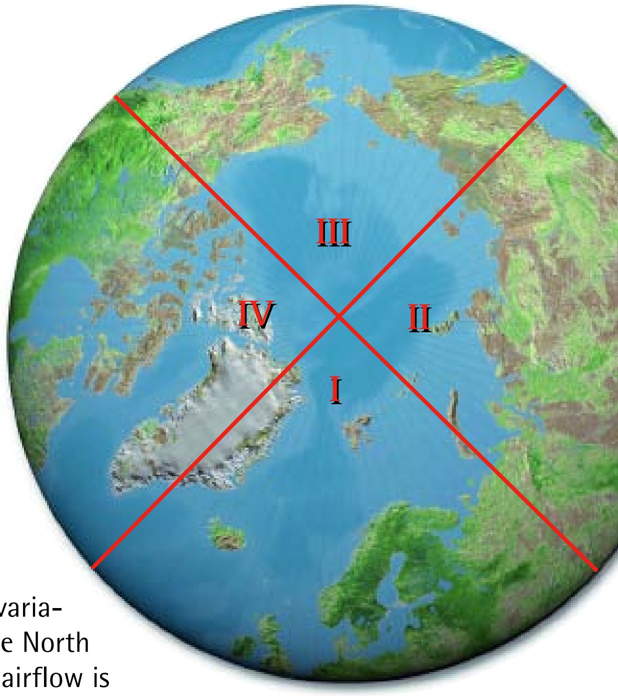
Selected Sub-Regional Impacts



About These Maps
The maps show observed and projected changes in climate in the four Arctic sub-regions as an annual average and for the winter season (December, January, and February).

The maps of observed temperature change show the difference from the middle of the 20th century to the present. For example, yellow indicates that an area has warmed by about 2˚C over the past 50 years. Black indicates areas for which there are insufficient observational data to determine the extent of the change.

The maps for the future show the projected temperature change from the 1990s to the 2090s, based on the average change calculated by the five ACIA climate models using the lower of the two emissions scenarios (B2) considered in this assessment. On these maps, orange indicates that an area is projected to warm by about 6˚C from the 1990s to the 2090s.

Changes in Climate in the ACIA Sub-Regions

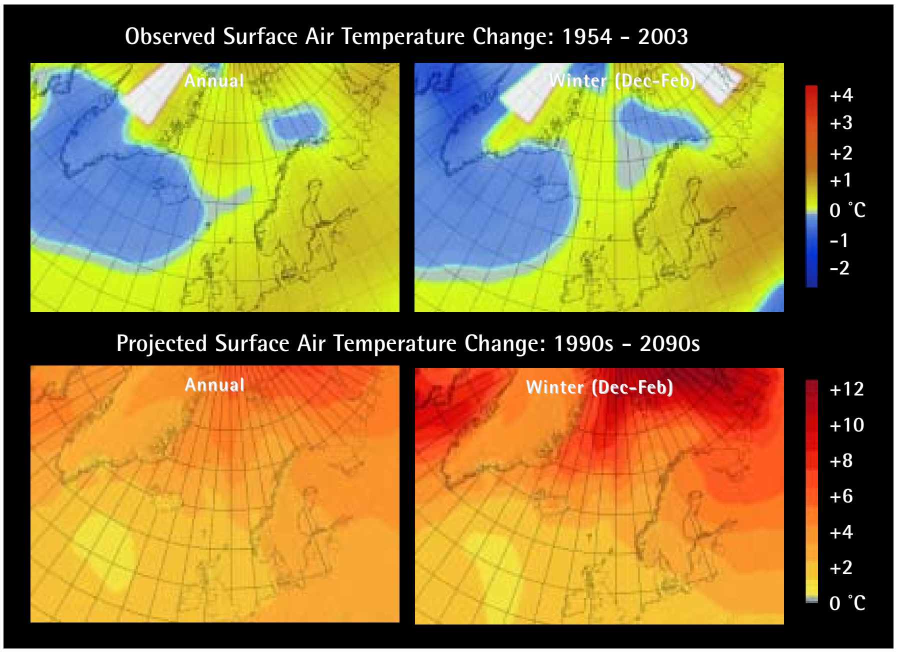
Because the atmospheric and oceanic couplings to the rest of the world vary by sub-region, climate change has varied around the Arctic over the past century, with some sub-regions warming more than others and some even cooling slightly. Projections suggest that all parts of the Arctic will warm in the future, with some warming more than others.

Some of the sub-regional variations are likely to result from shifts in atmospheric circulation patterns. For example, Region I is particularly susceptible to changes in the North Atlantic Oscillation, which is a variation in the strength of the eastward airflow across the North Atlantic Ocean and into Europe. When the eastward airflow is strong, warm maritime air penetrates northern Eurasia and the Arctic during winter, resulting in warmer-than-normal conditions. This airflow pattern is consistent with and may be responsible for some of the warming of the Eurasian Arctic in recent decades. A critical issue in projections of 21st-century climate for this region is the state of the North Atlantic Oscillation, including its possible response to increasing greenhouse gas concentrations.

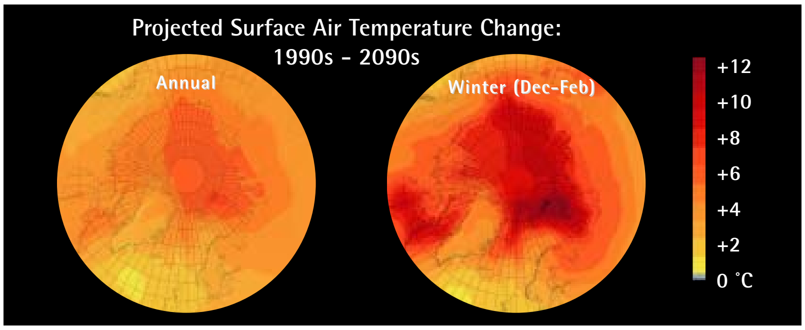
SUB-REGION I (East Greenland, Iceland, Norway, Sweden, Finland, Northwest Russia, and adjacent seas)

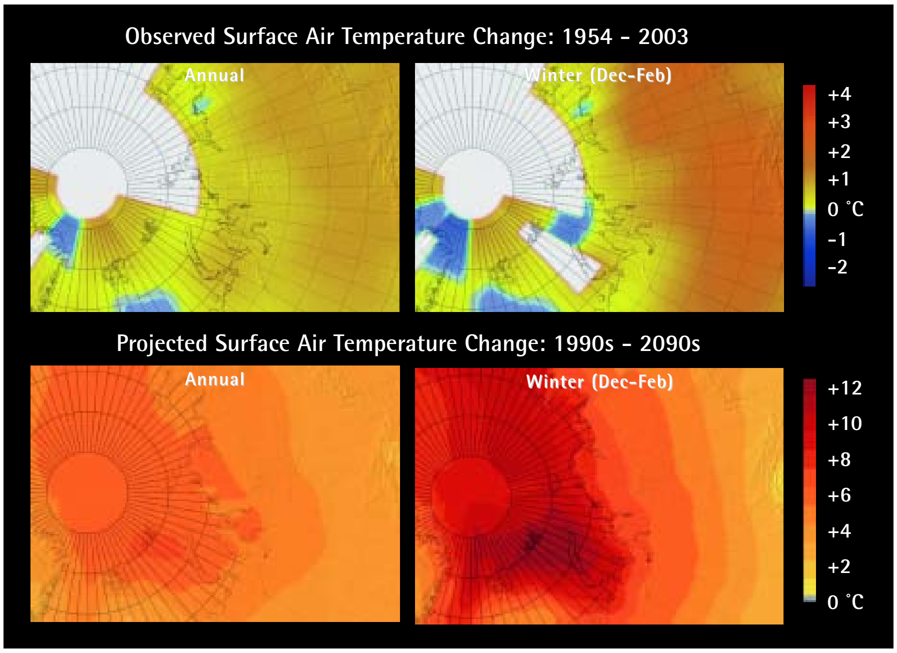
Over the last 50 years, annual average temperatures have increased by about 1˚C over East Greenland, Scandinavia, and Northwest Russia, while there has been cooling of up to 1˚C over Iceland and the North Atlantic Ocean. Near surface air temperatures over the Arctic and North Atlantic Oceans have remained very cold in winter, limiting the warming in coastal areas. Over inland areas, however, average wintertime temperatures have increased by about 2˚C over Scandinavia and 2-3˚C over Northwest Russia.

