

## 4.0 CLIMATE

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The Hudson Bay marine ecosystem is abnormally cold relative to other areas at the same latitude and exerts a strong influence on the surrounding land, contributing in particular to the unusual southern extent of the permafrost (Thompson 1968; Danielson 1969; Maxwell 1986; EWG 1989). The Kivalliq coast, in particular, is known for its strong winds and persistent low temperatures. Indeed, the region's earlier name "Keewatin" means "land of the north wind" in Inuktitut (Danielson 1969), and Chesterfield Inlet on the northwest coast has some of the most extreme wind chills in Canada. Coastal areas, with Hudson Bay on one side and treeless tundra on the other, are particularly exposed.

Most of our understanding of weather over the marine ecosystem has been inferred from coastal data. This biases some inferences. Land-based wind measurements, for example, tend to underestimate winds over the ice and water. Larouche (1990), who conducted winter studies at Kuujuarapik, found the mean wind speed was 29% higher over landfast ice and 66% higher over open water than at the coast.

Journals maintained by employees of the Hudson's Bay Company Posts contain daily references to the weather that date back to at least 1715 at Churchill and 1720 at York Factory and in James Bay (Catchpole and Ball 1981; Ball 1985). These systematic records provide useful data for long-term climatic comparisons (e.g., Moodie and Catchpole 1975; Catchpole 1980, 1985; Catchpole and Ball 1981; Jacoby and Ulan 1982; Catchpole and Faurer 1985; Wilson 1985a+b). Development of a comprehensive network of weather observing stations along the shores of Hudson Bay was not begun until 1931 (Thompson 1968). Its' purpose was to provide weather information and navigational assistance to ships using the northern sea route to transport grain and other goods from Churchill, through Hudson Bay and Hudson Strait, to European markets. Comprehensive, systematic weather data have been collected longest at Churchill, since 1931 at Inukjuak, Kuujuarapik and Chesterfield Inlet, since 1932 at Moosonee, 1941 at Chisasibi, and since 1943 at Coral Harbour. Shorter periods of observation are available for other communities bordering the ecosystem. Shipboard observations have provided a modest data set of offshore weather observations that allows comparison between coastal and offshore conditions during the navigation season (EAG 1984; Prinsenberg and Danard 1985; Maxwell 1986; Cohen et al. 1994)--late July through mid-October (Jones 1968). These data are not evenly distributed over the region. Few data are available from offshore areas outside the navigation season, and we know of no offshore precipitation records.

This section provides general historical background information on the climatic features that affect Hudson Bay and James Bay. As such, it does not discuss linkages with oceanographic processes or the wide variability of climatic components. That comes later. The impacts of climate on key physical and biological oceanographic processes, such as circulation, ice formation and production are discussed in Chapter 5 (Oceanography), and in the other Chapters that follow. The dynamic nature of the climate system as it affects the Hudson Bay marine ecosystem is discussed further in Chapter 17 (Climate Change). Unless otherwise noted the following treatment of climate draws on studies prepared by Thompson (1968), Danielson (1969), Fletcher and Young (1976), and Maxwell (1986). Data presented are taken from the 1951-80 normals period where available (after Maxwell 1986). More recent data on the 1971-2000 normals period are available from Environment Canada ([http://www.climat.meteo.ec.gc.ca/prods\\_servs/index\\_e.html](http://www.climat.meteo.ec.gc.ca/prods_servs/index_e.html)).

#### **4.1 CLIMATE CONTROLS**

The climate system is an interactive system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the land surface, and the biosphere, influenced by various external forces (Figure 4-1). The most important of these forcing mechanisms is the Sun but human activities also have a direct forcing effect on climate (Figure 4-2).

To understand the climate of the marine ecosystem one must consider the basic climatic controls such as distance from the equator, the nature of adjacent surfaces, continental and maritime influences, and the major features of atmospheric and hydrospheric circulation. The effects of human activities on climate are discussed in Chapter 17.

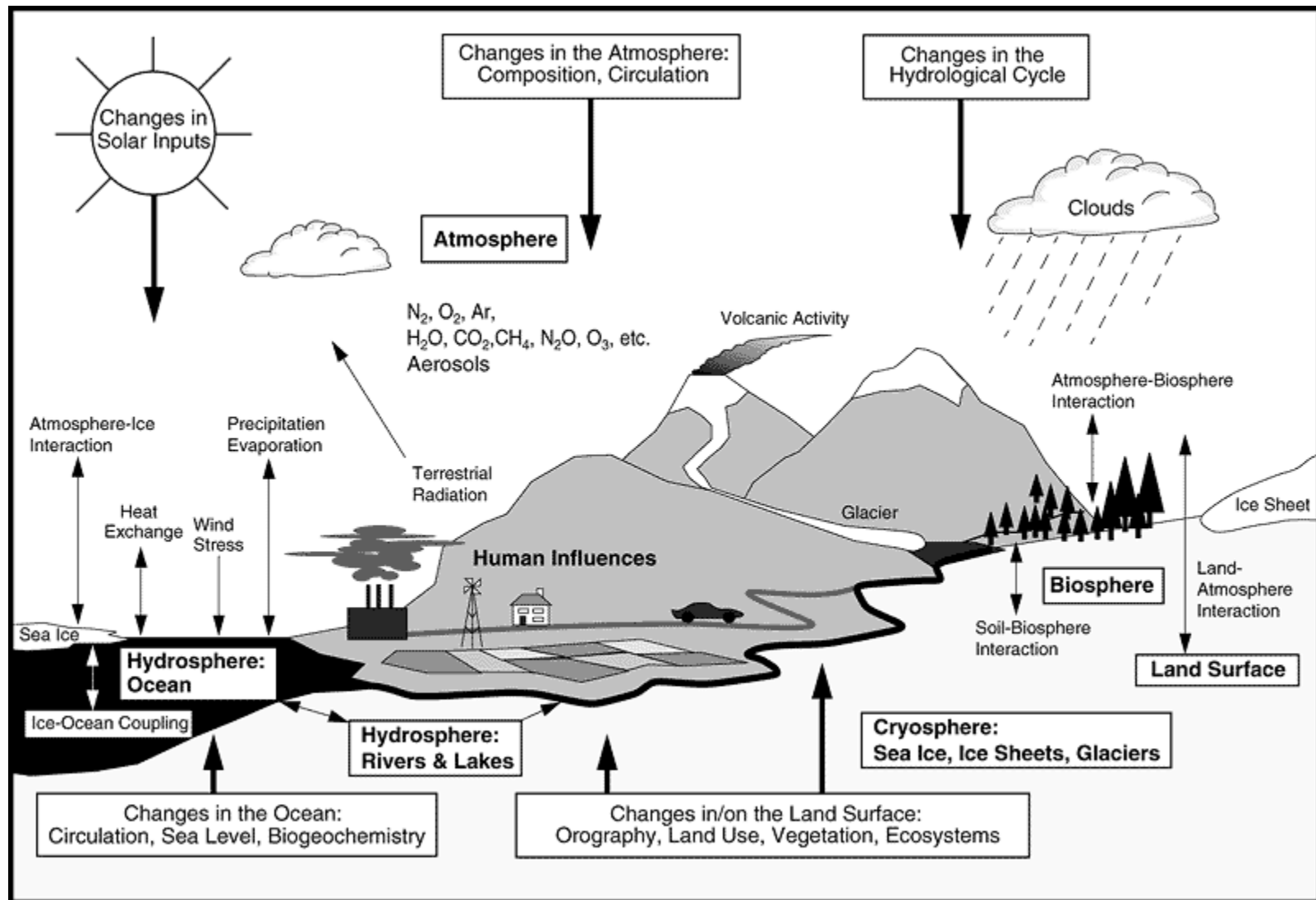


Figure 4-1. Schematic view of the components of the global climate system (bold), their processes and interactions (thin arrows) and some aspects that may change (bold arrows) (from IPCC 2001).

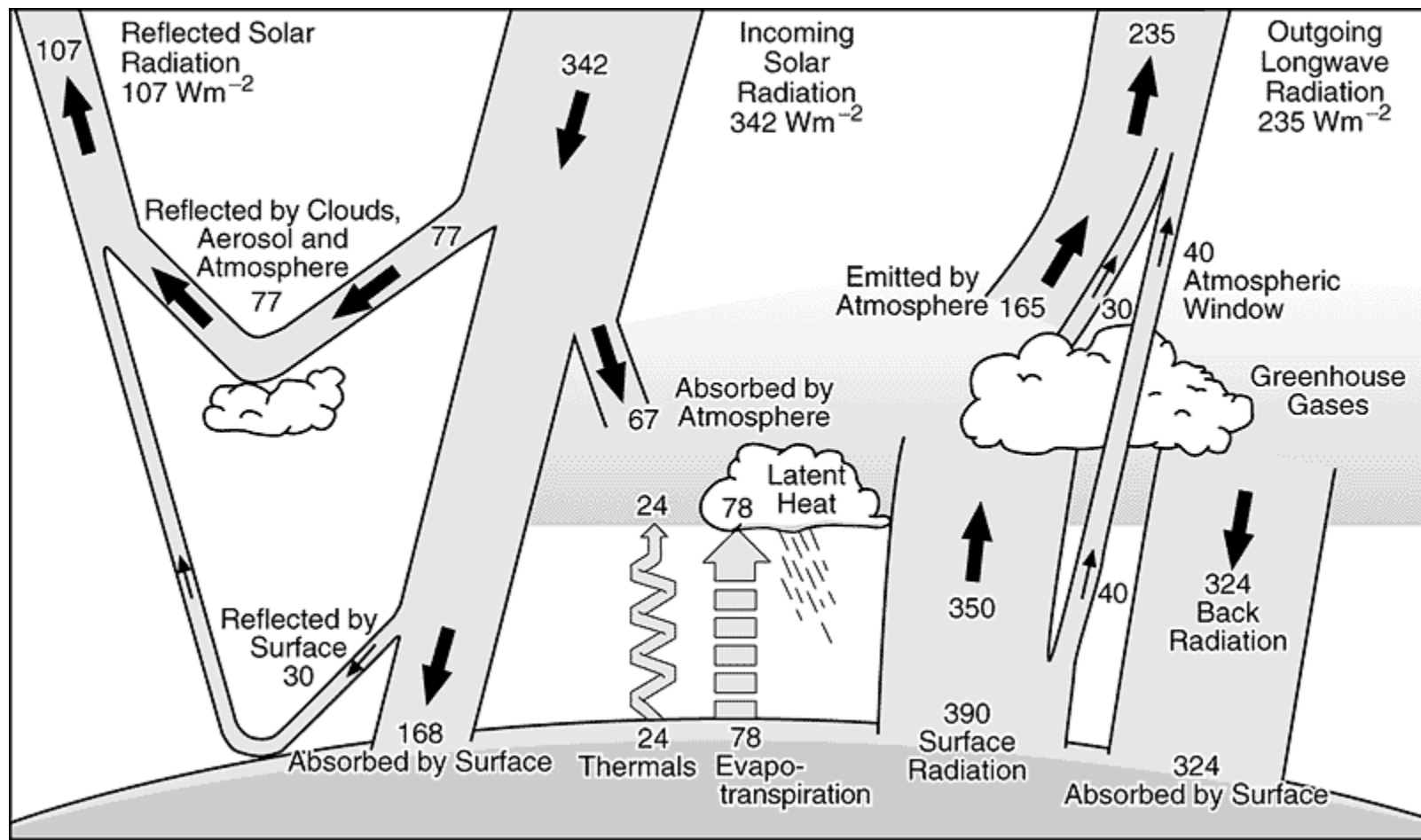
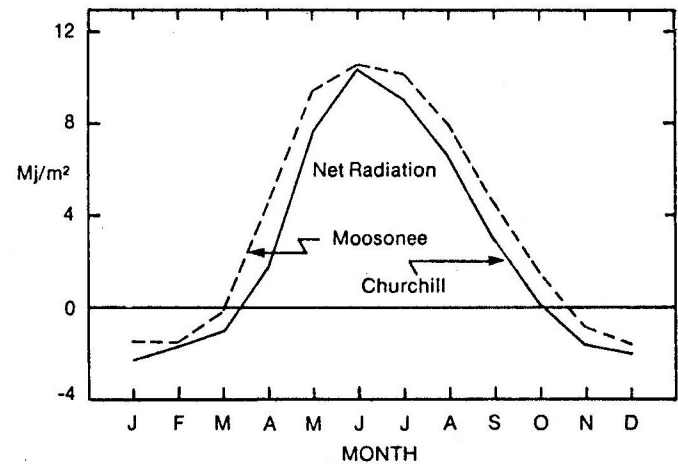


