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# The Hudson Bay Complex in Flux: Contemplating the future of the world's largest seasonally ice-covered inland sea

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## Preface

On October 28, 1978, a Delta rocket delivered its payload: the NIMBUS 7 satellite, an orbiting satellite designed to monitor a number of environmental parameters including surface air and sea temperatures and ice cover. Climate change was not, at that time, of much public, political or media interest. A small number of experts, mostly oceanographers and atmospheric scientists, were raising the alarm over increases in the carbon dioxide concentration in the atmosphere and were expressing concern as to what this "greenhouse" gas might mean for global climate. NIMBUS 7 and other satellites have become very important witnesses to the warming of the planet and have provided a wealth of data documenting the changes that are occurring in the Arctic Ocean and in subarctic seas such as Hudson Bay. It is unlikely that many would have foreseen that the September extent of sea ice in the Arctic Ocean (at the end of the melt season) would, between 1979 and 2011, have been decreasing at a rate of 12 per cent year. Similarly few would have predicted that the ice-free season in the Hudson Bay Complex would be increasing by 10 or more days per decade.

In 1978 people did not have personal computers, cell phones or global positioning systems and the Cold War was a fact of life. Nunavut did not exist and the Inuit and Cree living around the coastline of the Hudson Bay Complex (Hudson and James Bay, Foxe Basin, Hudson Strait and Ungava Bay) were adjusting, with difficulty, to changes that were occurring around them. The Churchill River had been diverted and hydro developments on the Nelson River were being developed while the massive James Bay hydroelectricity development was in the planning stage, and its major impacts on the James Bay Cree would occur later. Generations of Inuit and Cree were losing much of their traditional connection with the land and the sea, a connection that had been central to their culture and value system. Some, though not all, of this disconnect can be traced to the Residential Schools program. Then, as now, there was a desire to ensure that the option of continuing to harvest marine mammals, waterfowl, fish and invertebrates from the sea would still be available to them and their descendants.

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## 1 Appreciating a Majestic Canadian Ecosystem

Hudson Bay is historically important and played a defining role in the early history of Canada. Hudson Bay, and the forts and trading posts established around its margins and in its watershed, played a pivotal role in the early fur trade, the economic engine that shaped much of the exploration and settlement of the lands that would eventually become part of Canada. While Hudson Bay continues to occupy a large part of the map of Canada, it is mostly ignored by Canadians and there is little appreciation of this vast and unique part of our country. The Arctic Ocean has, comparatively, garnered much more public, political, scientific and media attention. The warming of the Arctic, sovereignty issues, oil and gas reserves, decreases in the volume of the polar ice cap and reductions in the extent of the summer ice cover have all helped to make Canadians more aware of Canada's interests in the Arctic.

The Hudson Bay Complex consists of Hudson Bay, James Bay, Foxe Basin, and Hudson Strait, including Ungava Bay. Covering 1,242,000 square kilometers ($km^2$), this complex is the world's largest seasonally ice-covered inland sea. It is also relatively shallow. Hudson Bay has a mean depth of 125 to 150 metres with a maximum depth of 250 metres. James Bay is even shallower. The corresponding values for Foxe Basin and Hudson Strait are mean depths of 90 and 300 metres with maximum depths of 450 and 900 metres. The Hudson Bay Complex has, since the last ice age, been undergoing isostatic rebound and, while the rate is declining, the region is still rebounding at approximately 1.2 metres/century.

The Hudson Bay Complex has two direct connections to the world's oceans. Fury and Hecla Strait, at the northwest corner of Foxe Basin, carries Arctic Ocean water (much of it being of Pacific origin) into the Foxe Basin. Here, a portion of this flow is carried south along the western coast into northwestern Hudson Bay via Roes Welcome Sound, which lies between Southampton Island and the mainland. A proportion of the Arctic Ocean input mixes in Foxe Basin with marine waters of Atlantic origin, which are transported from the Labrador Sea within a coastal current on the north side of Hudson Strait. The waters mixed in Foxe Basin exit southeastern Foxe Basin where a proportion, likely relatively small, enters northeastern Hudson Bay. The bulk of this mass of water is joined by less-saline waters from Hudson Bay and James Bay and transported out of Hudson Bay in a coastal current along the south side of Hudson Strait.

The Hudson Bay Complex is a unique and majestic ecosystem. It may not raise sovereignty issues, but it is of national and international significance. It is changing rapidly, and the cumulative impact of climate change/warming together with a range of other important stressors is large and apparently increasing. Other major drivers of change include hydroelectricity development, increasing international shipping, atmospheric transport of contaminants and, in all likelihood, the exploration for, and development of, mineral and oil and gas reserves. The marine ecosystem and the living resources that have adapted over millennia within this unique Arctic/subarctic setting are, or will soon be, fundamentally changed.

The aboriginal cultures and economies that have developed around the harvest of marine mammals, waterfowl, fish and invertebrates from this marine system are most directly affected. The scope and significance of some of the reasonably foreseeable changes are potentially very large. Reductions in the volume and duration of the seasonal ice cover and the cumulative impacts of hydroelectricity development have the potential to fundamentally change the freshwater budget of the complex and, in turn, the stratification, circulation, availability of nutrients, biological productivity and food webs in this marine ecosystem. Changes in the amounts and timing of the freshwater components and nutrient contents of waters leaving Hudson Bay have potentially very important implications for the productivity and circulation of the Labrador Sea and North Atlantic.

The Hudson Bay Complex is big—indeed, very big! With an area of 1,242,000 $km^2$ it is the world's largest seasonally ice-covered inland sea and is slightly larger than the Province of Ontario. Each year about 940 $km^3$ of freshwater is discharged into the system via the rivers along its coastline. This volume of freshwater is comparable to the combined annual discharges of the Mackenzie and St Lawrence Rivers and almost one quarter of the combined discharges from all the rivers emptying into the Arctic Ocean and its associated regional seas. The Hudson Bay watershed is correspondingly huge, covering an area in excess of 4,000,000 $km^2$ including all of Manitoba and parts of Quebec, Ontario, Saskatchewan, Alberta and Nunavut, as well as portions of Minnesota, North Dakota, South Dakota and Montana.

The largest population of beluga whales (in excess of 50,000 individuals) on the planet spends much of the summer season in southwestern Hudson Bay, primarily in the Nelson, Churchill and Seal River estuaries where it feeds primarily on capelin (Kelley, Loseto, Stewart & Yurkowski, 2010). There are also sizeable populations of narwhales and bowhead whales, especially in Foxe Basin and Northern Hudson Bay (Higdon & Ferguson, 2010). Killer whales are increasingly observed in the Hudson Bay Complex (Ferguson et al., 2010), possibly as a result of the reduced ice cover in Hudson Strait and elsewhere in the system that facilitates their movement from the Labrador Sea. The world's most southerly populations of polar bears occur along the Manitoba, Ontario and Quebec coastlines (Peacock, Derocher, Lunn, & Obbard, 2010), where, at least until recently, the seasonal ice cover has enabled them to successfully hunt the ringed seals that live and reproduce on the sea ice. Enormous numbers of shorebirds and waterfowl migrate through the region and nesting, feeding and staging areas of national and international significance occur within the region.

## 2 Long-Term Climate Change Trends in a Highly Variable System

Climate change is not new to the Hudson Bay Ecosystem. Dramatic seasonal changes in temperature, as well as interannual differences in air and sea temperatures and in the nature, extent and duration of the sea ice cover are commonplace. Periodic interdecadal warming and cooling periods occur and are also features of this unique ecosystem. What are, however, unprecedented are the speed, magnitude and significance of the climate changes that have occurred and are predicted to occur in the foreseeable future. In essence, we now have undeniable evidence of a persistent and probably accelerating warming trend that is being transposed upon a dynamic and variable system that has, until recently, fluctuated within a predictable range.