By the 2090s, model simulations project additional annual average warming of around 3˚C for Scandinavia and East Greenland, about 2˚C for Iceland, and roughly 6˚C over the central Arctic Ocean. Average wintertime temperatures are projected to rise by 3-5˚C over most land areas and up to 6˚C over Northwest Russia, with the increase becoming larger near the coasts as a result of the 6-10˚C warming over the nearby Arctic Ocean.



The Central Arctic Ocean is projected by all the models to warm more strongly than any of the four sub-regions, warming by up to 7˚C annually and by up to 10˚C in winter by the 2090s.

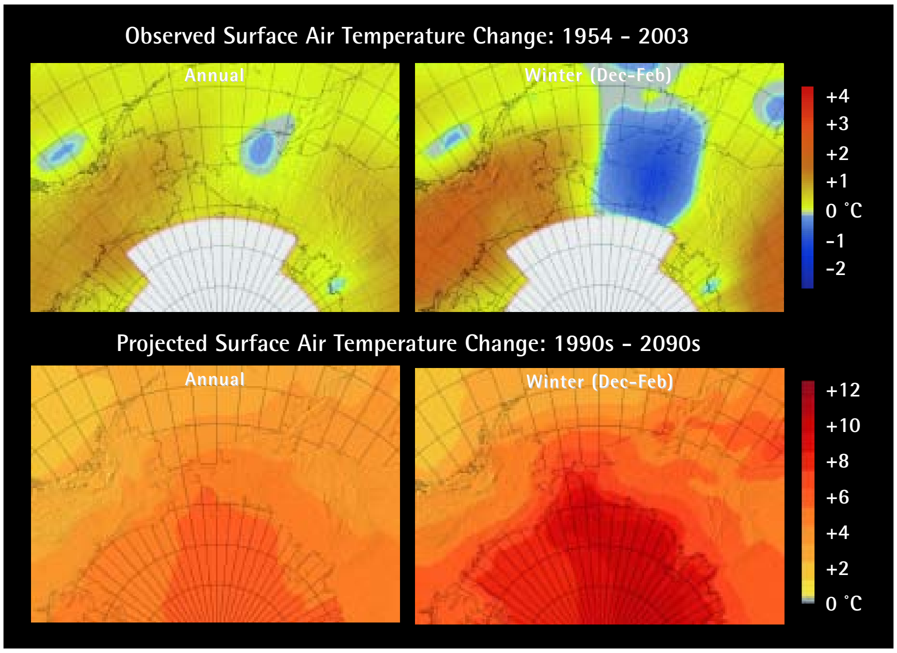




SUB-REGION II (Siberia and adjacent seas)

Annual average temperatures over Siberia have increased by about 1-3°C over the past 50 years, with most of the warming occurring during the winter, when temperatures increased about 3-5°C. The largest warming occurred inland in areas where reduced duration of snow cover helped amplify the warming.

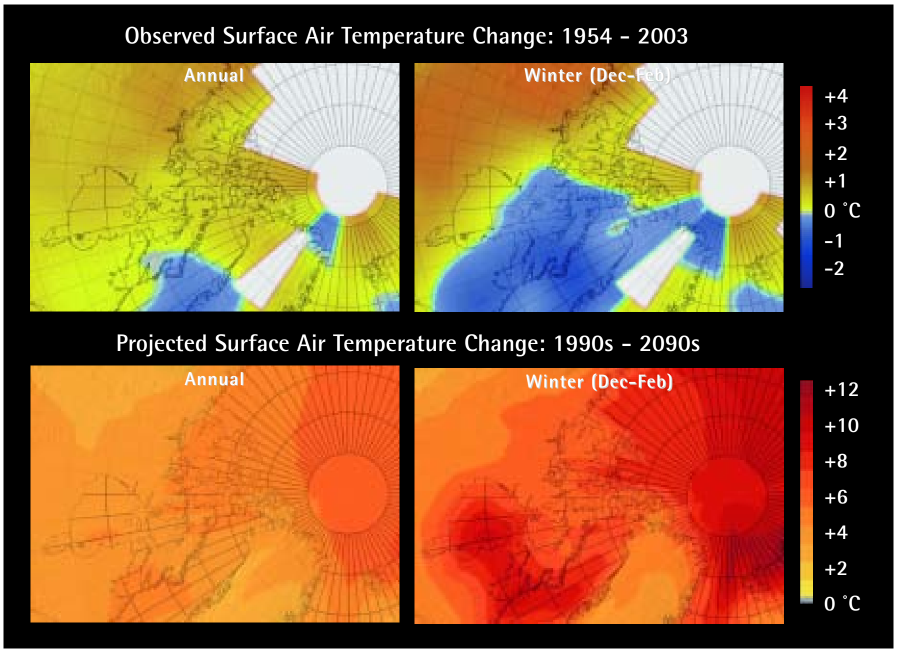
By the 2090s, model simulations project additional annual average warming of around 3-5°C over land, with the increase becoming greater closer to the Arctic Ocean where air temperatures are expected to rise by about 5-7°C. Wintertime increases are projected to be 3-7°C over land, also increasing near Siberia's northern coastline due to the increases of 10°C or more over the adjacent ocean areas.



SUB-REGION III (Chukotka, Alaska, Western Canadian Arctic, and adjacent seas)

Over the last 50 years, annual average temperatures have risen by about 2-3°C in Alaska and the Canadian Yukon, and by about 0.5°C over the Bering Sea and most of Chukotka. The largest changes have been during winter, when near-surface air temperatures increased by about 3-5°C over Alaska, the Canadian Yukon, and the Bering Sea, while winters in Chukotka got 1-2°C colder.

For the 2090s, model simulations project annual average warming of 3-4°C over the land areas and Bering Sea, and about 6°C over the central Arctic Ocean. Winter temperatures are projected to rise by 4-7°C over the land areas, and up to 10°C over the Arctic Ocean.



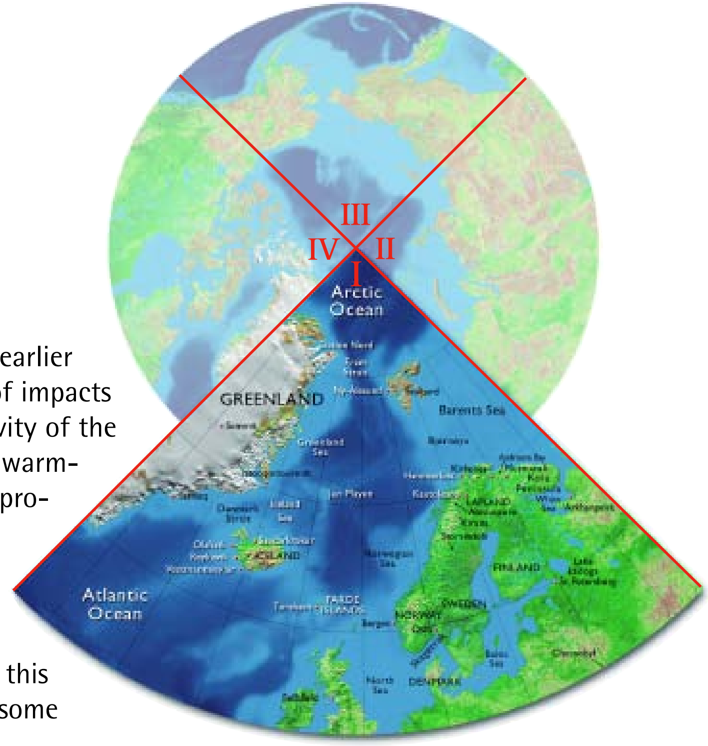
SUB-REGION IV (Central and Eastern Canadian Arctic, West Greenland, and adjacent seas)

Over the past 50 years, annual average temperatures increased by roughly 1-2°C over most of the Canadian Arctic and northwest Greenland. The Labrador Sea remained cold and nearby areas of Canada and southwest Greenland cooled by up to 1°C. Wintertime temperatures over central Canada increased by as much as 3-5°C, while areas of Canada and Greenland surrounding the Labrador Sea cooled by as much as 1-2°C.