Figure 4-2. The Earth's annual and global mean energy balance. Of the incoming solar radiation, 49% ( $168 \text{ W}\cdot\text{m}^{-2}$ ) is absorbed by the surface. That heat is returned to the atmosphere as sensible heat, as evapotranspiration (latent heat) and as thermal radiation. Most of this radiation is absorbed by the atmosphere, which in turn emits radiation both up and down. The radiation lost to space comes from cloud tops and atmospheric regions much colder than the surface. This causes a greenhouse effect. (from IPCC 2001 after Kiehl and Trenberth 1997).

#### 4.1.1 Radiation Regime

While the Hudson Bay marine ecosystem is situated well south of the Arctic Circle, there is a large seasonal variation in incoming solar radiation, and the percentage of that radiation reflected (albedo) by snow, ice, wet surfaces, fog, and cloud is high (see also Wilson 1976; Lafl ur et al. 1987; Rouse et al. 1989; Silis et al. 1989). At Churchill and Moosonee the mean daily net radiation is positive from mid-March through October and negative for the remainder of the year (Figure 4-3). The highest mean daily net radiation occurs from May through August when solar radiation is greatest, despite the high surface albedo, and warm air over the cold water or ice keeps long-wave heat loss to a minimum. Solar heating decreases thereafter while long-wave and turbulent heat losses increase. The lowest mean daily net radiation occurs in December and January when solar heating is least and long-wave heat losses are greatest. Long-wave heat losses that continue though the winter allow ice cover to reach its' maximum in April at Churchill and in late March at Moosonee (Bilello 1980; Markham 1986, 1988), after which there is a sharp increase in solar radiation.



**Figure 4-3. Mean daily net radiation at Moosonee and Churchill (from Maxwell 1986).**

#### 4.1.2 Nature of Immediate and Adjacent Surfaces

Ice cover or very cold surface waters are characteristic of the Hudson Bay marine ecosystem except at the height of summer. In winter, ice cover causes its surface to experience the same climate as the adjacent coast. Ice and snow drastically reduce light penetration to the water, and thereby marine productivity. In summer, the cold Arctic water limits air temperatures in the immediate coastal areas to little more than 5 or 7°C over the temperature of the water and contributes to the presence of permafrost well past its normal southern latitude (Figure 3-7). Permafrost affects the summer climate, particularly that of western Hudson Bay and northwestern James Bay, by preventing moisture penetration into the soil. The resultant evaporation consumes energy that might otherwise be available to increase air temperatures.

#### 4.1.3 Physical Geography

While it is exposed to cold Arctic air masses year-round and to occasional intrusions of warm air from the south in summer, the Hudson Bay marine ecosystem is buffered from the direct entry of air masses from the Pacific and Atlantic oceans by mountains and distance. There are no major topographical features near the coast, but the inshore islands and coastline of southeastern Hudson Bay rise to elevations of 500 m asl in some areas. These heights of land act to modify climate on their leeward sides. The lack of major topographical features elsewhere means that other local coastal climates are often dependant on variations in terrain, vegetation, or drainage.

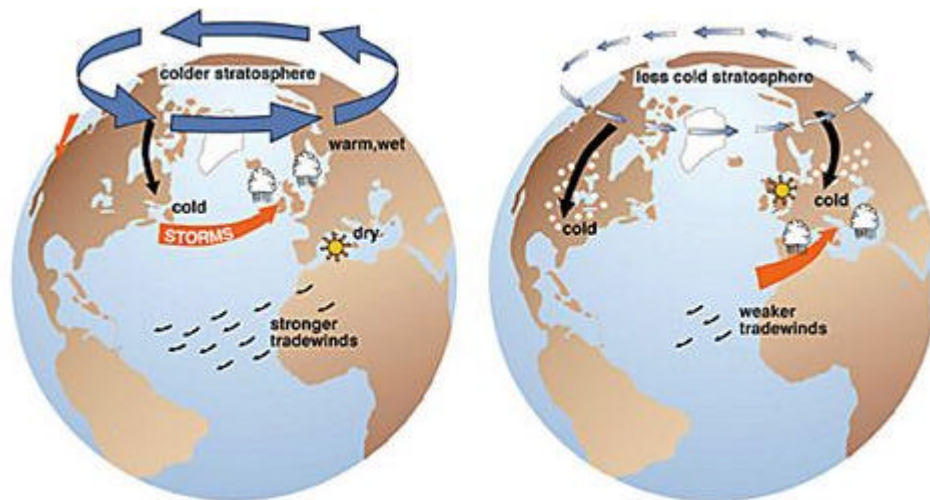
#### 4.1.4 Circulation and Weather Systems

The upper-air circulation controlling movement of weather systems over the water is mainly related to the persistent, counter-clockwise air flow around a low pressure vortex or trough (polar vortex) which is situated over Baffin Island in winter but weakens and retreats northward in summer. In winter there is a general flow of cold Arctic air from the northwest or west over the western half of Hudson Bay and from the west or southwest over James Bay and eastern Hudson Bay. Low-pressure areas generally pass south of James Bay but can

induce strong surface winds from the north or northwest as they recurve northward over Davis Strait. In spring the cold marine water has a stabilizing effect on the air. Its cooling effects reduce vertical convection and thereby wind stress and evaporation, and increase the heat flux into the water (Prinsenbergh and Danard 1985). In summer there is a general, but less intense, flow of air from the west through to the north (EAG 1984) over the water that exerts a moderating influence on the eastern coast. Summer storms often move directly across central Hudson Bay from the west or southwest, and thunderstorms are common on the Belcher Islands in summer. Currents of relatively warm, moisture-laden air from the south frequently precede these low-pressure areas. In autumn the relatively warm waters have a destabilizing effect on the cooler air, and the west to east storm tracks move southward to cross James Bay.

The position and intensity of the trough strongly influence year-to-year variability of the region's climate and affect the timing of ice breakup and freezeup (Cohen et al. 1994; Wang et al. 1994c; Mysak et al. 1996; Mysak and Venegas 1998). A more intense trough or an eastward shift in its position brings cold northerly air into the region more frequently, and *vice versa*. These shifts can occur in a very short time, forced primarily by natural variation in the atmospheric pressure field associated with the Arctic Oscillation (Macdonald et al. 2003a).

The Arctic Oscillation is an atmospheric circulation pattern in which the atmospheric pressure over the polar region varies in opposition with that over middle latitudes (about 45 degrees North) on time scales ranging from weeks to decades. It extends through the depth of the troposphere and from January through March upward into the stratosphere, where it modulates the strength of the westerly vortex that encircles the Arctic polar cap (<http://nsidc.org/arcticmet/>). The Arctic Oscillation correlates strongly (85-95%) with the North Atlantic Oscillation, a more commonly used indicator of large-scale wind forcing. The latter is the normalized gradient in sea-level air pressure between Iceland and the Azores. The terms carry much the same information and can be used more or less interchangeably (Macdonald et al. 2003a). When the Arctic Oscillation is in its "negative phase", pressure is higher over the polar region than at mid-latitudes and frigid winter air extends further south—and *vice versa* (Figure 4-4).



**Figure 4-4.** Effects of the positive (left) and negative (right) phases of the Arctic Oscillation (Figure from the NSIDC Arctic Climatology and Meteorology Primer, attributed to J. Wallace, University of Washington [ <http://www.nsidc.org/arcticmet/> ]).

The effects of these large-scale changes in atmospheric pressure on the Hudson Bay marine ecosystem are not fully understood (Macdonald et al. 2003a). However, both the North Atlantic Oscillation and the El Niño-Southern Oscillation have been correlated with decadal changes in the concentration of the sea ice (Wang et al. 1994c; Mysak et al. 1996; Mysak and Venegas 1998). During strong winter westerly winds of the

North Atlantic Oscillation and Low/Wet summer episodes of the El Nino-Southern Oscillation, thicker sea ice forms in Hudson Bay and breakup is delayed.

Atmospheric pressure systems also influence water circulation in Hudson Bay directly by wind stress and indirectly by tilting the sea surface (Larouche and Dubois 1988, 1990). Changes in the direction and amplitude of surface currents in the spring near Kuujjuarapik correlate well with direct wind action, with a lag time of hours or days depending upon the strength of the changing wind; the effect of surface tilting is small by comparison.

## 4.2 SEASONS

Seasons in the Hudson Bay marine ecosystem do not correspond exactly to those in southern Canada or in Foxe Basin, and vary from north to south. In northern Hudson Bay, autumn usually lasts from early September through October; winter from November to the end of April; spring through May and June; and summer through July and August. In southern Hudson Bay and James Bay, autumn usually lasts from mid-September through mid-November; winter from mid-November to the end of March; spring from April through mid-June; and summer from mid-June to mid-September. The following sections briefly describe seasonal changes in temperature, wind, precipitation, and the frequency of fog and blowing snow.

