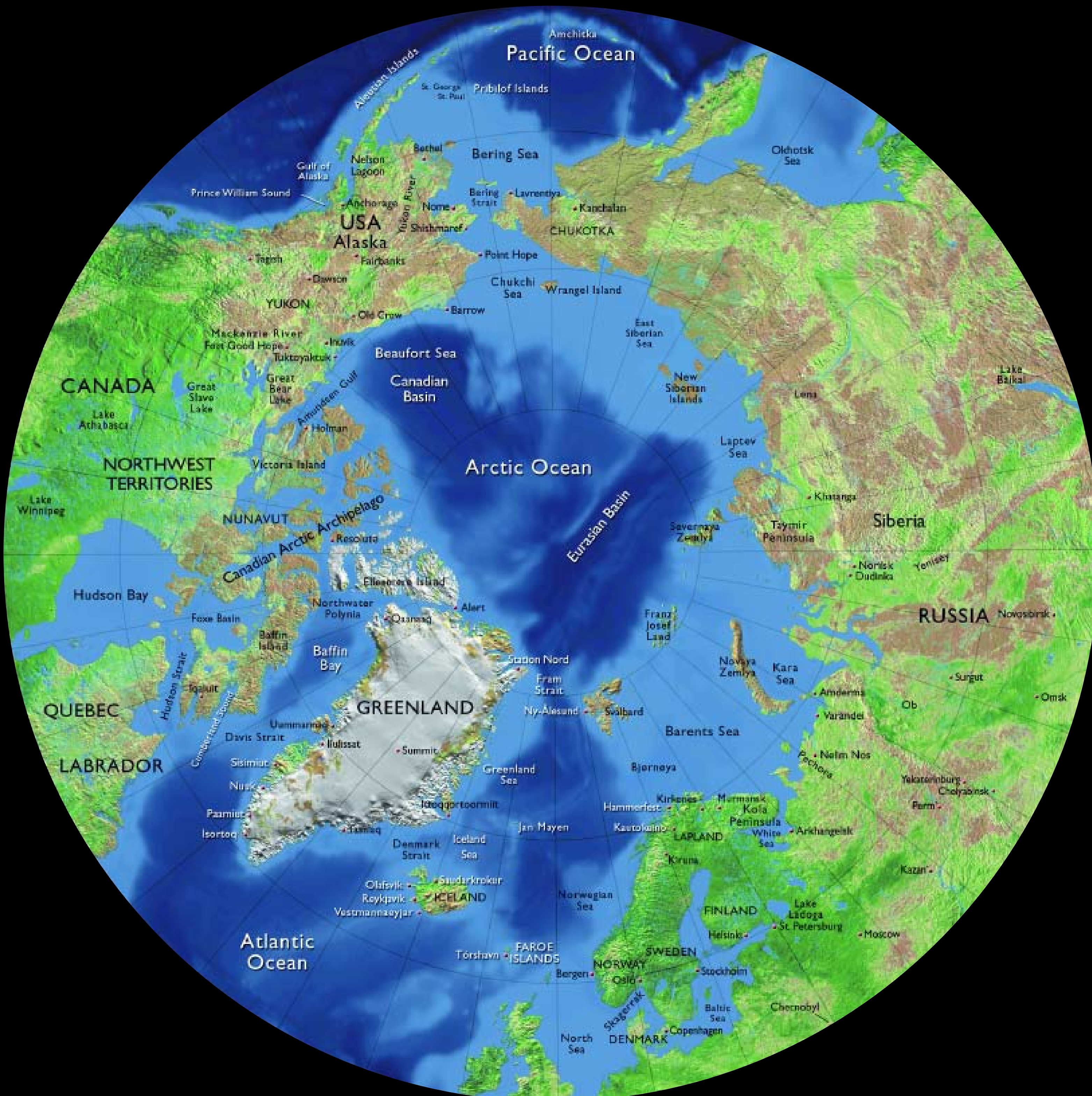
IMPACTS OF A WARMING ARCTIC


Amchitka
Pacific Ocean
Aleutian Islands
St. George
St. Paul
Pribilof Islands
Bethel
Bering Sea
Okhotsk Sea
Gulf of Alaska
Nelson Lagoon
Prince William Sound
Anchorage
Yukon River
Bering Strait
Lavrentiya
Kanchalan
Nome
USA
Alaska
Shishmaref
CHUKOTKA
Tagish
Fairbanks
Point Hope
Dawson
Chukchi Sea
Wrangel Island
YUKON
Old Crow
Barrow
East Siberian Sea
Mackenzie River
Fort Good Hope
Inuvik
Tuktoyaktuk
Beaufort Sea
Lake Baikal
CANADA
Great Slave Lake
Great Bear Lake
Amundsen Gulf
Canadian Basin
New Siberian Islands
Lena
Lake Athabasca
Holman
Laptev Sea
NORTHWEST TERRITORIES
Victoria Island
Arctic Ocean
Lake Winnipeg
Khatanga
NUNAVUT
Canadian Arctic Archipelago
Eurasian Basin
Severnaya Zemlya
Taymir Peninsula
Siberia
Resolute
Norilsk
Dudinka
Yenisey
Hudson Bay
Ellesmere Island
Alert