By the 2090s, the entire region shows warming. Average annual warming of up to 3-5°C is projected over the Canadian Archipelago and 5-7°C over the oceans. Wintertime temperatures are projected to increase by 4-7°C over most of Canada and 3-5°C over Greenland, with increases of 8 to more than 10°C over Hudson Bay, the northern Labrador Sea, and the Arctic Ocean as sea ice declines.

KEY IMPACTS - SUB-REGION I

East Greenland, Iceland, Norway, Sweden, Finland,
Northwest Russia, and adjacent seas



...On the Environment

Species Impacts Due to Sea-Ice Decline

Major decreases in sea-ice cover in summer and earlier ice melt and later freeze-up will have a variety of impacts in this region. As examples, the reduced reflectivity of the ocean's surface will increase regional and global warming; the reduction in sea ice is likely to enhance productivity at the base of the marine food chain, possibly increasing the productivity of some fisheries; sea-ice retreat will decrease habitat for polar bears and ice-living seals to an extent likely to threaten the survival of these species in this region; and more open water is likely to benefit some whale species.

Forest Changes

Observations in this region indicate that treelines advanced upslope by up to 60 meters in altitude in northern Sweden during the 20th century. The rate of advance in recent decades has been half a meter per year and 40 meters per ˚C. In the Russian part of this region, there has actually been a southward shift in treeline, apparently associated with pollution, deforestation, agriculture, and the growth of bogs that leads to the death of trees. In some areas of Finland and northern Sweden, an apparent increase in rapidly changing warm and cold episodes in winter has led to increasing bud damage in birch trees.

Projected warming is very likely to cause northward shifts of the boreal conifer forest and woodlands and the arctic/alpine tundra of this region. The potential for vegetation change is perhaps greatest in northern Scandinavia, where large shifts occurred historically in response to warming. In this area, the pine forest is expected to invade the lower belt of mountain birch forest, while the birch treeline is projected to move upward in altitude and northward, displacing shrub tundra vegetation, which would, in turn, displace alpine tundra. Warmer winters are expected to result in an increase in insect damage to forests. Some of the larger butterflies and moths have already been observed to be expanding their ranges northward, and some of their larvae are known to defoliate local tree species.

Biodiversity Loss

In this sub-region, recent warmer winters and changing snow conditions are thought to have contributed to declines in some reindeer populations and to the observed collapse in lemming and small rodent population peaks in recent decades. Such collapses in turn lead to a decrease in populations of birds and other animals, with the most severe declines in carnivores such as arctic foxes and raptors such as snowy owls. Populations of these two species are already in decline, along with several other bird species. As species ranges shift northward, alpine species in northern Norway, Sweden, Finland, and Russia are most threatened because there is nowhere for them to go as suitable habitats disappear from the mainland. The strip of tundra habitat between the forest and the ocean is particularly narrow and vulnerable to loss.

For freshwater fish species in this region, local diversity is projected to increase initially as new species migrate northward. However, as warming continues in the decades to come, temperatures are very likely to exceed the thermal tolerances of some native species, thus decreasing species diversity. The end result may be a similar number of species, but a different species composition, with some species added and others lost. However, in general, the species added to the Arctic will be those from lower latitudes, while those lost are very likely to be lost globally as there is nowhere else for them to go. The end result would be a global loss in biodiversity.

"The weather has changed to worse and to us it is a bad thing. It affects mobility at work. In the olden days the permanent ice cover came in October... These days you can venture to the ice only beginning in December. This is how things have changed."

Arkady Khodzinsky
Lovozero, Russia

...On the Economy

Marine Fisheries

This region is home to some of the most productive marine fishing grounds in the Arctic. Higher ocean temperatures are likely to cause northward shifts of some fish species, as well as changes in the timing of their migration, possible expansion of feeding areas, and increased growth rates. Under a moderate warming scenario, it is possible that a valuable cod stock could be established in West Greenland waters if larvae drifted over from Iceland and if fishing pressure were kept off long enough to allow a spawning stock to become established. On the other hand, under those circumstances, northern shrimp catches would be expected to decline by 70%, since these shrimp are an important part of the diet of cod. More southern fish species, such as mackerel could move into the region, providing a new opportunity, although capelin catches would be likely to dwindle.

Forestry

Forestry has already been affected by climate change and impacts are likely to become more severe in the future. Forest pest outbreaks in the Russian part of the region have caused the most extensive damage. The European pine sawfly affected a number of areas, each covering more than 5000 hectares. The annual number of insect outbreaks in 1989-1998 was 3.5 times higher than in 1956-1965 and the average intensity of forest damage doubled. While most of the region has seen modest growth in forestry, Russia has experienced a decline due to political and economic factors. These factors are likely to be aggravated by warming, which in the short term negatively impacts timber quality through insect damage, and infrastructure and winter transport through ground thawing.

...On People's Lives

Reindeer Herding

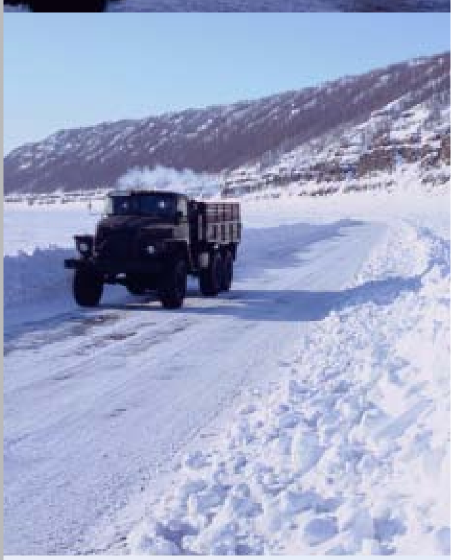
Reindeer herding by the Saami and other Indigenous Peoples is an important economic and cultural activity in this region, and people who herd reindeer are concerned about the impacts of climate change. In recent years, autumn weather in some areas has fluctuated between raining and freezing, often creating an ice layer on the ground that has reduced reindeer's access to the underlying lichen. These conditions represent a major change from the norm, and in some years, have resulted in extensive losses of reindeer. Changes in snow conditions also pose problems. When herding has become motorized, herders relying on snowmobiles have had to delay moving their herds until the first snows. In some years, this has led to delays up to mid-November. Also, the terrain has often been too difficult to travel over when the snow cover is light. Future changes in snow extent and condition have the potential to lead to major adverse consequences for reindeer herding and the associated physical, social, and cultural livelihood of the herders.

Socioeconomic Changes

The prospects and opportunities of gaining access to important natural resources have attracted a large number of people to this region. The relatively intense industrial activities, particularly on the Kola Peninsula, have resulted in population densities that are the highest in the circumpolar North. Increased opportunities for agriculture are projected as warming progresses. Impacts of climate change and their implications for the availability of resources could lead to major changes in economic conditions and subsequent shifts in demographics, societal structure, and cultural traditions of the region.