### 4.2.1 Autumn (mid-September to mid-November in the south; September to October in the north)

In autumn the cold Arctic air masses move progressively southward as the days shorten and upper-air westerlies intensify, until by October the main west to east storm tracks cross Hudson Bay and northern James Bay at 3 to 4 day intervals (Figure 4-5 and Figure 4-6) (see also EAG 1984). The heat and moisture they

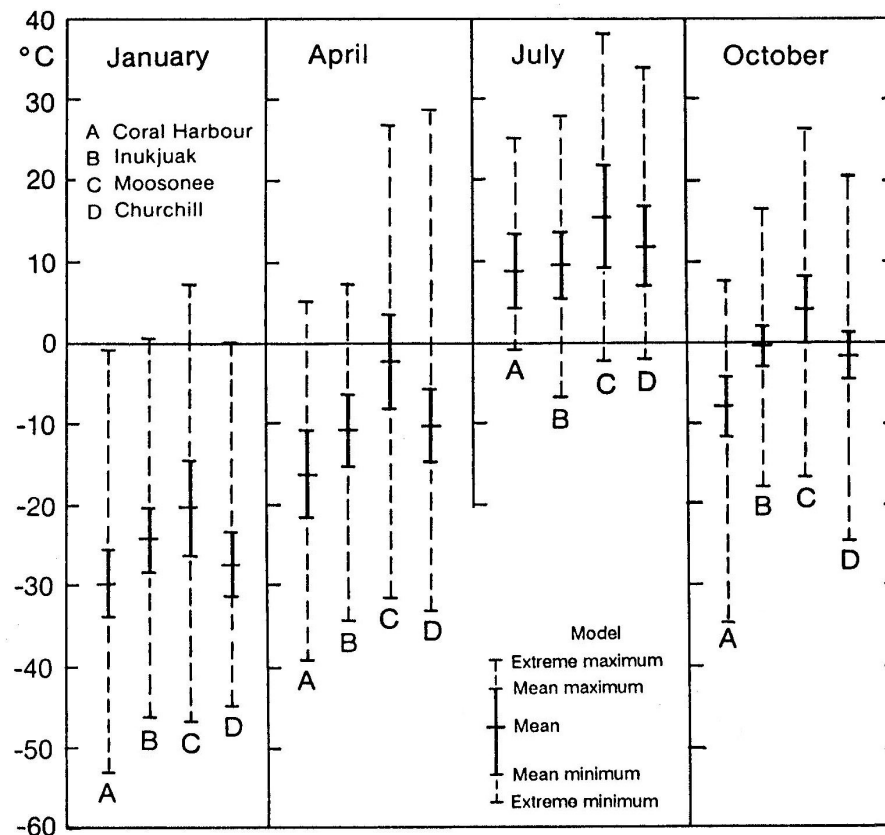
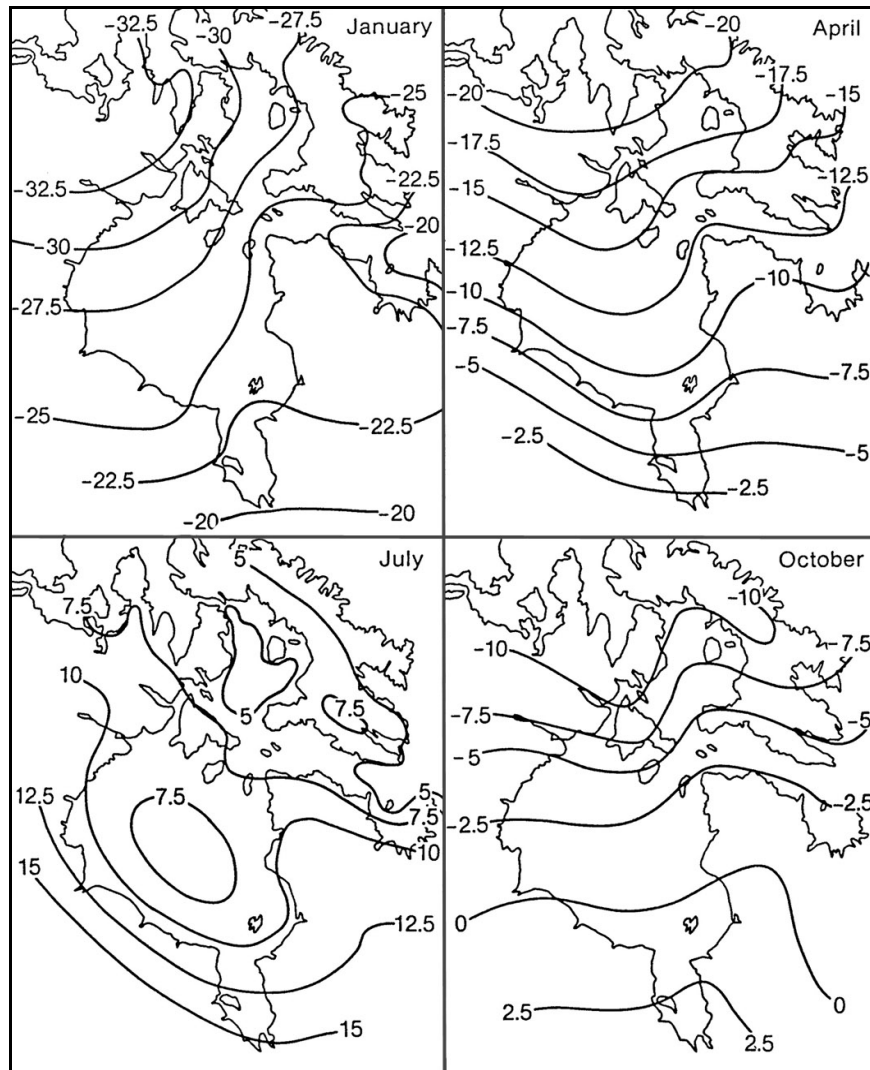


Figure 4-5. Mean annual and extreme air temperatures at Coral Harbour (A), Inukjuak (B), Moosonee (C) and Churchill (D) (from Maxwell 1986).

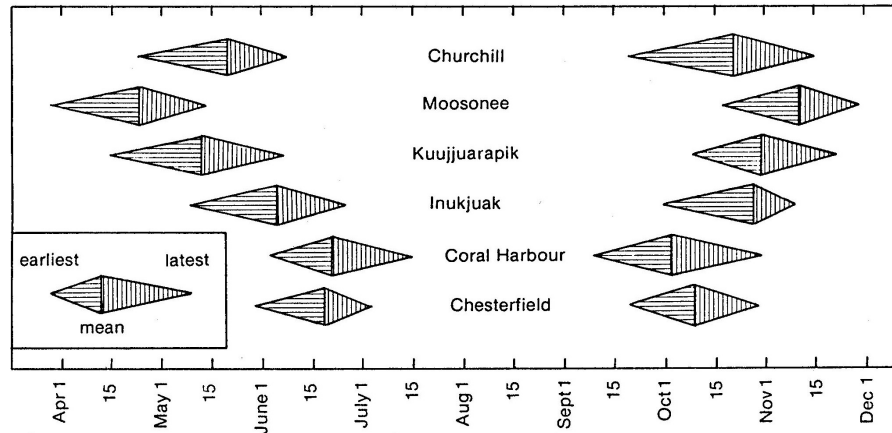


**Figure 4-6. Mean daily air temperature (°C) (from Maxwell 1986).**

accumulate in passing over the still-open waters result in cloudiness and snowfall (Figure 4-7), particularly along the southeastern coast. In Hudson Bay, the prevailing autumn winds are generally northwesterlies except in the southeast where the last remaining open water surface is reflected by frequent easterly winds at Kuujjuarapik. The surface wind speed averages about  $20$  to  $25 \text{ km}\cdot\text{h}^{-1}$  – a bit higher in Hudson Strait and lower in James Bay (Table 4-1). On average the mean daily temperature drops below  $0^{\circ}\text{C}$  in late September at Coral Harbour and in late October at Moosonee (Markham 1988). Low-lying cloud and fog are common. The wind velocities, frequency of fog, and mean total cloud cover are expected to be greater over the smoother, moister marine surface than on the coasts (see also EAG 1984).

In northern and western Hudson Bay the stormiest months with the highest surface winds and snowfall occur in late fall (October) and early winter (November), a bit later in James Bay (Table 4-1; see also EAG 1984). During this period, turbulence, poor visibility caused by snowstorms, and severe icing in low-lying cloud hampers air travel to communities along the northern coasts of Hudson Bay. Strong autumn winds can cause tidal storm surges of at least  $1.2 \text{ m}$  in southern James Bay--sometimes with fatal consequences (Godin 1975). Coastal boat travel is also hampered by strong winds, fog, superstructure icing (see also EAG 1984), and coastal ice formation. Local coastal travel by snowmobile begins soon after the landfast ice begins to form, usually in late November in the north and early December in the south, but is not widespread until about mid-





**Figure 4-7. Disappearance and formation dates of continuous snow cover (from Maxwell 1986).**

December in the north and late December in the south when the ice is stronger and extends well down the east and west coasts.

#### **4.2.2 Winter (mid-November to March in the south; November to April in the north)**

Cold conditions that persist over long periods and frequent, severe wind chill are characteristic of the Hudson Bay marine ecosystem in winter, particularly along the barren northwestern coast. To the south the winters are long and cold but not as severe, especially in southern James Bay where forests offer protection from the wind. The shortest day of the year, 21 December, is about 8 h 24 min in the south and 4 h in the north (Canada 1987). Temperatures less than  $-15^{\circ}\text{C}$  persist for much of the time and thaws are infrequent. Extreme low temperatures in the  $-45^{\circ}$  to  $-50^{\circ}\text{C}$  range, about  $5^{\circ}\text{C}$  cooler in northern Hudson Bay, generally occur in January or February (Figure 4-5, Figure 4-6).

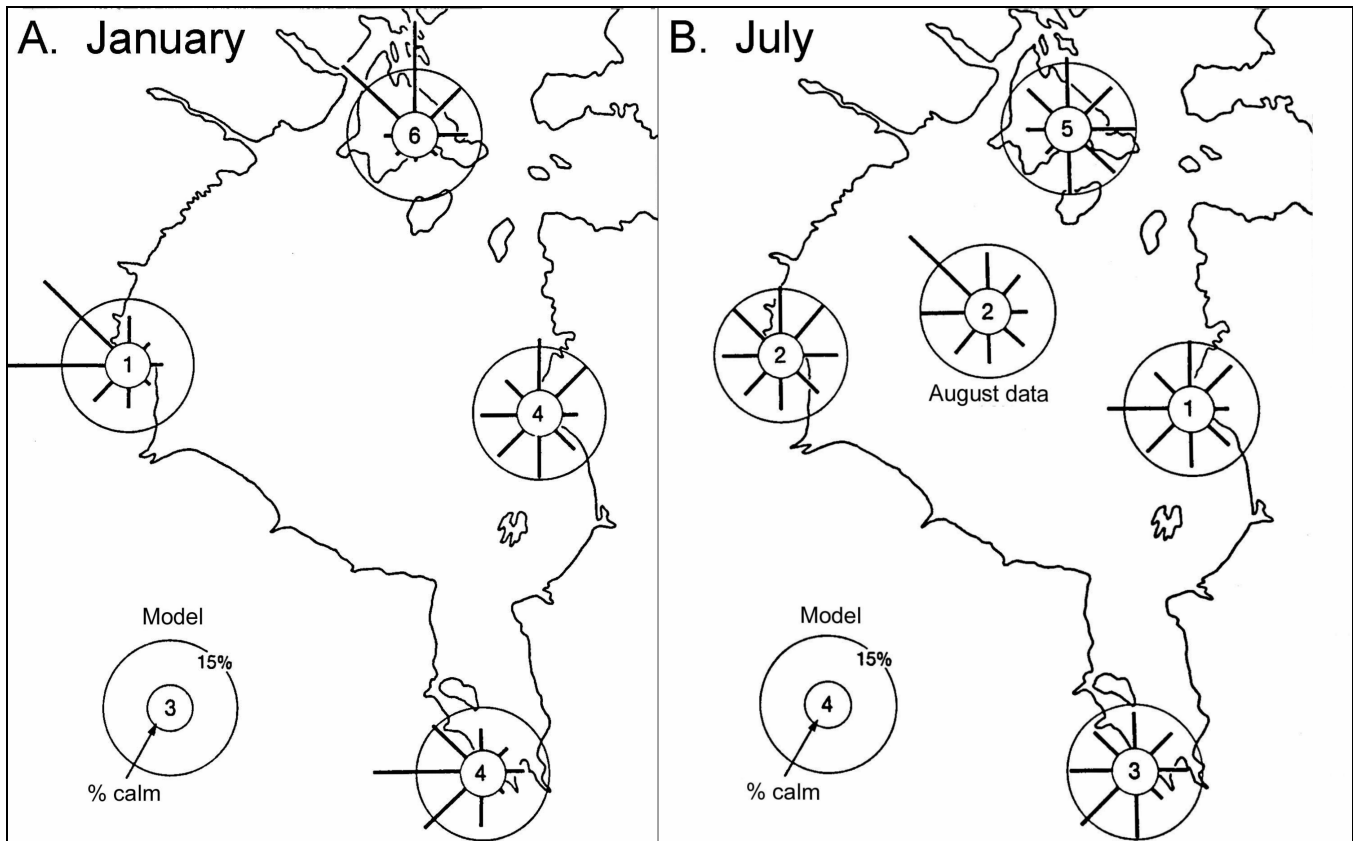
The relatively warm water has a moderating influence on air temperatures along the leeward east coast of the ecosystem, particularly before ice formation is completed in mid-December (Markham 1986, 1988). Afterwards, the marine surface resembles that of the adjacent land and cloud, snowfall, and temperature regimes show less west-to-east variation.