Northwater Polynia
Franz Josef Land
RUSSIA
Novosibirsk
Foxe Basin
Qaanaaq
Baffin Island
Baffin Bay
Station Nord
Novaya Zemlya
Kara Sea
Fram Strait
Surgut
Hudson Strait
Iqaluit
Amderma
Omsk
QUEBEC
GREENLAND
Ny-Ålesund
Svalbard
Ob
Cumberland Sound
Uummannaq
Varandei
Davis Strait
Ilulissat
Barents Sea
Summit
Nelm Nos
Pechora
LABRADOR
Sisimiut
Greenland Sea
Bjørnøya
Yekaterinburg
Chelyabinsk
Nuuk
Kirkenes
Murmansk
Perm
Ittoqqortoormiit
Hammerfest
Kola Peninsula
Paamiut
Jan Mayen
Kautokeino
Arkhangelsk
Isortoq
Tasiilaq
LAPLAND
White Sea
Denmark Strait
Iceland Sea
Kiruna
Kazan
Saudarkrokur
Olafsvik
Reykjavik
ICELAND
Norwegian Sea
Lake Ladoga
FINLAND
Vestmannaeyjar
St. Petersburg
Helsinki
Moscow
Atlantic Ocean
FAROE ISLANDS
Tórshavn
SWEDEN
NORWAY
Bergen
Stockholm
Oslo
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Chernobyl
North Sea
DENMARK
Copenhagen

