GreenFacts
Facts on Health and the Environment

Scientific Facts on

Arctic Climate Change

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GreenFacts

Level 2 - Details on Arctic Climate Change

This Digest is a faithful summary of the leading scientific consensus report
produced in 2004 by the Arctic Climate Impact Assessment (ACIA):
"Impacts of a Warming Arctic: Arctic Climate Impact Assessment"

The full Digest is available at: https://www.greenfacts.org/en/arctic-climate-change/

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- These answers are developed in more detail in Level 2.
- Level 3 consists of the Source document, the internationally recognised scientific consensus report which is faithfully summarised in Level 2 and further in Level 1.

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1. Introduction: Global climate change and the Arctic region

1.1 How is the global climate changing?

Evidence of climatic conditions in the distant past has established a link between rising atmospheric CO_2 levels and rising global temperatures. Such evidence is for instance obtained from ice cores extracted from polar ice caps or glaciers that formed from the gradual buildup of snow throughout the years.

Greenhouse effect
[see Annex 26, p. 49]

Over the last two centuries, the world's global mean temperature has increased by 0.6°C (1°F) and it seems that the current trend goes beyond the natural climate variability. In the Arctic, average temperatures have risen almost twice as fast as in the rest of the world and climate changes are being felt particularly intensely. This warming is attributed in good part to human activities. Indeed, the amount of carbon dioxide (CO_2) in the atmosphere has increased by 35% since the industrial revolution, mostly due to human activities such as the burning of fossil fuels and the clearing of land. Continuing greenhouse gas releases are projected to cause significant changes in climatic conditions: an increase of 1.4 to 5.8°C (2.5-10.4°F) in global average temperature between 2000 and 2100, as well as changes in ocean currents, sea level and in the amount and distribution of precipitation. Such changes would have significant impacts on human communities as well as ecosystems.

About 80% of the world's growing energy demand is met by burning fossil fuels, which causes a long-lasting increase of CO_2 levels in the atmosphere. Therefore, altering the warming trend will be a slow process, even if concerted efforts to reduce emissions are made today.

1.2 What makes up the Arctic region?

The Arctic, Earth's northern polar region, is an ocean surrounded by land. Snow and ice cover much of the Arctic land and sea surfaces, particularly at the far north. The southernmost part of the Arctic, which includes the northern part of North America and Eurasia, is covered by boreal forests, separated from the icy North by a wide expanse of tundra.

The Arctic Circle is the line around the globe, north of which the sun does not rise at winter solstice or set below at summer solstice – "the land of the midnight sun". In this assessment, the Arctic refers not only to the area north of the Arctic circle but also to regions further south that interact with the rest of the Arctic Ecosystem. In other contexts , other criteria such as northern treeline, climatic boundaries, the area of land covered by permafrost, or the area of ocean covered by sea ice are sometimes used to define the boundaries of 'the Arctic'.

The far north of the Arctic is home to an array of plants, animals and people uniquely adapted to surviving in some of the most extreme conditions on the planet. Increasingly rapid climate change poses additional challenges to life in the Arctic. Moreover, populations and ecosystems are being increasingly disturbed by other factors linked to human activities such as habitat change, growing resource use, population growth, and air and water pollution.

1.3 Who is living in the Arctic region?

People of the Arctic
[see Annex 19, p. 43]

Today the Arctic region is home to almost 4 million people, a majority of which are non-indigenous settlers. They live in cities, work as hunters or animal herders in rural areas, or are involved in the exploitation of other natural resources. Indigenous people make up roughly 10% of the population of the Arctic and they continue to carry out traditional activities while adapting to the modern way of life.

The Arctic includes part of eight nations: Norway, Sweden, Finland, Denmark (i.e. Greenland), Iceland, Canada, Russia, and the United States. People have occupied parts of the Arctic at least since the peak of the last ice age (around 20 000 years ago). Innovations such as the harpoon and reindeer husbandry allowed the exploitation of food sources and made it possible to live in remote areas where the land was largely barren. Over the past thousand years, in Eurasia and across the North Atlantic, new groups of people moved northward, colonizing new lands and interacting with indigenous populations, for instance in West Greenland and northern Eurasia.

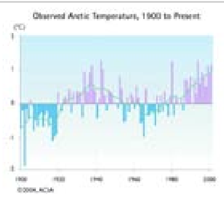
The non-indigenous population currently outnumbers the indigenous population in most regions, due to an increase in immigration in the 20th century. This population increase and the incompatibility of some aspects of traditional and modern ways of life has given rise to conflicts over land and resources. In North America, the claims of indigenous people have been addressed to some extent by political and economic actions such as the creation of largely self-governed regions like the Nunavut Territory, in Canada. In Eurasia, by contrast, indigenous claims and rights have only begun to be addressed as matters of national policy in recent years.

Northern regions are becoming more tightly related to national mainstreams – economically, politically, and socially. Some of the differences in terms of living standards, income and education are decreasing between northern and southern Arctic communities. On the one hand, there have been certain improvements, such as an increase in life expectancy, but on the other hand there have been some negative consequences to the coming together of these different cultures. With continuing changes, it is feared that certain indigenous languages will soon disappear. Economically, the region depends largely on natural resources such as oil, gas, metal ores, fish, reindeer, and birds. In recent decades, tourism has become an important sector of the economy in many Arctic regions.

2. How is the climate changing in the Arctic?

Arctic climate is now warming rapidly and much larger changes are projected.

2.1 What changes have already been observed?

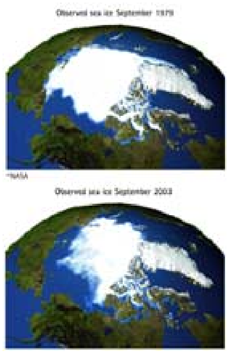


Arctic temperatures, 1900-present
[see Annex 15, p. 38]

2.1.1 Recent records of increasing temperatures; melting glaciers, sea ice and permafrost; and rising sea levels provide clear evidence of a warming trend for the Arctic as a whole. For example, in Alaska and western Canada, winter temperatures have increased by as much as 3-4°C in the past 50 years (i.e. 5.4-7.2°F). In general, winter temperatures are rising more rapidly than summer temperatures.

Observations also suggest that precipitation may have increased by roughly 8% across the Arctic over the past 100 years, and that rain now falls mainly in winter, rather than in spring or autumn.

Both natural factors, such as variations in solar radiation, major volcanic eruptions and interactions between the atmosphere and oceans, and factors linked to human activities can influence the climate. Ice cores and other sources of information about past climatic conditions reveal that the current warming trend is unusual, and that it reflects the increase of greenhouse gases in the atmosphere induced by human activities.



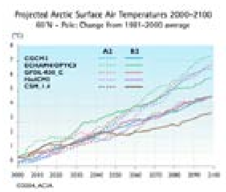
Sea-Ice extent, 1979-2003
[see Annex 17, p. 41]

2.1.2 The sea ice presently covering the Arctic Ocean and neighboring seas is highly sensitive to temperature changes of the air and of the ocean. Over the past 30 years, the average area covered by sea ice has decreased by about 8%, an area larger than Norway, Sweden and Denmark combined. The average thickness of Arctic sea ice has also decreased by about 10 to 15% over this time period. A reduction of sea ice as a result of the warming climate can in turn affect the climate through changes in water temperatures, ocean currents, and ocean evaporation rates.

2.2 How is the Arctic climate expected to change in the future?

2.2.1 In order to foresee future climate change and its potential impacts, two major factors that determine the impact of human activities need to be assessed:

- the overall level of future greenhouse gas emissions,
- the response of the climate system to these emissions based on possible changes in clouds, ice cover, and effects on sea level.



Projected Arctic Surface Air Temperatures
[see Annex 20, p. 44]

Even the most conservative forecasts expect the Earth to warm more than twice as much in this century than it did during the 20th century. Furthermore, climate models indicate that the warming in the Arctic will be substantially greater than the average warming of the planet (in some places of the Arctic up to twice as much).

2.2.2 Towards the end of this century, annual average **temperatures** are projected to rise across the entire Arctic, with increases of roughly 3-5°C over the land areas and up to 7°C over the oceans. Winter temperatures are projected to rise significantly more (see table below).

	Over land areas	Over oceans
Increase in average temperatures	3-5°C (5.4-9°F)	up to 7°C (12.6°F)
Increase in winter temperatures	4-7°C (7.2-12.6°F)	7-10°C (12.6-18°F)

2.2.3 Global warming is already leading to increased evaporation and, in turn, to increased **precipitation**. Over the Arctic, annual total precipitation is projected to increase by roughly 20% by 2100, with most of the additional precipitation in the form of rain. The greatest increases are expected over coastal regions, especially in the winter and autumn when they are projected to exceed 30%.

2.2.4 **Sea ice** has already declined considerably over the past 50 years. By 2100, the average area covered by sea ice is expected to have declined further and some models project a complete disappearance of summer sea ice. These reductions in sea ice will increase regional and global warming as more solar energy will be absorbed by the darker sea surface and less will be reflected by the ice.

2.2.5 The area of Arctic land covered by **snow** has declined by about 10% over the past 30 years, and an additional decrease of 10-20% is projected before the end of this century. This will reduce the beneficial effects of snow cover on certain plants and animals. Increased rates of melting and refreezing could prevent some creatures from accessing food or their nesting sites. This will also affect flows of freshwater across the land to the ocean, and transfers of moisture and heat from the land to the atmosphere and marine systems.

2.3 At what speed are those changes expected to happen?

2.3.1 While most analyses of climate impacts focus on scenarios of steady gradual warming, there is a possibility that the warming could trigger **abrupt changes** in climate. The mechanisms that underlie such potential abrupt changes are not adequately taken into account by current climate models, which means that surprises are possible.

Records indicate that very large shifts in Arctic climate patterns occurred very rapidly in the past. For example, ice core records indicate that temperatures over Greenland dropped by as much as 5°C (9°F) within a few years during the period of warming that followed the last ice age, before abruptly warming again. This sudden change in the weather over Greenland was apparently driven by changes in North Atlantic Ocean salinity that led to a sharp reduction in the ocean currents that brought warmth to Europe and the Arctic.

2.3.2 There are many **thresholds** in the Arctic environment which, if crossed, could lead to substantial changes in that region and the world.

For instance, the likely temperature increase of 3ºC during the 21st century is thought to be sufficient to initiate the widespread and long-term melting of the Greenland ice sheet. Over many centuries, this could eventually result in its complete disappearance and raise global sea level by 7 metres.

Moreover, observed changes in deep water currents in the Atlantic Ocean, as a result of changes in sea ice, a…re warning signals that another threshold may soon be crossed. These changes in currents could potentially disrupt the Gulf Stream that brings warm ocean water to north–west Europe. Its potential interruption would have massive consequences for the European climate (see section on thermohaline circulation).

While much uncertainty remains about which of these thresholds will be crossed and when exactly this might occur, records of the past suggest that the potential for abrupt changes is real. Compared to changes that occur gradually, abrupt changes will be harder both (for scientists) to predict and (for societies) to adapt to.

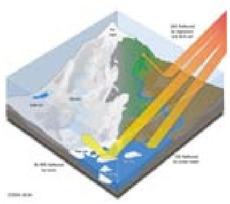
2.3.3 The **speed** at which a change takes place may be more important than the amount of change. For example, if thawing of permafrost or increasing coastal erosion were to occur very slowly, people might be able to replace buildings and roads as part of the normal replacement cycle of infrastructure. If changes occur rapidly, adaptation costs will be significantly higher.

3. How will Arctic warming affect the rest of the planet?

Arctic warming and its consequences have worldwide implications

The Arctic influences global climate through three major feedback mechanisms, all of which could be affected by global warming. These mechanisms involve the reflection of sunlight, ocean currents, and greenhouse gas releases.

3.1 How can the reflection of sunlight on snow and ice affect the climate?


Changes in surface reflectivity
[see Annex 25, p. 48]

As snow and ice are bright white, most of the solar energy that reaches them is reflected back to space. This is one reason why the Arctic remains so cold. As air temperatures are increasing, snow and ice now tend to form later in the autumn and melt earlier in the spring. The darker land and water surfaces, which absorb more of the sun's energy, are thus longer uncovered. This warms the surface further, which, in turn, causes faster melting, creating a 'positive feedback loop' that amplifies and accelerates the warming trend (see also Question 4.2). This is one reason why climate change is particularly rapid in the Arctic.

With Arctic warming, forests are projected to expand northward into areas that are currently tundra. Forests are darker than tundra and mask snow cover on the ground, reducing the reflection of sunlight and further increasing warming. However, the resulting warming could be partly offset by larger expanses of forests absorbing more CO_2.

3.2 How can Arctic warming affect ocean currents?


Ocean currents in the Arctic
[see Annex 2, p. 28]

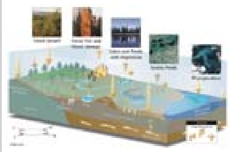
One of the ways the sun's energy is transported from the equator toward the poles is through the globally interconnected movement of ocean waters primarily driven by differences in heat and salt content, known as the thermohaline circulation ("thermo" for heat and "haline" for salt).

At present, the Gulf Stream current that flows from the Gulf of Mexico to the coasts of Europe warms the winds and provides much of the moisture that falls as precipitation over northwestern Europe. As the water moves northward, it becomes cooler, saltier and denser. As a result, surface water eventually becomes heavier than the water(s) below it and sinks deep into the ocean. This process drives the global seawater "thermohaline circulation" (sometimes referred to as the "conveyor belt") which pulls warm waters northward. Part of this global circulation is known as the Gulf Stream, providing some of the heat that keeps Europe warmer in winter than regions of North America at the same latitude. Climate change could interfere with the formation of the cold, dense water that drives oceanic circulation and thus bring about further changes in climate.

Slowing the thermohaline circulation would have several major global effects:

- The decreasing transport of CO_2, contained in water from the surface to the deep ocean. This would contribute to further increases in the level of CO_2 in the atmosphere and thus to further warming (due to CO_2).
- Regional cooling, for instance in Europe. This could result from the slowing of the northward transport of heat by Atlantic Ocean currents, even while the rest of the planet warms rapidly.
- Reduced sinking of cold, dense water in the Arctic. This would, in turn, reduce the amount of nutrients carried back toward the surface elsewhere in the world that sustain marine life living near the surface.

3.3 How could Arctic warming contribute to greenhouse gas emissions?


Carbon cycle in the Arctic
[see Annex 3, p. 29]

Greenhouse gases are exchanged between the atmosphere and Arctic soils and sediments. These processes can also be affected by global climate change and in turn affect it.

3.3.1 Carbon is currently trapped as organic matter in the permafrost (frozen soil) of the Arctic. During the summer, when the top layer of permafrost thaws, and plant material on dry land or ponds decomposes, methane – a very potent greenhouse gas – and CO_2 are released. Higher temperatures lead to an increase in the rate of decomposition and gas production, and possibly to a feedback loop with more warming that results in more releases, causing more warming, and so on (see also Question 3.1). The replacement of Arctic vegetation by denser and faster growing vegetation from the south could in part offset this effect through a greater uptake of carbon.

3.3.2 In the Arctic, vast amounts of methane are trapped in permafrost and in cold ocean sediments in a solid icy form (as methane hydrates or clathrates). A rise in temperature within the soil could initiate the release of methane from permafrost to the atmosphere. This release is a less certain outcome of climate change than the other emissions discussed here because it would probably require greater warming and take more time to occur. If such releases were to take place, the climate impacts could be very large.