The changes occurring in Hudson Bay and elsewhere in the Arctic are unlikely to be simple extensions of past trends. It is important that serious effort be devoted to understanding and preparing for a future that is likely to be fundamentally different from anything previously experienced. The scale and significance of changes that are occurring and that can be reasonably predicted to occur in the future will almost certainly lead to a fundamentally altered marine ecosystem. This shift will in turn present a host of unprecedented cultural and economic challenges (and opportunities) for the aboriginal peoples that have lived with and harvested resources from the system. The safety and predictability of the sea ice is a major concern for Inuit hunters (Laidler et al., 2009). It is essential that Hudson Bay's past, present and (especially) future become more of an issue for Canada and Canadians. The Hudson Bay Complex is huge, but it is also a vulnerable ecosystem that is the vanguard of a high-stakes, uncontrolled planetary experiment.

Major hydroelectricity projects, especially in Quebec and Manitoba, are fundamentally altering the seasonal flow patterns in regulated rivers. The natural spring freshet no longer occurs in the La Grande and Nelson Rivers, the two largest rivers discharging into the system. Instead, the maximum discharges now occur in winter months (Déry, Miynowski, Hernandez-Henriquez, & Straneo, 2011). The implications of altered discharges from these huge rivers on the circulation, stratification and mixing of freshwater and marine waters on biological productivity of Hudson Bay, Hudson Strait and the Labrador Sea are not very well understood.

While communities along the coast of the Hudson Bay Complex are increasingly concerned with the changes that are taking place along their coastlines, this local concern is not widely shared by Canadians in the rest of the country. Generally the Canadian public has shown little interest or concern as to the scale and significance of existing trends and projected future conditions in the Hudson Bay marine ecosystem. Similarly, there is little understanding of the human-induced stresses that are driving many of these changes to the system. Climate change, the cumulative impact of some of the largest hydroelectric developments on earth, and the long-range transport of chemical contaminants to the region are three major drivers of change.

Public concern, where it does exist, has focused primarily on the polar bear and its vulnerability to climate warming and, to a lesser extent, contamination through the bioaccumulation of contaminants in the marine food web. Excellent documentaries such as *Polar Bear Fever* have helped to make the polar bear a very important symbol of the threats associated with climate warming. Changes in the ice regime of the Hudson Bay Complex will clearly affect polar bear populations and other ice-adapted species such as the ringed seal, but changes in ice cover will also have other major far-reaching consequences for the chemical, physical and biological oceanography of the Hudson Bay marine ecosystem.

A challenge will be to focus greater public, political and scientific attention on the need to understand the full scope of the stresses on, and the changes to, the Hudson Bay regional ecosystem. In so doing, it is hoped that more Canadians will become better acquainted with the often unique challenges and opportunities that are likely to arise in response to the changes in the world's largest seasonally ice-covered inland sea. An enhanced understanding of what is happening to the Hudson Bay marine ecosystem is a prerequisite to the making of more informed decisions concerning the conservation, protection and use of this magnificent ecosystem.

The Arctic Climate Impact Assessment (ACIA, 2005) indicates that the Hudson Bay region is likely to warm at rate far exceeding the global average. Satellite surveillance is enabling scientists to track changes in ice cover, sea-surface temperatures, and the timing of ice break-up and freeze-up over the entire region. Locally, generations of Inuit hunters and trappers have relied on the coastal ice and their knowledge of this habitat to enable them to safely hunt the marine mammals associated with the ice. Their observations of coastal ice conditions as well as the changes that they see in the abundance, condition and foods of the animals that they harvest provide a sense of what is really at stake with the declining ice cover that is now being tracked by satellite.

These local observations, traditional ecological knowledge (TEK) of aboriginal observers, are increasingly seen as being an important complement to Western science. McDonald, Arragutainaq and Novalinga (1997) provide an excellent synthesis of the observations of Inuit and Cree living in coastal communities around the Hudson Bay Complex. The knowledge of the ice and snow conditions is particularly insightful. More recently, Feinup-Riordon and Carmack (2011) examine a number of ways in which shared knowledge of sea ice and coastal swells can benefit both local communities and scientists working to better understand coastal processes. Carmack and MacDonald (2008) provide an excellent example of how the observations and wisdom of aboriginal elders was the stimulus that led to a successful research project on the Mackenzie Delta. Henri, Gilchrist, and Peacock (2010) provide an overview of the ways that TEK and Western science have interacted and complemented one another with respect to managing wildlife in the Hudson Bay region and discusses ways in which these two perspectives could converge in addressing the potential impacts of climate change on marine mammals and birds.

Evidence from a variety of sources paints a compelling picture of a rapidly changing marine ecosystem. Satellite observations provide a unique capacity to document the earlier break-up and later freeze-up of the seasonal ice cover and changes in sea-surface temperatures, while aboriginal hunters and trappers have a first-hand understanding of changes in the near-shore ice environment. Both categories of information can generate testable hypotheses for explaining the situations and changes that are observed.

Unfortunately, in most instances, there is very limited detailed understanding of how this system actually works. The vastness of the system and its harsh environment make it extremely difficult to carry out monitoring and research initiatives at spatial and temporal scales that can be readily extrapolated to the entire Hudson Bay Complex. Modelling initiatives continue to fill this need, but without corroborating monitoring and research the outputs of models, however sophisticated they may be, will have limited credibility.

## 3 Ominous Signals From the Arctic Ocean

The waters of Pacific and Atlantic origin meet in the Arctic Ocean, as they do in the Hudson Bay. This interaction has long been recognized as an important component of the global ocean circulation and climate system. The speed of climate warming in the Arctic and the decline of sea ice in the Arctic Ocean have added a new level of urgency and alarm. The title of one recent publication (McLaughlin et al., 2011) is: "The rapid response of the Canada Basin to climate forcing: From bellwether to alarm bells." This title is fully consistent with the findings reported in many of the publications now appearing in the scientific literature. While the state of the Arctic Ocean clearly has implications for the global climate, it is entirely plausible that the rapid and accelerating loss of ice cover on the Arctic Ocean could be the harbinger of things to come in the Hudson Bay Complex.

Since 1979, enabled scientists have been able to track the precipitous decline in the extent and volume of ice cover on the Arctic Ocean through satellite monitoring. This decline in the ice cover is both an indicator and a driver of climate change in the Arctic, the subarctic and indeed the rest of the planet. The documented declines in sea ice in the Arctic along with increasingly sophisticated climate modelling are fueling an unprecedented interest in the potential for the Arctic Ocean to become a major international route for commercial shipping and Arctic tourism. The potential reserves of oil and gas in the region are also driving activity in the Arctic and underlay much of the current interest in Arctic sovereignty.

The extent of the ice cover (15 per cent or more of the sea surface) of the Arctic Ocean reached its minimum on September 9, 2011. That minimum and the average ice cover for the month (4.6 million $km^2$) are the second lowest in the 1979–2011 period (United States National Snow and Ice Data Center, 2011a). Figure 1 illustrates the decline in the extent of the average September ice cover. Atmospheric conditions were exceptionally conducive to rapid ice melt in 2007, the record year for the lowest September average ice cover (4.3 million $km^2$). The last 5 years (2007–2011) are the five lowest September averages in the satellite record. The current trend in September average ice extents relative to the 1979–2000 average (7.04 million $km^2$) is 12 per cent per decade. This trend is ominous, apparently relentless and, in the opinion of many experts, unstoppable in the foreseeable future.

