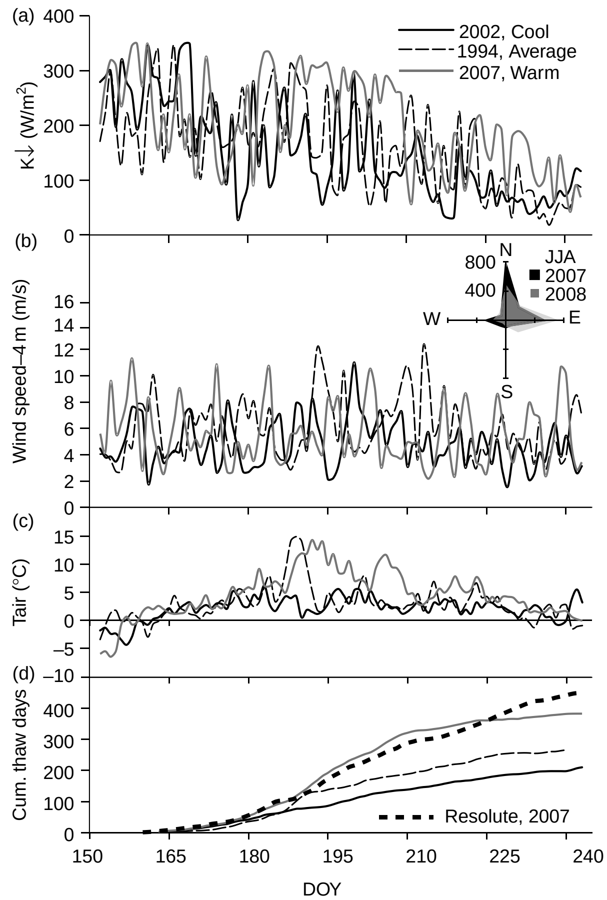

Figure 3 | Daily climatic conditions (June–August) for typical years at Polar Bear Pass. (a)–(c) are daily averages. Inset diagram (see (b)) is wind direction frequency. Cumulative thaw days in 2007 (Resolute Bay) are provided for comparison.

which is then followed by a steep decline, from 1 July onwards. By the end of August, radiation levels are reduced to 1/3 of the June values. There is considerable variability between these "typical summers", with the greatest variations occurring in June and less in August. Later in the season, frequent low clouds and a declining solar angle diminishes the amount of solar radiation received, no matter what kind of summer season (favourable or poor). Notably, the summer of 2007 was an especially sunny season (see Figure 3(a)).

Windspeed

In Figure 3(b), a "cool" summer (2002) appears to experience the lowest wind speeds. Only about 20% of the time did winds exceed 6 m/s, whereas in 2007 (a "warm" summer) wind speeds exceeded 6 m/s 45% of the time.

In "cool" years, lower windspeeds could be attributed to frequent foggy and calm conditions. Wind direction (2007 and 2008 data only) suggests winds generally blow from the northern sector and less frequently from the southwest (see Figure 3(b) (inset)).

Air temperature

Temperatures tend to linger below 5°C in June for most summers and then rise above 5°C or 10°C for a period of a few days (i.e. 2005) or longer (i.e. 2007). In a cool season (i.e. 2002), air temperatures rarely extend much above 5°C. Overall, there is considerable variability in July temperatures between these "typical summers" (Figure 3(c)). In a warm summer (e.g. 2007) the cumulative number of ground thaw days is almost double that of a cool season (e.g. 2002) (see Figure 3(d)).

Precipitation

Precipitation records are limited due to equipment failure and damage by wind and polar bears. Here, we provide daily precipitation only for the central wetland site (CAWS) for part of 2007 and for 2008 (June, July and August) (see Figure 4). Resolute summer precipitation (2007 and 2008) is plotted here for comparison. In 2007, due to a warm, dry season, summer precipitation was limited in amount and duration (Figure 4). Total summer precipitation (mm) for Resolute Bay in 2007 can be considered to be the second driest on record (Figure 5). This drought was far-reaching in 2007, extending well into the Low Arctic.

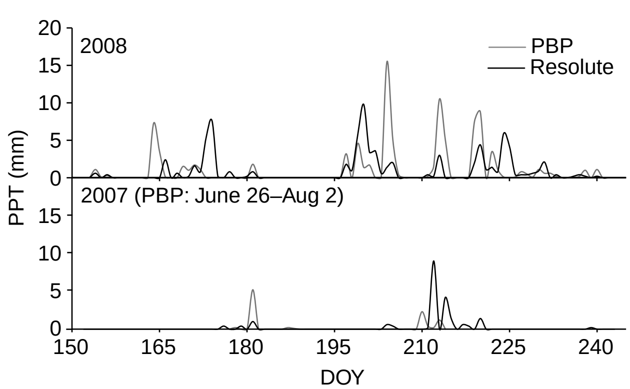

Figure 4 | Daily precipitation (mm) at the CWAS and Resolute Bay, June–August, 2007 and 2008.