3.3.3 Currently, the direct effect of the Arctic Ocean on the level of CO_2 in the atmosphere is limited. This is due to the presence of sea ice that limits the absorption of CO_2 by the water and its uptake by organisms living near the water surface. A reduced ice cover could significantly increase the amount of carbon taken up by the Arctic Ocean. While these changes are likely to be important regionally, the total area affected is not large enough to significantly reduce global CO_2 concentrations in the atmosphere.

3.4 How can climate change cause sea level rise?

3.4.1 There are 3 100 000 km^3 of ice on Arctic lands around the world, containing enough water to raise the global sea level by 8m. Most Arctic glaciers and ice caps have been in decline since the early 1960s, with this trend speeding up in the 1990s. In some areas, the increase in precipitation has outpaced the melting so that a small number of glaciers, especially in Scandinavia, have gained mass during some recent years.

The Greenland Ice Sheet is the largest area of ice on Arctic lands. Part of the top layer of ice of this ice sheet is melting during summer and the area where this is happening increased by about 16% between 1979 and 2002, (which represents) an area roughly the size of Sweden.

Projections from global climate models suggest that the contribution of Arctic glaciers to global sea-level rise will accelerate over the next 100 years. By 2100, the melt of these glaciers will have contributed to a rise of roughly four to six centimeters or even more according to recent estimates. In the longer term, the Arctic contribution to global sea-level rise is projected to be much greater. Some climate models project that local warming over the Greenland Ice Sheet will eventually lead to its complete disappearance, with a resulting sea-level rise of about seven meters.

3.4.2 Climate change causes sea level to rise in two ways:

- First, and most significantly, water expands as it warms, and this is projected to be the largest component of sea-level rise over the next 100 years.

- Secondly, warming increases melting of glaciers and ice sheets, adding to the amount of water flowing into the oceans.

Global average sea level rose almost 3mm (0.12 inches) per year during the 1990s. This is about one millimeter (0.04 inches) more per year than during the decades before that. Global average sea level is projected to rise 10 to 90cm (4 to 36 inches) between 2000 and 2100, with the rise speeding up with time. Over the longer term, much larger increases in sea level are projected.

Sea-level rise is projected to have serious implications for coastal communities and industries, islands, river deltas and harbors. A number of the world’s most populous cities such at Calcutta and Bangkok will be severely affected.

3.5 How will changes in the arctic affect the rest of the world?

3.5.1 Arctic wildlife resources such as seals, reindeer, birds and fish have long been sold on world markets. Arctic seas contain some of the world's oldest and most productive commercial fishing grounds, which provide significant catches for many Arctic countries, as well as for the rest of the world.

Moreover, the Arctic has significant oil and gas reserves, and the mineral reserves in parts of Russia and Canada provide large quantities of raw materials to the world economy. Marine access to resources is likely to be enhanced in many places in a warmer Arctic with less sea ice, but access by land is likely to be hampered due to a shortening of the season during which the ground is sufficiently frozen to drive on.

3.5.2 Climate-related changes in Arctic ecosystems will have consequences not only at local level but also on a global scale because of the many links between the Arctic and the rest of the planet. Many species from around the world migrate to the Arctic in summer and depend on it for breeding and feeding. Climate change will alter some of their habitats significantly.

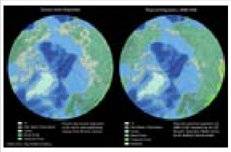
Expansion of the forests towards the North, for instance, may reduce the size of tundra areas, which are important breeding grounds for hundreds of millions of migratory birds. Indeed, a number of bird species are projected to lose more than 50% of their breeding area during this century, including several globally endangered seabird species.

4. How will the vegetation be affected by Arctic warming?

Arctic vegetation zones are likely to shift, causing wide-ranging impacts.

4.1 How will vegetation zones shift?

The main vegetation zones in the Arctic are polar deserts in the north, boreal forests in the south, and a wide expanse of tundra in-between. Polar deserts are characterized by open patches of bare ground and an absence of even the smallest woody shrubs, whereas tundra is characterized by low shrub vegetation.



Projected changes in vegetation
[see Annex 22, p. 46]

Climate change is expected to cause the northward expansion of forests into the Arctic tundra, and of tundra into polar deserts. Such changes are likely to take place this century in areas where suitable soils and other conditions exist. This is expected to result in the area of tundra becoming smaller than it has ever been during the past 21 000 years, reducing the breeding area for many birds and the grazing areas for certain land animals.

The total number of species in the Arctic is projected to increase under a warmer climate due to migration of species from the south. Many of the adaptations that enable plants and animals to survive in the Arctic environment also limit their ability to compete with species that move in from the south. Moreover, Arctic species are limited in their northward migration by the Arctic Ocean.

Changes in the ranges of certain bird, fish, and butterfly species have already been observed. At present, there are more varieties of moss and lichens in the Arctic than anywhere else in the world. This type of vegetation is particularly likely to decline as the Arctic warms.

The geographical spread of animals can generally shift much faster than that of plants, and large migratory animals such as caribou can move much more readily than small animals such as lemmings. In addition to mobility, the availability of food sources is another factor that influences the pace at which different species will shift northward. All of these differences will result in the break-up of currently interdependent communities and ecosystems and the formation of new ones, with unknown consequences.

4.2 How will boreal forests be affected?

4.2.1 The projected northward expansion of boreal forest will cause a decrease in the amount of sunlight reflected by the surface of the Arctic, as the newly forested areas are darker and will absorb more solar radiation than lighter, smoother tundra or bare snow. In this feedback loop warming could thus leads to more tree-cover and, in turn, to still more warming (see also Question 3.1). However, the expanding forest will be denser and grow more quickly than the existing tundra, and the tundra more than the polar deserts it displaces. This could increase the amount of carbon stored within ecosystems, slightly offsetting the projected warming linked to the increased absorption of solar energy.

Total annual precipitation is expected to increase along with temperatures. These changes could, nonetheless, lead to desertification in certain land areas if evaporation increases more rapidly than precipitation. The thawing permafrost could also drain moisture from soils and lead to desertification in some areas if warming continues.

4.2.2 Almost one third of the world's forests are located in Arctic nations, particularly in Siberia and North America. These forests contribute to:

- timber production providing significant export earnings for Finland, Sweden, and Canada.
- the freshwater cycle in Arctic regions.
- provision of breeding zones for migratory forest birds and habitat for animals such as wolves and caribou that are very important for local economies.

After the last ice age, a warmer period for the Earth's climate allowed trees to grow much further north than at present. However, whilst current warming seems likely to bring about a similar shift, the actual northern movement of the treeline is highly unpredictable as various factors, including fires, floods and human activities, can influence it.

4.2.3 In different areas of the boreal forests, different climatic conditions are favouring or limiting the extent of tree growth. Climate change could, thus, produce two different kinds of response:

- a simple gradual change in conditions leading to a type of forest being replaced by another from the south,

- a more complex pattern of abrupt change in conditions leading in some areas to the retreat of the treeline southward and to the formation of grasslands between tundra and the retreating forest.

Either type of change may allow the formation of ecosystems that are not present in today's landscape.

4.2.4 White spruce is the most widespread boreal conifer, making up most of the forest near the border of the tundra, and a valuable timber resource, especially in North America. This species is highly dependant on climatic conditions and any change could hamper its reproduction by affecting the production of cones and the release of seeds following forest fires.

4.2.5 Black spruce is the dominant tree in a large portion of the boreal forest in Alaska. It absorbs a lot of solar energy, thus increasing warming, and it is a highly flammable species that can carry fire across the landscape. The projected warming may affect the survival and geographic spread of the black spruce, as this species can be influenced by changes in permafrost, high temperatures in early spring, and droughts.

4.3 Will there be an increase in forest fires or insect pests?

4.3.1 Large areas of forest are increasingly likely to be disturbed by insect outbreaks linked to warming. Indeed, the warming will create new opportunities for invasive species, such as the Spruce Bark Beetle and the Spruce Budworm, to move in from other regions.

Spruce Bark Beetle [see Annex 23, p. 46]

Spruce Budworm [see Annex 24, p. 47]


Forest fires could become more frequent

4.3.2 Fire is another major disturbance factor in the boreal forest and it has a wide range of ecological effects. The average area of forest burned each year in western North America has doubled over the past thirty years, and it is expected to increase by as much as 80% over the next 100 years. The area of boreal forest burned in Russia averaged four million hectares every year over the last three decades. This area more than doubled in the 1990s. Projected changes in climate would greatly increase the area subjected to the types of weather that cause extreme fire danger.

4.4 Will agricultural opportunities increase in the Arctic?

At present, agriculture in the north consists mostly of raising cattle, sheep, goats, pigs, and poultry, herding reindeer, growing cool-season vegetables such as turnips and spinach, and small grains such as rye and oats. In addition to limitations imposed by climatic conditions in the Arctic such as lack of warmth and moisture, and short growing seasons, agriculture is also limited by the lack of infrastructure, a small population base, remoteness from markets, and land ownership issues.

Climate change is expected to increase the range of crops that can be grown in the Arctic. As far north as the Arctic circle, it may soon be possible to cultivate crops that currently only grow in the warmer parts of the arctic region, for instance. Yield increases might actually be constrained by factors such as a rapid but shorter ripening and certain winter conditions. Water deficits are likely to increase over the next century in most parts of the boreal region, because evaporation is likely to increase more rapidly than precipitation as a result of higher temperatures. Irrigation systems will be needed in these areas in order to minimize the effects of water stress on crop yields.

Insects, diseases, and weeds are likely to increase throughout the Arctic with climate warming but, in most cases, their impact is unlikely to offset yield increases or the potential for new crops.

Overall, lack of infrastructure, limited local markets, and long distances to large markets are likely to continue to limit agricultural development in most of the Arctic during this century.

5. How will animals be affected by Arctic warming?

Animal species' diversity, ranges, and distribution will change.

5.1 How will climate change affect the Arctic marine environment?

Ocean accounts for more than half of the surface area of the Arctic region. Many Arctic life forms rely on the sea's biological productivity and on the presence of sea ice, two factors that are highly dependant on climatic conditions.

5.1.1 **Polar bears** give birth and hunt on sea ice and they need it to travel from one region to another. Survival of mothers and cubs in the spring depends on the mothers' hunting success, which, in turn, depends on the stability and extent of sea ice. Less winter sea ice means that female polar bears have to go longer without food, which impacts their fat stores, and, in turn, their reproductive success.

Arctic Marine Food Web
[see Annex 1, p. 27]

Complete loss of summer sea-ice cover, which may occur in the course of this century, could threaten the survival of polar bears as a species or force them to adopt a land-based summer lifestyle. Living on land would not be without risks due to competition with other predators, possible cross breeding with brown or grizzly bears, and interactions with humans.

Polar Bears depend on sea ice for their survival

5.1.2 Certain **seal** species that rarely come to land, such as the harp seal, spotted seal and the ringed seal, depend on Arctic sea ice. Not only does sea ice provide a home for resting, giving birth and raising pups, it is also a feeding ground for some of them. Ice-dependent seal species are likely to have difficulty adapting to ice-free summers. Other species that currently live farther south, such as the harbour and grey seals, are likely to expand their geographic spread if the Arctic has less ice coverage.

5.1.3 Some **seabirds** such as ivory gulls and little auks are likely to be negatively affected by a decline in sea ice. Ivory gulls nest on rocky cliffs and fly out to the sea ice to fish through cracks in the ice and scavenge on top of the ice. A retreat of sea ice away from the coastal nesting sites would have serious consequences. The number of ivory gulls in Canada has already dropped by 90% over the last 20 years.

5.1.4 The ice edge in coastal areas is an important feeding ground for the **walrus** that use the ice as diving platforms to feed on clams on the sea floor. As the ice edge retreats away from the continental shelves to deeper areas, there will be no clams nearby to feed on. Walrus also travel large distances on floating ice, which allows them to feed over a wide area.


Walrus rely on sea ice for easier access to food

5.1.5 Ice algae grow at the porous bottom of sea ice and form the base of the unique **marine food web connected to sea ice**. The melting of ice can affect the availability of physical habitats for algae, as well as the temperature and salinity of surface waters, potentially disrupting the whole food web.

5.1.6 In addition to loss of habitat and feeding grounds, climate change poses other threats to Arctic **marine mammals** and some **seabirds**:

- Increased risk of disease.
- Increased precipitation, which will carry pollution from the south.
- Expansion of the geographic spread of species ranges, which will increase competition between them.
- Increased human activity, which will increasingly affect previously untouched areas.

5.1.7 Many marine communities depend on polar bears, walrus, seals, whales, seabirds, and other marine animals. Changes in the numbers and ranges of Arctic animals and birds may greatly affect northern communities' way of life. So will changes in ice conditions which are critical to the **hunters'** mobility.

5.2 What will be the impact on marine fisheries?

Arctic **marine fisheries** provide an important food source globally, and are a vital part of the region's economy. In the past climate change has induced major ecosystem shifts in some areas and this could happen again resulting in radical unpredictable changes in species present.


See our study on Fisheries [see https://www.greenfacts.org/en/fisheries/index.htm]

5.2.1 An example of a positive impact of climate change is the **cod** population in West Greenland which thrived between the 1920s and 1960s, a time period when the waters were warmer then they are now. A warming of the climate is thus likely to have a positive effect on the cod population allowing more fishing. An example of a negative impact is the fishing of shrimp in Greenlandic waters which is likely to suffer, both from the predicted changes in climatic conditions and from the growing cod population who feed on shrimp.

5.2.2 In the early 1950s, the Norwegian **herring** stock was the largest in the world, and was important to Norway, Iceland, Russia, and the Faroe Islands. In the 1960s, a sudden and severe cooling of the waters west of the Norwegian Sea where the herrings were feeding, combined with high intensity fishing, contributed to the collapse of the Norwegian Herring Stock. Since the 1970s the return of favorable climatic conditions and international agreements on restricting the capture of herring permitted a gradual recovery of the stock. Such international agreements will be crucial in future as climate change alters fish stocks and their ranges.

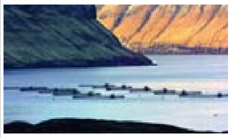
5.2.3 A climate shift also occurred in the Bering Sea in 1977, bringing about an abrupt warming that favored a number of commercially fished species, such as herring, pollock and cod, and led to record catches of salmon in subsequent years.

In some areas, such as most of the North Atlantic, where only a relatively slight warming is expected, the total effect of climate change on fish stocks is likely to be less strong than the effects of fisheries management, at least for the next few decades. In the Bering Sea, however, the impacts of rapid climate change are already apparent, with a displacement or a decline of cold-water species brought about by the warming of bottom waters. While it seems unlikely that the effects of climate change on fisheries will have long-term social and economic impacts throughout the Arctic, particular people and places may be strongly affected.

5.2.4 In the past century, certain fishing towns, such as Paamiut in West Greenland, which concentrated on a single fishery resource, such as cod, have been particularly vulnerable when water temperature changes led to the decline of local fish populations.

5.3 How will climate change affect aquaculture?

5.3.1 Salmon and trout are the two main **aquaculture** species farmed in the Arctic. Norway has developed a large industry over the past two decades and is now the world's largest farmed salmon producer.


Aquaculture in the Faroe Islands

The speed at which fish grow might be expected to increase in slightly warmer water. Greater water temperature increases, however, may have a negative impact on growth rates and the general health of farmed species. Other negative impacts of warmer waters on aquaculture may include increases in diseases and toxic algal blooms. Relocating aquaculture infrastructure further north to adjust to increasing water temperatures would be costly.