While the decline in sea ice has been apparent for decades, the 2007 melt season was exceptional with atmospheric conditions leading to an unprecedented and unexpected loss of sea ice. Sonar readings from under-ice submarine voyages as well as from satellite observations indicate that the ice pack is now only about half as thick as it was in the 1980s. Many scientists (McCullough et al., 2011) now expect that the Arctic Ocean will be seasonally ice free in as little as one or two decades and that the Intergovernmental Panel on Climate Change was much too cautious when it predicted that the ice-free Arctic Ocean would not likely occur until 2030–2050 in its 2007 report.

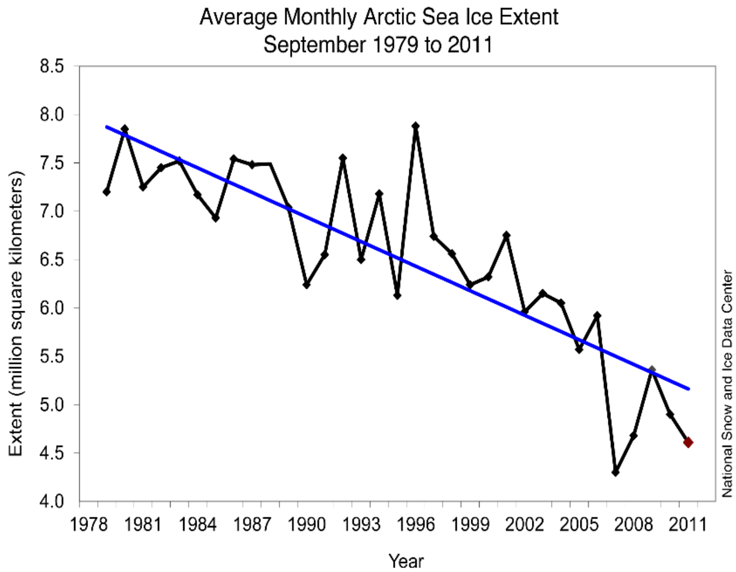


Figure 1. Declining extent of September sea ice in the Arctic Ocean.

The United States National Snow and Ice Data Center publishes an online monthly news letter, *Arctic Sea Ice News & Analysis*, on changing ice conditions in the Arctic. Figures 1 and 2 are from the October and December issues respectively. Figure 2 illustrates how the Arctic ice cover changed during 2011 compared to the average ice cover for the period from 1979–2000, as well for the years 2007, 2008, 2009 and 2010. This figure is for December 1, 2011 and, as noted, 2011 has tracked 2007 (the ice minimum year) very closely.

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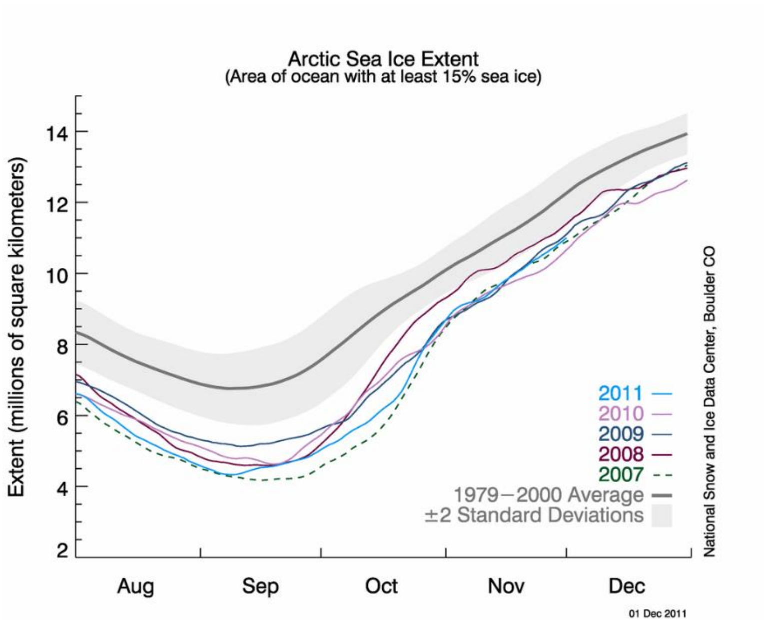

Figure 2. Summary of Arctic sea-ice extent from August 2011 to December 2011.

## 4 Dramatic Changes in the Hudson Bay Complex

While climate change research has focused primarily on the dramatic changes that are taking place in the high arctic many of the publications documenting and interpreting these changes are very relevant to what is happening in the Hudson Bay region. Satellite monitoring since 1971, and especially after 1979, has enabled scientists to monitor parameters such as the extent and volume of sea-ice and sea-surface temperatures in the Arctic Ocean as well as in subarctic seas such as Hudson Bay. There have also been a number of books and special issues of science journals that focus primarily on the conditions in the Hudson Bay region.

As in the high Arctic, much of the focus is on the ice regime, and satellite surveillance has provided a powerful means of real-time monitoring of the status and trends in ice cover. There are important differences in the ice regimes. The Arctic Ocean has a perennial ice cap that partially melts each melt season. An important signal of climate warming is the minimal extent of ice cover at the end of the melt season, which ordinarily occurs in September of each year. In contrast, the Hudson Bay Complex is typically ice free in the late summer and early fall, so the focus for documenting the pace of change has been primarily on ice break-up and freeze-up dates with a warming climate resulting in earlier break-up and later freeze-up.

While results are variable depending on the time frames and regions chosen for study, most have documented significantly advancing break-up dates and delayed freeze-up dates for most areas over most time periods. In recent years, especially since about 1995, the indicators of a warming climate have become more general and more pronounced throughout the region.

The Hudson Bay System is featured in a number of recent major compilations. The December 2011 issue of the *Journal of Marine Systems* (Macdonald & Kruzyk, eds.) has a preface aptly entitled: "The Hudson Bay system: A northern inland sea in transition." The 12 papers in this special issue constitute a major contribution to our understanding of the Hudson Bay marine system, with a special focus on the changes occurring in the system. They also provide a glimpse of what to expect in the future. In addition, a 2010 book entitled *A Little Less Arctic: Top Predators in the World's Largest Northern Inland Sea* (Ferguson, Loseto, & Mallory, eds.) provides an up-to-date assessment of the status and trends in major mammal and waterfowl populations in this system. Most importantly, many of the authors emphasize the many direct and indirect links between these ice-adapted top predators, including humans and climate change. Finally, Stewart and Lockhart (2005) put together a major compendium entitled "An overview of the Hudson Bay marine ecosystem."

The seasonal ice cover of the Hudson Bay Complex has a profound and overarching influence on the ecology of the marine system and on the plants and animals that are adapted to living in this system. The ice cover also has a major impact on regional climate and terrestrial ecosystems. The sea-ice platform is also of great importance to the inhabitants of the region who, for thousands of years, have relied on a safe and predictable ice cover to enable them to hunt and harvest marine mammals, waterfowl, fish and invertebrates from the sea. Until recently the aboriginal peoples living along the coastline were almost entirely dependent on the harvesting of animals from the sea for their livelihood and survival. These bounties from the sea continue to provide "country food" and to be culturally and economically important to Inuit communities around the Hudson Bay Complex.

Many of the investigators have, for obvious reasons, focused on the linkages between surface air temperatures and the timing of freeze-up and sea-ice melt. The seasonal sea-ice cover is a defining feature of the system and has a profound impact on its physical, chemical and biological characteristics. The ice cover directly influences sea-ice-atmosphere connections and the ice regime is both an indicator of climate change and a significant driver of regional climate. Figure 3 is a simple schematic that illustrates how the snow and ice cover reflect the sun's energy back into space.