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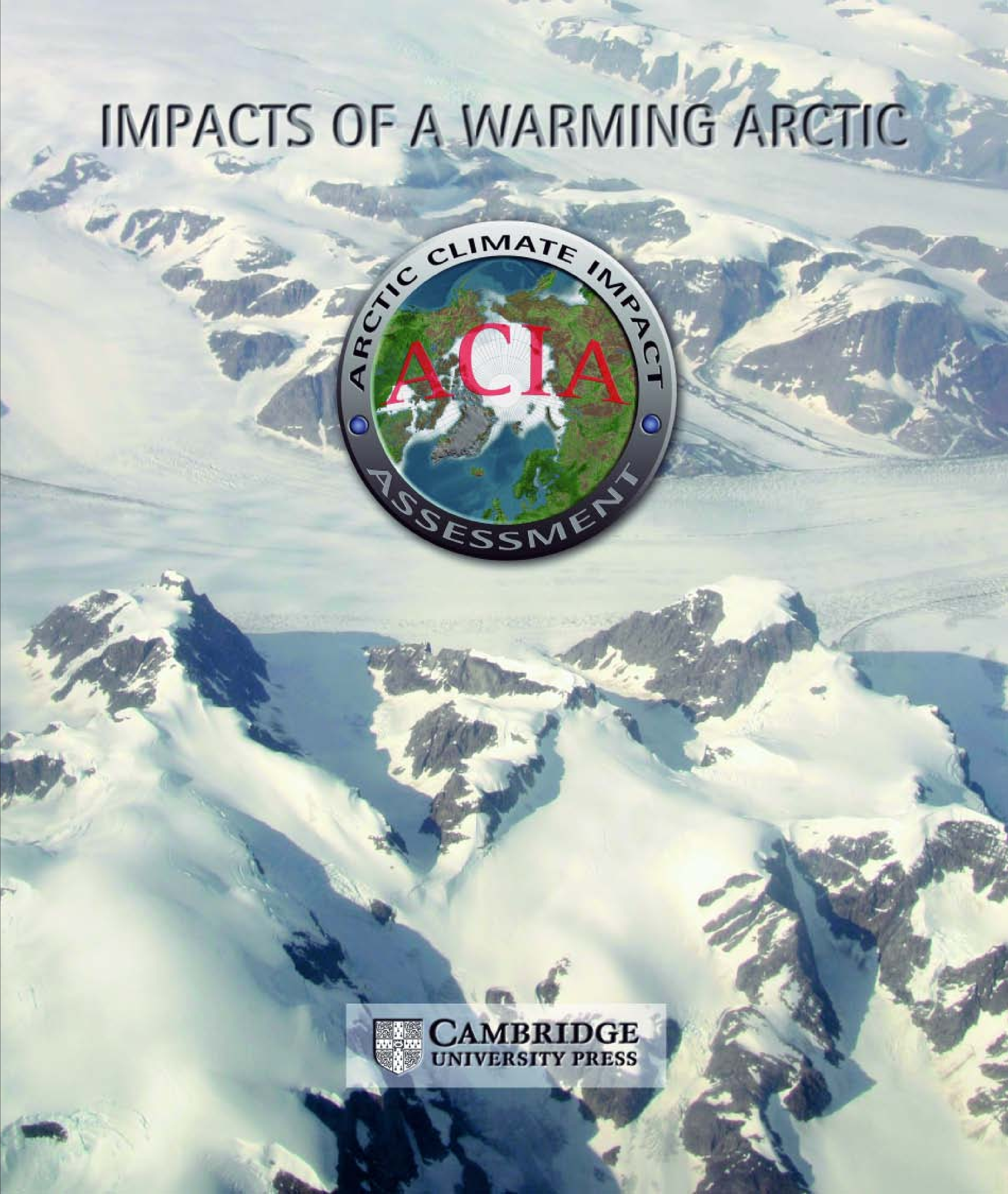

ARCTIC CLIMATE IMPACT ASSESSMENT

ACIA

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Preface

The Arctic is of special importance to the world and it is changing rapidly. It is thus essential that decision makers have the latest and best information available regarding ongoing changes in the Arctic. This report is a plain language synthesis of the key findings of the Arctic Climate Impact Assessment (ACIA), designed to make the scientific findings accessible to policymakers and the broader public. The ACIA is a comprehensively researched, fully referenced, and independently reviewed evaluation of arctic climate change and its impacts for the region and for the world. It has involved an international effort by hundreds of scientists over four years, and also includes the special knowledge of indigenous people.

The Arctic Council called for this assessment, and charged two of its working groups, the Arctic Monitoring and Assessment Programme (AMAP) and the Conservation of Arctic Flora and Fauna (CAFF), along with the International Arctic Science Committee (IASC), with its implementation. Recognizing the central importance of the Arctic and this information to society as it contemplates responses to the growing challenge of climate change, the cooperating organizations are honored to forward this report to the Arctic Council and the international science community.

ACIA is a project implemented by AMAP, CAFF, and IASC

The Arctic Council

The Arctic Council is a high-level intergovernmental forum that provides a mechanism to address the common concerns and challenges faced by arctic people and governments. It is comprised of the eight arctic nations (Canada, Denmark/Greenland/Faroe Islands, Finland, Iceland, Norway, Russia, Sweden, and the United States of America), six Indigenous Peoples organizations (Permanent Participants: Aleut International Association, Arctic Athabaskan Council, Gwich'in Council International, Inuit Circumpolar Conference, Russian Association of Indigenous Peoples of the North, and Saami Council), and official observers (including France, Germany, the Netherlands, Poland, United Kingdom, non-governmental organizations, and scientific and other international bodies).