Key Impacts - SUB-REGION II

Siberia and adjacent seas



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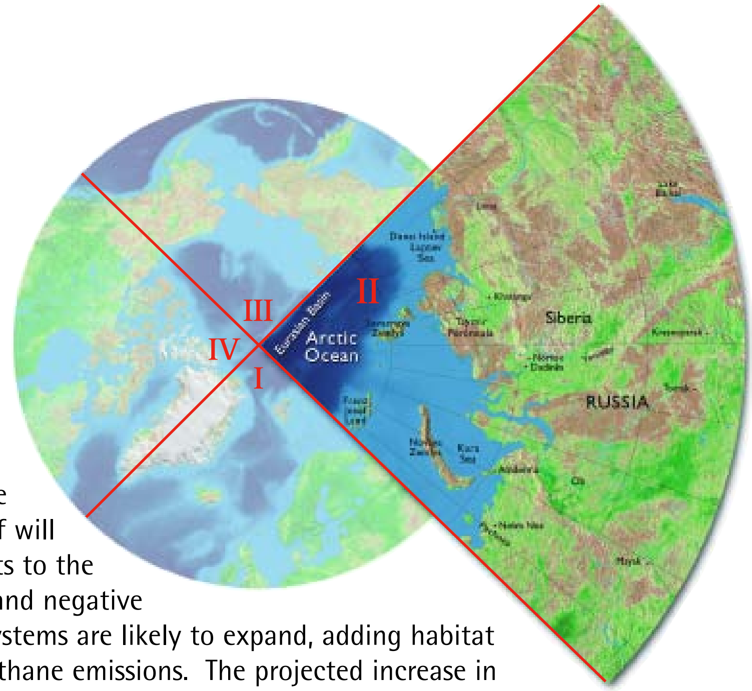


Siberian River Flows

Changes in climate will have major impacts on the large Siberian rivers that flow into the Arctic. Projected increases in wintertime precipitation will increase river runoff, with a projected 15% annual increase in freshwater entering the Arctic Ocean by the later decades of this century, and a shift in the timing of peak flows to earlier in the spring. Greater winter and spring runoff will increase flows of nutrients and sediments to the Arctic Ocean, resulting in both positive and negative impacts. Coastal wetland and bog ecosystems are likely to expand, adding habitat for some species, but also increasing methane emissions. The projected increase in freshwater input to the ocean is likely to have important implications for factors that influence ocean currents and sea ice, with global as well as regional impacts. The increased water flows across the coastal zone are also likely to accelerate the thawing of coastal and sub-sea permafrost along most of the region's coastline.

Precipitation and Soils

The expected increase in precipitation will generally lead to wetter soils when soils are not frozen, and greater ice content of upper soil layers during winter. While snowfall during winter is likely to increase, the duration of the snow cover season is expected to shorten as warming accompanies the increased precipitation. The projected increase in moisture availability is likely to favor plant growth in areas that are otherwise moisture-limited.

...On the Economy

Northern Sea Route Opening

A potentially major impact on the region's economy could be the opening of the Northern Sea Route to commercial shipping. Summertime access to most coastal waters of the Eurasian Arctic is projected to be relatively ice-free within a few decades, with much more extensive melting later in the century. With the continued retreat of winter multi-year sea ice in the Arctic Ocean, it is plausible that the entire Eurasian maritime Arctic will be dominated by first-year sea ice in winter, with a decreasing frequency of multi-year ice intrusions into the coastal seas and more open water during summer. Such a change is likely to have important implications for route selection in this region. By the end of this century, the length of the navigation season (the period with sea ice concentrations below 50%) along the Northern Sea Route is projected to increase to about 120 days from the current 20-30 days.

Coal and Mineral Transport

The coal and mineral extraction industries are important parts of Russia's economy. Transportation of coal and minerals is likely to be affected in both positive and negative ways by climate change. Mines in Siberia that export their products by ocean shipping are very likely to experience savings due to reduced sea ice and a longer navigation season. Mining facilities that rely on roads over permafrost for transport are very likely to experience higher maintenance costs as permafrost thaws. The oil and natural gas industries are likely to be similarly affected, with improved access by sea and more problematic access on land.

...On People's Lives

The projected increase in freshwater input to the ocean is likely to have important implications for factors that influence ocean currents and sea ice, with global as well as regional impacts.

Water Resources

The change to a wetter climate is likely to lead to increased water resources for the region's residents. In permafrost-free areas, water tables are very likely to be closer to the surface, and more moisture is projected to be available for agricultural production. During the spring, when increased precipitation and runoff are very likely to cause higher river levels, the risk of flooding will increase. Lower water levels are projected for the summer, when they are likely to negatively affect river navigation and hydroelectric power generation and increase the risk of forest fires.

Infrastructure Damage

The combination of rising ground temperatures and inadequate design and construction practices for building on permafrost have resulted in major damage to infrastructure in Siberia in recent decades. Surveys in the 1990s in the region found nearly half of all buildings to be in poor condition, with buildings considered dangerous ranging from 22% in the village of Tiksi to 80% in the city of Vorkuta. In the last decade, building deformations increased to 42% in Norilsk, 61% in Yakutsk, and 90% in Amderma. Land transport routes are also faring poorly. In the early 1990s, 10-16% of sub-grade train tracks in the permafrost zone on the Baikal-Amur line were deformed because of permafrost thawing; this increased to 46% by 1998. The majority of airport runways in Norilsk, Yakutsk, Magadan, and other cities are currently in an emergency state. Damage to oil and gas transmission lines in the permafrost zone presents a particularly serious situation; 16 breaks were recorded on the Messoyakha-Norilsk pipeline in the last year. In the Khanty-Mansi autonomous district, 1702 accidents involving spills occurred and more than 640 square kilometers of land were removed from use in one year because of soil contamination.

Savings on Heating Cost

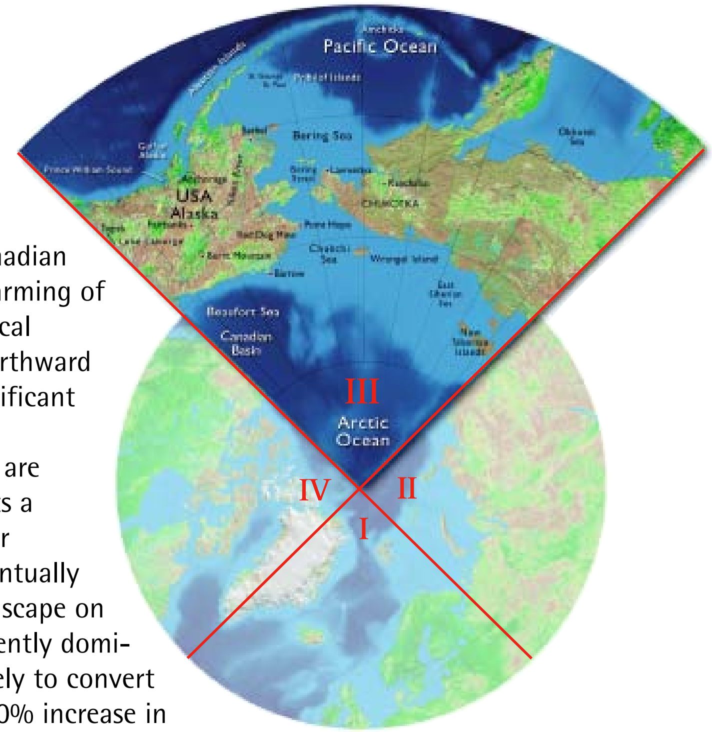
A reduction in the demand for heating fuel is a potential positive effect of climatic warming in this and other sub-regions. In Eastern Europe and Russia, most urban buildings have centralized heating systems that operate throughout the winter. Under scenarios of future warming, the duration of the period when building heating is required and the amount of energy required for heating are likely to decrease. The energy savings from decreased demand for heating in northern areas are likely to be offset by increases in the temperature and duration of the warm season in more southern parts of the region, where air conditioning will become desirable.

Impacts on Indigenous People

Many indigenous people of this region are reindeer herders. Large areas of pastureland are being lost to petroleum extraction and other industrial activities. Climate change is likely to add a new set of stresses. Frozen ground underlies most of the region and if warming degrades this permafrost, traditional reindeer migration routes are very likely to be disrupted. Warming is also projected to cause earlier melting and later freezing of sea ice in the Ob River delta, which could cut off access between winter and summer pastures. In addition, retreating sea ice will increase access to the region via the Northern Sea Route; this is likely to increase development, with potentially detrimental effects on local people and their traditional cultures.