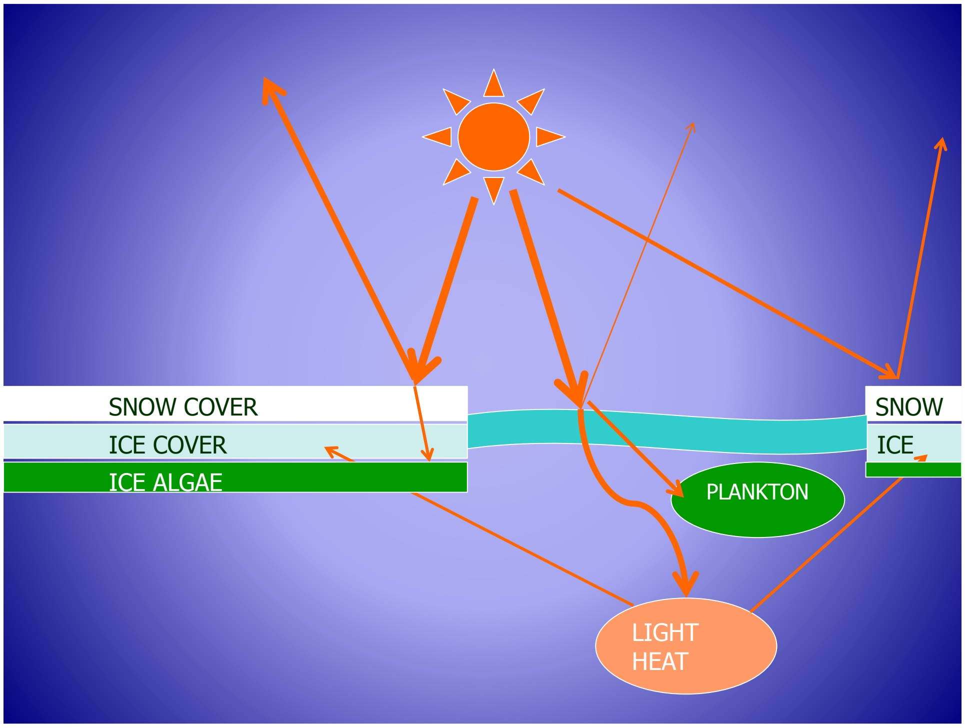


Figure 3. A schematic illustration of the albedo effect of the snow and ice cover that reflect solar energy back into space. In the absence of ice cover, much more of the solar energy is absorbed. This absorbed energy adds heat and contributes to the further melting of the ice cover. Ice algae and their associated food webs are currently very important to ice-associated species such as ringed seal.

Ice and snow cover has a dramatic effect on the fate of solar energy reaching the Earth's surface. Typically about 80 per cent of the incoming radiation that strikes a snow covered ice surface is reflected back into space, whereas an ice-free sea surface absorbs some 90–95 per cent of incoming radiation into the water body. This absorbed energy is then available to accelerate the melting of the remaining ice cover and delays the formation of ice in the fall and winter. When, as is now the case, atmospheric forcing (warming) is advancing the dates of ice melt, the positive feedback from the increased absorbance of energy further advances the melt dates while delaying freeze-up dates. All of this leads to a longer ice-free season.

The Hudson Bay Complex is profoundly influenced by its freshwater budget and also annually receives approximately 940 $km^3$ of freshwater from rivers entering the Hudson Bay Complex, a quantity comparable to the combined discharges of the St Lawrence and Mackenzie rivers. The melting of sea ice adds an even large volume (~1,500 $km^3$) of freshwater to the surface of the complex. The river runoff is largely confined within a counterclockwise current that transports freshwater along the coastline to Hudson Strait and then to the Labrador Sea and the North Atlantic. Precipitation exceeds evaporation in the James Bay region, but over most of the complex the evaporation exceeds precipitation.

The formation of seasonal ice cover on the Hudson Bay Complex also results in brine rejection during freeze-up and the downward convection of denser and more saline waters. The sea-ice melt that adds freshwater to the sea surface during the spring/summer melt season reinforces the vertical stratification of the system. Some of this sea-ice melt combines with the outflow from rivers discharging into the complex. Much of this annual input of freshwater to the system is then transported in the counterclockwise coastal current that moves northward along the Quebec coast of Hudson Bay before entering Hudson Strait, along the south coast of Hudson Strait and eventually reaching the Labrador Sea and the North Atlantic Ocean. St-Laurent, Straneo, Dumais, & Barber (2011) examine what happens to the freshwater runoff after in enters the Hudson Bay Complex.

Freshwater and the seasonal ice cover play fundamental and defining roles in the Hudson Bay ecosystem. Stratification, vertical mixing, circulation, salinity, heat fluxes, light penetration, nutrient cycling and biological productivity are all profoundly influenced by the freshwater in the system regardless of whether that freshwater is solid in the form of snow, ice or permafrost, or liquid derived from ice melt, rainfall or runoff from streams and rivers. The seasonal ice cover also makes for a much more continental climate throughout the region. Less ice cover will make for a less continental climate and an ocean system that is warmer, probably less stratified, less light and nutrient limiting and, perhaps, more productive.

At the same time, less ice cover will be detrimental to the flora and fauna that are associated with this habitat. Reductions in the amount and duration of ice cover are recognized as being a threat to marine mammals such as the polar bears and ringed seals that depend on the land-fast ice cover along the coasts of the Hudson Bay Complex. Much less attention is usually given to the ice-dependent food web that is based, in large part, on algae that thrive within the sea ice and on its undersurface. The presence of a predictable and reliable ice cover is also essential for the aboriginal hunters and trappers who harvest mammals, fish and waterfowl associated with the sea ice.

The Nelson and La Grande Rivers, which are now regulated for the production of hydroelectricity, are the two largest rivers entering the Hudson Bay Complex. Both have had their flows augmented by some of the largest river diversions on the planet and their maximum flows have been shifted from the annual freshet (May, June and July) to the winter months when the demands for electricity are greatest. Their combined annual discharges account for about a third of the annual runoff to the system, but during winter months they contribute almost two thirds of the total runoff. Clearly the shift in the volume and the annual runoff pattern from these rivers has some effect on coastal salinity and circulation and on the timing of the annual freshwater pulse that moves along the coast of Hudson Bay and eventually to the Labrador Sea and North Atlantic. The consequences of these changes in the freshwater budget on biological productivity and ocean circulation in, and beyond, Hudson Bay are not well understood.

The La Grande River, after receiving major diversions from the Caniapiscau, Eastmain and Rupert rivers, is now the largest river discharging into the Hudson Bay Complex. Its pattern of discharge has been fundamentally altered. The average natural monthly flow prior to regulation (1960–1978) was 1,703 $m^3$/second (Hydro-Québec and GENIVAR Group Conseil Inc., 2005) compared to an average monthly flow of about 4,000 $m^3$/second after adding a flow of 450 $m^3$/second from the diverted Rupert River (Messier, 2002; Hydro-Quebec Production, 2004).

The seasonal changes are much more dramatic. The five lowest-flow months (December to April) averaged 725 $m^3$/second, which is less than 20 per cent of flows now occurring during these months. Conversely, prior to regulation, the month of June was the month of peak flow (3,472 $m^3$/second), which is similar to present mean flows during that month. The spring freshet, a natural feature of unregulated rivers in the region, is now gone and the maximum discharges now occur in the winter months to meet the demand for electricity users in southern Quebec and the northeastern United States. While the pattern of flow of the Nelson River, now the second largest discharge into the Hudson Bay Complex, has not been altered to the same degree as with the La Grande, it now has maximum discharges in the winter months.