During the winter, the main storm tracks lie south of James Bay. The winds are constant due to a strong pressure gradient between the high over the Mackenzie-Kivalliq area and low over the Baffin Bay-Davis Strait area. Most of the bad weather results from temporary changes in the direction of upper wind flow, which causes southern storms to deviate northward, or from fluctuations in the pressure gradient. The former may bring clouds, snow and wind, and the latter strong wind. Closer proximity to the storm tracks results in greater cloud cover along the southern coast, and localized steam fog occurs at persistent shore leads and wind-induced patches of open water.

Characteristic features of the winter weather in northern and western Hudson Bay are strong winds, persistent low temperatures, and snow cover (Table 4-1; Figure 4-5, Figure 4-6 and Figure 4-8). In combination, the average January wind speeds, 20 to  $25\text{ km}\cdot\text{h}^{-1}$ , and temperatures,  $-25$  to  $-30^{\circ}\text{C}$ , in coastal areas correspond to a cooling rate (wind chill) of nearly  $2300\text{ watts}\cdot\text{m}^{-2}$ , a level at which exposed skin freezes in less than a minute for the average person. Wind chill at Chesterfield Inlet can reach  $3118\text{ watts}\cdot\text{m}^{-2}$  in January and is at the extreme for all of Canada. The snow is generally fine and powdery. It is carried easily by the strong winds and frequently restricts visibility (Table 4-1). Blizzards caused by strong winds, low temperatures,

**Table 4-1. Monthly and annual wind speed, precipitation, and frequency of fog or blowing snow, 1961-80 normals (from Maxwell 1986; tr = trace amount).**

		Feb.	Apr.	Jun.	Aug.	Oct.	Dec.	Annual
<b>Wind speed (km·h<sup>-1</sup>)</b>								
Moosonee	mean	12.2	14.5	14.1	12.3	14.4	11.8	13.5
	maximum	60	51	45	48	56	56	61
Kuujjuarapik	mean	16.9	17.0	16.7	17.9	21.2	20.4	18.3
	maximum	74	80	64	77	80	84	97
Inukjuak	mean	17.2	32.6	20.8	21.6	22.4	20.8	21.2
	maximum	59	74	52	61	65	63	74
Churchill	mean	24.1	22.6	20.7	20.5	24.9	22.4	22.7
	maximum	80	74	77	95	82	80	116
Chesterfield Inlet	mean	24.6	21.4	18.5	20.4	27.9	23.8	22.3
	maximum	80	78	93	70	95	74	95
Coral Harbour	mean	20.2	19.3	19.6	19.8	22.1	20.5	20.2
	maximum	135	93	74	97	90	109	145
<b>Mean precipitation</b>								
Moosonee	rain (mm)	1.8	21.4	77.9	79.2	60.2	3.9	501.5
	snow (cm)	30.0	21.2	0.8	0.0	14.5	39.9	239.3
Kuujjuarapik	rain (mm)	0.3	5.2	51.7	94.0	46.3	1.0	401.3
	snow (cm)	24.2	22.1	4.8	0.0	27.3	42.0	241.2
Inukjuak	rain (mm)	0.0	1.9	31.1	64.9	24.4	0.1	246.3
	snow (cm)	8.7	13.3	3.7	tr	22.0	23.2	144.2
Churchill	rain (mm)	0.1	2.0	39.9	58.3	15.4	0.2	221.1
	snow (cm)	14.6	22.3	3.5	0.0	29.3	22.8	195.5
Chesterfield Inlet	rain (mm)	0.0	4.0	17.9	38.6	9.4	tr	145.5
	snow (cm)	4.5	11.5	5.1	0.2	24.3	13.8	112.5
Coral Harbour	rain (mm)	tr	tr	18.5	44.2	11.3	tr	141.4
	snow (cm)	9.2	14.4	8.1	0.3	26.7	10.8	131.9
<b>Frequency of fog or blowing snow (mean number of days)</b>								
Moosonee	fog	1	2	1	2	1	1	17
	blowing snow	4	1	<1	0	<1	3	18
Kuujjuarapik	fog	1	3	9	9	1	1	45
	blowing snow	7	5	<1	0	3	10	52
Inukjuak	fog	1	3	7	9	3	1	46
	blowing snow	9	8	*	0	2	11	62
Churchill	fog	2	4	8	6	4	1	48
	blowing snow	11	5	*	0	4	10	64
Chesterfield Inlet	fog	1	3	5	6	4	2	42
	blowing snow	11	7	*	0	5	10	72
Coral Harbour	fog	3	2	5	5	5	2	44
	blowing snow	9	8	1	0	5	9	64



**Figure 4-8. Percentage frequency of wind occurrence by direction in January (A) and July (B) (from Maxwell 1986).**

and falling snow make outdoor human and animal activity impossible--blowing snow can maintain blizzard conditions long after the snowfall. In northwestern Hudson Bay, blizzard conditions occur 5 to 7 percent of the time in January and February--less often further south. During winter much of the initial snowfall in the Churchill area is blown off the sea ice and tundra and accumulates in the woodlands (Scott et al. 1993).

Southeastern Hudson Bay and James Bay also experience the persistent low temperatures and snow cover but not the extreme wind chills and frequent blizzards characteristic of the west coast of Hudson Bay. Despite this, the average January wind speeds of 15 to 20 km·h<sup>-1</sup> and temperatures of -20 to -25°C in coastal areas do correspond to a cooling rate (wind chill) of 1600 to 1900 watts·m<sup>-2</sup>, at which exposed skin freezes in less than a minute for the average person. Maximum cooling rates generally occur in January and range from about 2800 watts·m<sup>-2</sup> in the north to 2500 watts·m<sup>-2</sup> in the south. The snow is soft and deep in the coastal forests, but drifted and hard packed over the exposed sea ice. Southern coasts receive considerably more snow than those in the north but are snow covered for a shorter period (Figure 4-7). Blizzards occur less often in the south.

#### **4.2.3 Spring (April to mid-June in the south; May to June in the north)**

Spring is late and cool relative to southern Canada. It is characterized by rapidly lengthening daylight hours, above-freezing temperatures, and snowmelt. Warm southern air masses gradually penetrate further northward, increasing temperatures and storm frequencies. Low-lying clouds and fog are common as the snow and ice begin to thaw (Figure 4-7) and travel on the sea ice becomes increasingly difficult with runoff and surface melting. On average the mean daily temperature exceeds 0°C beginning in late April at Moosonee and in early June at Coral Harbour (Markham 1988). The longest day of the year, 21 June, is about 16 h 35 min. in the south and 21 h in the north (Canada 1987).

#### 4.2.4 Summer (mid-June to mid-September in the south; July and August in the north)

Summer extends from the time snowmelt is complete until the first snow flurries of autumn. Because Hudson Bay remains frozen or is dominated by ice cover over the summer solstice and throughout much of the high-sun season, it has a strong cooling effect on the surrounding terrestrial environments during the summer. Rouse (1991) described it as the “winterization of summer”.

During July and August the temperatures are lower on the eastern coasts of James Bay and Hudson Bay than on the western coasts, due mainly to the cooling westerly winds over the partially ice-covered waters. Freezing temperatures have been recorded during every month of the year along the entire coastline. Temperatures are generally cooler over the water—typically from 1°C in the north to 10°C in the south (see also Gachon et al. 2002), and extreme coastal temperatures are in the range of 30 to 38°C (Figure 4-5 and Figure 4-6). Sharp temperature inversions are common as warm air moves over the cold water and the lower air is cooled. These shallow, low-level inversions increase the near surface atmospheric stability over the bay. They affect humidity, temperature and wind profiles, as well as low-level clouds and radiation, which in turn control the seasonal oceanic heating of the mixed layer (see also Gachon et al. 2002). Warm air masses passing over the cooler water result in extensive fog and cloud coverage both over the water and along the coasts, depending upon wind direction. Fog is very common along the southeastern Hudson Bay coast where the prevailing summer winds blow onshore but less common in western Hudson Bay where offshore winds prevail (Table 4-1) (see also Markham 1988). It lifts to form low cloud as the wind strengthens. During August the Belchers are cloud-covered over 80% of the time (EAG 1984).

Summer surface winds are generally the lightest of the year and can be quite variable in direction (Figure 4-8). Onshore winds can lower coastal land temperatures drastically, while offshore winds are generally warming (see also Wilson 1976; Lafl  ur et al. 1987; Rouse et al. 1987, 1989; Silis et al. 1989). On the Hudson Bay Lowlands, this cooling effect extends well inland during periods of onshore winds (Figure 4-9). Most summer precipitation is in the form of rain, but snow may fall at almost any time of the summer in northern Hudson Bay. July and August snowfalls are rare in the region's other coastal communities. Monthly rainfall ranges from 25 to 100 mm and generally is greatest in the south. Thunderstorms occur at Moosonee 3-4 times per month in summer, but are markedly less frequent to the north and to the east where the colder waters exert a stabilizing influence on the air masses. Most summer storms pass from west to east across central Hudson Bay.

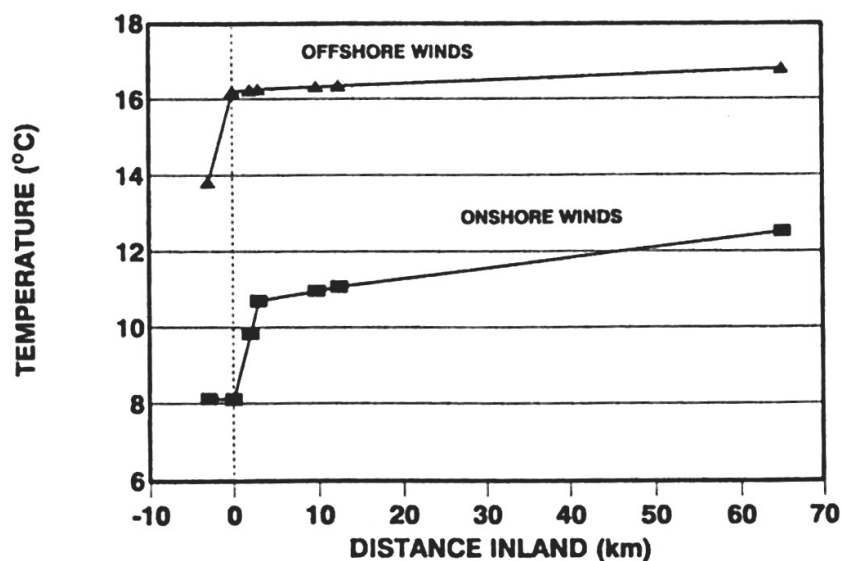


Figure 4-9. Air temperature from the intertidal zone, near Churchill, inland for onshore and offshore winds (from Rouse 1991, p. 28).