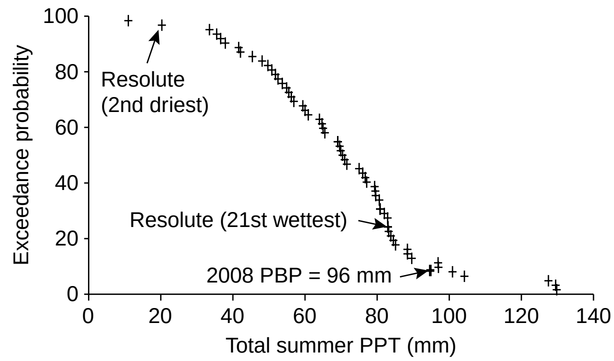

Figure 5 | Summer precipitation exceedence probability curve (June–August), Resolute Bay.

Woo *et al.* (2008) report that several streams in the vicinity of the Kuparuk River, Northern Alaska went dry along channel segments in 2007. They found that precipitation was 15 mm along the coast, 30–50 mm in the northern foothills and 80–100 mm in the headwaters. This differed significantly from a previous average of 241 mm (1985–2003).

In comparison, 2008 can be considered quite wet. It was the 21st wettest season recorded for Resolute Bay (Figure 5). However, if Resolute Bay had attained as much rain as measured at PBP (96 mm), then this amount would have placed it among the top 10% wettest years (Figure 5). Rainfall, while high in 2008, was not as high as reported by Kane *et al.* (2003) for an extreme rainfall event in the Low Arctic. Here, 80 mm of rain fell within a 50 h interval. Limited storage and steep slopes in the Kuparuk basin created a high runoff ratio of 0.73, even larger than snowmelt-runoff-generated runoff ratios. Finally, Figure 6 shows that there has been an upward trend in liquid to solid summer precipitation at Resolute Bay since about 1998.

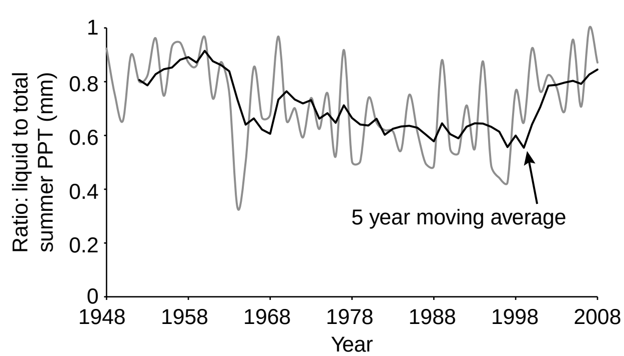

Figure 6 | Ratio of liquid to total summer precipitation, Resolute Bay.

This is consistent with climate models which report a shift to higher rainfall than snowfall in northern environments (ACIA 2005). Studies are also reporting more frequent rain-on-snow events (Floyd & Weiler 2008; Ye *et al.* 2008).

Climatology across PBP

Polar Bear Pass is 20 km long and is bounded by Goodsir Inlet on the east and Bridgeport Inlet on the west. Here we compare the difference in the climatology from the central part of the wetland to the western and eastern edges in terms of available climatic data (e.g. radiation, temperature, relative humidity, windspeed, etc.). A polar bear damaged the eastern AWS station in 2007, so for this comparison, we rely on 2008 data to explore similarities and differences (Table 2). In 2008, the western pass is only slightly warmer than the central site and this was comparable to 2007 as well (data not shown here). This departure, along with slight differences in relative humidity and wind, can be attributed largely to error uncertainty in instrumentation (see Table 2). What is clearly evident is that the western pass receives slightly less radiation than the middle of the wetland, which is reasonable since it would be more susceptible to sea breezes and fog (see Table 2). Given variations in incoming solar radiation, moisture and vegetation conditions between sites, it is reasonable to expect significant differences in net radiation and the ground heat flux (see Table 2). Chapin *et al.* (2000) found that mid-summer net radiation varied by 29% amongst a range of Arctic ecosystems and they attributed this to a range in albedo. Differences were significant enough that they suggested that they be taken into account for regional scale climate models that seek to accurately simulate high latitude processes.