Granskog, Kuzyk, Azetsu-Scott and MacDonald (2011) provide important new insights into how the runoff and sea-ice melt inputs of freshwater are transported, stored and mixed within the system. The authors used oxygen 18 isotope and salinity measurements to differentiate freshwater originating from runoff from that due to ice melt. The ability to differentiate these different sources of freshwater in samples from throughout the complex provides a powerful tool for assessing the circulation, mixing, transport and residence times of water masses throughout the system. It also provides important insights into how the freshwater budget of the system is likely to respond under climate warming when runoff is expected to increase (Déry et al., 2011) and sea-ice melt to decline.

Carmack (2000) discusses the complex ways in which the freshwater budget of the Arctic Ocean is so interwoven with Arctic climate and oceanography:

> *The study of Arctic climate is truly about the sources, disposition and export of its freshwater components. As such, understanding the Arctic Ocean's freshwater budget transcends the*

*collection of "numbers" and their manipulation. It is much more about obtaining a fundamental appreciation of the hydrological cycle that explains how a large and complex ocean system works.*

Similarly the freshwater in the Hudson Bay complex, whether in the form of river runoff, sea ice, sea-ice melt, precipitation or evaporation is extremely important to regional climate as well as to the circulation, stratification and biological production of the marine ecosystem.

Especially since 1992, the system has been warming. For the period from 1926–2009, 12 of the 19 warmest years occurred after 1991 (Galbraith & Larouche, 2011). While the warming trend, largely attributable to the accumulation of greenhouse gases in the atmosphere, appears to be relentless and apparently increasing, there is significant annual and multi-year variability in air and sea surface temperatures (up to 5 Cº). Annual and multiyear variations in temperatures are associated with atmospheric and oceanic oscillations such as the North Atlantic (NAO) and the Southern oscillation index (SOI). The East Pacific/North Pacific indices (EP/NP) and the Arctic oscillation (AO) and North Pacific index are related to subsequent surface air and sea temperatures and ice cover in Hudson Bay.

Other climate-forcing events also play a role. The Mount Pinatubo eruption in the Philippines in June 1991 led to a drop of about 0.5ºC in mean global temperatures in 1992, and in the Hudson Bay region the surface air temperatures were typically more than one degree lower than that expected based on the regional long-term trend line. Surface air temperatures, surface sea temperatures, concentrations of ice and break-up and freeze-up dates are correlated in the Hudson Bay region. Winds over Hudson Bay are also correlated with ice break-up and sea surface temperatures, probably because of their influence on the direction and magnitude of ice movement over the bay (Hochheim, Lukovich, & Barber, 2011).

Recent regional trends in air temperatures, sea surface temperatures, and dates of ice break-up and freeze-up are summarized in Table 1.

Table 1. Summary of recently reported trends in the climate of the Hudson Bay Complex

| Indicator/source | Time frame | Trends | Comment |
|---|---|---|---|
| Ice break-up (Gagnon & Gough, 2005) | 1971–2003 | Statistically significant earlier break-up (-0.4–1.25 days/year) in James Bay, along the southern shore of Hudson Bay and western Hudson Bay. | Similar though not statistically significant trends to earlier break-up in almost all locations |

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| | | | |
|---|---|---|---|
| Ice freeze-up (Gagnon & Gough, 2005) | 1971–2003 | Statistically significant later freeze-up (0.32–0.55 days/year) in northern and northeastern Hudson Bay | Similar though not statistically significant trends to later freeze-up at almost all locations |

| | | | |
|---|---|---|---|
| Air temperature at coastal stations (Gagnon & Gough, 2005) | 1971–2003 | Statistically significant warming trend (0.5–0.8ºC/decade) at seven of eight stations. | The warming trend at Inukjuak (0.4ºC/decade) was not statistically significant. |
| Ice break-up Hudson Bay (Stirling and Parkinson, 2006) | 1978–2004 | Statistically significant earlier break-up (-0.75+/- 0.25 days per year) in western Hudson Bay | The trend value in Eastern Hudson Bay (-0.14+/- o.31) was not significant |
| Ice break-up Foxe Basin (Stirling and Parkinson, 2006) | 1978–2004 | Statistically significant earlier break-up (-0.66+/- 0.20 days per year) | |
| Ice break-up Hudson Bay (Stirling and Parkinson, 2006) | 1971–2009<br>1990–2009 | Statistically significant earlier break-up (-3.2 days/decade) from 1971–2009. Earlier break-up (-1.9 days /decade) after 1990 not significant | Ice break-up dates highly correlated with surface air temperatures and sea surface temperatures |
| Ice break-up Foxe Basin (Galbraith and LaRoche, 2011) | 1971-2009<br>1990-2009 | Statistically significant earlier break-up (-4.9 days/decade) from 1971–2009 and 9.0 days/decade after 1990 | Ice break-up dates highly correlated with surface air temperatures and sea surface temperatures |
| Ice break-up Hudson Strait (Galbraith and LaRoche, 2011) | 1971–2009<br>1990–2009 | Statistically significant earlier break-up (-5.6 days/decade) from 1971-2009 and 13.5 days/decade after 1990 | Ice break-up dates highly correlated with surface air temperatures and sea surface temperatures |
| Air temperatures (Galbraith and LaRoche, 2011) | 1926–2009 | Warming trend after 1992 with 12 of the 19 warmest years on record (1926–2009) occurring after 1992. | |
| Sea surface temperatures (Galbraith and LaRoche, 2011) | 1985–2009 | Warmest week of the year trending to higher temperatures. Most areas with significant increases (0.2–1.4ºC/decade) | Warmest temperatures correlated with air temperatures and, especially, the date of break-up. |

| | | | |
|---|---|---|---|
| Break-up and freeze-up dates. Hudson and James Bay (Hochheim, Barber & Lukovich, 2010) | 1996–2000 compared to 1980–1995 | Mean break-up dates earlier by 0.4–2.0 weeks. 63 per cent of area is 0.8 to1.6 weeks earlier<br>Mean freeze-up dates later by 04–2.0 weeks. 58 per cent of area is 0.8 to 1.6 weeks later. | |

## 5 Contemplating the Future of the Hudson Bay Marine Ecosystem

Predicting the future is not an exact science, but the broad outlines of probable futures for the Hudson Bay Complex have been emerging for several decades. Some things can be predicted with a high level of confidence. The concentrations of greenhouse gases in the Earth's atmosphere will, at least for most of the next century, continue to increase. This ensures a continuing and increasing upward pressure on global temperatures, although there is less certainty as to where, and by how much, temperatures will rise. The increasingly sophisticated global circulation models are generally effective at reconstructing the climate changes that have occurred in the past, which lends credence to projections that Arctic and subarctic regions will, as they have in previous decades, warm more rapidly than temperate and tropical regions. The Arctic Climate Impact Assessment (ACIA, 2005) projected that Hudson Bay and Baffin Island would warm by 3 to 9ºC over the next century. We can also be sure that significant interannual and interdecadal variation will continue to be a feature of the regional climate.

Indeed, climate change/warming is the overarching "elephant in the room" that is already having a marked influence on the region. The seasonal ice cover has changed, with earlier break-up, later freeze-up, and more open water. Polar bear populations in western and southern Hudson Bay are seen as being particularly vulnerable because the longer ice-free season prevents them from hunting seals on the ice. While the uncertain future for the majestic and iconic polar bear has our attention, the changing sea ice is becoming less safe and less predictable for Inuit hunters and trappers who have relied, for many generations, on the ice cover to harvest resources from the sea (Laidler et al., 2009). This aspect and its impact on cultural traditions and community economies are not widely appreciated.

Another critical factor is the role that ice algae has and will likely continue to play in the system. These tiny plants that are on and imbedded in the lower surface of the sea ice form the base of the food web associated with the ice pack, yet they are mostly out of sight and out of mind. Less ice cover will inevitably shift more of the primary production to phytoplankton living in the water column, with an inevitable cascade of changes in the food webs of the Hudson Bay Complex.