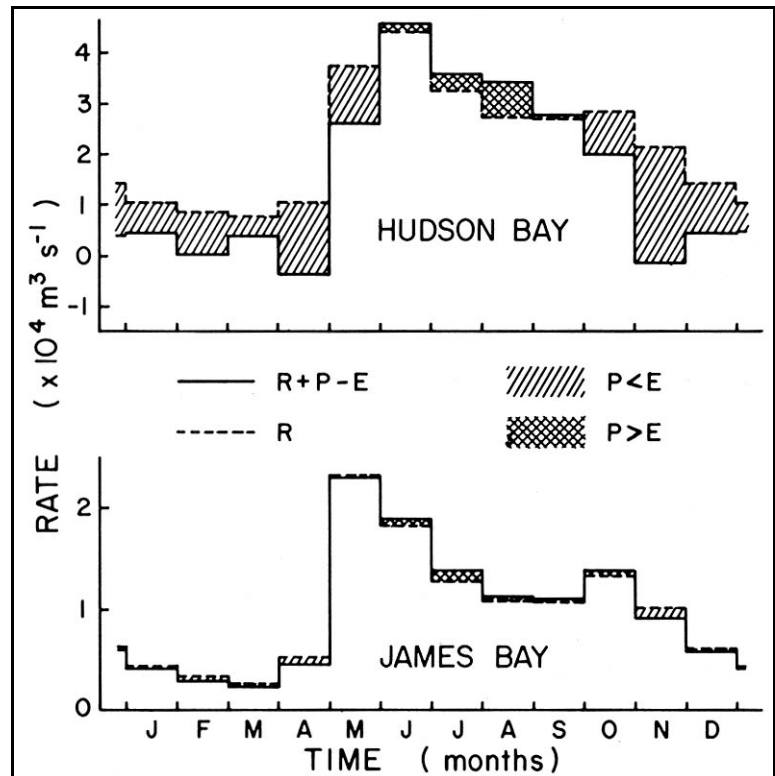
### 4.3 FRESHWATER INPUT CYCLE

The surface waters of the Hudson Bay marine ecosystem receive unusually large volumes of freshwater in the spring in the form of runoff and from melting sea ice. Their catchment basin for runoff is  $3.1 \times 10^6 \text{ km}^2$ , larger than those of the St. Lawrence and Mackenzie rivers combined, with double the combined average annual discharge rate (i.e.,  $20,700 \text{ m}^3 \cdot \text{s}^{-1}$ ; Prinsenberg 1988b). These large runoff volumes have a strong influence on the timing and pattern of the breakup of ice cover, the surface circulation, water column stability, species distributions, and biological productivity. Ice cover does not make a net contribution of fresh water over a one-year period but, on a weekly basis, it contributes as much or more than runoff.

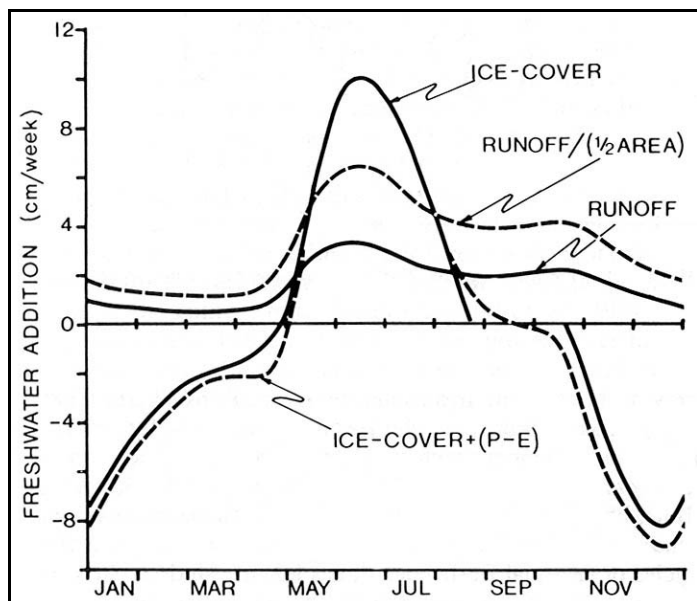
The annual cycle of freshwater inputs can be determined from monthly calculations of runoff plus precipitation less evaporation ( $R+P-E$ ) (Figure 4-10). Each year a 64 cm layer of freshwater is added to the entire surface of Hudson/James Bay, mostly during the spring and summer months (Prinsenberg 1977, 1980, 1986a). On average, a 10.0 cm layer of water is added to the area monthly from May to October, while only a 0.5 cm layer is added monthly from November to April. Taken alone, James Bay receives a 473 cm layer of freshwater annually over its entire surface (Prinsenberg 1984, 1986a). It receives much more fresh water by precipitation than it loses by evaporation, and more runoff. James Bay's average net monthly gain of freshwater is a layer of 61 cm during the summer months, and 19 cm during the winter months.

River runoff is low during the winter, peaks in spring, remains constant over the summer, and decreases slowly during autumn (Prinsenberg 1977, 1980, 1988b, 1991; Figure 4-11). Major processes associated with the spring breakup of small subarctic rivers entering Hudson Bay and James Bay include the snowmelt, impoundment of meltwater by snow dams, the disintegration and ablation of ice cover, the formation and destruction of ice jams, and an exchange of flow between the river channels and their adjacent wetlands (Woo and Heron 1987). Ice jams play a greater role in the breakup of larger rivers; snow a greater role in the breakup of small Arctic rivers. In the Churchill area, snowmelt occurs about three weeks earlier on the exposed tundra than in the woodlands (Scott et al. 1993). Wetland drainages generally have little stream discharge under ice conditions in winter, peak discharge at snowmelt, and a secondary peak during autumn rains (Winter and Woo 1990). They delay runoff from rainfall but not from snowmelt, partly because the presence of frost hinders infiltration (Roulet and Woo 1986a+b).

While the James Bay marine region has only 25% of the freshwater drainage area of Hudson/James Bay, it receives over 50% of the total runoff (Prinsenberg 1980). James Bay, excluding southeastern Hudson Bay, has only 9% of the Hudson/James Bay surface area and 1.5% of the volume, yet it receives 44.6% of the runoff--its oceanographic and ice conditions are, therefore, very dependant upon runoff. Peak spring runoff flows are more



**Figure 4-10.** Monthly rates of freshwater input to Hudson Bay and James Bay from runoff (R), precipitation (P), and evaporation (E) (adapted from Prinsenberg 1986a).



**Figure 4-11. Freshwater addition by ice cover, runoff (R), precipitation (P), and evaporation (E) for Hudson Bay, using a 1.6 m maximum ice-cover thickness (adapted from Prinsenberg 1988b).**

to south as the wind strength decreases, even though the vapour pressure increases slightly. The evaporative losses from James Bay are offset by precipitation which is nearly double that of Hudson Bay. The evaporative cycle exhibits two peaks, one in the spring when the air temperature increases due to solar radiation, and one in autumn when the air is heated by the water itself.

Seasonal ice cover is the other large contributor to this region's freshwater budget (Prinsenberg 1988b; 1991). When the sea ice forms in the fall it sequesters fresh water and rejects salt, and when it melts in the spring it releases a layer of freshwater at the surface. The maximum thickness of ice averaged over Hudson Bay and James Bay is 160 cm, which represents a 140 cm layer of fresh water when sublimation is accounted for (20 cm, Danielson 1969). The freshwater budgets suggest that ice contributes 66% more fresh water to Hudson Bay and 40% more to James Bay than can be accounted for by the ice thickness data. Some of this water, 25 cm in Hudson Bay, is contributed by the melting of ice accumulated in thick ice ridges (Prinsenberg 1988b). Ice formation has a greater effect on the surface waters of Hudson Bay than on those of James Bay. It adds almost twice as much freshwater annually to the surface of Hudson-James Bay as is added annually by runoff and precipitation combined. In James Bay alone, however, the addition of freshwater by ice melt is small relative to the amount of freshwater added annually by runoff and precipitation.

The volume of runoff that enters Hudson Bay each summer affects salinity on the Newfoundland Shelf. There is a significant negative correlation between the interannual variation of summer runoff into Hudson Bay and salinity anomalies on the Newfoundland Shelf, with a time lag of 9 months (Myers, et al. 1990). This linkage may be important if the volume of runoff entering Hudson Bay in summer changes significantly over the long term. Ice melt in the Bay was not similarly correlated with salinity on the Shelf.

#### 4.4 HEAT BUDGET

The surface heat flux, advection by ice, circulation, runoff, and seasonal ice cover all contribute to the heat budgets of Hudson and James bays (Danielson 1969; Prinsenberg 1984; Prinsenberg and Danard 1985). Between May and August, the incoming surface heat flux is the main contributor to these heat budgets and is

abrupt in James Bay than in Hudson Bay. Hydroelectric developments may not be altering the overall runoff, but they are changing its timing and spatial distribution.

Precipitation increases from winter to summer and from north to south (Table 4-1) (Prinsenberg 1977, 1980). Warm air in the south can carry more moisture than the colder air to the north and when it is cooled by the cold water surface produces more precipitation. Most of the fresh water that is lost by evaporation shows up as the large runoff per unit drainage area of rivers on the eastern coast.

Evaporation over Hudson Bay decreases from west to east as eastward-moving air picks up moisture and cools, and from south to north since the cooler northern air holds less moisture (Prinsenberg 1977, 1980). Hudson Bay loses more water on a yearly basis through evaporation to the atmosphere than it gains from precipitation. Evaporation over James Bay decreases from north

balanced by the heat required to melt the seasonal ice cover and warm the water column—mainly above the pycnocline, to observed summer values (Table 4-2). The temperature difference between air and water, which determines the stability and degree of vertical convection of the air, is the most important factor determining air-sea heat fluxes (Prinsenberg and Danard 1985). In the spring, the colder water stabilizes the air and depresses vertical convection. This reduces wind stress and evaporation and increases the heat fluxes into the water. In fall, the opposite occurs. In Hudson Bay, the contributions of runoff and circulation to the heat budget are an order of magnitude smaller than the surface heat flux; in James Bay, the relative contributions of runoff and circulation to the heat budget are much greater. This strong coupling between the atmospheric environment, seasonal ice cover, and oceanographic conditions is important as it means that changes to one will affect the others (see also Cohen et al. 1994).