The mean air temperature at the eastern end of the pass is significantly cooler than the central station owing to its close proximity to the Arctic Ocean; even closer than the Western AWS (Table 2). This coastal effect, with cool temperatures and sea breezes, has been reported widely in the north (see Haugen & Brown 1980; Jacobs & Grondin 1988; Woo & Ohmura 1997; Atkinson 2000). Relative humidity is slightly lower at the eastern edge than the central pass, but again owing to instrumental error (±5%) this difference is not likely significant. Wind speed is slightly lower at the eastern end and solar radiation is reduced owing to its coastal position. Sea breezes and coastal fog often develop as a pressure deficit occurs due to the warming of the land surface during the day which causes an inland flow of cooler air from the partially ice-covered ocean. Like the western edge, the greatest differences between the eastern and central parts of the pass are reserved for net radiation and ground heat flux, which are intimately tied to variations in both atmospheric and local surficial conditions (e.g. snow depth, soil moisture, soil texture and plant cover).

Table 2 | Comparison of climatic conditions (2008) at the Central Automatic Weather Station (CAWS) versus the west (WAWS) and the east (EAWS) stations. Slope of the line (*b*), strength of relationship (R^2), standard deviation (s.d.) and sample size (*n*) are included

Locations equation: $y = bx$	Tair (°C)	RH (%)	*U* (m/s)	$K\downarrow$ (W/m^2)	Q^* (W/m^2)	*Qg* (W/m^2)
CAWS (*x*) vs. WAWS (*y*)						
b	1.04	1.0	0.97	0.92	0.80	0.75
R^2	0.97	0.91	0.70	0.86	0.77	0.64
s.d.	4.5	12.0	2.2	184.7	108.2	29.3
n	2135	2135	1481	1481	1481	1242
CAWS (*x*) vs. EAWS (*y*)						
b	0.86	1.03	0.93	0.94	0.83	0.64
R^2	0.91	0.74	0.71	0.92	0.62	0.65
s.d.	4.0	11.2	2.1	186.1	103.7	27.6
n	1408	1408	1408	1408	1408	1408

Environmental response to climate variability

In this subsection we consider how this large low-gradient wetland responds to these climatic variations by considering pond temperatures and evaporation rates.

Pond temperatures

Pond temperature plays an important role in driving evaporation, modifying water quality (e.g. pH, dissolved oxygen, chemistry) and encouraging ground thaw. Pond temperatures for 2007 and 2008 are plotted in Figure 7. To provide some historical context, pond temperatures from an earlier study at PBP are reported here for pond-P1M (Danks 1971). In 2007, little variation in pond temperatures occurred for linked, isolated or ponds situated

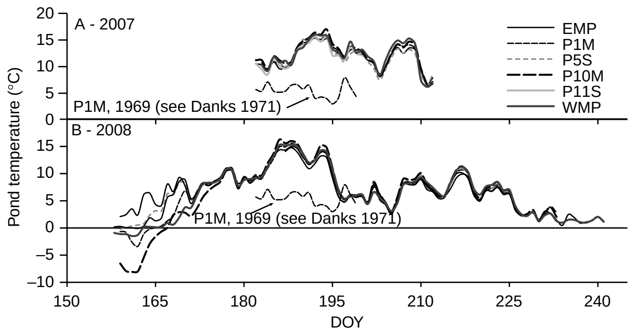

Figure 7 | Daily average pond temperatures (2007, 2008), Polar Bear Pass. Pond temperatures from an earlier 1969 study are plotted for comparison (see Danks 1971).

at either end of the pass (Figure 7). Only one pond (P10) was significantly warmer, and it is located 2.2 km further inland from CAWS. Overall, pond temperatures are now much higher than that reported by Danks (1971) in his 1969 study. His study showed that pond temperatures never rose above 10°C, whereas in 2007 pond temperatures were >10°C for over 20 d and >15°C for at least 3 to 4 d. In 2008, despite being a cooler year than 2007, pond temperatures still rose above 10°C for about 11 d, and remained higher than temperatures in 1969, except for a few days when weather conditions deteriorated and pond temperatures fell. In the early season during and following melt, pond temperatures are quite variable; thereafter they grow similar, in response to shallow depths and well-mixed conditions (see Figure 9).

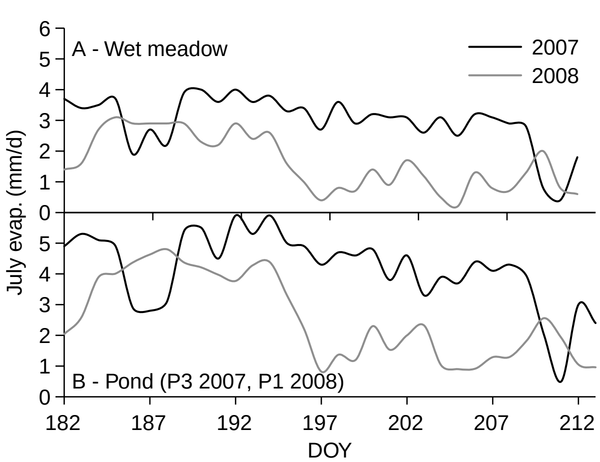

Figure 8 | Daily evaporation from wet meadow and pond sites, July 2007 and 2008, Polar Bear Pass.