Recently, Hoover (2010) used a food chain model to simulate what might happen with respect to food webs. Present and future declines in ice algae are expected to have a strongly negative impact on most large mammals, although reduced ice cover is also associated with more killer whales and more predation on seals, bowhead whales, narwhals and belugas. The author estimates that a 50 per cent reduction in ice algae biomass would lead to an overall decline of 30 per cent in total biomass of marine mammals, a 25 per cent decline in biomass of all fishes, a 40 per cent decline in the biomass of zooplankton, a 20 per cent decline in biomass of benthic biomass and a 15 per cent increase in pelagic primary production.

This projection might be overly pessimistic. Less ice cover will also mean a greater energy input into the marine system, and that system is likely to be less stratified with more upwelling of nutrients. The combination of more light penetration and greater nutrient availability could lead to a substantial increase in pelagic primary production with a cascading effect that could be of particular benefit to species that are not dependant on the seasonal ice cover. New species not present in the system could also invade and flourish in a warming system.

Future changes in the Hudson Bay marine ecosystem will occur within a changing climate system that sets the boundaries on how the Hudson Bay marine ecosystem will evolve. A changing climate will have a profound influence on the physical, chemical and biological oceanography of the marine ecosystem to the advantage of some species and to the detriment of others. Similarly the social, cultural and economic benefits associated with the system will change and aboriginal communities will likely be called upon to adapt to the new realities—both positive and negative. A major challenge is to develop an improved capacity to anticipate and prepare for a future that is likely to be quite different from the past. Ideally this will involve close cooperation between aboriginal observers, who continue to harvest resources from the sea, and Western scientists, who seek to understand how this large system functions, especially with respect to the mammals, fish and waterfowl that are harvested as part of traditional cultures and economies.

Changes in climate will also have a direct bearing on future development in the region. One must assume that there will be additional hydroelectricity development. While these developments will not be on the scale of the James Bay or Nelson River projects, their cumulative impact on the timing and location of runoff into the Hudson Bay Complex will have a large impact on the freshwater budget and the overall functioning of the ecosystem. The combined effect of river regulation and a warming climate will likely increase runoff into the marine system while reducing the volume of the seasonal ice cover and the amounts of freshwater from sea-ice melt that is added to the surface of the system.

Similarly, at freeze-up the amount of brine rejected and the amount of high salinity waters convected to the layer of deep dense water will decrease. The overall impact of such shifts in the freshwater budget on biological productivity in the system is not well understood. While it has been recognized that the outflow from Hudson Strait does have a positive impact on biological productivity along the Labrador Coast (Sutcliff, Loucks, Drinkwater, & Coote, 1983; Myers, Aikenhead, & Drinkwater, 1990), it is not at all clear what the effect of an altered freshwater budget would have on the productivity of the region, on the Labrador current or on the formation of deep water in the Labrador Sea.

We can expect to see continuing and growing interest by companies interested in exploring and extracting minerals and oil and gas from the region. As the open water season lengthens, we can also expect that shipping and tourism will increase. It is virtually certain that both the aboriginal and non-aboriginal populations in the region will continue to increase and that this will in turn lead to increased pressure on fish and wildlife in the region, perhaps leading to allocative conflicts over the harvesting of these resources.

Climatologists have relied on a number of sophisticated global circulation models (GCMs) to help explain current and previous climatic conditions and, most importantly, to predict future climatic conditions under different greenhouse gas emission scenarios. These models all predict rising global temperatures over the next century. The Intergovernmental Panel on Climate Change (IPCC, 2007) has consistently found that Arctic and subarctic regions are warming more rapidly than other regions of the planet and that Arctic and subarctic regions are also likely to experience more rapid warming in the next century. The recent dramatic warming signals from Arctic and subarctic regions reinforce the expectation that the changes in the Arctic will be more amplified than those in temperate and tropical regions. Overland (2011) and Serreze and Barry (2011) discuss the evidence and reasons for this Arctic amplification.

The recently completed Arctic Climate Impact Assessment (ACIA, 2005) has projected that temperatures throughout Canada's central and eastern Arctic region will increase in all seasons. Increases between 1991 and 2001 are predicted to be hghest in winter when temperatures are projected to be higher by 3 to 9ºC. The greatest increases in this region are projected to occur around Baffin Island and Hudson Bay. The projections relied on five GCMs that were used by IPCC and were made before the recent record-setting losses of sea ice on the Arctic Ocean. The dramatic reductions over the last 15 years in the minimal (September) ice cover on the Arctic Ocean are unprecedented. They have led many to conclude that the

IPCC and ACIA projections are unduly conservative and that a seasonally ice-free Arctic Ocean could, as McLaughlin et al. (2011) have suggested, occur within one or two decades.

Joly, Senneville, Caya and Saucier (2011) have recently completed a modelling exercise on the sensitivity of Hudson Bay sea ice and ocean climate to atmospheric temperature forcing. The objective was to investigate the impact of a warmer climate scenario on the Hudson Bay marine system using the sea-ice-ocean model presented by Saucier et al. (2004). They generated future temperatures using global and regional circulation models for the 2041–2070 period and then used these generated values with the sea-ice-ocean model. They found that the warmer climate led to an increase of 7–9 weeks in the ice-free season and a decrease of 31 per cent in ice volume. However, the extent of maximum ice cover was relatively unchanged with only a 2.6 per cent decrease indicating that at this level of warming (about 3.9ºC, compared to the base period from August 1, 2001 to July 31, 2005) the complex would continue to be almost completely ice covered during at least some times of the year. Some of their major findings are shown in Table 2.

These simulations are consistent with the findings of the IPCC (2007) and provide a reasonably foreseeable glimpse of the future. They may or may not be overly conservative. It is worth noting that the period selected to represent the present was in reality already considerably milder than earlier times in the period of record. It is also possible, as some experts have suggested that the Arctic is warming quicker than forecast by the IPCC (McLaughlin et al., 2011).

<table>
<tr><th colspan="4">Table 2. Summary of major changes between a simulation of current conditions (August 1, 2001 to July 31, 2005) and projected future conditions (2041–2070)</th></tr>
<tr><td>Ice break-up and freeze-up median dates; ice volume: Hudson Bay</td><td>2001–2005 (Present)<br>2041–2070 (Future)</td><td>Present break-up: July 8; future 24 days earlier<br>Present freeze-up: December 4; future 25 days later<br>Sea ice season reduced by 49 days<br>Ice volume decreased by 31 per cent</td><td rowspan="4">Air temperatures increase by 3.9 per cent; summer increase 0.8ºC;<br>winter increase 10.0 ºC;<br>summer sea surface temperatures increase 3–5ºC<br><br>The greatest change in sea-ice climate and heat content projected to occur in southeastern Hudson Bay, James Bay and Hudson Strait. The reduced ice melt will result in a less stratified water column and brine rejection, and the downward convection of dense water is expected to be reduced by 50 per cent.</td></tr>
<tr><td>Ice break-up and freeze-up median dates: Foxe Basin</td><td>2001–2005 (Present)<br>2041–2070 (Future)</td><td>Present break-up: July 13; future 22 days earlier<br>Present freeze-up: November 4; future 31 days later<br>Sea ice season reduced by 53 days</td></tr>
<tr><td>Ice break-up and freeze-up median dates: James Bay</td><td>2001–2005 (Present)<br>2041–2070 (Future)</td><td>Present break-up: June 22; future 39 days earlier<br>Present freeze-up: December 18; future 26 days later<br>Sea ice season reduced by 65 days</td></tr>
<tr><td>Ice conditions: Hudson Strait</td><td>2001–2005 (Present)<br>2041–2070 (Future)</td><td>In the present climate scenario the north shore is partially covered with sparse and thin ice and is ice free in the future climate scenario.</td></tr>
</table>

Source: Joly et al. (2011)
Note: A high resolution regional ocean model was used for both simulations and an effective carbon dioxide concentration of 707–950 ppmv was used in the future scenario with the Canadian Regional Climate Model (CCRM) driven by the Global General Circulation Model 3.1/T47.