**Table 4-2. Heat budget results of Hudson Bay and James Bay for an observation period from 1 May to the end of August (from Prinsenberg 1984).**

	James Bay (x 10 <sup>18</sup> J)	Hudson Bay (x 10 <sup>20</sup> J)
Winter heat content	-0.1	1.2
Surface heat flux	107.0	11.7
Heat due to runoff	9.2	0.2
Ice and snow cover	-38.4	-5.0
Heat of ice transport	-4.2	~0
Advection of heat in	14.6	0.2
Advection of heat out	-35.4	-0.6
Balance	52.7	7.7
Summer heat content	48.5	7.6
Difference	4.2	0.1

#### 4.5 TERRESTRIAL ECOZONES

While the Hudson Bay marine ecosystem is essentially Arctic, its coastlines, which extend over fourteen latitudinal degrees, exhibits a strong north-south climatic gradient. This gradient is reflected in the coastal vegetation, which changes from boreal forest in the south to tundra in the north (Hare 1950; Ducruc et al. 1976; Martini 1986b; EWG 1989; ESWG 1995; Marshall and Schut 1999). It is also reflected in the permafrost and the organic cover.

Four Terrestrial Ecozones are represented around the coasts of Hudson Bay and James Bay: 1) Hudson Plains, 2) Taiga Shield, 3) Southern Arctic, and 4) Northern Arctic (ESWG 1995; Marshall and Schut 1999). (Figure 4-12). These regions are not delineated based on climatic data, rather on their responses to climate as expressed by vegetation and reflected in soils, wildlife, and water. Moving from south (Hudson Plains) to north (Northern Arctic) trends are apparent in the vegetation, which changes from boreal forest to tundra; the soil, which becomes increasingly cryolosic; and the wildlife (see Chapters 9 and 10), which become better adapted to cold and often undertake extensive seasonal migrations. The southward deflection of these broad east-west Ecozones in the Hudson Bay-James Bay area emphasizes the magnitude of the climatic effect of the extreme southerly penetration of Arctic waters in this marine ecosystem.



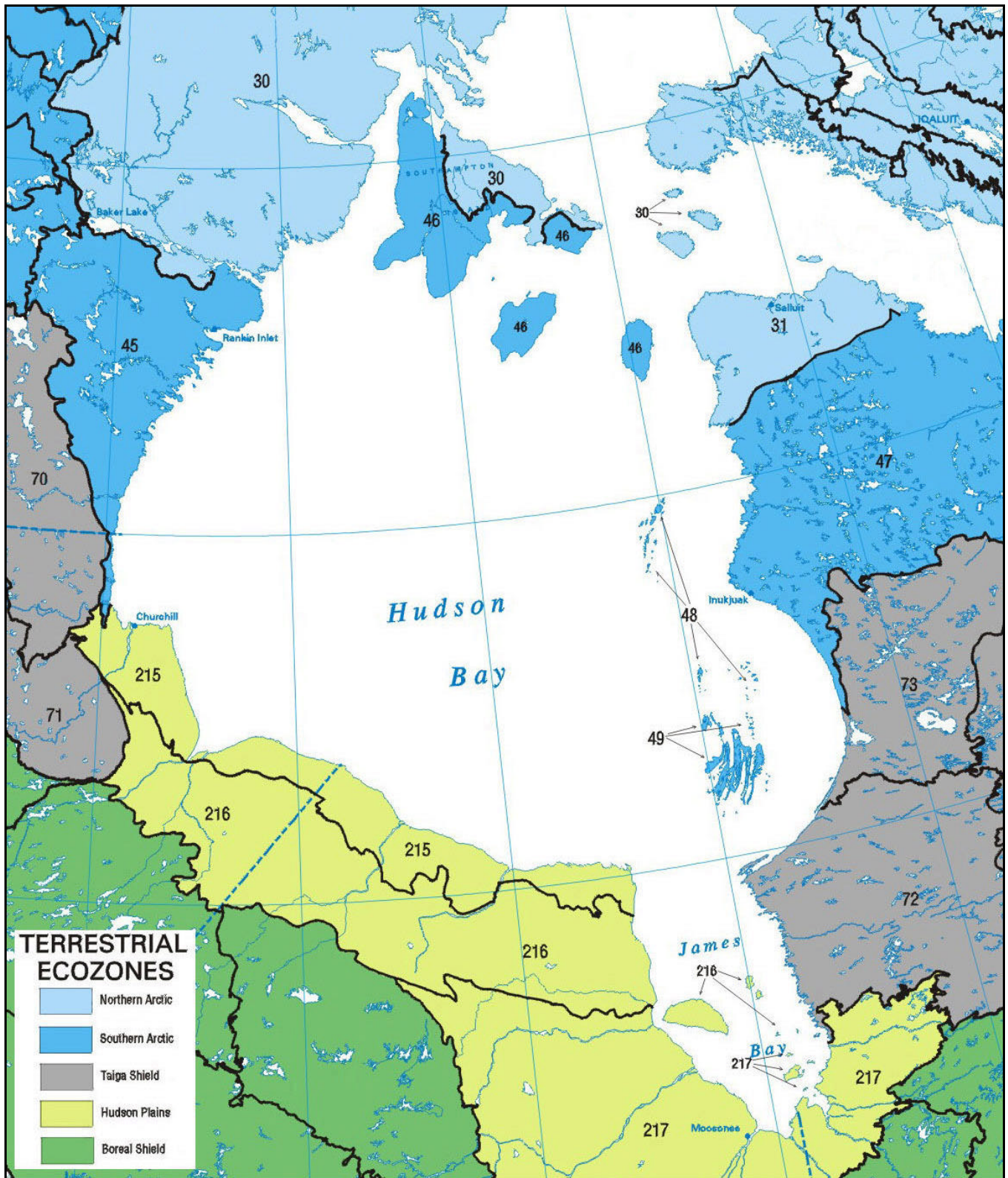


Figure 4-12. Terrestrial ecozones and ecoregions bordering Hudson Bay and James Bay (from ESWG 1995). Numbers refer to ecoregion descriptions in Table 4-3.



**Table 4-3. Features of ecoregions bordering Hudson Bay and James Bay (Sources: Marshall and Schutt 1999; NAC 1974 *et seq.*; NLUIS maps; or as cited).**

	ECOZONE:	NORTHERN ARCTIC		SOUTHERN ARCTIC
	Ecoregion:	30 Wager Plateau	31 Northern Ungava Peninsula	45 Maguse River Upland
<b>TERRAIN</b>		Archean rocks of the Canadian Shield form broad, sloping uplands, plains and valleys; lichen covered rock outcroppings are prominent. Elevation rises gradually westward from Chesterfield Inlet to 600 m asl.	Folded Archean granite and granitic gneiss bedrock of the Canadian Shield forms a series of east-west ridges and valleys with a relatively high relief in the west; more subdued relief in the east where hills merge with plateaux. The undulating surface rises from 100 m asl near Hudson Bay to 675 m asl in the northeast. Raised beaches occur along the coast. Postglacial limits of marine inundation are 120-167 m asl. The Hudson Bay coastline is complex north to near Ivujivik.	Archean rocks of the Canadian Shield form broad, sloping uplands and lowlands. Hummocky bedrock outcrops covered with discontinuous acidic, sandy, granitic tills are dominant. Prominent eskers. Elevations rise gradually from the coast to 330 m asl in the north and west; relief and elevation increase moving inland and northward. Postglacial marine limits 127-187 m asl. Low-lying marshy coast with little coastal development, few islands or shoals, and wide tidal flats south of Arviat; complex rocky coast north to Rankin Inlet; cliff and headland coast further north.
<b>ECOCLIMATIC REGION</b>		<b>LOW ARCTIC</b>	<b>LOW ARCTIC</b>	<b>LOW ARCTIC</b>
<b>Mean temperatures</b>		Annual -11°C, summer 4.5°C, winter -26.5°C	Annual -8.5°C, summer 3°C, winter -20°C.	Annual -11°C (north) to -8°C (south), summer 6°C, winter -24°C.
<b>Mean annual precipitation</b>		200-300 mm	200-300 mm.	250-400 mm; >400 mm south of Arviat.
<b>PERMAFROST</b>		Continuous, low ice content.	Continuous, low ice content.	Continuous, medium ice content.
<b>SURFACE MATERIALS</b> (Figure 3-11)		Mainly bedrock outcrops near the coast, with increasing cover of glacial tills, drumlins, eskers, and organics inland.	Mainly unconsolidated materials (glacial tills, glaciomarine deposits, and organics) near the southwest coast; bedrock is increasingly exposed moving northeast. Some frost-shattered bedrock cover in the Povungnituk Hills.	Unconsolidated glacial tills, glaciomarine deposits, and organics; scattered bedrock outcrops inland. Many drumlins and eskers.
<b>WETLANDS</b> (NAC 1986)		Well drained, <5%.	Well drained, <5%.	Wetlands, mostly lowland low- and high-centred polygon fens, cover 26-50% of the ecoregion.
<b>DOMINANT SOILS</b>		Turbic and Static Cryosols developed on discontinuous, thin, sandy moraine and alluvial deposits; large areas of Regosolic Static Cryosols are associated with marine deposits along the coast.	Turbic Cryosols developed on loamy marine sediments along the coast and on thin, discontinuous glacial drift deposits inland; rock outcrops and inclusions of Organic Cryosols are also present.	Turbic Cryosols dominate but unfrozen Organic (Mesisol) and Regosolic soils also occur.
<b>VEGETATION</b> (FORMATION TYPE: Physiognomy: <u>characteristic</u> and dominant species)		TUNDRA: discontinuous cover of Arctic stoney lichen-heath: lichens, Labrador tea, Arctic bell, and heather north of Wager Bay with Arctic dwarf shrubs-sedges-lichen-heath: dwarf birch and willow, sedges, Labrador tea, crowberry, <i>Dryas</i> spp., and <i>Vaccinium</i> spp. to the south. Taller birch, willow, and alder occur on warm sites; willow and sedge dominate wet sites. Frost free period 20-65 days.	TUNDRA: nearly continuous cover of <u>Arctic dwarf shrubs-sedges-lichen-heath</u> : dwarf birch and willow, sedges, Labrador tea, crowberry, <i>Dryas</i> spp., and <i>Vaccinium</i> spp. along the northern coast and <u>Arctic stoney lichen-heath</u> : lichens, Labrador tea, Arctic bell, and heather elsewhere. Taller birch, willow, and alder occur on warm sites; willow and sedge dominate wet sites. Frost free period 20-40 days.	TUNDRA: cover of <u>Arctic dwarf shrubs-sedges-lichen-heath</u> : dwarf birch and willow, sedges, Labrador tea, crowberry, <i>Dryas</i> spp., and <i>Vaccinium</i> spp.. Taller birch, willow, and alder occur on warm sites; wet sites are dominated by willow, sphagnum moss, and sedge. Frost free period 60-80 days.
<b>SETTLEMENTS</b> (change in population from 1996 to 2001)		Repulse Bay (559 to 612); Baker Lake (1305 to 1507).	Ivujivik (274 to 298); Salluit (929 to 1072).	Arviat (1559 to 1899); Chesterfield Inlet (337 to 345); Rankin Inlet (2058 to 2177).

Dominant soils (see also <http://sis.agr.gc.ca/cansis/nsdb/slc/webmap.html>); Settlements (see <http://www12.statcan.ca> )

Table 4-3 Continued.