Key Impacts - SUB-REGION III

Chukotka, Alaska, Western Canadian Arctic and adjacent seas



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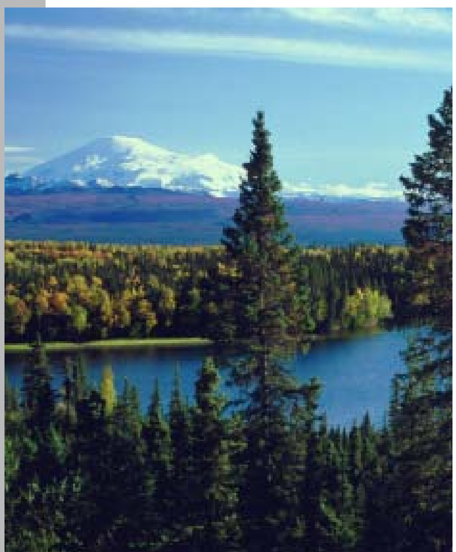


Forest Changes

This sub-region, especially Alaska and the Canadian Yukon, has experienced the most dramatic warming of all the sub-regions, resulting in major ecological impacts. Rising temperatures have caused northward expansion of boreal forest in some areas, significant increases in fire frequency and intensity, and unprecedented insect outbreaks; these trends are projected to increase. One projection suggests a threefold increase in the total area burned per decade, destroying coniferous forests and eventually leading to a deciduous forest-dominated landscape on the Seward Peninsula in Alaska, which is presently dominated by tundra. Some forested areas are likely to convert to bogs as permafrost thaws. The observed 20% increase in growing-degree days has benefited agriculture and forest productivity on some sites, while reducing growth on other sites.

Marine Species Impacts

Recent climate-related impacts observed in the Bering Sea include significant reductions in seabird and marine mammal populations, unusual algal blooms, abnormally high water temperatures, and low harvests of salmon on their return to spawning areas. While the Bering Sea fishery has become one of the world's largest, over the past few decades, the abundance of sea lions has declined between 50% and 80%. Numbers of northern fur seal pups on the Pribilof Islands – the major Bering Sea breeding grounds – declined by half between the 1950s and 1980s. There have been significant declines in the populations of some seabird species, including common murres, thick-billed murres, and red- and blacklegged kittiwakes. Numbers of salmon have been far below expected levels, fish have been smaller than average, and their traditional migratory patterns appear to have been altered. Future projections for the Bering Sea suggest productivity increases at the base of the food chain, poleward shifts of some cold-water species, and negative effects on ice-dwelling species.

Biodiversity at Risk

Arctic biodiversity is highly concentrated in this region, which is home to over 70% of the rare arctic plant species that occur nowhere else on earth. This region also contains significantly more threatened animal and plant species than any other arctic sub-region, making the biodiversity of this region quite vulnerable to climate change. Species concentrated in small areas, such as Wrangel Island, are particularly at risk from the direct effects of climate change coupled with the threat of non-native species that will move in and provide competition as climate warms. Northward expansion of dwarf shrub and tree dominated vegetation into Wrangel Island could result in the loss of many plant species. This region contains a long list of threatened species including the Wrangel lemming, whooping crane, Steller's sea eagle, lesser white-fronted goose, and the spoonbill sandpiper.

...On the Economy

Oil and Gas Industries

Extensive oil and gas reserves have been discovered in Alaska along the Beaufort Sea coast and in Canada's Mackenzie River/Beaufort Sea area. Climate impacts on oil and gas development in the region are likely to result in both financial benefits and costs in the future. For example, offshore oil exploration and production are likely to benefit from less extensive and thinner sea ice, although equipment will have to be designed to withstand increased wave forces and ice movement.

Ice roads, now used widely for access to facilities, are likely to be useable for shorter periods and to be less safe; this also applies to over-snow transport when there is less snow for a shorter duration. As a result of the warming since 1970, the number of days in which oil and gas exploration on the Alaskan tundra has been allowed under state standards has already fallen from 200 to 100 days per year. The standards, based on tundra hardness and snow conditions, are designed to limit damage to the tundra. The thawing of permafrost, on which buildings, pipelines, airfields, and coastal installations supporting oil and gas development are located, is very likely to adversely affect these structures and increase the cost of maintaining them.

Fisheries

It is difficult to project impacts on the lucrative Bering Sea fisheries because numerous factors other than climate are involved, including fisheries policies, market demands and prices, and harvesting practices and technologies. Large northward shifts in fish and shellfish species are expected to accompany a warmer climate. Relocating fisheries infrastructure including fishing vessels, ports, and processing plants, may become necessary, entailing financial costs. Warmer waters are likely to lead to increased primary production in some areas, but a decline in cold-water species such as salmon and pollock.

...On People's Lives

Traditional Livelihoods

Livelihoods that sustain indigenous communities include hunting, trapping, gathering, and fishing. While making significant contributions to the diet and health of many indigenous populations, these activities also play large and important social and cultural roles. These livelihoods are already being threatened by multiple climate-related factors, including reduced or displaced populations of marine mammals, seabirds, and other wildlife, and reduction and thinning of sea ice, making hunting more difficult and dangerous. The Porcupine Caribou Herd is of particular importance to Indigenous Peoples in Alaska and Canada's Yukon and Northwest Territories, and climate-related impacts on this herd are already being observed.

Salmon and other fish that go up-river from the sea to spawn make up 60% of the wildlife resources that provide food for local users. Recent declines in these fish populations have thus directly affected the dietary and economic well-being of these people. Climate change is likely to have significant impacts on the availability of key food sources by shifting the range and abundance of salmon, herring, walrus, seals, whales, caribou, moose, and various species of seabird and waterfowl. The continued decline of summer sea ice is likely to push the populations of polar bears and ringed seals toward extinction in this century, with major implications for people who depend on these species.

Coastal Infrastructure Threatened

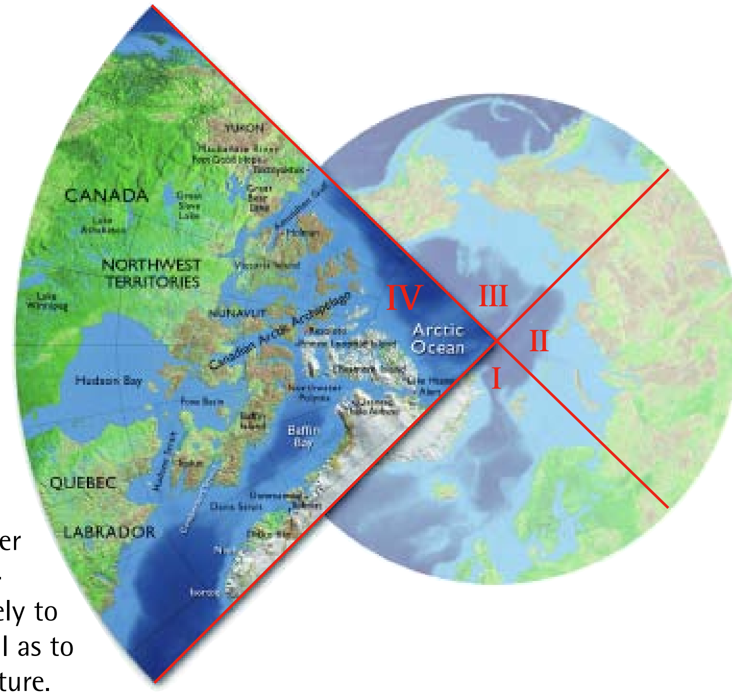
Increases in the frequency and ferocity of storm surges have triggered increased coastal erosion that is already threatening several villages along the coasts of the Bering and Beaufort Seas. The only available option is to plan for relocation of the villages, which will be very costly. Storm surges have also reduced the protection of coastal habitats provided by barrier islands and spits, which are highly vulnerable to erosion and wave destruction. Other climate-related impacts on village infrastructure are projected to continue to increase. Water and sanitation infrastructure is threatened in many places by thawing permafrost. Roads, buildings, pipelines, powerlines, and other infrastructure are also threatened by coastal erosion and degrading permafrost.