The ability to track what is happening to the ice cover provides scientists with a powerful means of documenting the status of and changes in this most important indicator of climate change. The nature, extent and duration of ice cover in Arctic and subarctic seas also profoundly influence the physical, chemical, and biological characteristics of these ecosystems and the fluxes between the sea, sea ice and atmosphere. Clearly, ice-dependant species such as polar bears and ringed seals are directly affected. Likewise, ice algae and the ice-associated fauna that these algae support are also directly affected.

However, the many less obvious and less predictable changes in the system are likely to be equally, if not more, important.

Some of the complex linkages and components of the Hudson Bay marine system are illustrated in Figure 4. The ice cover serves as a barrier that insulates the sea surface from the atmosphere and its presence or absence has much to do with how the system functions. While many ice-dependent species will undoubtedly be affected, the complex systemic nature of the ecosystem components and linkages will inevitably lead to surprises where there will be major winners as well as major losers. This figure is also intended to provide a perspective on the aspects that are most directly observed and valued by aboriginal hunters and gatherers, as well as other aspects that are typically used by Western scientists to help understand causes and relationships.

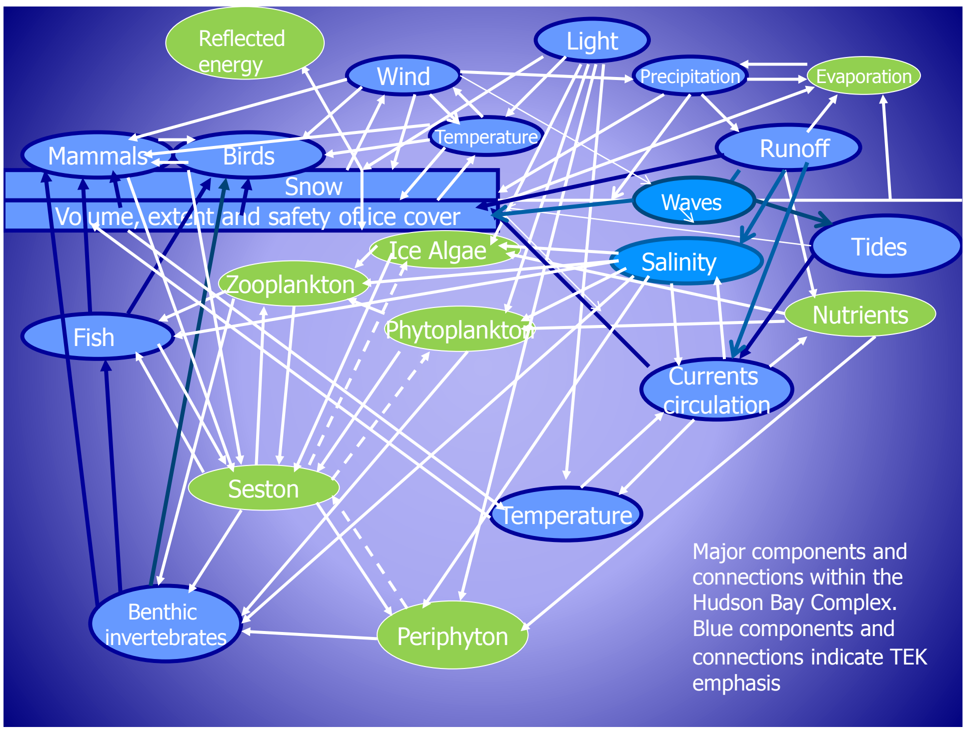


Figure 4. Selected pathways and valued ecosystem components within the Hudson Bay marine ecosystem.

Predictions made in the recent Arctic Climate Impact Assessment suggest that the Arctic will be dramatically altered as a result of global climate change, that the warming trends that have occurred in

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the Arctic will continue and that temperatures, especially in winter months, are likely to be many degrees warmer than in recent decades

As a consequence of sustained effort, contaminants in Arctic food chains have been recognized as a global challenge that warrants a global response. Indian and Northern Affairs Canada led much of this effort, mobilizing research and monitoring efforts to assess the nature, scope and significance of the contaminants threat. The active participation of northerners and the leadership roles played by Inuit leaders were especially important in building public and political support. The Stockholm Convention is an international recognition of the need for coordinated global actions to address the long-range atmospheric transport of persistent organic pollutants.

## 6 On our Understanding of the Bay: Recognizing Ominous Signs Without Knowing Where We Are Headed

Many scientific disciplines have contributed to our understanding of the Hudson Bay, and the satellite observing systems have provided a means of watching selected parameters over both short and long periods of time. They also make it possible to watch some of what is happening over vast areas. Periodic cruises of research vessels (usually in August, September and October) provide a means of validating the satellite Earth observations as well as opportunities to carry out detailed investigations of oceanographic conditions along specific transects.

Several major compilations of research on the Hudson Bay system have recently added substantially to our understanding of the Hudson Bay Complex. Peter Sly's 1995 comprehensive review of human impacts on the Hudson Bay system is a very useful basin-wide summary. Stewart and Lockhart (2005) provide an encyclopedic review of research on Hudson and James bays while Stewart and Barber (2010) provide a summary of the ocean-sea ice- atmosphere system of the Hudson Bay Complex.

Over countless generations, Inuit and Cree have depended upon their practical knowledge of the sea and coastal regions. Their TEK of the coastal zone, sea-ice conditions and the wildlife that are harvested is another source of complementary understanding. This knowledge provides a common-sense perspective on both the short-term and long-term changes that may be occurring in the Hudson Bay Complex. *Voices from the Bay* (McDonald et al., 1997) synthesizes the range and sophistication of the accumulated knowledge of elders, hunters, trappers and others who have lived in the Hudson Bay area.

Hunters from Sanikiluaq and others who process the animal skins have observed that the condition and quality of pelts of the seals that they are harvesting from around the Belcher Islands has declined. They have also noted major changes in stomach contents of these harvested seals. They can speculate as to whether or not these changes are associated with changes in the ice regime, with high winter discharges of freshwater into James Bay, or a manifestation of climate warming. Similarly, Western scientiss can document changes in the feeding behaviour of marine waterfowl and link these to changing ice conditions and regional warming (Mallory, Mallory, Loseto, & Ferguson, 2010).

The Hudson Bay Complex is a very large, diverse and remote ecosystem that is very difficult to study, especially during the winter months when it is ice covered. Research initiatives have gathered information outside the usual August–October sampling window, but these initiatives have typically been spatially very restricted, often to James Bay, southeastern Hudson Bay and the Nelson and Churchill River estuaries. Generally, the scientific initiatives have had a local focus and have addressed manageable and narrowly defined research questions. While these research initiatives provide useful insights, their findings are difficult to compare and are of limited value for extrapolating over space and/or time. They are, similarly, of limited value in assessing the overall implications of climate warming on the marine system. Our very limited ability to document and assess the cumulative effects of multiple and diverse stresses on the overall system is a major shortcoming that limits our capacity to anticipate, plan and adapt to the future.

For some parameters—such as ice cover, stratification, salinity and temperature—it is likely that models of the system may be the best available means of examining the interrelationships between these and other characteristics of the Hudson Bay Complex. Nevertheless, real data from the system, especially for seasons that are especially data-sparse, are essential to validate and refine the models developed for the system. Joly et al. (2010) have coupled a very promising sea-ice-ocean model of the seasonal cycle in the Hudson Bay Complex (Saucier et al., 2004) with GCMs as a means of estimating future conditions in the system.