ECOZONE:		SOUTHERN ARCTIC	
	Ecoregion: 46 Southampton Island Plain	47 Central Ungava Peninsula	48 Ottawa Islands
<b>TERRAIN</b>	Low-lying coastal plain underlain by flat-lying Palaeozoic carbonate rocks. Bedrock outcrops are common. Little relief; elevation generally < 90 m but rising inland to 200 m asl. Postglacial limits of marine inundation 150-175 m asl. Low-lying sometimes marshy coast often with tidal flats, little coastal development, and few islands.	The undulating surface is situated on Archean granites and gneisses of the Canadian Shield. Elevation mostly > 200 m asl but can reach about 500 m asl; coastal islands mostly <100 m asl. Bare rock outcrops are common; small lakes cover about 20% of the area. Region drains east into Ungava Bay, via the aux Feuilles and Arnaud rivers, and west into Hudson Bay via the Povungnituk and Kogaluc rivers. Postglacial limits of marine inundation along the Hudson Bay coast are 105-242 m asl -highest in the south. Bold, rugged coastline. Cliff and headland coast north to the Hopwell Islands and near Cape Smith; complex coastline in-between.	Situated on Proterozoic rock of the Canadian Shield. Bedrock outcrops are common. Gilmour Island is the highest, rising abruptly to 340 m asl. Post-glacial limits of marine inundation 158 m asl.
<b>ECOCLIMATIC REGION</b>	<b>LOW ARCTIC</b>	<b>LOW ARCTIC</b>	<b>LOW ARCTIC</b>
<b>Mean temperatures</b>	Annual -11°C, summer 3°C, winter -24.5°C.	Annual -7°C, summer 3.5°C, winter -17.5°C.	Annual -9°C, summer 3°C, winter -20°C.
<b>Mean annual precipitation</b>	200-300 mm	400-500 mm	About 300 mm.
<b>PERMAFROST</b>	Continuous, medium ice content composed of ice wedges.	Continuous, low ice content.	Extensive discontinuous.
<b>SURFACE MATERIALS</b> (Figure 3-11)	Glaciomarine deposits and organics in the west and southeast; glacial till on uplands northeast of Cape Low; many drumlins.	Unconsolidated glaciomarine deposits along the Hudson Bay coast south to near the Hudson Bay Arc; bedrock exposed or covered with glacial tills, glaciolacustrine deposits, and/or organics to the south and inland,. Drumlins and eskers are common inland.	Bedrock with some organic cover.
<b>WETLANDS</b> (NAC 1986)	26-50% wetlands in the southwest (Boas River-Cape Kendal area), 6-25% west of Hansine Lake; <5% elsewhere	Well drained, <5%.	Well drained, <5%.
<b>DOMINANT SOILS</b>	Static and Turbic Cryosols developed on level to undulating morainal and marine deposits.	Turbic Cryosols with inclusions of Organic Cryosols.	Turbic and Static Cryosols developed on level to undulating morainal and marine deposits.
<b>VEGETATION</b> (FORMATION TYPE: Physiognomy: <u>characteristic</u> and dominant species)	TUNDRA: nearly continuous cover of Arctic stoney lichen-heath: lichens, Labrador tea, Arctic bell, and heather north of Hansine Lake and on Bell Peninsula with Arctic dwarf shrubs-sedges-lichen-heath: dwarf birch and willow, sedges, Labrador tea, crowberry, <i>Dryas</i> spp., and <i>Vaccinium</i> spp. elsewhere. Wet sites are dominated by willow, sedge, and moss. Frost free period 30-60 days.	TUNDRA: nearly continuous cover of <u>Arctic stoney lichen-heath</u> : lichens, Labrador tea, Arctic bell, and heather along the northeast coast; with <u>Arctic dwarf shrubs-sedges-lichen-heath</u> : dwarf birch and willow, sedges, Labrador tea, crowberry, <i>Dryas</i> spp., and <i>Vaccinium</i> spp. elsewhere except along the southern border, where there is TUNDRA-OPEN WOODLAND: <u>lichen-heath-shrubs-patches of needle bearing trees</u> : lichen and black spruce. Wet sites are dominated by willow, sedge, and moss. The southern portion of the region has a mix of tundra vegetation and open, dwarf coniferous forest. Frost free period 60-80 days.	TUNDRA: <u>Arctic dwarf shrubs-sedges-lichen-heath</u> : dwarf birch and willow, sedges, Labrador tea, crowberry, <i>Dryas</i> sp. and <i>Vaccinium</i> spp.. Wet sites are dominated by willow and sedge. Frost free period 60-80 days.
<b>SETTLEMENTS</b> (change in population from 1996 to 2001)	Coral Harbour (669 to 712)	Inukjuak (1184 to 1294); Povungnituk (1169 to 1287); Aupaluk (159 to 159).	

Table 4-3 Continued.

SOUTHERN ARCTIC	TAIGA SHIELD
49 Belcher Islands	70 Kazan River Upland
<p>Situated on elaborately folded Proterozoic sedimentary and volcanic rocks. Less than 100 m asl except on northeastern Flaherty I. (122 m asl) and Tukarak I. (182 m asl). Relief generally low. Coastline rocky. The island group was covered by the sea following the last glaciation.</p>	<p>Crystalline, massive Archean rocks of the Canadian Shield form broad, sloping uplands and lowlands. Ridged to hummocky bedrock outcrops covered with discontinuous acidic, sandy, granitic till are characteristic. Prominent eskers and small to medium-sized lakes are common. Relief is low and elevations rise from about 100 m near the Hudson Bay coast, to 300-400 m asl in the west. Postglacial limits of marine inundation 152-180 m asl.</p>
HIGH SUBARCTIC	HIGH SUBARCTIC
<p>Annual -5.5°C, summer 5.5°C, winter -18.5°C. About 500 mm.</p>	<p>Annual -8°C, summer 8°C, winter -24.5°C. &gt;200 mm (north) to &gt;400 mm (south).</p>
<p>Extensive discontinuous, low to no ice content.</p>	<p>Nearly continuous, low to medium ice content. Grades to extensive discontinuous permafrost at southern margins. Ice wedges are sparse throughout.</p>
<p>Bedrock with some organic cover.</p>	<p>Unconsolidated glacial tills, glaciomarine deposits, and organics; scattered bedrock outcrops inland. Many drumlins and eskers.</p>
<p>Well drained, &lt;5%.</p>	<p>6-25% wetland cover, drainage improves moving northwest from the coast</p>
<p>Dominantly rockland with Cryosols, and some Brunisols in well-drained coarse-textured substrates.</p>	<p>Dystic Brunisols on sandy eskers dominate; Turbic Cryosols in permanently frozen sites; Organic Cryosols on wetlands. Patterned ground is widespread, and mineral soils exhibit discontinuous or distorted soil horizon development.</p>
<p>TUNDRA: <u>Arctic dwarf shrubs-sedges-lichen-heath</u>: dwarf birch and willow, sedges, Labrador tea, crowberry, <i>Dryas</i> sp. and <i>Vaccinium</i> spp.. Frost free period 60-80 days.</p>	<p>Transitional between tundra and open woodland. TUNDRA: Arctic dwarf shrubs-sedges-lichen-heath: dwarf birch and willow, sedges, Labrador tea, crowberry, <i>Dryas</i> spp., and <i>Vaccinium</i> spp. in the northeast; TUNDRA-OPEN WOODLAND: lichen-heath-shrubs-patches of needle bearing trees: lichen and black spruce in the middle; OPEN WOODLAND: Lichen floor with scattered needle leaf trees: lichen, spruce, and tamarack in the southwest. Very stunted stands of black spruce and tamarack with secondary quantities of white spruce; a shrub layer of dwarf birch, willow, and ericaceous shrubs; and ground cover of cottongrass, lichen, and moss predominate. Drier sites dominated by open stands of white spruce, ericaceous shrubs, and ground cover of mosses and lichens; wet sites by tussocks of sedge, cottongrass, and sphagnum moss. Low shrub tundra is common. Frost free period 60-80 days.</p>
<p>Sanikiluaq (631 to 684)</p>	
	72 La Grande Hills
	<p>Mostly Archean Shield bedrock overlain by morainal deposits. Rises inland to 450 m asl. Varied, mostly low lying (&lt;100 m asl), coast: CONN R. TO PAUL BAY: rocky, glaciomarine plain. Relief increases to the north from undulating to rolling. Irregular shoreline with many islands. Wide tidal flats often fringed in bays by wide salt marshes. CACACHISCHOUANE PT. TO PT. LOUIS XIV: irregular bedrock unevenly covered by thin marine and coastal deposits. Very complex shoreline with many low islands. Tidal flats in most bays, narrow marshes only in larger bays. Sand and boulder beaches. Low rocky hills and drumlins are major relief (Dionne 1980a). Pt. LOUIS XIV TO KUJJUARAPIK: mainly rocky hills or plains, some raised beaches; land rises northward to 250 m near Kuujuarapik. Relief increases with elevation from undulating to rolling. Post-glacial limits of marine inundation, 200-270 m asl, lowest in the south.</p>
	LOW SUBARCTIC
	<p>Annual -4°C, summer 8.5°C, winter -16.5°C. &lt;600 mm along Hudson Bay to 800 mm in the southeast.</p>
	<p>Limited to isolated patches, mainly in wetlands, with little or no ice content.</p>
	<p>Unconsolidated glaciomarine deposits and organics along the coast, with some bedrock outcrops along the Hudson Bay Arc; increasing bedrock exposure and glacial till cover moving inland.</p>
	<p>51-75% in the southwest near James Bay, decreasing to 6-25% inland to the northeast.</p>
	<p>Dystic Brunisols with significant inclusions of Humo-Ferric Podzols and Organic (Mesisol and Fibrisol) soils. Regisols and rockland near much of the coastline. Active layer of 40 cm at Kuujuarapik (see also Vincent et al. 1987)</p>
	<p>Transitional area between tundra in the north and boreal forest in the south. TUNDRA: <u>Arctic dwarf shrubs-sedges-lichen-heath</u>: dwarf birch and willow, sedges, <i>Dryas</i> sp., <i>Vaccinium</i> spp., and Labrador tea on the islands and along the coast north of Roggan River. OPEN WOODLAND: <u>Lichen floor with scattered needleleaf trees</u>: lichens, spruce and tamarack along the coast from Paul Bay north to Roggan River and inland to the south and east. BOREAL FOREST: <u>Needleleaf trees</u>: spruce and balsam fir along the James Bay coast south of Paul Bay flanked by BOGS-ORGANIC TERRAIN: <u>Small lakes-moss and sedge covered floor and strings of needleleaf trees</u>: sphagnum moss, sedges, black spruce, tamarack. Frost free period 70-90 days.</p>
	<p>Chisasibi (3251 to 3467); Kuujuarapik (579 to 555).</p>

Table 4-3 Continued.