The International Arctic Science Committee

The International Arctic Science Committee is a non-governmental organization whose aim is to encourage and facilitate cooperation in all aspects of arctic research among scientists and institutions of countries with active arctic research programs. IASC's members are national scientific organizations, generally academies of science, which seek to identify priority research needs, and provide a venue for project development and implementation.

Assessment Steering Committee

The ACIA Assessment Steering Committee was responsible for scientific oversight and coordination of all work related to the preparation of the assessment reports. A list of the members of this committee is found on page 138. The scientific content of the ACIA has been published in two separate reports: this synthesis volume, and a more comprehensive and detailed technical volume that includes references to the scientific literature. AMAP, CAFF, and IASC have received written certification by the ACIA leadership and all lead authors that the final scientific report reflects their expert views, and that this synthesis report is fully consistent with the scientific volume.

How To Read This Report

In presenting these findings, the stated likelihood of particular impacts occurring is based on expert evaluation of results from multiple lines of evidence including field and laboratory experiments, observed trends, theoretical analyses, and model simulations.

Judgments of likelihood based on these inputs are indicated using a five-tier lexicon consistent with everyday usage (very unlikely, unlikely, possible, likely, and very likely). Confidence in results is highest at both ends of this scale. A conclusion that an impact "will" result is reserved for situations where experience and multiple methods of analysis all make clear that the consequence would follow inevitably from the projected change in climate. Although many details of how climate, environment, and society will evolve in the future remain uncertain, experts do have more confidence in some findings than others. The use of the lexicon is thus designed to convey the current state of scientific understanding.

The projected impacts described in this report are based on observed data and a moderate scenario of future warming, *not a worst-case scenario.* Compared to the full range of scenarios analyzed by the Intergovernmental Panel on Climate Change (IPCC), the primary scenario used in the ACIA analyses falls below the middle of the IPCC range of projected temperature rise.

The results summarized in this report, like the extensive, fully referenced technical report upon which it is based, do not include thorough economic analyses of climate change impacts because the necessary information is not presently available. While adaptation strategies are sometimes mentioned, they are not analyzed in detail. The scope of this assessment did not include analysis of efforts to mitigate climate change impacts by reducing emissions of greenhouse gases.

A notation of which chapters of the full technical report have been principally drawn upon for the synthesis presented in this document is indicated in the bottom corner of each left-hand page (with the exception of the Executive Summary and Selected Sub-Regional Impacts, for which all chapters were drawn upon).

Finally, this assessment focused on impacts that are expected to occur within this century. Important longer-term impacts are occasionally mentioned, but not analyzed in detail.