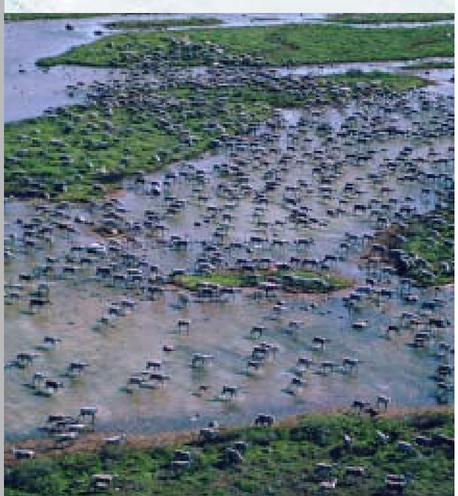
"Our community has seen real and dramatic effects as a result of the warming that is occurring in the Arctic Ocean and the arctic environment. In the springtime, we are seeing the ice disappearing faster, which reduces our hunting time for walrus, seals, and whales."

Caleb Pungowiyi
Nome, Alaska

Key Impacts - SUB-REGION IV

Central and Eastern Canadian Arctic, West Greenland, and adjacent seas





...On the Environment

Widespread Thawing

The maximum northward retreat of sea ice during the summer is projected to increase from the current 150-200 kilometers to 500-800 kilometers during this century. The thickness of fast ice (ice attached to the coast) in the Northwest Passage is projected to decrease substantially from its current one- to two-meter thickness. The Greenland Ice Sheet has experienced record melting in recent years and is likely to contribute substantially to sea-level rise as well as to possible changes in ocean circulation in the future. New research suggests that melting of the Greenland Ice Sheet is likely to occur more rapidly than previously believed.

Significant areas of permafrost in the Canadian part of this sub-region are at risk of thawing as air temperatures rise throughout this century. The boundary between continuous and discontinuous permafrost is projected to shift poleward by several hundred kilometers, resulting in the disappearance of a substantial amount of the permafrost in the present discontinuous zone. Many permafrost areas are also likely to experience more widespread thermokarsting (where the ground collapses due to thawing, producing craters or lakes) and increases in slope instability.

Ecosystem Shifts

Large ecosystem changes are projected. Shrinking of arctic tundra extent is very likely to result from a northward movement of treeline by as much as 750 kilometers in some areas. In recent decades, sparse stands of trees at the tundra edge in northeastern Canada have already begun filling in, creating dense stands that no longer retain the features of tundra. Forest health problems have become widespread in the region, driven by insects, fire, and tree stress all associated with recent mild winters and increasing heat during the growing season. It is very likely that such forest health problems will become increasingly intense and pervasive in response to future regional warming.

Changes in timing and abundance of forage availability, insect harassment, and parasite infestations will increase stress on caribou, tending to reduce their populations. North of the mainland, as the ability of High Arctic Peary caribou and musk ox to forage becomes increasingly limited as a result of adverse snow conditions, numbers will decline, with local extinctions in some areas. The fragmented land of the archipelago and large glaciated areas of the High Arctic in this sub-region constrain many land-based species from migrating as climate changes, placing them at greater risk than if they were on a mainland. In West Greenland, loss of habitat, displacement of species, and delayed migration of new species from the south will lead to a loss of present biodiversity.

If suitable pathways and habitats exist, ranges of many fish species in lakes and streams are likely to shift northward. Fish species in the southern part of the region such as Atlantic salmon and brook trout, are very likely to spread northward via near-shore marine waters, where they will out-compete more northerly local species such as Arctic char, causing local extinctions of these native species. Many marine mammal populations are likely to decline as sea ice recedes. The shortening of the sea ice season will negatively affect polar bear survival, decreasing populations, especially along southern margins of their distribution. Should the Arctic Ocean remain ice-free in summer for a number of consecutive years, it is likely that polar bears would be driven toward extinction.

...On the Economy

Increased Shipping

The costs and benefits of a longer shipping season in the Canadian Arctic areas are likely to be significant, but at this point, both are quite speculative. Increased ship traffic in the Northwest Passage, while providing economic opportunities, will also increase the risks and potential environmental damage from oil and other chemical spills. Increased costs are also likely to result from changes needed to cope with greater wave heights and possible flooding and erosion threats to coastal facilities. Increased sedimentation due to longer open water seasons could increase dredging costs.

Fisheries Changes

Under a moderate, gradual warming scenario, cod and capelin are likely to shift northward into the region, while northern shrimp and snow crabs are likely to decline. Many existing capelin-spawning beaches may disappear as sea level rises, potentially reducing survival. Seals are expected to experience higher pup mortality as sea ice thins and storm intensity increases. A reduction in the extent and duration of sea ice is likely to allow fishing further to the north, though it is also likely to reduce Greenland halibut fisheries that are conducted through fast ice.

In rivers and lakes, freshwater fish productivity is likely to increase initially as habitats warm and nutrient inputs increase. However, as critical thresholds are reached (such as thermal limits), arctic-adapted species are projected to decline; some of these fisheries are mainstays of local diets. Similarly, loss of suitable thermal habitat for fish such as lake trout will result in decreased growth and declines of many populations, with impacts on sport fisheries and local tourism.

Infrastructure Impacts

Use of ice roads in near-shore areas and over-snow transport on land, which are important at present, are already being impacted by a warming climate and are likely to be further curtailed in the future because of thawing ground, reduced snow cover, and shorter ice seasons. Higher air temperatures are likely to reduce the energy needed for heating buildings. The summer construction season is expected to lengthen. For the next 100 years at least, mostly negative impacts are projected for existing infrastructure such as northern pipelines, pile foundations in permafrost, bridges, pipeline river crossings, dikes, erosion protection structures, and stability of open pit mine walls.

...On People's Lives

Impacts on Indigenous Peoples

The health of indigenous people is likely to be affected through dietary, social, cultural, and other impacts of the projected changes in climate, many of which are already being observed. Climate change will affect the distribution and quality of animals and other resources on which the health and lifestyles of many northern communities are based. A shorter winter season, increased snowfall, and less extensive and thinner sea ice are likely to decrease opportunities for Indigenous Peoples to hunt and trap. Threats to the survival of polar bears and seals are of major concern in this sub-region.

Adapting to climate-driven changes is constrained by the present social and economic situations of Indigenous Peoples. For example, in the past, Inuit might have moved to follow animal movements. They now live in permanent settlements that foreclose this option. The impacts of climate change on Indigenous Peoples are also complicated by other factors such as resource regulations, industrial development, and global economic pressures. The potential for increased marine access to some of the region's resources through the Northwest Passage, while providing economic benefits to some, could pose problems for Indigenous Peoples in the region as the expansion of industrial activities can have cumulative effects on traditional lifestyles.

"Change has been so dramatic that during the coldest month of the year, the month of December 2001, torrential rains have fallen in the Thule region so much that there appeared a thick layer of solid ice on top of the sea ice and the surface of the land... which was very bad for the paws of our sled dogs."

Uusaqqak Qujaukitsoq
Qaanaaq, Greenland

Improving Future Assessments

The Arctic Climate Impact Assessment represents the first effort to comprehensively examine climate change and its impacts in the Arctic region. As such, it represents the beginning of a process. The assessment brought together the findings of hundreds of scientists from around the world whose research focuses on the Arctic. It also included the insights of Indigenous Peoples who have developed deep understandings through their long history of living and gathering knowledge in this region. Linking these scientific and indigenous perspectives is still in its early stages, and clearly has potential to improve understanding of climate change and its impacts. A great deal has been learned from the ACIA process and interactions, though much remains to be studied and better understood. This process should continue, with a focus on reducing uncertainties, filling gaps in knowledge identified during the assessment, and more explicitly including issues that interact with climate change and its impacts.

A critical self-assessment of the ACIA reveals achievements as well as deficiencies. The assessment covered potential arctic-wide impacts on the environment extensively. Estimates of economic impacts, on the other hand, and of impacts at the sub-regional level, were covered in a more cursory and exploratory manner, and greater development of such estimates must be a future priority task. Studies that integrate climate change impacts with effects due to other stresses (and thus assess the cumulative vulnerability of communities) were covered only in a preliminary fashion in this assessment.