The aquaculture industry depends on huge supplies of wild fish (in the form of fishmeal and oil) in order to feed farmed salmon and trout. These wild fish are caught elsewhere in the world, like anchovies from the South Pacific, and can also be affected by climate change. Many of the species that are fished to make fishmeal are also an important part of the diet of certain wild species that are of high commercial value but that are currently not abundant due to overfishing. Reductions in the production of fishmeal and oil might be needed in order for these stocks to recover.

5.3.2 The ocean surrounding the **Faroe Islands** is an important feeding ground for wild stocks of northern European Atlantic salmon. These islands enjoy particularly good conditions for farming Atlantic salmon and rainbow trout.

Despite early setbacks due to disease and market fluctuations, the Faroe Islands have become an important international player in salmon farming. Many people are employed both in fish farming and in related industries, and aquaculture accounts for 25% of the total income from exported goods. Global warming will increase fish growth rates, provided it does not exceed 5°C (9°F). This positive impact (on fish production) would, however, be offset by some warming-related increases in fish diseases and toxic algae blooms.

5.4 How will animals on land be affected?

5.4.1 Arctic animals on land include:

- small plant-eaters like ground squirrels, hares, lemmings and voles;
- large plant-eaters like moose, caribou/reindeer and musk ox; and
- meat-eaters like weasels, wolverines, wolves, foxes, bears and birds of prey.

Climate-induced changes are likely to cause a series of cascading effects involving many species of plants and animals. If grasses, mosses and lichens no longer live in the same areas due to a changing climate, it will have implications for the animals that feed on them, and on the predators or human communities that depend on those animals.


Arctic Fox

In snow-covered areas, warming could increase the occurrence of repeated freezing and thawing which could lead to the formation of an ice crust thus preventing animals from eating grasses and mosses and sometimes even killing the plants. Lemmings, musk ox and reindeer/caribou are all affected. Dramatic population crashes resulting from this phenomenon have been reported increasingly frequently over recent decades.

Mild weather and wet snow lead to collapse of spaces between the frozen ground and the snow where lemmings and voles live and forage. Furthermore, when the surface of the snow melts and re-freezes the resulting ice crust reduces the insulating properties of the snow pack that is vital to the survival of these animals. Declines in their populations can in turn lead to declines in animal population that feed on them, such as snowy owls, skuas, weasels and ermine. When lemming populations are low, more generalist predators, such as the Arctic fox, switch to other prey species such as waders and other birds, increasing pressure on those populations.

5.4.2 **Caribou** (in North America) and **reindeer** (in Eurasia) are of primary importance to people throughout the Arctic both for food and for cultural reasons. The herds depend on the availability of food and good foraging conditions, especially at the time when calves are born.

Climate-induced changes are expected to reduce the area of tundra and thus the feeding area of these herds. It will also increase the occurrence of freeze-thaw cycles and freezing rain that make it harder for caribou and reindeer populations to find food and raise calves. Future climate change could potentially lead to a decline in caribou and reindeer populations, threatening the way of life for some Arctic communities.

Peary Carribou [see Annex 18, p. 42]

The Porcupine Caribou Herd [see Annex 28, p. 50]

The Gwich'in and the Porcupine Caribou Herd [see Annex 27, p. 49]

5.5 What will be the impacts on freshwater ecosystems?


Freshwater food web
[see Annex 6, p. 32]

Freshwater ecosystems in the Arctic include inland waters such as rivers, lakes, ponds, wetlands and their surroundings. They are home to a variety of animal life including fish, mammals, waterfowls, and fish-eating birds. These ecosystems act as intermediaries between land and ocean ecosystems.

5.5.1 Increases in the temperature of inland waters can significantly reduce the geographic spread of some species, such as the Arctic char, that may not be able to adapt to warmer conditions or to compete with invasive species that thrive in warmer waters.

5.5.2 The thawing of frozen soil can lead to the drainage of surface waters, eventually eliminating aquatic habitats. The thawing of permafrost can also lead to the collapse of the ground surface, create hollows in which ponds and wetlands can form. The balance of these changes is not known, but as freshwater habitats disappear, re-form, and are modified, major shifts in aquatic habitats are likely.

5.5.3 The timing of ice break-up in spring strongly affects supplies of nutrients, sediments, and water that are essential to the health of delta and floodplain ecosystems. Changes in ice cover also affect water temperature, levels of oxygen in the water and the exposure of underwater life forms to ultraviolet rays. In some areas, as a result of later freeze-up and earlier break-up, the ice season is now up to three weeks shorter compared to 100 years ago, and this trend is expected to continue. Evaporation and precipitation are expected to increase and flood patterns are likely to change, as will levels of sediments and nutrients carried by rivers to the Arctic Ocean.

5.5.4 Warming and increased precipitation are very likely to increase the amount of persistent organic chemicals and mercury that are deposited on the Arctic. As temperatures rise, snow, ice and permafrost which contain contaminants will melt, leading to the release of these contaminants. The resulting increase in the concentrations of contaminants in rivers and ponds may have harmful effects on aquatic plants and animals and also contaminate sea waters.

5.5.5 Species of freshwater fish that live in the southernmost part of the Arctic are expected to move northward, competing for food and habitat with species that live in northern inland waters, such as the Arctic char and Arctic cisco. Invasive species from the South may introduce new parasites and diseases. As water temperatures rise, the areas where cold-water species can lay their eggs will also shift northward and are likely to diminish. Inland fishing in the far north is likely to be seriously affected by such changes as the most vulnerable species are often the only fishable species present. However, in some areas of the Arctic, new arrivals from the south and increased growth of species already present may also bring new fishing opportunities.

5.5.6 The geographic spread of aquatic mammals and waterfowl is likely to expand northward as habitats change with warming. Mammal and bird species moving northward could carry new diseases and parasites, and take over habitats and resources currently used by northern species. These northern species may be reproducing less successfully due to temperature-induced habitat changes, while changes affecting breeding grounds and access to food may cause seasonal migrations to take place earlier in spring and later in autumn.

6. How will settlements and infrastructures be affected by Arctic warming?

6.1 How will coastal communities be affected?

Many coastal communities and facilities face increasing exposure to storms.

Coastal communities face increasing exposure to storms

Rising temperatures are already changing the Arctic coastline and more drastic changes are expected over the coming century. Reduced sea ice allows stronger waves to form, increasing shore erosion. This problem will be worsened by thawing permafrost and rising sea levels. All around the world, higher sea levels are likely to cause flooding of marshes and coastal plains, accelerate beach erosion, and force salt water into bays, rivers, and groundwater.

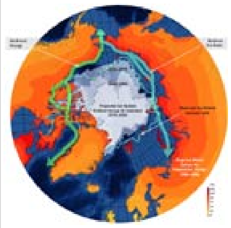
As warming begins to take its toll on Arctic coastlines, some towns and industrial facilities are already suffering severe damage and facing relocation.

- In the Alaskan village of Nelson Lagoon, break walls were built to protect the shore from storms. With increasing temperatures shore ice has melted and thes protective walls have repeatedly been destroyed by increasingly violent coastal storms. The pipeline that provides drinking water for the village was also at risk when storm waves washed away the soil covering it.
- Shishmaref, a village on an island off the coast of northern Alaska, is facing the prospect of evacuation. Rising temperatures have reduced sea ice and melted the coastal permafrost, making the coast vulnerable to erosion by storms that threaten homes, the water system, and other infrastructure, as well as access to hunting grounds.
- Tuktoyaktuk, is a major port in the western Canadian Arctic and the only permanent settlement on the low-lying Beaufort Sea coast. Erosion in and around Tuktoyaktuk threatens cultural and archeological sites and has already forced the abandonment of an elementary school, housing, and other buildings. As warming continues and sea-level rise accelerates, the site could ultimately become uninhabitable.
- The construction of an oil storage facility at Varandei, a barrier island in the Pechora Sea, damaged the dunes and beaches, accelerating the natural coastal erosion and making the site more vulnerable to storms and rising sea levels. This illustrates how sites that are already affected by human activity are often more vulnerable to the impacts of climate change.

6.2 How will changes in sea ice affect marine transport?

Reduced sea ice is very likely to increase marine transport and access to resources.

Over the past 50 years, the area of Arctic sea-ice has declined and more recently the ice thickness has decreased by 10 to 15%. Observed trends enable the opening of new shipping routes around the margins of the Arctic Basin and a longer period during which shipping is feasible (when the extent of sea ice in a given location is less than 50%). This could have significantly facilitate transportation and access to natural resources.


Projected opening of northern navigation routes
[see Annex 21, p. 45]

6.2.1 The opening of historically closed passages raises questions regarding sovereignty over shipping routes and seabed resources, and regarding security and safety. Commercial fishing, hunting of marine wildlife by indigenous people, tourism and shipping all compete for use of the narrow straits of these waterways. Moreover, these are also the preferred routes for marine mammal migration.

Increased marine access has implications for national and regional governments which will be called upon for services such as icebreaking, ice charting and forecasting as well emergency preparedness. Ships themselves will have to be built to higher (and more expensive) standards to ensure safety in ice-laden waters.

6.2.2 However, recent changes suggest that actual conditions will in fact be harder to predict which will make planning for regular sea transport very difficult, and may restrict the use of the new shipping routes. The amount of sea ice and icebergs drifting into the Northwest Passage is limited by “ice bridges” that block northern channels and straits of the Canadian Arctic Archipelago. As warming causes the melting and weakening of these ‘ice bridges’ more ice and icebergs could drift into the transport routes of the Northwest Passage, presenting additional hazards to navigation.

6.2.3 Increased access to shipping routes and resources entails an increased risk of environmental degradation caused by these activities. A recent study suggests that oil spills and other industrial accidents could have serious, long-lasting effects in a high-latitude, cold ocean environment.

In 1989, the Exxon Valdez oil tanker slammed into a reef while maneuvering to avoid ice in the shipping lanes and poured 42 million liters (11 million gallons) of crude oil into Alaska's Prince William Sound. The spill was the worst tanker disaster ever in U.S. waters, killing at least 250 000 seabirds and thousands of marine mammals. It forced the closure of commercial fishing grounds and areas traditionally used to gather wild foods. Though some scientists' predicted a rapid environmental recovery, small patches of oil remain and continue to cause problems for fish, seabirds, and marine mammals.

Despite preventive measures such as improved boat-building standards, and better port facilities and operating procedures, oil spills are still anticipated. Spill response operations are more complex and demanding in ice-covered waters, and effective response strategies have yet to be developed.

6.3 How will infrastructures be affected by the thawing ground?

Thawing ground will disrupt transportation, buildings and other infrastructure

6.3.1 Arctic land is generally more accessible in winter, when the tundra is frozen and ice roads and bridges are available. In summer, when the top layer of permafrost thaws and the terrain is boggy, the transport of food and other raw materials over land can be difficult. Land transportation routes are thus likely to be affected by changing climate. Increased precipitation can cause landslides and rising temperatures can shorten the season during which ice roads can be used.

Travel on the Alaskan tundra is now only possible during 100 days per year compared to over 200 days thirty years ago. This results in a 50% reduction in the time period where oil and gas exploration and extraction equipment can be used. The timber industry also depends on frozen ground and rivers and transporting wood is increasingly difficult.

6.3.2 Increasing temperatures pose significant engineering challenges to infrastructure built on permafrost, such as buildings and industrial facilities. As a result of changing soil temperatures and more extensive melting and refreezing, new construction will require deeper foundations and thicker insulation, which entail greater costs.

In northern Russia, damage to railway lines, airport runways, and oil and gas pipelines due to thawing permafrost is now more frequent. Future thawing might weaken open pit mine walls, and lead to the release of contaminants from mine tailing disposal facilities into the groundwater.

Complete thawing of permafrost, which would eventually make the construction environment more predictable, is expected to take centuries.

Building damaged due to permafrost thawing in Russia

Important and complex interactions exist between climate induced changes in permafrost and in ecosystems.

- Vegetation contributes to insulating and maintaining permafrost. Forest disturbances such as fires and insect outbreaks due to warming could thus lead to further degradation of the underlying permafrost.

- Certain tree species (notably black spruce) need ice-rich permafrost to be stably rooted. Thawing of the ground can lead to severe leaning or toppling of trees and undermine their growth.
- Many shallow streams, ponds, lakes and wetlands in the Arctic hold water because of surrounding permafrost. Loss of permafrost may result in these waters bodies disappearing as water drains into the ground.
- Elsewhere, collapse of ground surfaces due to thawing permafrost could increase the formation of wetlands, ponds, and drainage networks while increasing sediment transport and deposition, with significant impacts on aquatic life.
- Northern peatlands are especially important since these can either absorb or emit carbon, depending on specific temperature and water level conditions. In western Canada, a northward shift of the southern boundary of peatlands (by 200 to 300 km) is expected as well as a significant change in their structure and vegetation. However, the net impact on climate change is difficult to predict.

7. How will people and their environment be affected by Arctic warming?

7.1 How will indigenous people be affected?

Indigenous communities are facing major economic and cultural impacts:


Indigenous communities are facing major changes

The Arctic is home to numerous Indigenous Peoples whose cultures and activities are shaped by its environment. Past generations have skillfully adjusted harvesting activities and lifestyles to environmental changes, but now the rapid climate change, combined with social, economic and political conditions, presents new challenges.

Through ways of life closely linked to their surroundings, Indigenous Peoples have particulaly insightful ways of observing and interpreting environmental changes. Across the Arctic, indigenous people are already reporting climate change effects and noticing changes that are unprecedented in the long experience of their Peoples.

Indigenous knowledge and observations of current trends:

- The weather seems less stable and predictable. Hunters and elders experienced in predicting the weather are now frequently unable to do so. Read quotes [see Annex 7, p. 32]
- Snow quality and characteristics are changing and there is more freezing rain. Hunters are increasingly unable to build igloos, which they still rely upon for temporary or emergency shelters. Read quotes [see Annex 8, p. 32]
- Sea ice is declining, and its quality and timing are changing. The pack ice is further from shore and often too thin to allow safe travel for marine hunters. Read quotes [see Annex 9, p. 33]
- Seasonal weather patterns are changing, including more rain in autumn and winter, and more extreme heat in summer. Read quotes [see Annex 10, p. 34]

Other common themes emerge from their observations:

- Water levels in many lakes are dropping.
- Species not previously seen are now appearing in the Arctic.
- Storm surges are causing increased erosion in coastal areas.
- The sun feels “stronger, stinging, sharp”. Sunburns and strange skin rashes, never experienced before, are becoming common.
- Climate change is occurring faster than people can adapt.

- Climate change is strongly affecting people in many communities, in some cases threatening their cultural survival.

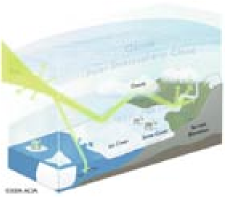
For Indigenous communities, the Arctic is becoming an environment at risk. Sea ice is less stable, unusual weather patterns are occurring, vegetation cover is changing, and particular animals are no longer found in traditional hunting areas during specific seasons. Their local surroundings are becoming unfamiliar, making people feel like strangers in their own land.

For the Inuit of Nunavut, the ringed seal is the single most important food source throughout the year. The reduction and destabilization of the sea ice has affected the seal populations and, in turn, polar bear populations. The increasing disappearance of summer sea ice will have a huge impact on the Inuit as hunting, catching and sharing seals and polar bears is as important for their diet as for their culture.