ECOZONE:	TAIGA SHIELD	HUDSON PLAINS
	Ecoregion: 73 Southern Ungava Peninsula	215 Coastal Hudson Bay Lowland
<b>TERRAIN</b>	This ecoregion includes the south-central section of Larch Plateau and the Richmond Hills. Larch Plateau has a hummocky to undulating surface with elevations that reach ~ 500 m asl. Inland, elevations typically 100-300 m asl; local relief is seldom >30 m. The Richmond Hills are highlands in the west, where mainly east-facing cuestas of Proterozoic sedimentary and volcanic rocks dip steeply into Hudson Bay. The rugged cliff and headland coast rises from 250 m near Kuujuarapik to 450 m asl west of Richmond Gulf; coastal islands are generally <100 m asl. Runoff flows east into Ungava Bay, via the Du Gue and Melezes rivers and Riviere aux Feuilles, and west into Hudson Bay via Petite riviere de la Baleine. Small, generally shallow lakes cover ~20% of the area. Post-glacial limits of marine inundation, 225 m asl east of Richmond Gulf rising to 315 m asl east of Manitouk Sound. The Sakami End Moraine occurs in the Kuujuarapik area. There are well-developed raised marine beaches in the Richmond Gulf area.	Low-lying, marshy coastal plain with extensive tidal flats, developed on flat-lying Palaeozoic limestone bedrock. Rises to ~120 m asl in the south; very little local relief or coastal development; few small coastal islands or shoals. Large estuaries at the outlets of the Churchill and Nelson rivers. Post-glacial limits of marine inundation are 120-180 m asl. Along the coast east of the Nelson River numerous, parallel, well-drained raised beaches present a striking pattern of successive white spruce-covered ridges, alternating with fens, polygonal peat plateaus, and peat plateaus. North of the Nelson River beaches are more subdued and the terrain is dominated by fens, polygonal peat plateaus, and peat plateaus. Peat plateaus occur often in parallel rows marking the underlying beaches. In the fens, small incipient palsa bogs are common. The coastal areas are dominated by marshes and shallow waters and extensive tidal flats, especially north of the Nelson River.
<b>ECOCLIMATIC REGION</b>	<b>MID-HIGH SUBARCTIC</b>	<b>HIGH SUBARCTIC</b>
<b>Mean temperatures</b>	Annual -6°C, summer 6°C, winter -18°C.	Annual -4°C but lower -4°C in Manitoba, summer 10.5°C, winter -19°C.
<b>Mean annual precipitation</b>	475-650 mm (north-south)	400 mm in the northwest to 600 mm in the east.
<b>PERMAFROST</b>	Extensive and discontinuous with low to medium ice content in the northern two-thirds, and sporadic discontinuous elsewhere.	Permafrost with low to high ice content is widespread. Ekwan Point is the southernmost extension of continuous permafrost in the Hudson Bay Lowland (Rouse and Bello
<b>SURFACE MATERIALS</b> (Figure 3-11)	Extensive bedrock outcrops along the coast and in the north, covered by organics and by glaciomarine deposits near the coast and glacial tills inland.	Unconsolidated coarse and fine-grained glaciomarine deposits mostly beneath organics (peat bogs); some alluvial deposits along the Manitoba coast; few, if any, bedrock outcrops.
<b>WETLANDS</b> (NAC 1986)	Well-drained, <5%	Poorly drained, > 75%
<b>DOMINANT SOILS</b>	Turbic Cryosolic and Dystric Brunisolic soils with significant inclusions of Humo-Ferric Podzols, Organic Cryosols. Regosols and rockland near the coast.	Organic Cryosols formed on sedge and fibrous sphagnum peat are dominant; Mesisols formed on moderately decomposed sedge and woody peat are significant; and saline Regosols and Gleysols occur on silty to clayey marine sediments along the coast. (see also Canada Soil Inventory 1989).
<b>VEGETATION</b> (FORMATION TYPE: Physiognomy: <u>characteristic</u> and dominant species)	TUNDRA: <u>Arctic dwarf shrubs-sedges-lichen-heath</u> : dwarf birch and willow, sedges, Labrador tea, crowberry, <i>Dryas</i> spp., and <i>Vaccinium</i> spp. in a narrow band along the coast and north of Richmond Gulf; TUNDRA-OPEN WOODLAND: <u>Lichen-heath-shrubs-patches of needle bearing trees</u> : lichen and black spruce from Richmond Gulf south and in the east. Poorly drained sites often support tussocks of sedge, cottongrass, and sphagnum moss. The ecoregion's northern boundary is where the limit of trees is reached in Quebec. Frost free period 60-80 d.	TUNDRA: <u>Arctic dwarf shrubs-sedges-lichen-heath</u> : dwarf birch and willow, sedges, <i>Dryas</i> sp., <i>Vaccinium</i> spp., and Labrador tea near the coast; BOGS-ORGANIC TERRAIN: <u>Small lakes-moss and sedge covered floor and strings of needleleaf trees</u> : sphagnum moss, sedges, black spruce and tamarack inland. The vegetation is characterized by very open stands of stunted black spruce and tamarack with secondary quantities of white spruce; a shrub layer of dwarf birch, willow or ericaceous shrubs; and ground cover of cottongrass or lichen and moss. Poorly drained sites usually support tussock vegetation of sedge, cottongrass, and sphagnum moss. Low shrub tundra vegetation consisting of dwarf birch and willow is also common. Frost free period 60-80 days.
<b>SETTLEMENTS</b> (change in population from 1996 to 2001)	Umiujuaq (315 to 348).	Churchill (1089 to 963); Fort Severn (362 to 401); Peawanuck (239 to 193).

Table 4-3 Continued.

HUDSON PLAINS	
216 Hudson Bay Lowland	217 James Bay Lowland
Low-lying, marshy coastal plain with extensive tidal flats, developed on flat-lying Palaeozoic limestone bedrock. Rises to about 120 m asl in the south; very little local relief; slopes of coastal marshes often <2 m per km. Little coastal development; few small coastal islands or shoals. Post-glacial limits of marine inundation, 150-180 m asl.	Low-lying, flat to undulating marshy clay coastal plain with a few rocky hills and drumlin ridges forming points and islands. Underlain by flat-lying, Palaeozoic limestone bedrock that slopes gently towards James Bay. Nearshore zone shallow with few islands and shoals. Coastline of large open bays; sandy and muddy tidal flats up to 2 km wide are common (some with boulders), often fringed on the landward side by wide tidal marshes. Elevation <100 m with very little local relief; slopes of coastal marshes often <2 m per km. Post-glacial limits of marine inundation, 137-270 m asl, lowest in the southwest. Hurricanaw Interlobate Moraine in the Rupert Bay area and on islands northward to North Twin Island.
<b>LOW SUBARCTIC</b>	<b>PERHUMID HIGH BOREAL</b>
Annual -3.5°C but can be -5°C in Manitoba, summer 11°C, winter -18.5°C. <500 mm in the west to <700 mm near James Bay	Annual -2°C, summer 11.5°C, winter -16°C. 700-800 mm
Moderate to high ice content permafrost is widespread, especially in organic deposits and along the northern boundary.	Sporadic and discontinuous with medium to high ice content north and west of Kashechewan, isolated patches elsewhere.
Unconsolidated coarse and fine-grained glaciomarine deposits, mostly beneath organics (peat bogs), near James Bay; more glaciolacustrine deposits, glacial till, and organic deposits to the west; few, if any, bedrock outcrops.	Unconsolidated coarse and fine-grained glaciomarine deposits, mostly beneath organics (peat bogs), and organic deposits near James Bay; glacial till and organic deposits inland; drumlins common, few bedrock outcrops.
Wetlands, mainly peat plateau and palsa bogs and horizontal fens cover >75% of the mainland and 51-75% of Akimiski and the Twin islands.	Wetlands, mainly northern ribbed fens, northern plateau bogs, and palsa bogs cover from 50% of the area in the south to >75% in the north, around James Bay, and on Charlton I..
Organic Cryosols, Mesisols, and Fbrisols are the dominant soils developed on organic materials; Eutric Brunisols are associated with marine and till upland deposits (see also Protz 1982b).	Organic Mesisols and Fbrisols with some Organic Cryosols. Limited areas of Dystric and Eutric Brunisols on upland sands. Eutric Brunisols and Gleysols are associated with river levees; clayey uplands may have Gray Luvisol soils. Gleysols are characteristic of the marshes and Regesols to Podzols of sand and gravel beach ridges (see also Protz 1982b).
TUNDRA: <u>Arctic dwarf shrubs-sedges-lichen-heath</u> : shrubby birch and willows, sedges, blueberry, crowberry, and Labrador tea near the coast north of Ekwan Point and on Akimiski Island and the Twin islands. BOGS-ORGANIC TERRAIN: <u>Small lakes-moss and sedge covered floor and strings of needleleaf trees</u> : sphagnum moss, sedges, black spruce and tamarack elsewhere. Open stands of stunted black spruce, tamarack and white spruce dominate, with a shrub layer of dwarf birch, willow and northern Labrador tea, and ground cover of cottongrass or moss and lichen. Dry sites often support open stands of white spruce with an ericaceous shrub layer and ground cover of lichen; wet sites sedge and cottongrass tussocks or sphagnum hummocks. Balsam, poplar, white spruce and paper birch are common along rivers. Frost free period 75-100 days.	TUNDRA: <u>Arctic dwarf shrubs-sedges-lichen-heath</u> : shrubby birch and willows, sedges, blueberry, crowberry, and Labrador tea on Charlton Island. BOGS-ORGANIC TERRAIN: <u>Small lakes, moss and sedge covered floor and strings of needleleaf trees</u> : sphagnum moss, sedges, black spruce, and tamarack elsewhere except in the south where there is BOREAL FOREST: <u>needleleaf trees</u> : spruce, jack pine, tamarack. Most of the ecoregion is poorly drained, and the dominant vegetation consists of sedge, mosses, and lichens with or without stunted black spruce and tamarack. Frost free period 75-100 days.
Shamattawa (749 to 897).	Attawapiskat (1253 to 1293); Waskaganish (1548 to 1699); Moosonee (1939 to 936); Eastmain (1978 to 1422).

## 4.6 SUMMARY

The Hudson Bay marine ecosystem is abnormally cold relative to other areas at the same latitude, and extends through five ecoclimatic regions from humid high boreal in the south to low Arctic in the north. Its climate differs from north to south and east to west. The winters are long and cold; the summers are cool. The harshest climate is found in northwestern Hudson Bay where there is the greatest influence of cold Arctic air masses. Strong winds and persistent low temperatures are characteristic of this area. While neither is as extreme as in some continental areas, in combination they make it the coldest part of Canada based on wind chill. Other areas have either moderating southern or marine influences and do not exhibit the extremes of western Hudson Bay--particularly the high wind chills and frequent blizzards.

The marine environment depends strongly on local wind stress, runoff, radiation heat flux, and annual ice cover. There is an annual net gain of 473 cm of fresh water over the entire surface of James Bay, where precipitation is much greater than evaporation and runoff is high. This is much greater than the average for Hudson/James Bay, which has an annual net gain of only 64 cm over the entire marine surface. Hudson Bay loses more fresh water through evaporation than it gains from precipitation. Runoff has a strong influence on oceanographic and ice conditions, particularly in James Bay.

There is extreme variation in the range of average temperatures and average total precipitation in time, seasonally and annually, and in space throughout the region. There is a strong average precipitation gradient across the region, from less than 200 mm per year in the northwest to over 800 mm per year in the southeast. Evidence for change in these patterns related to global warming is discussed in Section 17-1.

The marine ecosystem has a strong influence on the surrounding land area, contributing particularly to the unusual southern extent of the permafrost. This influence is demonstrated by the presence of four ecozones along the coastline, each of which reflects the response of vegetation, soils, wildlife, and water to climatic and geological factors. Moving from south (Hudson Plains) to north (Northern Arctic) trends are apparent in the vegetation, which changes from boreal forest to tundra; the soil, which becomes increasingly cryosolic; and the wildlife, which become better adapted to cold and often undertake extensive seasonal migrations. The southward deflection of these broad east-west Ecozones in the Hudson Bay-James Bay area emphasizes the magnitude of the climatic effect of the extreme southerly penetration of Arctic waters in this marine ecosystem.