Documenting and assessing the cumulative effects of hydroelectricity developments, especially in combination with one another and with other major developments—all in the context of climate change/warming—is a specific challenge that begs for attention. Common sense tells us that project-by-project assessments can, at best, only provide a sense of the incremental effects of the latest project. The Hudson Bay Complex has a downstream, downwind problem. The diversion and regulation of rivers clearly have an impact on the timing, locations and magnitude of river runoff (Déry et al., 2011). Upwind atmospheric loading of contaminants is related to contaminant levels in the Hudson Bay food web. The cumulative effects of the long-term greenhouse gas loading into the atmosphere has implications for global climate and is apparently a major driver of climate warming signals from the Hudson Bay region.

The Federal Panel (CEAA, 2006) was established as part of the process for Assessing the Eastmain-1-A and Rupert Diversion Project, a part of the James Bay hydro project. In its final report, the panel recognized the significance and the challenges associated with the cumulative impact issue. Recommendation #34 to the federal government provides an important reference point:

***"To the federal government the Panel recommends***

*34. The issue of cumulative effects affects several jurisdictions, including the federal government, the provinces of Quebec, Ontario and Manitoba, the territory of Nunavut as well as several government departments linked to these various levels of government. Assessing cumulative effects therefore goes far beyond the responsibility of a single proponent. Within this context, it would be imperative for the federal government to implement a large scale research and monitoring program for the James Bay and Hudson Bay Ecosystems. Such a program could be coordinated by an independent body whose structure is akin to that of the International Joint Commission. Such a structure could foster the pooling of efforts and resources of all government agencies, as well as those of the academic community, which is already working on various problems related to the cumulative effects in this sector. Whatever the chosen structure, it would be essential for the various Aboriginal communities affected to be stakeholders in this research and monitoring program, in order to integrate into it traditional knowledge and local expertise."*

Sustained effort involving monitoring, research, surveys and modeling as well as community-based observations can all help fill important gaps in our understanding of how the Hudson Bay Complex functions and how it is likely to respond under different climate and development scenarios. Such sustained effort, perhaps carried out under a mechanism such as that proposed by the CEAA Federal Panel, would help to facilitate cooperation amongst the many stakeholders. It would also help to instill a greater appreciation of the cumulative effects of decisions and actions that, considered together and in combination, are affecting the Hudson Bay system.

Such a sustained effort would also provide a stronger foundation for addressing some very fundamental questions concerning the future of the Hudson Bay Complex. We know that the duration of the seasonal ice cover is, on average, weeks less than it was only a few decades ago. There is every reason to expect this trend to less ice cover will continue, and while it seems obvious that ice-dependent species, most notably polar bears, will be negatively affected, there are many regional and system-wide questions that cannot now be answered. The following examples are illustrative of two of the basic and related questions that do not, as of now, have clear answers.

First, will reductions in the duration and volume of ice cover have a net positive impact on the biological productivity of the system? What is change in biological productivity likely to mean for the marine food webs and for species that have been of cultural and economic importance to inhabitants of the region? It seems reasonable to predict that lengthening the open-water season would negatively affect ice algae and the ice-associated food web that is based on this food source. At the same time things are rarely simple. Lee et al. (2011) report that the melting of sea ice can, in some instances, create new niches for ice algae.

Would the additional solar energy entering the system lead to enough primary production by algae in the water column to more than compensate for this loss, and if so, would this primary production be readily available to other components of the food web? Using a food chain model, Hoover (2010) has projected, that the loss of ice algae will have a large, mostly negative, on the system. Slagstad, Ellingsen and Wassmann (2011) concluded that the loss of sea ice in the Arctic Ocean would usually result in higher primary production and, sometimes, in higher secondary production. It is also certain that some species would be negatively affected by a warmer system, whereas others, including those that are not presently part of the system, would benefit. Unfortunately, it is very difficult to predict the future biodiversity and species composition of a warmer system.

There is clear evidence that, at least for the late summer and fall, primary production in Hudson Bay is nutrient-limited because of the stratification of the water column (Ferland, Gosselin, & Starr, 2011), and the lack of significant upwelling of nutrient-rich waters from below the surface mixed layer. That raises the question of whether reduced duration of ice cover will lead to significantly less stratification in the system and hence greater availability of nutrients for primary production. Would greater accessibility to surface winds, less ice melt added to the surface each melt season and less brine rejection and convection of dense water to deeper layers during the ice season all interact to make the system less stratified and less nutrient limiting?

Second, are recent and reasonably anticipated changes in the freshwater budget of the Hudson Bay Complex important to the overall functioning of the system including such things as stratification and circulation, brine rejection and dense water convection, and nutrient limitation and biological productivity? Will the regulation of rivers for hydroelectricity and the shifting of runoff to winter months have more than a local impact on the marine ecosystem, or will these shifts, especially if accompanied by increased annual runoff and reductions in sea-ice melt, have a major impact on the functioning of the system? Will shifts in the timing, nature and quantity of freshwater entering the Labrador Sea have much impact on deep-water convection in the Labrador Sea or on biological productivity of the Labrador and Newfoundland shelf? Scientists who have documented and/or modelled the freshwater budget of the system have typically acknowledged our very limited knowledge of the impact of changing runoff on the overall system (Drinkwater, 1985; Saucier et al., 2004; Déry et al., 2011; Rennermalm, Rood, Weaver, eby, & Déry 2007; Sutherland, Straneo, Lentz, & Saint-Laurent, 2011),

## *7 Concluding Thoughts*

The economies and cultural values of aboriginal communities situated along the coast of the Hudson Bay Complex are closely linked to the marine ecosystem, especially to the marine mammals, fish, waterfowl and marine invertebrates harvested from this system. Coastal communities and their traditional cultures and economies are particularly vulnerable to changes that reduce wildlife populations and/or reduce the ability of aboriginal hunters and trappers to harvest wildlife resources associated with the land-fast ice cover along the coastlines. A challenge for these communities as well as for other Canadians is to anticipate and prepare for the challenges and opportunities that are likely to result from a "transformed" Hudson Bay marine ecosystem where the seasonal ice cover is much reduced or potentially even absent entirely.

Coastal communities and aboriginal organizations have much to add and their active involvement will help generate a readiness among others to become more engaged in understanding how the system is changing and in adapting to a changing Hudson Bay marine ecosystem. The substantial involvement of industrial interests would be a welcome development. Non-governmental organizations—especially those focusing on environmental, wildlife, and sustainable development concerns—are also seen as being important actors. It is also clear that the Hudson Bay Awareness Summit, as well as the issues that it addresses, will need to get the attention of national and local media if it and the activities associated with it are to raise the profile as needed. In the final analysis, it is likely that the success of the initiative will hinge, in large part, on the extent to which persons in positions of influence are motivated to become actively involved in planning and shaping this initiative and in individual and institutional responses to the issues and concerns raised through the process.

It is assumed that greater scientific, public and political awareness of the documented and predicted changes in the Hudson Bay marine ecosystem will help set the stage for meaningful and practical initiatives to address the future of the Hudson Bay region. The Hudson Bay Awareness Summit could contribute significantly to increased awareness and help to generate a readiness to address some of the major deficiencies in our ability to predict the future of the Hudson Bay Complex. Clearly the involvement of other stakeholders and actors will be required in to generate and stimulate an increased scientific, public and political interest and awareness.

One outcome might well be a clearer picture of how the many jurisdictions influencing the future of the Hudson Bay region could cooperate in forming appropriate governance institutions to help understand and manage the cumulative and multijurisdictional stresses that are influencing the environment and economies of coastal communities.

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