Observed Climate Change Impacts in Sachs Harbour, Canada [see Annex 16, p. 38]

7.2 What will be the effect of higher UV-radiation?

Elevated ultraviolet radiation levels will affect people, plants, and animals



Factors influencing UV at the surface
[see Annex 5, p. 31]

More ultraviolet radiation (UV) is now reaching the Earth's surface largely due to depletion of the ozone layer caused by emissions of manmade chemicals such as CFCs over the last 50 years.

It is worth noting that climate change and ozone depletion are driven by two different mechanisms:

- Human-induced climate change results from the build-up of greenhouse gases, such as CO_2 or methane, that trap heat in the lower atmosphere.
- Human-induced ozone depletion results from the build-up of certain chlorinated chemicals that break apart ozone molecules in the higher atmosphere.

Although the Montreal protocol phased out production of most ozone-depleting chemicals, many remain in the atmosphere for decades and continue to destroy the ozone layer.

7.2.1 The most severe depletion has occurred in polar regions, causing the so-called Antarctic "ozone whole", and a similar, though less severe, seasonal depletion over the Arctic in spring time. The average ozone depletion over the Arctic has been about 7% since 1979, but there have been large seasonal and annual variations. During seven of the past nine springs in the Arctic, ozone depletion exceeded 25% below normal during several weeks. On certain days levels dropped 40-45% below normal.

The amount of UV at the Earth's surface is directly influenced by ozone levels and to a certain extent by clouds, the angle of the sun's rays, altitude, the presence of particles in the atmosphere and how much radiation is reflected by the Earth's surface. Some of these factors can also be affected by climate change, such as snow cover or cloud patterns. No significant improvement of the ozone layer over the Arctic is projected for the next few decades.

7.2.2 Compared to the previous generation, young people today are likely to be exposed to 30% more UV radiation in the course of their lives. UV rays can contribute to skin cancer and a number of other health problems affecting mainly the skin and the eyes, but also the immune system. UV radiation can also harm materials used in construction and other outdoor applications such as plastics or paints, decreasing their useful life.

7.2.3 Plants and animals show a variety of effects from increased UV radiation that vary widely between species. Long-term effects of increased UV exposure remain largely unknown. Ozone depletion is highest during springtime, when animals are born and plants grow most, thus when they are most vulnerable.

Certain plants can increase pigmentation for protection from increased UV levels. These pigments can make the plants less digestible, and so affect grazing animals and thus the whole food web.

Climate change can contribute to increased exposure of aquatic organisms in freshwater ecosystems to UV radiation, for instance through the reduction of the springtime snow and ice covers which normally absorb UV very efficiently. However, climate warming is likely to increase the amount in dissolved matter in northern lakes and ponds due to increased plant growth and the amount of sediment stirred up in the water due to permafrost thawing. These changes will act as a sunscreen, helping to offset the increases in UV due to reduced snow and ice cover.

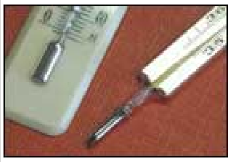
7.3 How can various factors interact to cause impacts on people and the environment?

Multiple influences interact to cause impacts to people and ecosystems

Rovaniemi, capital of Finnish Lapland, one of the largest cities north of the Arctic Circle

Climate change in the Arctic is taking place in the context of many other changes, some environmental, such as chemical pollution, and others affecting societies, such as growing populations and urbanization. The ability of the Arctic peoples to cope with the impacts of climate change will be greatly affected by political, legal, economic, social, and other factors.

7.3.1 Persistent organic pollutants (POPs) and heavy metals, from agricultural and industrial sources in other regions are carried to the Arctic by winds and precipitation. Though the use of persistent organic chemicals such as DDT and PCBs (that were heavily produced in the 1960s and 70s) has been banned in most countries, they remain present in the environment. These substances tend to build up in organisms along the food chain, resulting in high levels in polar bears, Arctic fox, and various seals, whales, fish, seabirds, and birds of prey. Arctic communities who eat these animals are thus exposed to potentially harmful levels of these pollutants.



See also GreenFacts' Mercury Study [see https://www.greenfacts.org/en/mercury/mercury-1.htm]

Mercury is the heavy metal of greatest concern in parts of the Arctic. Current levels pose a health risk to some Arctic people and animals, and the persistence of mercury means that levels in the Arctic are still increasing, despite emission reductions in Europe and North America.

Projected changes in wind patterns, precipitation and temperature can change the amount of contaminants transported and deposited in the Arctic. Furthermore, melting of sea-ice and glaciers can release pollutants that had been captured in the ice over years or decades. Changes in fish and bird migration patterns can also affect contaminant accumulation in Arctic waters.

Case study of interacting changes: Saami reindeer herders [see Annex 4, p. 29]

7.3.2 Climate change will influence human health in the Arctic, though impacts will differ as a result of regional differences in climate change, and personal differences in terms of age, gender, ease of access to resources, and health status.

Direct **positive impacts** on health could include a reduction in cold-induced injuries and conditions such as frostbite and hypothermia. Although milder winters in some regions could reduce the number of deaths during winter months, many winter deaths are due to respiratory infections such as influenza, and it is unclear how higher winter temperatures would affect influenza transmission.

Direct **negative impacts** on health are likely to include increased heat-related illnesses and accidents associated with unusual ice and weather conditions. Indirect impacts include effects on diet, increased mental and social stresses related to changes in the environment and lifestyle, potential changes in bacterial and viral growth, mosquito-borne disease outbreaks, changes in access to good quality drinking water, and illnesses resulting from problems with sanitation systems.

8. What changes are expected in specific areas of the Arctic?

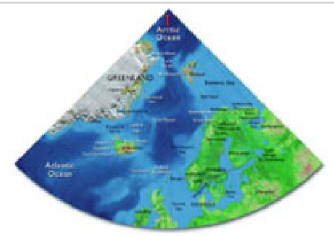
In a region as large as the Arctic, there are significant sub-regional variations in climate. Recent warming has been more dramatic in some regions than in others. Moreover, local features of the natural world and societies create differences in what impacts will occur and which will be most significant locally.

The Arctic Climate Impact Assessment (ACIA) focuses on four sub-regions and considers a series of key impacts:

- **impacts on the environment**, such as changes in habitats and in the geographic spread of plant and animal species,
- **impacts on the economy**, such as changes in access to resources, and
- **impacts on people’s lives**, such as effects on traditional lifestyles or damage to infrastructure.

8.1 Key impacts in sub-region I: From East-Greenland to Northwest Russia

Over the last 50 years, annual average temperatures have increased by about 1°C (1.8°F) over most land masses of this sub-region, while there has been a cooling of up to 1°C over Iceland and the North Atlantic Ocean.



Sub-region I: From East-Greenland to Northwest Russia
[see Annex 11, p. 34]

By the 2090s, model simulations project a further increase of annual average temperatures by around 3-7°C (5.4-10.8°F) in different parts of this sub-region. The Central Arctic Ocean is projected by all models to warm more strongly than any of the four sub-regions.

8.1.1 Impacts on the **environment** are very likely to include northward shifts of plant and animal species, with some tundra areas disappearing from the mainland. Low-lying coastal areas are increasingly likely to be flooded by storm surges as the sea level rises and sea ice retreats.

8.1.2 Impacts on the **economy** are likely to include improved marine access to oil, gas, and mineral resources as sea ice retreats. An increase in North Atlantic and Arctic fish stocks is likely for certain traditional species as well as for species moving in from the south.

8.1.3 Impacts on **people's lives** include effects on reindeer herding, which is likely to suffer as a result of changing snow conditions. Traditional harvests of animals are likely to become more risky and less predictable. Animal diseases that can be transmitted to humans are likely to emerge.

8.2 Key impacts in sub-region II: Siberia

Annual average temperatures over Siberia have increased by about 1-3°C (1.8-5.4°F) over the past 50 years, with most of the warming occurring during the winter.

By the 2090s, model simulations project additional annual average warming of around 3-5°C (5.4-9°F) over land, particularly near the Arctic Ocean. Increases in wintertime temperature are projected to reach 10°C (18°F) or more over the Arctic Ocean.

Sub-region II: Siberia
[see Annex 12, p. 35]

8.2.1 Impacts on the **environment** are very likely to include significant changes in forests as the climate warms, permafrost thaws, and fire and insect disturbances increase. It is very likely that forests and shrublands will replace tundra in many areas, and that plant and animal species will shift northward. The amount of water carried by rivers will increase.

8.2.2 Impacts on the **economy** are very likely to include a longer navigation season through the Northern Sea Route as a result of sea-ice retreat, giving rise to economic opportunities as well as pollution risks. Access to offshore oil and gas is likely to improve but some activities could be hindered by increased wave action.

8.2.3 Impacts on **people's lives** already include serious damage to buildings and industrial facilities due to permafrost thawing, which is projected to continue. A shorter river ice season and thawing permafrost are likely to hinder reindeer migration routes, affecting traditional livelihoods of indigenous people.

8.3 Key impacts in sub-region III: From Chukotka to the Western Canadian Arctic

Over the last 50 years, annual average temperatures have risen by about 0.5-3°C (0.9-5.4°F) in different parts of this sub-region and winter temperatures even more.

For the 2090s, model simulations project annual average warming of 3-4°C (5.4-7.2°F) over the land areas and Bering Sea, and about 6°C (10.8°F) over the central Arctic Ocean, with most of the warming occurring during the winter.

Sub-region III: From Chukotka to the Western Canadian Arctic
[see Annex 13, p. 36]

8.3.1 Impacts on the **environment** include an increased risk of biodiversity loss, particularly in this sub-region since it is currently home to the highest number of threatened plant and animal species in the Arctic. Increasing forest disturbances due to fires and insects are projected, while low-lying coastal areas are expected to experience more frequent flooding.

8.3.2 Impacts on the **economy** will include damage to infrastructure as a result of permafrost thawing and coastal erosion. Reductions in sea ice will improve ocean access to northern coastlines while thawing will reduce the opportunity of land transport in winter.

Traditional local economies based on resources that are vulnerable to climate change (such as polar bears and ringed seals) are very likely to be disrupted by rising temperatures.

8.3.3 Impacts on **people's lives** are very likely to include forced relocation of some villages as a result of coastal erosion brought about by sea-ice decline, sea-level rise, and thawing permafrost. Declines in ice-dependent animal species and increasing risks to hunters threaten the food security and traditional lifestyles of indigenous people.

8.4 Key impacts in sub-region IV: Central and East Canadian Arctic and West Greenland

Over the past 50 years, annual average temperatures have increased by roughly 1-2°C (1.8-3.6°F) over most of the Canadian Arctic and northwest Greenland, while the Labrador Sea remained cold and nearby areas of Canada and southwest Greenland cooled by up to 1°C (1.8°F).

Sub-region IV: Central and East Canadian Arctic and West-Greenland
[see Annex 14, p. 37]

By the 2090s, the entire region is expected to show an average annual warming of up to 3-7°C (5.4-12.6°F), with most of the warming occurring during the winter and over the water.

8.4.1 Impacts on the **environment** are likely to include a continued (record) melting of the Greenland Ice Sheet, changing the local environment and raising sea levels globally. Low-lying coastal areas will be more frequently flooded due to rising sea levels and storm surges.

8.4.2 Impacts on the **economy** are likely to include increased shipping through the Northwest Passage as a result of sea-ice retreat, providing economic opportunities while raising the risks of pollution due to oil spills and other accidents. More southerly marine fish species such as haddock, herring, and blue fin tuna could move into the region. Lake trout and other freshwater fish will decline, with impacts on local food supplies as well as on sport fishing and tourism.

8.4.3 Some Indigenous **Peoples**, particularly the Inuit, face major threats to their food security and hunting cultures as reduced sea ice and other warming-related changes reduce availability of and access to traditional food sources. Increases in sea level and storm surges could force the relocation of some low-lying coastal communities, causing substantial social impacts.

9. How can future assessments be improved?

The Arctic Climate Impact Assessment was 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 and the insights of Indigenous Peoples. This approach of linking scientific and indigenous perspectives is still in its early stages, and can potentially improve our understanding of climate change and its impacts.

While environmental impacts were covered extensively, estimates of economic impacts and of impacts at the sub-regional level need to be further developed. Studies that consider both climate change impacts and the effects due to other factors in an integrated way were covered only in a preliminary fashion. Three high-priority areas for future assessments have been identified:

- **Sub-regional Impacts**: future assessments will need to focus on smaller regions to be more relevant and useful to residents.
- **Socioeconomic Impacts**: Many important economic sectors will experience direct and indirect impacts due to climate change, but in most cases, only qualitative information is presently available.
- **Vulnerabilities**: Assessing vulnerability of a system to adverse effects requires better knowledge of the consequences of stresses and their interactions, but also of the capacity of the system to adapt.

This will require a series of improvements, such as an extensive long term monitoring network for climate-related parameters, studies focusing on Arctic ecosystem processes, improved modeling of various interactions and extreme events, as well as improved projection of impacts on society.

Finding effective ways of bringing the information gathered in the ACIA process to Arctic communities presents an additional challenge. Various 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.

See our study on climate change that summarizes IPCC III assessment [see https://www.greenfacts.org/en/climate-change-ar3/index.htm]

The ACIA has built on the substance and conclusions of the assessments prepared by the Intergovernmental Panel on Climate Change (IPCC). Just as the ACIA has built on IPCC's past evaluations, the next IPCC report, in 2007, will build on ACIA's findings with regard to the Arctic, doing so in a way that adds more global context.

Other national and international efforts offer opportunities to further understand climate change and ultraviolet radiation impacts. For instance, the International Polar Year (IPY), being planned by the world's scientific community for 2007/2009 will provide another opportunity to focus research attention on climate change and other important Arctic issues. The International Geophysical Year in 1957/8 first initiated systematic measurements of stratospheric ozone and atmospheric CO_2 enabling the discoveries of ozone depletion and greenhouse gas-induced climate change. ACIA's findings can help focus International Polar Year's and other research efforts.

10. Conclusion

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 even greater for future generations that will bear the consequences of current actions or inaction. Strong rapid 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 that 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.

10.1 Change Presents Risks and Opportunities

The ACIA report shows that climate change is very likely to result in major environmental changes, entailing risks as well as opportunities for the Arctic. For example, while the large reduction in summer sea ice threatens the future of several ice-dependent species, including polar bears and seals, and the peoples that depend upon them, it may also enable the expansion of Arctic shipping routes.

10.2 Potential Surprises

Some very likely climate-related changes in the Arctic environment are expected to have major impacts such as decline in sea ice, increase in coastal erosion, and thawing of permafrost. In addition, other changes that are much less likely could have very large impacts and lead to so-called "surprises". Due to the complexity of the Earth's climatic 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 could also have wide-reaching consequences. Although such changes could cause major impacts, very little information is currently available for considering such possibilities.