Understanding and gaps in knowledge vary across the breadth of the assessment. Not all aspects need to be re-assessed comprehensively and not all aspects need to be assessed at the same time; some developments in science and some environmental changes take longer than others. Three major topics are thus suggested as future priorities for analysis: regional impacts, socioeconomic impacts, and vulnerabilities. These all involve improving the understanding of impacts on society. In each of these areas, involvement of a range of experts and stakeholders, especially including arctic indigenous communities, would help fill gaps in knowledge and provide relevant information to decision makers at all levels.

Sub-regional Impacts: There is a need to focus future assessments on smaller regions, perhaps at the local level, where an assessment of impacts of climate change has the greatest relevance and utility for residents and their activities.

Socioeconomic Impacts: Important economic sectors in the Arctic include oil and gas production, mining, transportation, fisheries, forestry, and tourism. Most of these sectors will experience direct and indirect impacts due to climate change, but in most cases, only qualitative information on economic impacts is presently available.

Assessing Vulnerabilities: Vulnerability is the degree to which a system is susceptible to adverse effects of multiple interacting stresses. Assessing vulnerability involves knowledge not just of the consequences of stresses and their interactions, but also of the capacity of the system to adapt.

To address these three high-priority research agendas will require a suite of improvements in long-term monitoring, process studies, climate modeling, and analyses of impacts on society.

Long-Term Monitoring: Long-term time series of climate and climate-related parameters are available from only a few locations in the Arctic. Continuation of long-term records is crucial, along with upgrading and expanding the observing systems that monitor snow and ice features, runoff from major rivers, ocean parameters, and changes in vegetation, biodiversity, and ecosystem processes.

Process Studies: Many arctic processes require further study, both through scientific investigations and through more detailed and systematic documentation of indigenous knowledge. Priorities include collection and interpretation of data related to climate and the physical environment, and studies of the rates and ranges of change for plants, animals, and ecosystem function. Such studies often involve linking climate models with models of ecosystem processes and other elements of the arctic system.

Modeling: Improvements in modeling arctic climate and its impacts are needed, including in the representation of ocean mixing and linkages to sea ice, permafrost-soil-vegetation interactions, important feedback processes, and extreme events. Model refinement and validation is required for models within scientific disciplines, and there is also a need to link and integrate models across disciplines. Developing, verifying, and applying very high-resolution coupled regional models to improve projections of regional changes in climate would also help provide more useful information to local decision-makers.

Analysis of Impacts on Society: Improving projections of the consequences of climate change on society will depend in part on the advances in climate modeling mentioned above as well as on generating improved scenarios of population and economic development in the Arctic, developing and applying impact scenarios, forging improved links between scientific and indigenous knowledge, and more thoroughly identifying and evaluating potential measures to mitigate and adapt to climate change.

Outreach in the Arctic

Finding effective ways of bringing the information gathered in the ACIA process to the communities of the Arctic presents an additional challenge. A variety of scientific, governmental, and non-governmental organizations plan to work to make the results of the ACIA process useful to a wide variety of constituents, from those who live and work on the land to those who determine local, national, and international policies relevant to the climate challenge.

International Linkages

The ACIA has built on the substance and conclusions of the assessments prepared by the Intergovernmental Panel on Climate Change (IPCC), which evaluate and summarize the world's most authoritative information regarding global climate change and its impacts. The most recent report of the IPCC, the Third Assessment Report, was released in 2001. The next IPCC assessment is in the early stages of development and is planned for publication in 2007. Just as the ACIA has built on IPCC's past evaluations, the 2007 IPCC report will build on ACIA's findings with regard to the Arctic, doing so in a way that adds more global context.

There are also other national and international efforts that offer opportunities to further understanding of the impacts of climate change and ultraviolet radiation. For example, the United Nations Environment Programme and the World Meteorological Organization have organized ongoing assessments of ozone depletion and its impacts. The International Conference on Arctic Research Planning II is drawing upon ACIA results as it develops a research agenda for the coming decades. The International Polar Year (IPY), being planned by the world's scientific community for 2007/9 will provide another opportunity to focus research attention on climate change and other important arctic issues. It was the International Geophysical Year in 1957/8 that initiated the first systematic measurements of stratospheric ozone and atmospheric carbon dioxide, thus laying the basis for the discoveries of ozone depletion and greenhouse gas-induced climate change. Without these decades of observations, the downward trend in stratospheric ozone and the continuous increase in atmospheric carbon dioxide could not have been detected.

The gaps in knowledge and needs for improved monitoring identified during the ACIA process are already affecting a variety of international research agendas. One of the primary goals already approved for the upcoming IPY is to study and evaluate present and future changes in climate in the polar regions and to evaluate the global-scale impacts of these changes. ACIA's findings can help to focus the research efforts of the IPY and other efforts. In turn, research initiated by other efforts can help fill the gaps that ACIA has identified in order to help carry out more detailed assessments of the importance of climate change for the Arctic.

Concluding Thoughts

As the scientific results presented in this assessment clearly illustrate, climate change presents a major and growing challenge to the Arctic and the world as a whole. While the concerns this generates are important now, their implications are of even greater importance for the future generations that will inherit the legacy of the current actions or inaction. Strong near-term action to reduce emissions is required in order to alter the future path of human-induced warming. Action is also needed to begin to adapt to the warming that is already occurring and will continue. The findings of this first Arctic Climate Impact Assessment provide a scientific basis upon which decision makers can consider, craft, and implement appropriate actions to respond to this important and far-reaching challenge.

Change Presents Risks and Opportunities

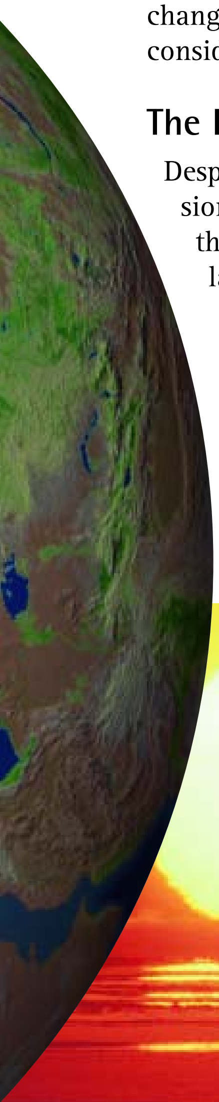
Trends are not destiny.
Rene Dubos

As this report has shown, climate change is very likely to result in major environmental changes that will present risks as well as opportunities across the Arctic. For example, the large reduction in summer sea ice threatens the future of several ice-dependent species including polar bears and seals, and thus the peoples that depend upon them. On the other hand, potential opportunities are likely to arise from expansion of marine access to resources, population centers, and distant markets via trans-arctic shipping routes.

Potential Surprises

Some of the climate-related changes in the arctic environment that are most likely to occur are expected to have major impacts; these include the decline in sea ice, the increase in coastal erosion, and the thawing of permafrost. In addition, other concerns emerge from possible outcomes that appear to have only a low likelihood, but the occurrence of which would have very large impacts – so-called "surprises". Due to the complexity of the Earth system, it is possible that climate change will evolve differently than the gradually changing scenarios used in this assessment. For example, storm intensities and tracks could change in unforeseen ways or temperatures could rise or fall abruptly due to unexpected disturbances of global weather systems. Possible changes in the global thermohaline circulation and widespread ramifications of such changes provide another example of a potential climate surprise. Although such changes could cause major impacts, very little information is currently available for considering such possibilities.

The Bottom Line



Despite the fact that a relatively small percentage of the world's greenhouse gas emissions originate in the Arctic, human-induced changes in arctic climate are among the largest on earth. As a consequence, the changes already underway in arctic landscapes, communities, and unique features provide an early indication for the rest of the world of the environmental and societal significance of global climate change. As this report illustrates, changes in climate and their impacts in the Arctic are already being widely noticed and felt, and are projected to become much greater. These changes will also reach far beyond the Arctic, affecting global climate, sea level, biodiversity, and many aspects of human social and economic systems. Climate change in the Arctic thus deserves and requires urgent attention by decision makers and the public worldwide.