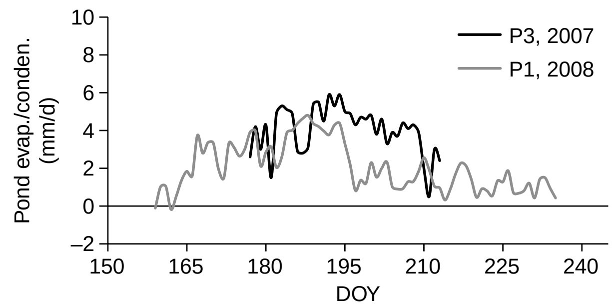

Figure 9 | Daily pond evaporation/condensation pattern, June–August, 2007 and 2008, Polar Bear Pass.

Evaporation

Owing to warmer conditions and higher net radiation receipt in July 2007 (mean Tair = 9.2°C, total $Q^* = 334$ MJ) than in July 2008 (mean Tair = 7.0°C, total $Q^* = 270$ MJ), evaporation was higher at a wet meadow site in July 2007 than in 2008 (Figure 8). In 2007, water losses averaged 3.0 mm/d (range = 0.4–4.0 mm/d), while in 2008 they fell to 1.6 mm/d (range = 0.2–3.1 mm/d). As expected, evaporation was slightly higher in ponds. Pond evaporation in July 2007 was 4.2 mm/d (range = 0.5–5.9 mm/d) and in 2008 it dropped to 2.6 mm/d (range = 0.8–4.8 mm/d) (Figure 8). Figure 9 indicates that July is the month when most evaporation occurs: however, rates can drop sharply in response to cloudy conditions and cool temperatures. In August 2008, evaporation rates were less than 2 mm/d (Figure 9). July 2007 estimates are equivalent to Low Arctic, Subarctic sites, in addition to High Arctic wetlands experiencing polar oasis climatic regimes (Woo & Guan 2006; Young & Woo 2006*a*,*b*). In 2008, evaporation rates are more applicable to polar desert environments (0.2–3.1 mm/d (Abnizova & Young 2009)). van der Kamp & Marsh (2004) suggest that any variation in climate that increases the relative importance of evaporation compared to precipitation is likely to result in the drying out of wetlands.

CONCLUSIONS

Woo *et al.* (2008) state that, while our understanding of permafrost hydrologic processes has advanced considerably in the past decades, there has been a disturbing circumpolar attrition of hydrometric and climatic monitoring networks (e.g. Shiklomanov *et al.* 2002). Evaluation of both the short-term and long-term climate data from Polar Bear Pass provides an adequate overview of the summer climatology of a critical High Arctic wetland ecosystem given its importance in modifying snowmelt, ground thaw, evaporation and freeze-back. These data also help to fill the gap in our understanding of the climatology of the central zone of the Canadian High Arctic Islands given the loss of two long-term government weather stations about 20 years ago (i.e. Mould Bay, Prince Patrick Island and Isachsen, Ellef Ringnes Island) (see Figure 1). Overall, this study has demonstrated that:

(1) Polar Bear Pass (PBP), despite being labelled a "biological oasis" (Edlund & Alt 1989), can be considered to possess a polar desert climatic regime. Both its long-term and short-term climate are quite similar to Resolute Bay (Woo & Young 1997).
(2) There is considerable variability year to year in the long-term climate record, and as such no defining trends or shifts in radiation, wind or temperature can yet be observed. However, two extreme summers have recently occurred (2007 and 2008). Warm and dry summer conditions persisted in 2007, while 2008 was extremely wet. It is expected that, due to climate warming, this critical wetland ecosystem will continue to experience strong variability from year to year. Pond temperatures and evaporation rates in 2007 and 2008 provide some indication of the potential range that this wetland might exhibit in response to future warmer, drier or wetter summers. Keller *et al.* (2008) recommends that extreme conditions need to be examined to determine if environmental thresholds will be passed (e.g. permanent loss of ponds). Woo *et al.* (2008) suggest that drought conditions have the potential to affect the future hydrological response of watersheds by altering vegetation in them, but because of sparse hydrologic networks and short durations of observation, extreme events usually go unreported.
(3) Modest variations in radiation, temperature and wind are observable across the wetland (east to west), but the most significant differences in energy fluxes occur for net radiation and ground heat flux, and can be attributed to subtle differences in ground conditions (e.g. snowcover, soil type and moisture conditions). These energy fluxes will continue to have the greatest impact on local differences in snowmelt, ground thaw and evaporation rates and so efforts to both measure and model them correctly are required.

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