10.3 The Bottom Line

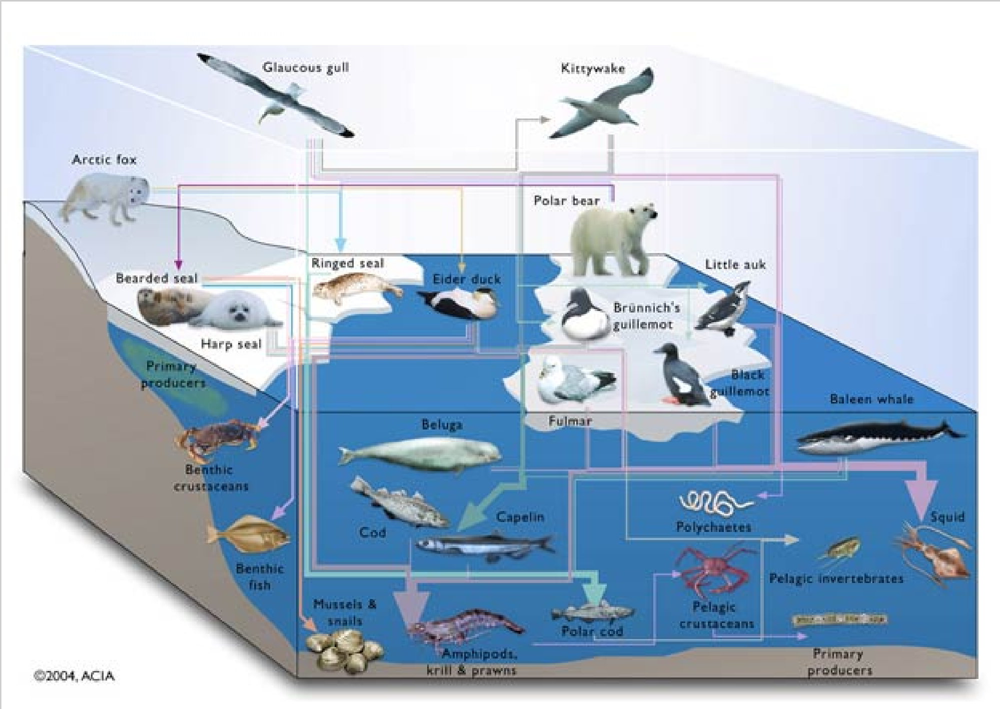
Despite the fact that a relatively small percentage of the world's greenhouse gas emissions originate in the Arctic, human-induced changes in Arctic climate are among the largest on Earth. As a consequence, the changes already underway in Arctic landscapes, communities, and unique features provide an 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 they 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.

The 10 key findings:

Arctic climate is now warming rapidly and much larger changes are projected.	*More in 2 ... [see https://www.greenfacts.org/en/arctic-climate-change/l-2/2-polar-ice-cap-melting.htm#0]*
Arctic warming and its consequences have worldwide implications.	*More in 3 ... [see https://www.greenfacts.org/en/arctic-climate-change/l-2/3-sea-level-rise.htm#0]*
Arctic vegetation zones are likely to shift, causing wide-ranging impacts.	*More in 4 ... [see https://www.greenfacts.org/en/arctic-climate-change/l-2/4-arctic-tundra.htm#0]*
Animal species' diversity, ranges, and distribution will change.	*More in 5 ... [see https://www.greenfacts.org/en/arctic-climate-change/l-2/5-arctic-animals.htm#0]*
Many coastal communities and facilities face increasing exposure to storms.	*More 6.1 [see https://www.greenfacts.org/en/arctic-climate-change/l-2/6-melting-permafrost.htm#1]*
Reduced sea ice is very likely to increase marine transport and access to resources.	*More in 6.2 ... [see https://www.greenfacts.org/en/arctic-climate-change/l-2/6-melting-permafrost.htm#2]*
Thawing ground will disrupt transportation, buildings and other infrastructure.	*More in 6.3 ... [see https://www.greenfacts.org/en/arctic-climate-change/l-2/6-melting-permafrost.htm#3]*
Indigenous communities are facing major economic and cultural impacts.	*More in 7.1 [see https://www.greenfacts.org/en/arctic-climate-change/l-2/7-effects-on-people.htm#1]*
Elevated ultraviolet radiation levels will affect people, plants, and animals.	*More in 7.2 [see https://www.greenfacts.org/en/arctic-climate-change/l-2/7-effects-on-people.htm#2]*
Multiple influences interact to cause impacts to people and ecosystems.	*More in 7.3 [see https://www.greenfacts.org/en/arctic-climate-change/l-2/7-effects-on-people.htm#3]*

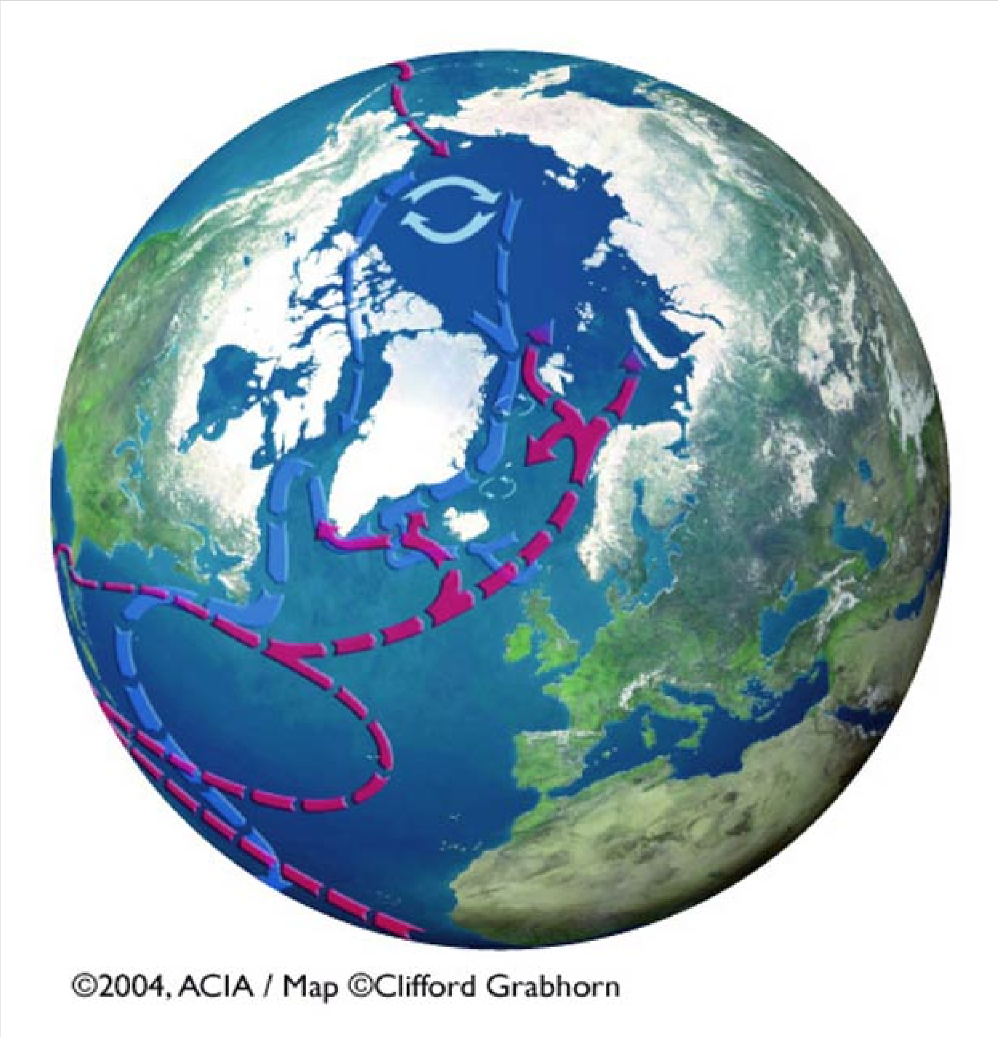
Annex

Annex 1:
Arctic Marine Food Web



Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #4, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding4%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.60

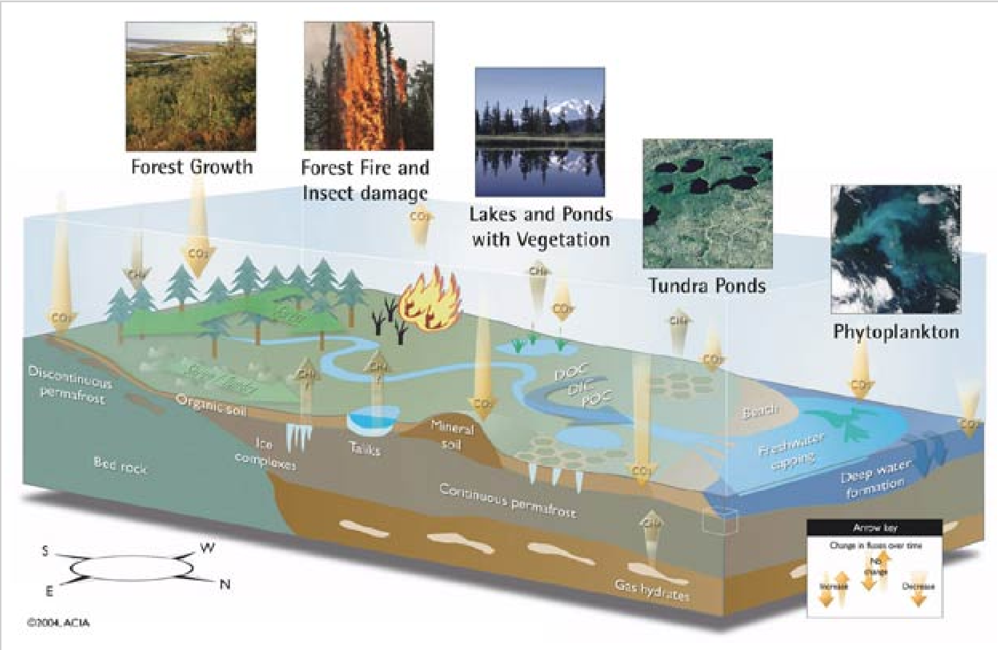
Annex 2:
Arctic Thermohaline Circulation



Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #2, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding2%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.36

Annex 3:
Carbon cycle in the Arctic

This schematic illustrates changes in the cycling of carbon in the Arctic as climate warms. For example, beginning at the left of the figure, the boreal forest absorbs CO2 from the atmosphere and this is expected to increase, although forest fires and insect damage will increase in some areas, releasing more carbon to the atmosphere. Increasing amounts of carbon will also move from the tundra to ponds, lakes, rivers, and the continental shelves in the form of carbon dissolved in water (dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), and particulate organic carbon (POC)).



Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004), Key Finding #2, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding2%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.39

Annex 4:
Case study of interacting changes: Saami reindeer herders

Observed and projected increases in temperature and precipitation and changes in the timing of the seasons affect reindeer herding in numerous ways. Increases in the frequency of rain on snow, and in periods of winter melting, result in the formation of ice crust layers that make forage less accessible. Increasing autumn temperatures might lead to a later start of the period with snow cover. Rising temperatures and precipitation could increase the frequency of snow falling on unfrozen ground. An increased number, density, and distribution of birch trees in grazing areas has already begun to decrease the availability of forage plants for reindeer in winter. Shifts of forest vegetation into tundra areas are likely to further reduce traditional pasture areas.

The characteristic seasonal pattern of moving herds between winter and summer pastures reflects the herders' knowledge of seasonal changes in the availability of key resources such as forage and water. In the warm winters of the 1930s, for example, when conditions were sometimes difficult owing to heavy precipitation, herds were moved to the coast earlier than normal in the spring. Similarly, the movement of herds from poorer to better grazing areas, including the "trading of good snow" by neighboring herders, reflects thorough knowledge of forage conditions. In every case, the success of the herders is contingent upon the freedom to move.

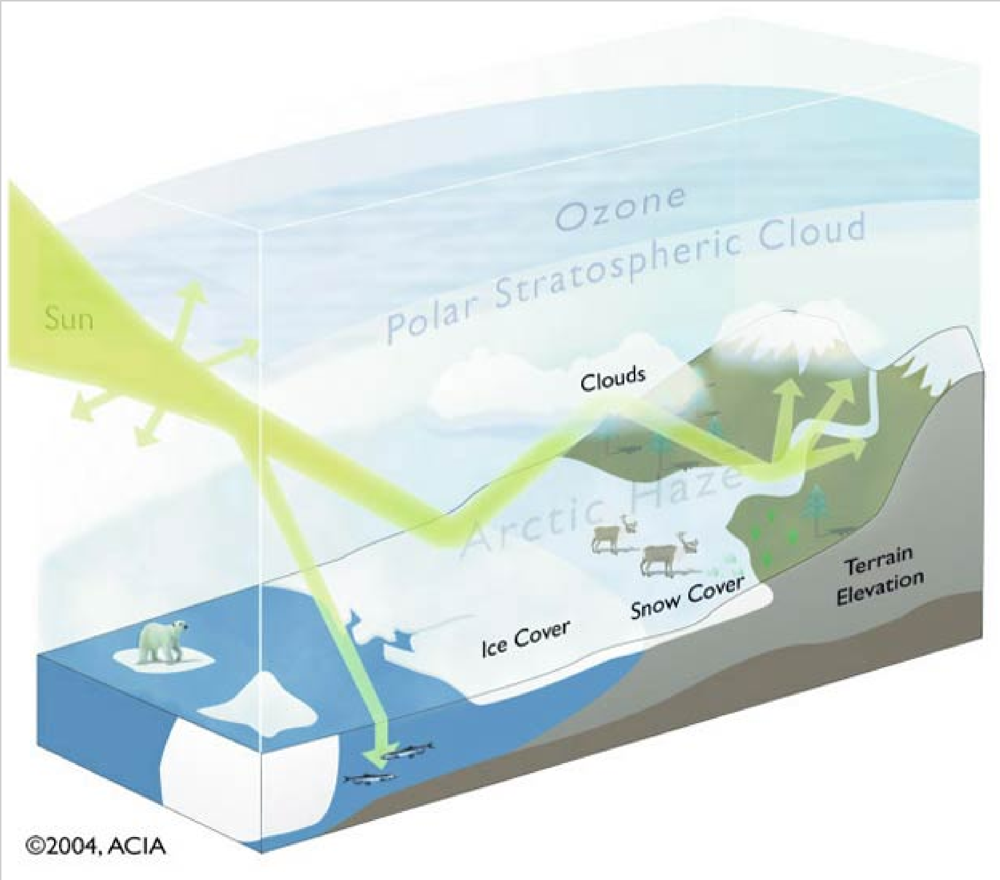
A variety of factors, including government policies in the past few decades, have constrained the ability of Saami reindeer herders to respond to and cope with climate warming and other changes. One important stress has come from the encroachment of roads and other infrastructure on traditional reindeer grazing lands. Another stress comes from conflicting objectives among parties. Norway's mountain pastures are an important resource for herders, but pastureland management is complicated by the presence of predators such as lynx, wolf, and wolverine, which are a major threat to the survival of reindeer calves, but are protected by wildlife conservation efforts.

Other changes come from laws that emphasize meat production, encouraging active breeders and discouraging small herds. These laws favor larger herds, which have thus increased from around 100 to 700 animals. These laws also favor herds dominated by females and calves (the calves are slaughtered for meat) and have resulted in a change in structure from a traditional herd consisting of about 40% bulls, to herds with only 5% bulls. In traditional Saami herding practices, the bulls are important because their superior ability to dig through deep or poor quality snow make forage plants available to the entire herd. The reduced proportion of bulls may become more of a problem in the future if snow conditions altered by climate change make grazing even more difficult for smaller reindeer.