Appendix - 1

The Emissions Scenarios Used in this Assessment

In its *Special Report on Emissions Scenarios* (SRES), the IPCC presented a wide range of plausible emissions scenarios for the 21st century based on various assumptions about future levels of population, economic growth, technological development, and other relevant factors. Of the six "illustrative scenarios" presented in the SRES, ACIA chose to focus primarily on one of these that fell slightly below the middle of the range of future emissions. That scenario, referred to as B2, is the basis for the projected climate maps in this report. A second scenario, A2, which falls above the middle of the SRES range, was also used in a few analyses, and is always identified as such. The focus on these scenarios here reflects a number of practical limits to conducting this assessment, and is not a judgment that these are the most likely outcomes.

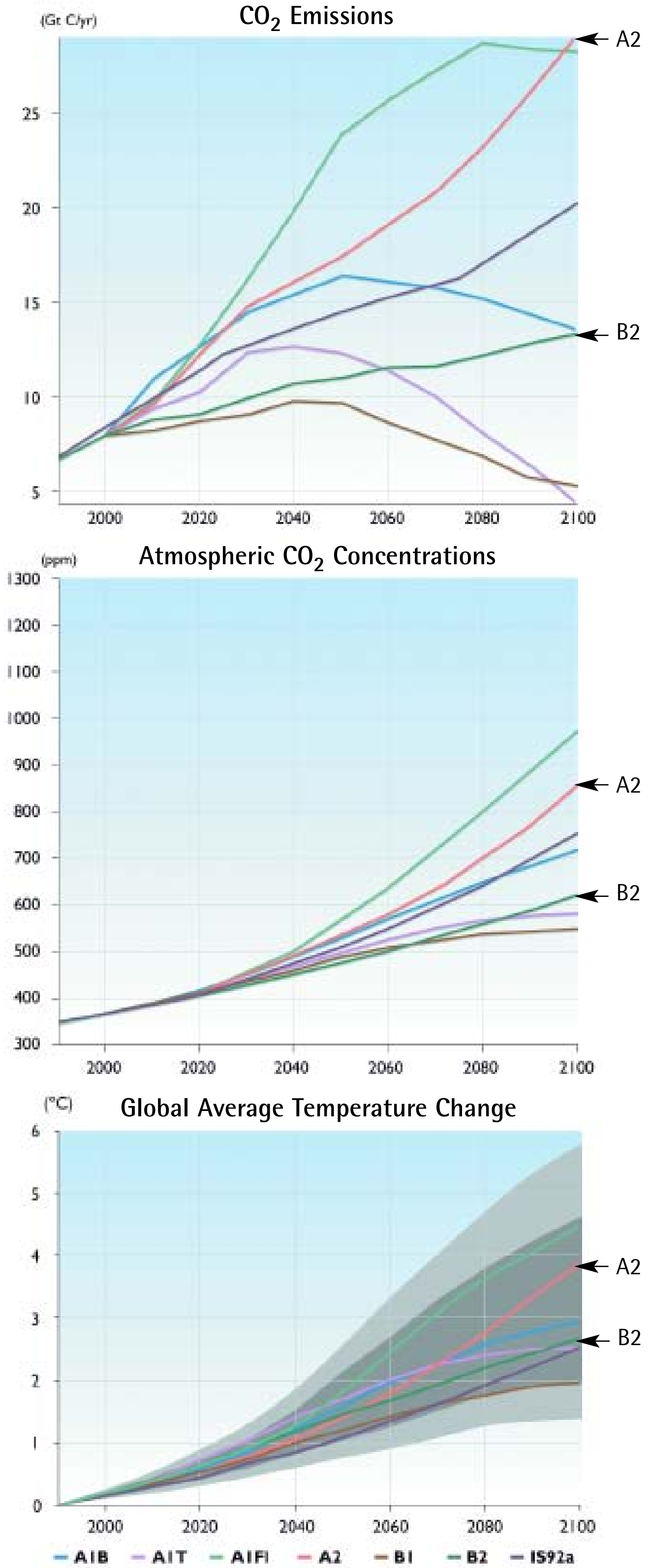
Under all of the IPCC emissions scenarios, global carbon dioxide concentration, average surface air temperature, and sea level are projected to increase during the 21st century. From 2000 to 2100, the range of warming resulting from these scenarios is projected to be between 1.4 and 5.8˚C. None of these scenarios include explicit policies to reduce greenhouse gas emissions. On the other hand, they do incorporate assumptions that involve major changes from the status quo for reasons other than limiting climate change, and these various factors influence the resulting levels of greenhouse gas emissions.

For example, the B2 emissions scenario assumes a world concerned with environmental protection and social equity, with solutions focused at the local and regional levels. It is a world in which global population grows to reach 10.4 billion by 2100, there is an intermediate level of economic development, and there is diverse technological change around the world. In a B2 world, by the year 2100, coal supplies 22% of the primary energy, and 49% of the world's energy is derived from sources that emit no carbon dioxide.

The A2 scenario also describes a world focused on self-reliance and preservation of local identities, but unlike B2, an A2 world is more concerned with economic growth than with environmental protection and social equity. Population growth is rapid, reaching 15 billion people by 2100. Economic development is primarily regionally oriented and per capita economic growth and technological change are relatively slow and fragmented. World GDP is slightly higher in 2100 in A2 than in B2. Coal provides 53% of the world's primary energy in 2100 in an A2 world, and 28% of the world's energy comes from sources than emit no carbon dioxide.

Other emission scenarios have been developed that consider the implication of policies that would reduce greenhouse gas emissions enough to stabilize their concentrations in the atmosphere at various levels, and thus limit the rate and magnitude of future climate change. Such scenarios were not considered in this assessment.

Projections for Six Illustrative Emissions Scenarios



The first graph (upper) shows projected CO_2 emissions for the six illustrative IPCC SRES scenarios. The second graph (middle) shows the atmospheric CO_2 concentrations that would result from these emissions. The third graph (lower) shows the projected temperature trends that would result from these concentrations.

Primary Models used in the Arctic Climate Impact Assessment

CGCM2 - Canadian Centre for Climate Modelling and Analysis, Canada

CSM_1.4 - National Center for Atmospheric Research, United States

ECHAM4/OPYC3 - Max-Planck Institute for Meteorology, Germany

GFDL-R30_c - Geophysical Fluid Dynamics Laboratory, United States

HadCM3 - Hadley Centre for Climate Prediction and Research, United Kingdom

Five climate models from top research centers around the world were used in this assessment. Their names and the associated acronyms used throughout this report are listed above. These models all utilized the same emissions scenario, B2, described in this appendix. The climate maps shown throughout this report are based on these models, for the B2 emissions scenario.

Appendix - 2

Science Chapter Titles and Authors

Chapter 1:	Introduction
Chapter 2:	Arctic Climate – Past and Present
Chapter 3:	The Changing Arctic: Indigenous Perspectives
Chapter 4:	Future Climate Change: Modeling and Scenarios for the Arctic Region
Chapter 5:	Ozone and Ultraviolet Radiation
Chapter 6:	Cryospheric and Hydrologic Variability
Chapter 7:	Arctic Tundra and Polar Desert Ecosystems
Chapter 8:	Freshwater Ecosystems and Fisheries
Chapter 9:	Marine Systems
Chapter 10:	Principles of Conserving the Arctic's Biodiversity
Chapter 11:	Management and Conservation of Wildlife in a Changing Arctic Environment
Chapter 12:	Hunting, Herding, Fishing and Gathering: Indigenous Peoples and Renewable Resource Use in the Arctic
Chapter 13:	Fisheries and Aquaculture
Chapter 14:	Forests, Land Management and Agriculture
Chapter 15:	Human Health
Chapter 16:	Infrastructure: Buildings, Support Systems, and Industrial Facilities
Chapter 17:	Climate Change in the Context of Multiple Stressors and Resilience
Chapter 18:	Summary and Synthesis

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