*Source & © ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #10, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding10%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.108*

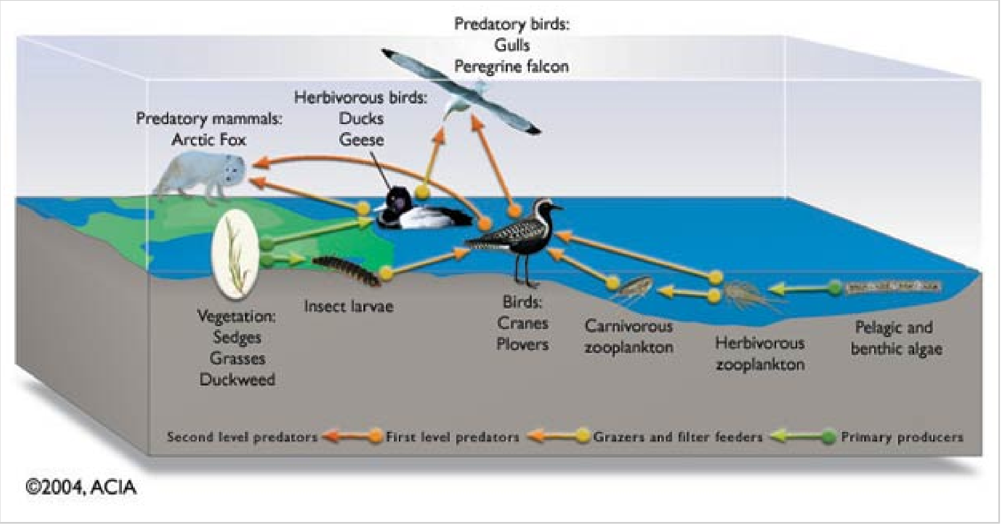
Annex 5:
Factors influencing UV at the surface

Ozone levels, clouds, the angle of the sun's rays, altitude, tiny particles in the atmosphere (which scientists refer to as aerosols), and the reflectivity of the surface (determined largely by the extent of snow cover, which is highly reflective), all influence the amount of UV reaching the surface.



Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #9, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding9%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.99

Annex 6:
Freshwater food web



Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #4, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding4%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.75

Annex 7:
Indigenous knowledge and observations of current trends

The weather seems less stable and predictable.

"From sources of indigenous knowledge across the Arctic come reports that the weather seems more variable, unfamiliar, and is behaving unexpectedly and outside the norm. Experienced hunters and elders who could predict the weather using traditional techniques are now frequently unable to do so. Storms often occur without warning. Wind direction changes suddenly. In many places it is increasingly cloudy. Storms bringing high winds and lightning occur with increasing frequency in some locations. As noted by several elders, "the weather today is harder to know". This presents problems for many activities, from hunting to drying fish, on which Indigenous Peoples depend.

- "Right now the weather is unpredictable. In the older days, the elders used to predict the weather and they were always right, but right now, when they try to predict the weather, it's always something different." Z. Aqqiaruq, Igloolik, Canada, 2000
- "The periods of weather are no longer the norm. We had certain stable decisive periods of the year that formed the traditional norms. These are no longer at their places… Nowadays the traditional weather forecasting cannot be done anymore as I could before… For the markers in the sky we look now in vain… Heikki Hirvasvuopio, Kakslauttanen, Finland, 2002

Source & © ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #8, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding8%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.96

Annex 8:

Indigenous knowledge and observations of current trends

Snow characteristics are changing, and there is more freezing rain. Changes in snow and ice characteristics are widely reported. Changing wind patterns cause the snow to be hard packed; hunters and travel parties are thus unable to build igloos, which are still commonly relied upon for temporary and emergency shelters. Injuries and deaths have been attributed to sudden storms and those involved not being able to find good snow with which to build shelters. More freezing rain and increasing frequency of freeze-thaw cycles are affecting the ability of reindeer, caribou, musk ox, and other wildlife to find food in winter, which in turn affects the Indigenous Peoples who depend upon these animals.

- "There used to be different layers of snow back then. The wind would not blow as hard, not make the snow as hard as it is now… It's really hard to make shelters with that kind of snow because it's usually way too hard right down to the ground." T. Qaqimat, Baker Lake, Canada, 2001
- "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, 2002
- "It used to be that there would be proper freezing which would dry the lichen and the snow would fall on top. There would be rain that would form the bottom, which would then freeze properly. Now it rains, and the bottom freezes wet, and this is bad for the reindeers. It ruins the lichen. Ice is everywhere and the reindeer cannot get through. This has meant death to a number of reindeers because they cannot get to the lichen." Niila Nikodemus, 86, the oldest reindeer herder in Purnumukka, Finland, 2002
- "First it snows, then it melts, like it would be summertime. And this all over again. First there is a big snowfall, then it warms up and then it freezes. During winter now it can rain, as happened last New Year. Before it never rained during wintertime. Rain in the middle of winter? To the extent that snow disappears? Yes, it is true. Rain, and snow melts!" Vladimir Lifov, Lovozero, Russia, 2002

Source & © ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #8, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding8%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.96

Annex 9:

Indigenous knowledge and observations of current trends

Sea ice is declining, and its quality and timing are changing, with important repercussions for marine hunters.

Sea ice is declining markedly, both in extent and thickness. The pack ice is further from shore and often too thin to allow safe travel. Less sea ice makes stormy seas more violent and dangerous for hunters. Marine mammals whose habitat is sea ice, including walrus, polar bear, and iceassociated seals are very likely to experience major population declines in this century and could be threatened with extinction.

- "Long ago, there was always ice all summer. You would see the [multiyear ice] all summer. Ice was moving back and forth this time of year. Now, no ice. Should be [multiyear]. You used to see that old ice coming from the west side of Sachs. No more. Now between Victoria Island and Banks Island, there is open water. Shouldn't be that way." Frank Kudlak, Sachs Harbour, Canada, 1999
- "I know that today that seals, it might be because of early spring break-up or that they are out on the ice floes, that the seals are nowhere." Man age 62, Kuujjuaq, Canada,
- "When there is lots of ice, you don't worry too much about storms. You get out there and travel in between the ice [floes]. But last few years there has been no ice. So if it storms, you can't get out…" Andy Carpenter, Sachs Harbour, Canada, 1999

Source & © ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #8, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding8%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.96

Annex 10:
Indigenous knowledge and observations of current trends

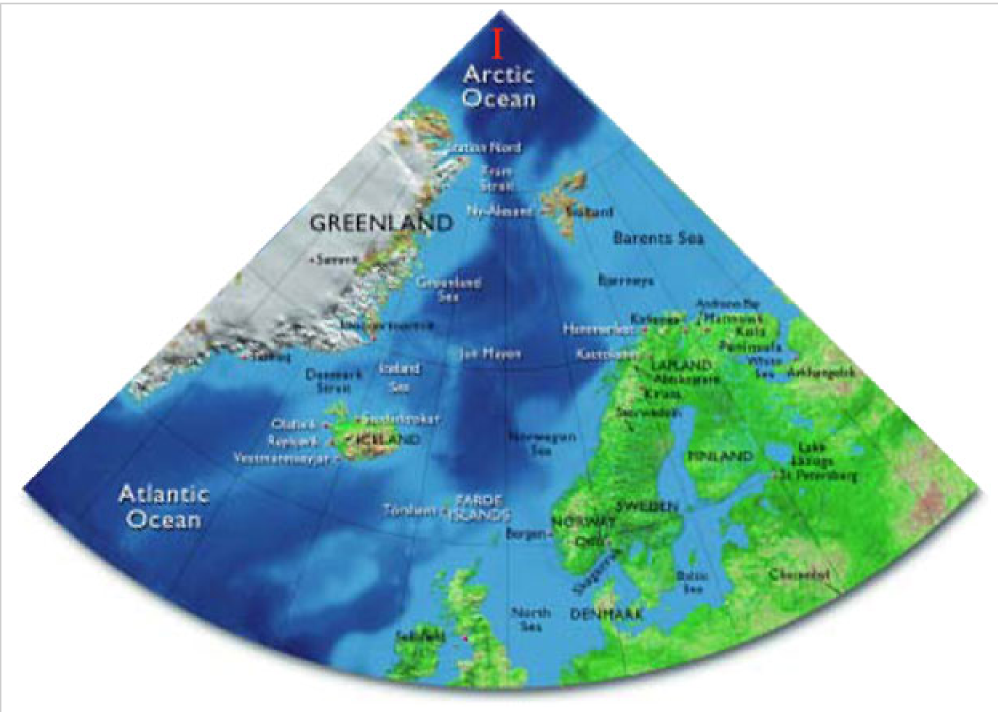
Seasonal weather patterns are changing.

Peoples across the Arctic report changes in the timing, length, and character of the seasons, including more rain in autumn and winter, and more extreme heat in summer.

- "Sila [the weather and climate] has changed alright. It is a really late falltime now, and really fast and early springtime. Long ago the summer was short, but not anymore." Sarah Kuptana, Sachs Harbour, Canada, 1999
- "It used to be really nice weather long ago when I was a kid. Bad weather now. So many mosquitoes. Sometimes it was hot, sometimes cold – not like now. [Things happen at the] wrong time now, it is way different now. August used to be cool-off time, now it is hot. It is really short in the winter now." Edith Haogak, Sachs Harbour, Canada, 2000
- "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, 2002

Source & © ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #8, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding8%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.96

Annex 11:
Map subregions sub-I

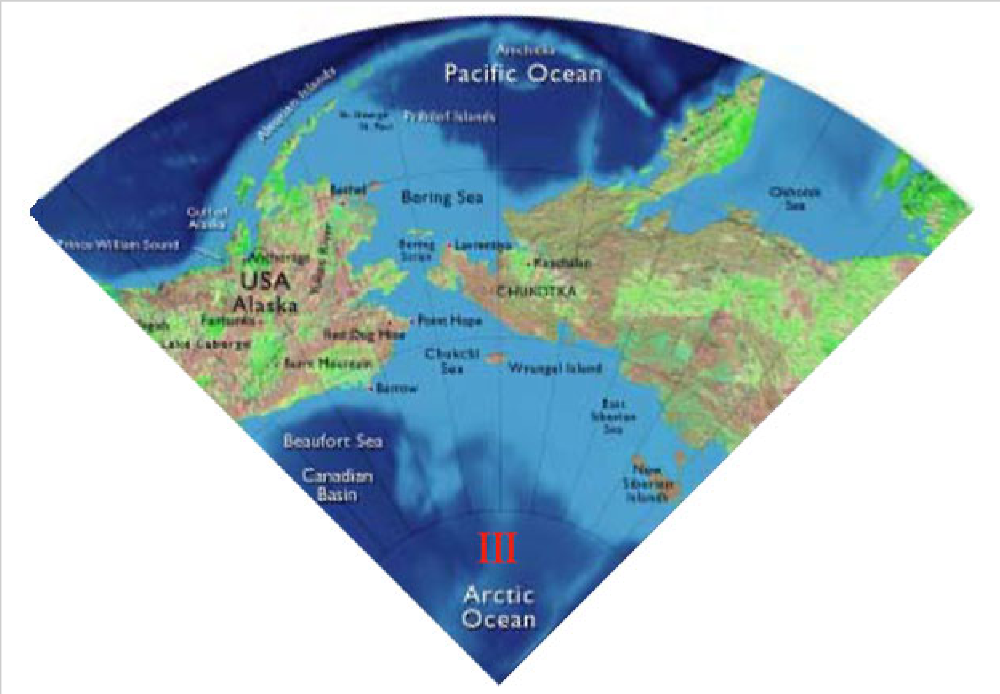


Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Impacts, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=zConclusion%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.114

Annex 12:
Map subregions sub-II

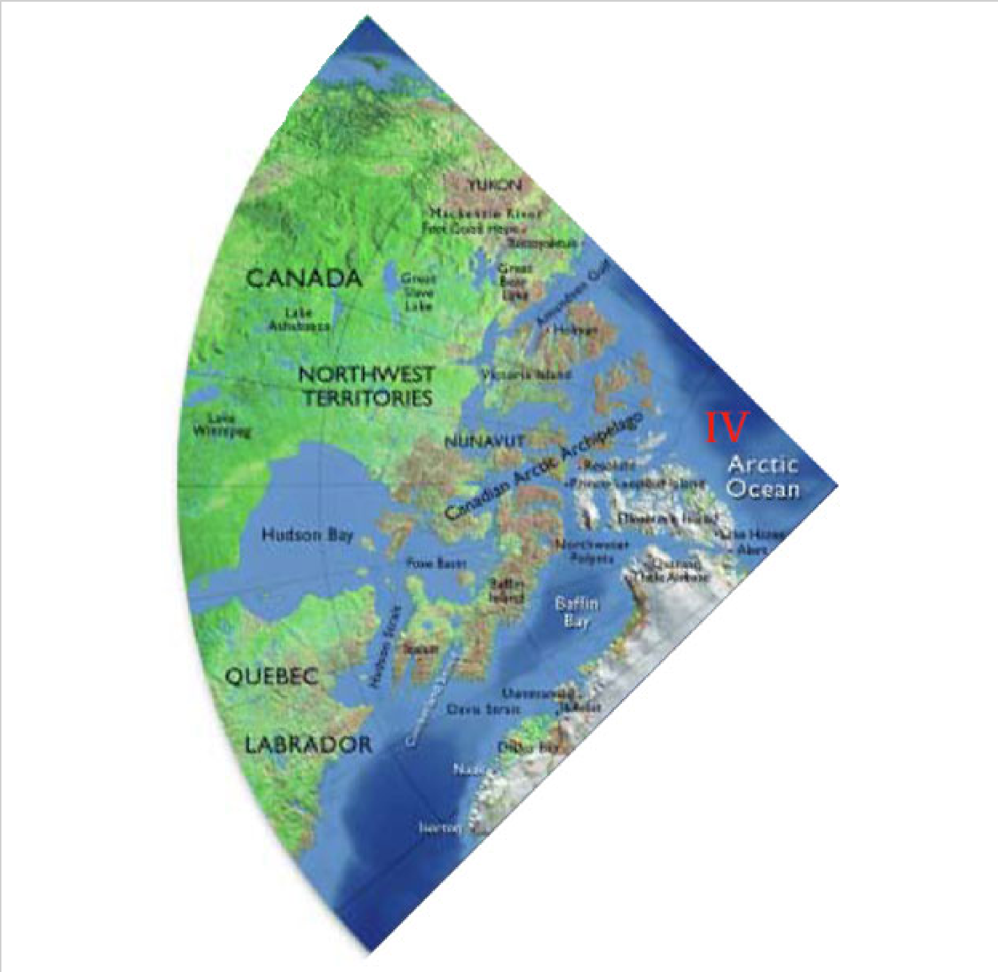
Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Impacts, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=zConclusion%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.116

Annex 13:
Map subregions sub-III



Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Impacts, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=zConclusion%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.118

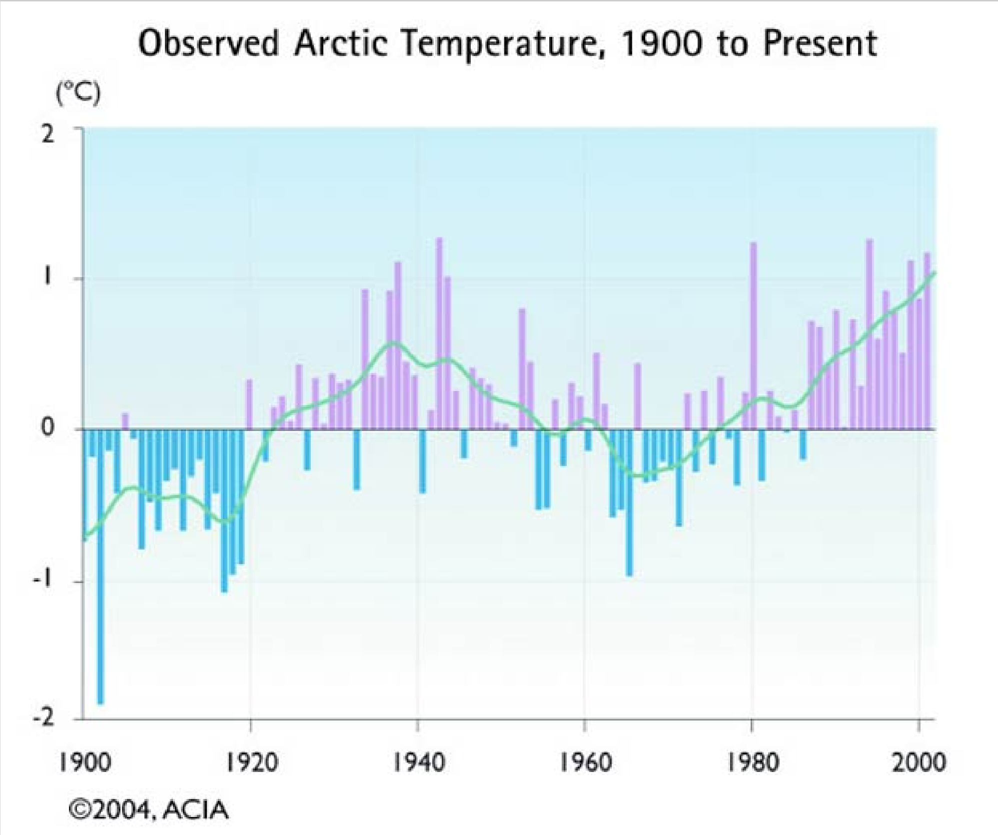
Annex 14:
Map subregions sub-IV



Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Impacts, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=zConclusion%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.120

Annex 15:
Observed Arctic Temperature, 1900 to Present

Observed Arctic Temperature, 1900 to Present: Annual average change in near surface air temperature from stations on land relative to the average for 1961-1990, for the region from 60 to 90°N.



Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #1, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding1%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.23

Annex 16:
Observed Climate Change Impacts in Sachs Harbour, Canada

"The community of Sachs Harbour is located on Banks Island in the Canadian western Arctic. Climate change impacts on this community have been studied intensively through the Inuit Observations of Climate Change project, undertaken by the Community of Sachs Harbour and the International Institute for Sustainable Development. The Inuvialuit (the Inuit of the Canadian western Arctic) initiated this study because they wanted to document the severe environmental changes they are witnessing as a result of climate change and to disseminate this information to the world. A brief summary of some of their findings follows.

1. Physical Environmental Changes

- Multiyear ice no longer comes close to Sachs Harbour in summer.

- Less sea ice in summer means that water is rougher.

- Open water is now closer to land in winter.

- More rain in summer and autumn makes travel difficult.

- Permafrost is no longer solid in places.

- Lakes are draining into the sea from permafrost thawing and ground slumping.

- Loose, soft snow (as opposed to hard-packed snow) makes it harder to travel.

2. Predictability of the Environment

- It has become difficult to tell when ice is going to break-up on rivers.

- Arrival of spring has become unpredictable.

- It is difficult to predict weather and storms.

- There are "wrong" winds sometimes.

- There is more snow, blowing snow, and whiteouts.

3.Travel Safety on Sea Ice

- Too much broken ice in winter makes travel dangerous.

- Unpredictable sea-ice conditions make travel dangerous.

- Less multiyear ice means traveling on first-year ice all winter; this is less safe.

- Less ice cover in summer means rougher, more dangerous storms at sea.

4. Access to Resources

- It is more difficult to hunt seals because of a lack of multiyear ice.

- Hunters cannot go out as far in winter because of a lack of firm ice cover.

- It is harder to hunt geese because the spring melt occurs so fast.

- Warmer summers and more rain mean more vegetation and food for animals.

5. Changes in Animal Distributions and Condition

- There is less fat on the seals.

- Fish and bird species are observed that have never been seen before.

- There is an increase in biting flies; never had mosquitoes before but do now.

- Fewer polar bears are seen in the autumn because of lack of ice.

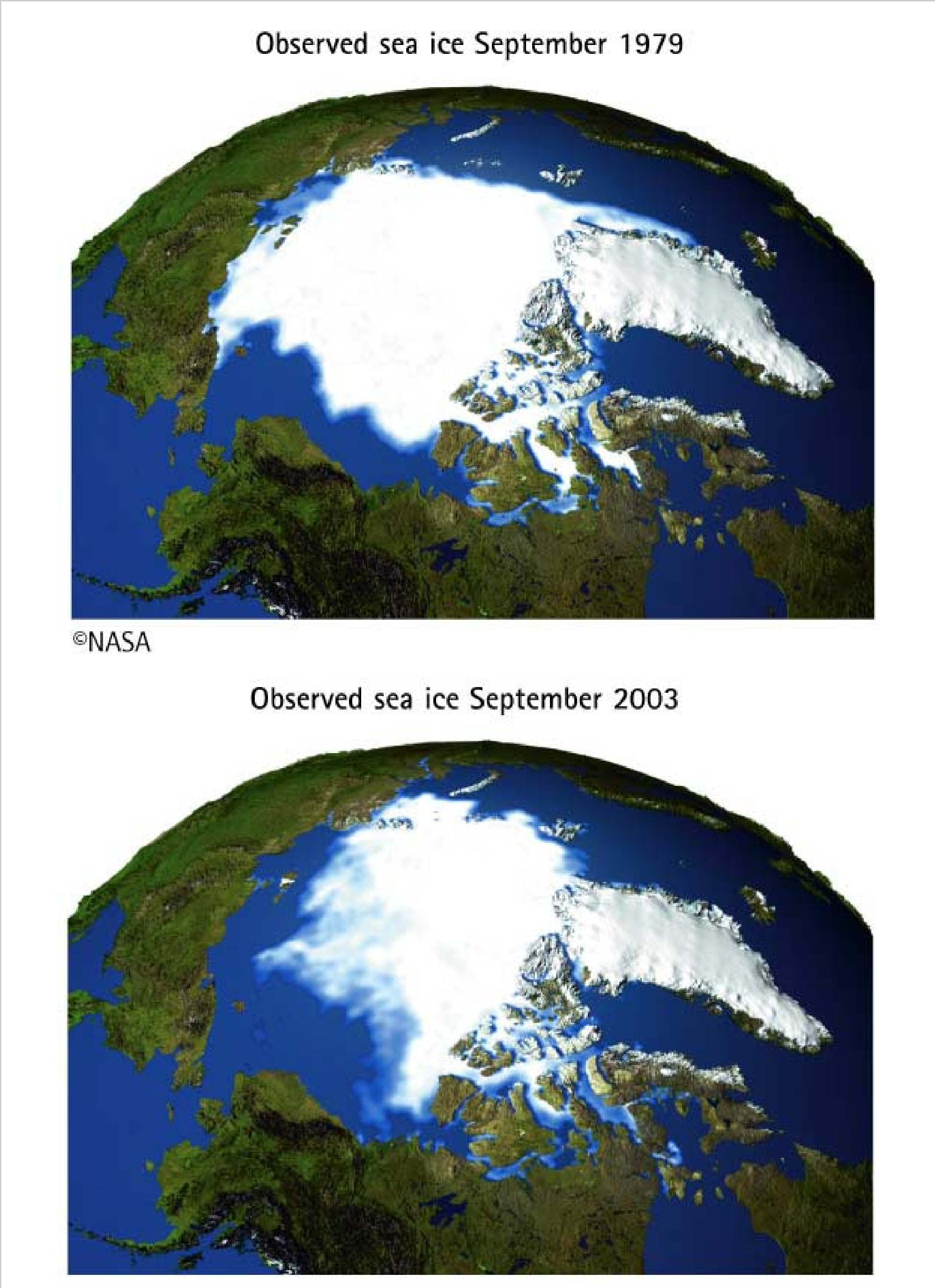
- The fish “least cisco" is now being caught in greater numbers.

Climate change is occurring faster than indigenous knowledge can adapt and is strongly affecting people in many communities. Unpredictable weather, snow, and ice conditions make travel hazardous, endangering lives. Impacts of climate change on wildlife, from caribou on land, to fish in the rivers, to seals and polar bears on the sea ice, are having enormous effects, not only for the diets of Indigenous Peoples, but also for their cultures.

Source & © ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #8, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding8%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.95

Annex 17:
Observed sea ice September 1979 and September 2003

These two images, constructed from satellite data, compare arctic sea ice concentrations in September of 1979 and 2003. September is the month in which sea ice is at its yearly minimum and 1979 marks the first year that data of this kind became available in meaningful form. The lowest concentration of sea ice on record was in September 2002.



Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #1, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding1%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.25

Annex 18:
Peary Caribou

The present reduced state of Peary caribou (a small, white sub-species found only in West Greenland and Canada's arctic islands) is serious enough that a number of communities have limited and even banned their subsistence harvests of the species. The number of Peary caribou on Canada's arctic islands dropped from 26 000 in 1961 to 1000 by 1997, causing the sub-species to be classified as endangered in 1991. The decline of Peary caribou appears to have been caused by autumn rains that iced the winter food supply and crusted the snow cover, limiting access to forage. Also, annual snowfall in the western Canadian Arctic increased during the 1990s and the three heaviest snowfall winters coincided with Peary caribou numbers on Bathurst Island dropping from 3000 to an estimated 75 between 1994 and 1997.

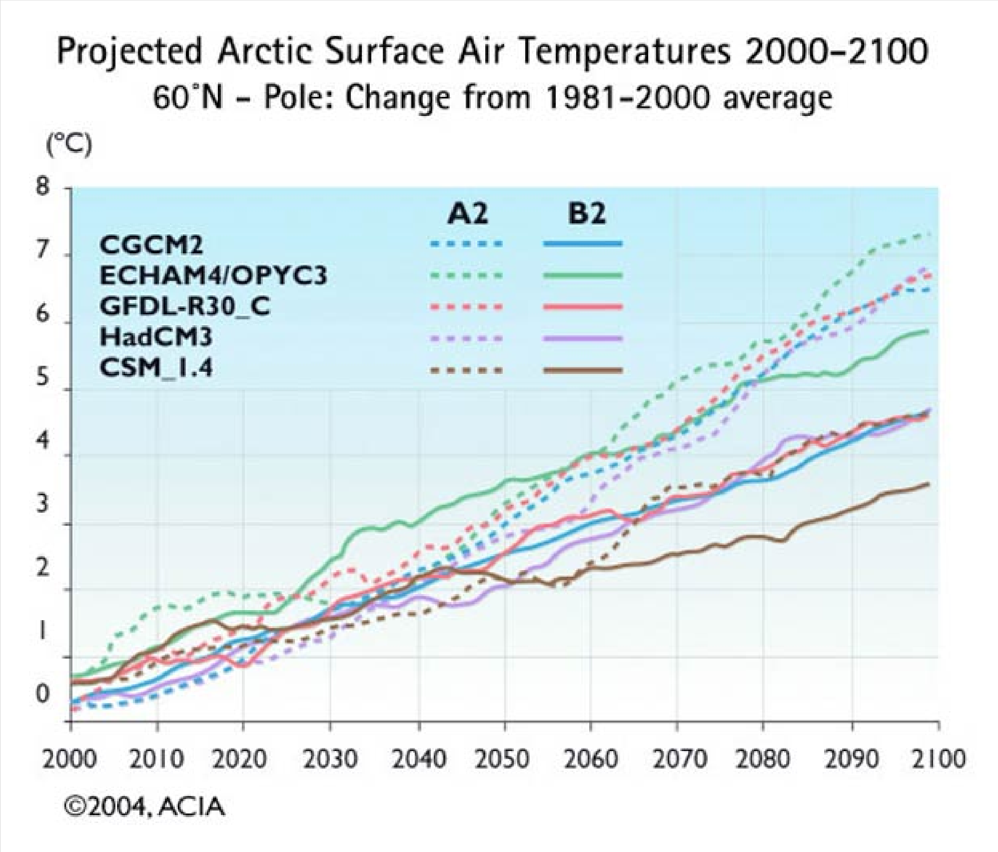
Source & © ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #4, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding4%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.70

Annex 19:
People of the Arctic

Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Context: People of the Arctic, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=ArcticImpactsa%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.7

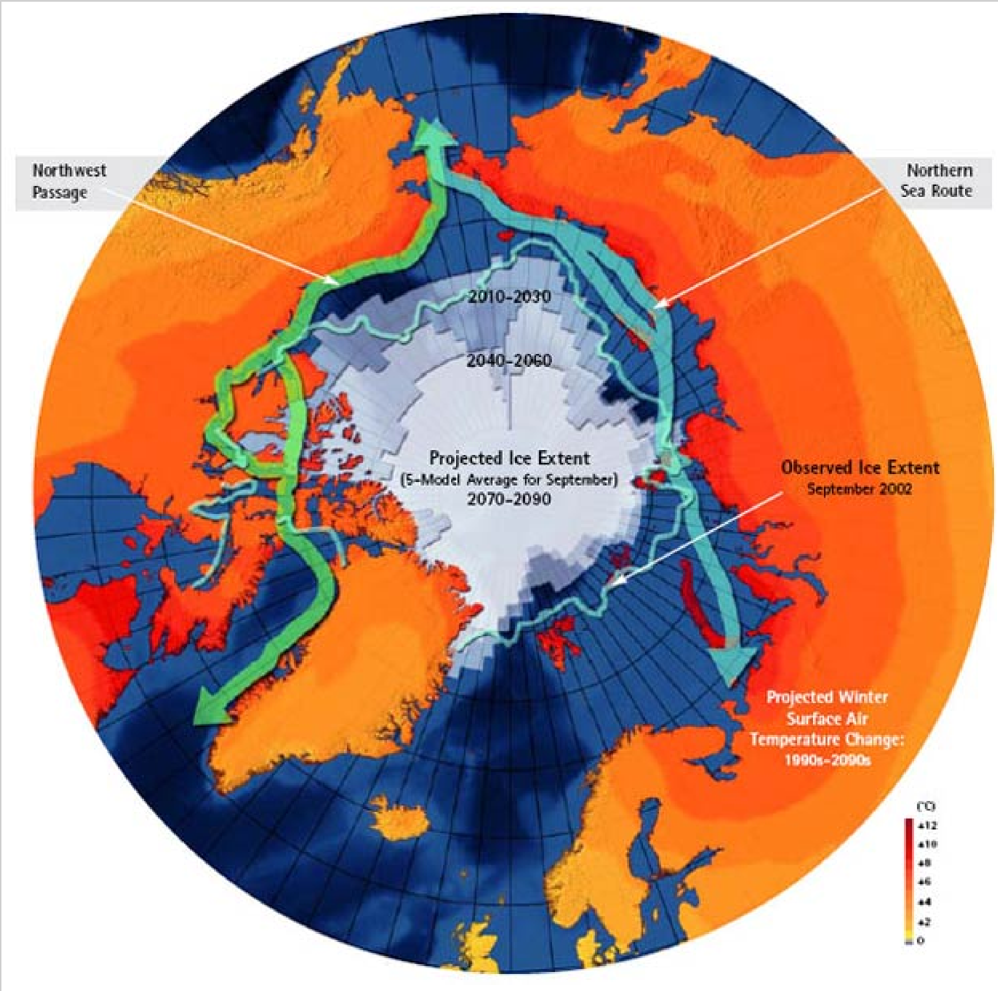
Annex 20:
Projected Arctic Surface Air Temperatures

Projected Arctic Surface Air Temperatures 2000-2100 60°N - Pole: Change from 1981-2000 average: The ten lines show air temperatures for the region from 60°N to the pole as projected by each of the five ACIA global climate models using two different emissions scenarios. The projections remain similar through about 2040, showing about a 2°C temperature rise, but then diverge, showing increases from around 4° to over 7°C by 2100. The full range of models and scenarios reviewed by the IPCC cover a wider range of possible futures. Those used in this assessment fall roughly in the middle of this range, and thus represent neither best- nor worst-case scenarios.



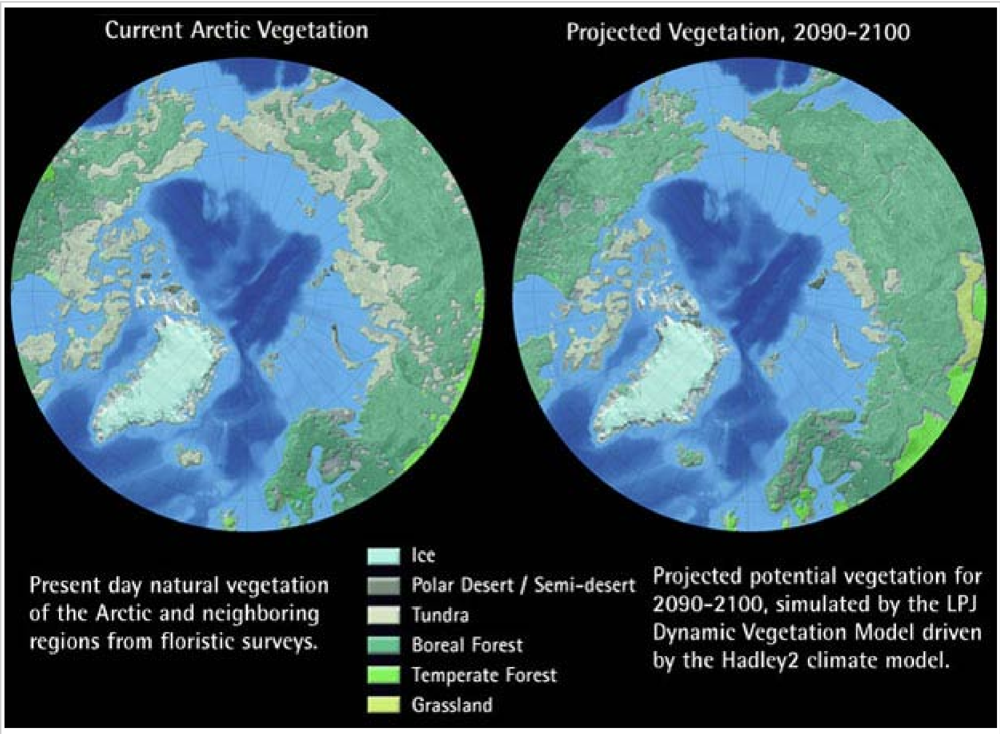
Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #1, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding1%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.27

Annex 21:
Projected opening of northern navigation routes



Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #6, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding6%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.82

Annex 22:
Projected Vegetation, 2090-2100



Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #3, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding3%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.47

Annex 23:
Spruce Bark Beetle

The relationship of the spruce bark beetle to climate involves three factors, including two direct controls on insect populations and an indirect control on tree resistance. First, two successive cold winters depress the survival rate of the bark beetle to a level low enough that there is little outbreak potential the following summer. However, winters have been abnormally warm for decades in the North American Arctic, so the conditions for this control have not been met for some time. Second, the bark beetle normally requires two years to complete its life cycle, but in abnormally warm summers, it can complete its life cycle in one year, dramatically increasing the population and the resulting damage. This has occurred recently in Alaska and Canada.

In addition, healthy spruce trees can successfully resist moderate numbers of beetle attacks by using their pitch, under high pressure, to push back against the female beetles trying to bore into the tree to lay eggs; the beetles are generally unable to overcome the flow of pitch. However, host trees under stress due to heat and drought have reduced growth reserves, leading to reduced amounts and lower pressure of pitch, and so a reduced ability to resist beetle attacks. When entire populations of trees are stressed by regional climatic events, such as has occurred recently in Alaska and parts of Canada, spruce bark beetle success is greatly increased and large-scale tree damage and loss occurs.

Source & © ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #3, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding3%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.54

Annex 24:
Spruce Budworm

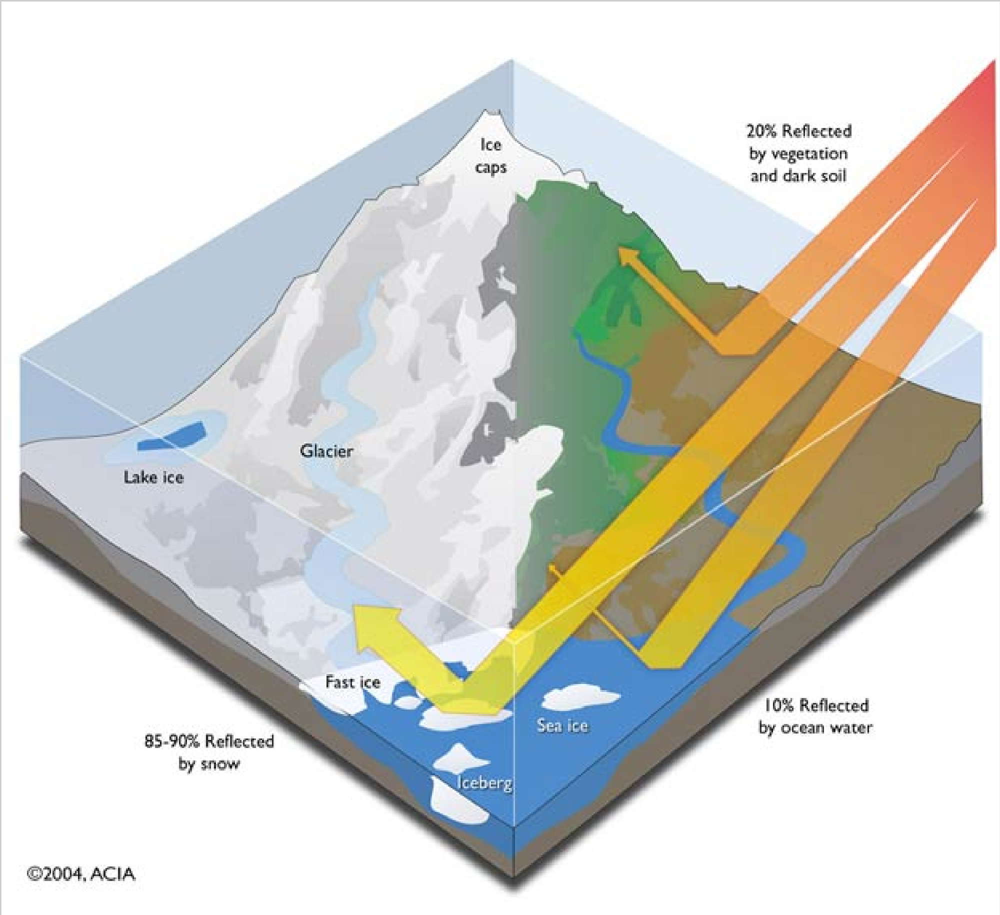
Weather is a critical factor in determining spruce budworm distribution. Sudden upsurges in budworm numbers generally follow drought and the visible effects of these outbreaks begin after hot, dry summers. Drought stresses the trees, reducing their resistance, and elevated summer temperatures increase budworm reproduction. For example, female budworms lay 50% more eggs at 25°C than at 15°C. Also, higher temperatures and drought can shift the timing of budworm reproduction such that their natural predators are no longer effective in limiting budworm numbers. Conversely, cold weather can stop a budworm outbreak. Budworms starve if a late spring frost kills the new shoot growth of the trees on which the larvae feed.

Thus it is to be expected that climate warming would result in the northward movement of the spruce budworm and this has already occurred. Before 1990, spruce budworm had not appeared able to reproduce in the boreal forest of central Alaska. Then, in 1990, after a series of warm summers, a sudden and major upsurge in spruce budworm numbers occurred and visible damage to the forest canopy spread over several tens of thousands of hectares of white spruce forest. Populations of spruce budworm have since persisted in this area near the Arctic Circle. The entire range of white spruce forests in North America is considered vulnerable to outbreaks of spruce budworm under projected climate change. In the Northwest Territories of Canada, for example, the northern limit of current spruce budworm outbreaks is approximately 400 kilometers south of the northern limit of its host, the white spruce. Therefore, there is potential for a northward expansion of spruce budworm to take over this remaining 400 kilometer-wide band of currently unaffected white spruce forest.

Source & © ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #3, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding3%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.55

Annex 25:
Surface Reflectivity

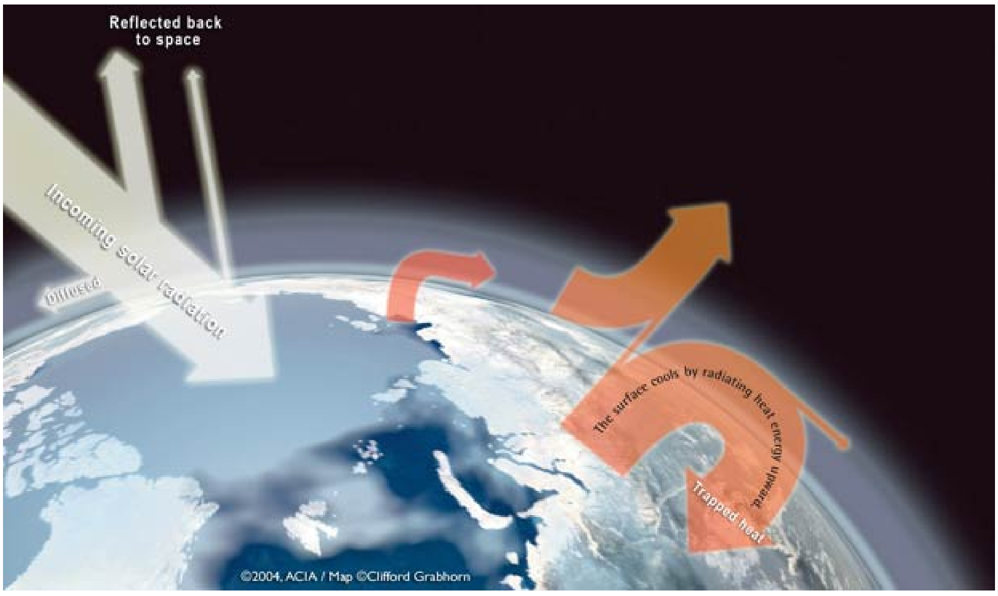
Sea ice covered with snow reflects about 85-90% of sunlight, while ocean water reflects just 10%. Thus, as sea ice melts, revealing more and more of the ocean beneath, the increasing absorption of solar radiation adds to global warming, which causes more melting, which in turn causes more warming, and so on…



Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #2, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding2%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.34

Annex 26:
The Earth's Greenhouse Effect

The Earth's Greenhouse Effect: Most of the heat energy emitted from the surface is absorbed by greenhouse gases which radiate heat back down to warm the lower atmosphere and the surface. Increasing the concentrations of greenhouse gases increases the warming of the surface and slows the loss of heat energy to space.



Source: ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004), Context: Global Climate Change, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=ArcticImpactsa%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.2

Annex 27:
The Gwich'in and the Porcupine Caribou Herd

The Gwich'in have been living in close relationship with the Porcupine Caribou Herd for thousands of years. Gwich'in communities are named for the rivers, lakes, and other aspects of the land with which they are associated. The Vuntut (lake) Gwich'in of Old Crow (population 300) in Canada's Yukon, are located in the center of the Porcupine Caribou Herd's range, providing opportunities to intercept caribou during both their autumn and spring migrations. Average harvest of caribou is as high as five animals per person per year. Sharing among households in the community and with neighboring communities is an important cultural tradition and is also believed to help ensure future hunting success.

Climate-related factors influence the health of the animals and the herd's seasonal and annual distribution and movement. Climate-related factors also affect hunters' access to hunting grounds, for example, through changes in the timing of freeze-up and break-up of river ice and the depth of snow cover

Every spring for many generations, the Porcupine Caribou Herd has crossed the frozen Porcupine River to its calving grounds in the Arctic National Wildlife Refuge in Alaska. In recent years, the herd has been delayed on its northern migration as deeper snows and increasing freeze-thaw cycles make their food less accessible, increase feeding and travel time, and generally reduce the health of the herd. At the same time, river ice is thawing earlier in the spring. Now when the herd reaches the river, the river is no longer frozen. Some cows have already calved on the south side and have to cross the rushing water with their newborn calves. Thousands of calves have been washed down the river and died, leaving their mothers to proceed without them to the calving grounds.

Source & © ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #4, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding4%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.72

Annex 28:

The Porcupine Caribou Herd

The Porcupine Caribou Herd is one of approximately 184 wild herds of caribou globally, the eighth largest herd in North America, and the largest migratory herd of mammals shared between the United States and Canada. The Porcupine Herd has been monitored periodically since the early 1970s. The population grew at about 4% per year from the initial censuses to a high of 178 000 animals in 1989. During the same period, the populations of all major herds increased throughout North America, suggesting that they were responding to continental-scale events, presumably climate-related. Since 1989, the herd has declined at 3.5% per year to a low of 123 000 animals in 2001. The Porcupine Caribou Herd appears to be more sensitive to the effects of climate change than other large herds.

The ecosystem defined by the range of the Porcupine Herd includes human communities, most of which depend on harvesting caribou for subsistence. Among these are the Gwich'in, Iñupiat, Inuvialuit, Han, and Northern Tuchone whose relationships with this herd have persisted over many millennia. Historically, caribou have served as a critical resource, allowing northern indigenous people to survive the hardships of the severe arctic and sub-arctic conditions. Times of caribou scarcity were often accompanied by great human hardship. Records and oral accounts suggest that periods of caribou scarcity in North America coincided with periods of climatic change.

Today, caribou remain an important component of the mixed subsistence-cash economy, while also enduring as a central feature of the mythology, spirituality, and cultural identity of Indigenous Peoples. The harvesting of the Porcupine Caribou Herd varies from year to year, depending on the distribution of animals, communities' access to them, and community need. The total annual harvest from this herd typically ranges from approximately 3000 to 7000 caribou. Responsibility for management of the herd and protection of its critical habitat is shared in Canada between those who harvest the caribou (mostly Indigenous Peoples) and the government agencies with legal management authority.

Source & © ACIA Impacts of a Warming Arctic: Arctic Climate Impact Assessment [see http://www.acia.uaf.edu/pages/overview.html] (2004),
Key Finding #4, [see http://amap.no/workdocs/index.cfm?action=getfile&dirsub=%2FACIA%2Foverview&filename=Finding4%2Epdf&CFID=3348836&CFTOKEN=59197662&sort=default] p.71

Partner for this publication

The Levels 1 & 2 of this study are summaries of "Impacts of a Warming Arctic", a report published in 2004 by the Arctic Climate Impact Assessment (ACIA).

The summaries were produced by GreenFacts in collaboration with the International Polar Foundation.