Contents

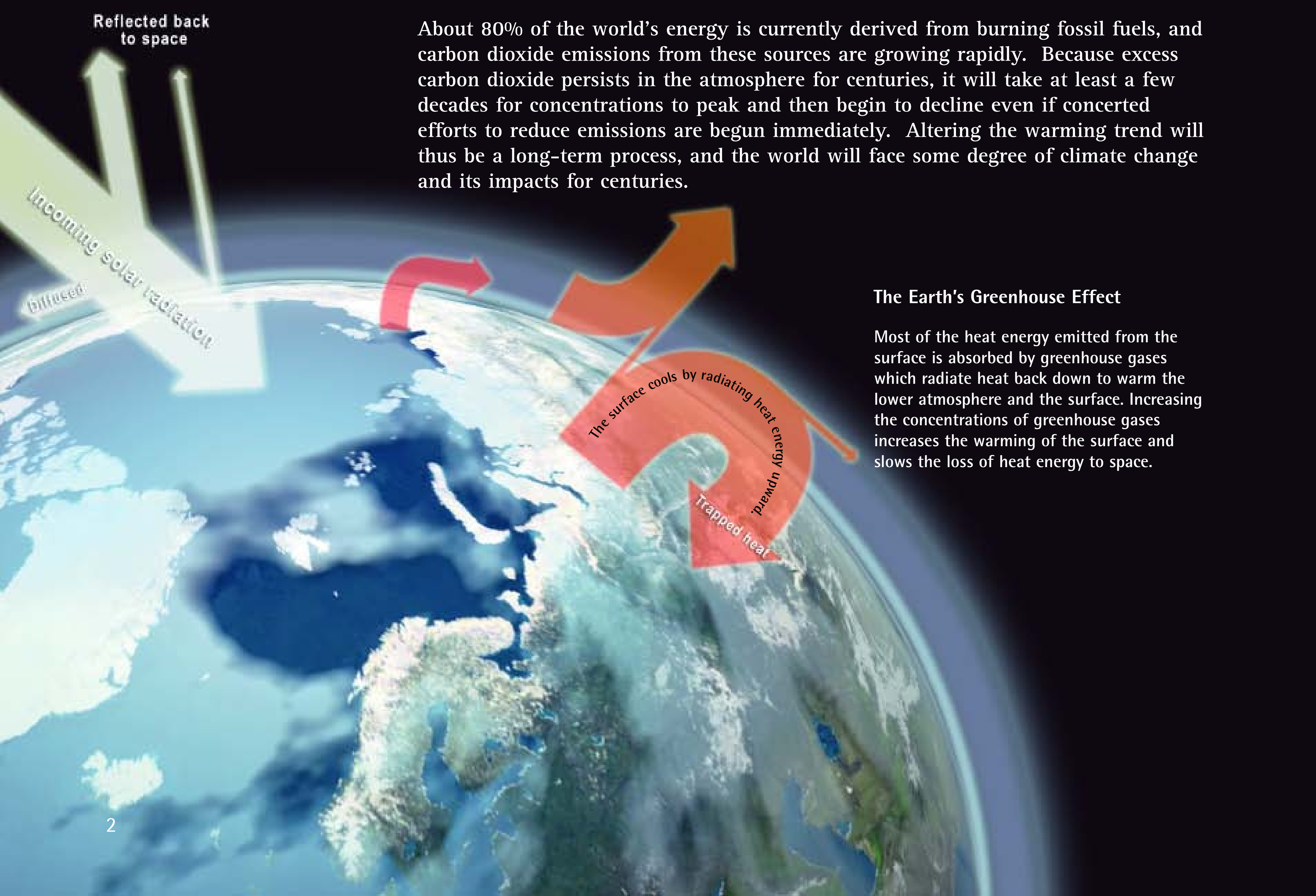
Global Climate Change

> *"There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities."*
>
> *Intergovernmental Panel on Climate Change (IPCC), 2001*

Ice cores and other evidence of climate conditions in the distant past provide evidence that rising atmospheric carbon dioxide levels are associated with rising global temperatures. Human activities, primarily the burning of fossil fuels (coal, oil, and natural gas), and secondarily the clearing of land, have increased the concentration of carbon dioxide, methane, and other heat-trapping ("greenhouse") gases in the atmosphere. Since the start of the industrial revolution, the atmospheric carbon dioxide concentration has increased by about 35% and the global average temperature has risen by about 0.6˚C. There is an international scientific consensus that most of the warming observed over the last 50 years is attributable to human activities.

Continuing to add carbon dioxide and other greenhouse gases to the atmosphere is projected to lead to significant and persistent changes in climate, including an increase in average global temperature of 1.4 to 5.8˚C (according to the IPCC) over the course of this century. Climatic changes are projected to include shifts in atmospheric and oceanic circulation patterns, an accelerating rate of sea-level rise, and wider variations in precipitation. Together, these changes are projected to lead to wide-ranging consequences including significant impacts on coastal communities, animal and plant species, water resources, and human health and well-being.

About 80% of the world's energy is currently derived from burning fossil fuels, and carbon dioxide emissions from these sources are growing rapidly. Because excess carbon dioxide persists in the atmosphere for centuries, it will take at least a few decades for concentrations to peak and then begin to decline even if concerted efforts to reduce emissions are begun immediately. Altering the warming trend will thus be a long-term process, and the world will face some degree of climate change and its impacts for centuries.



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.

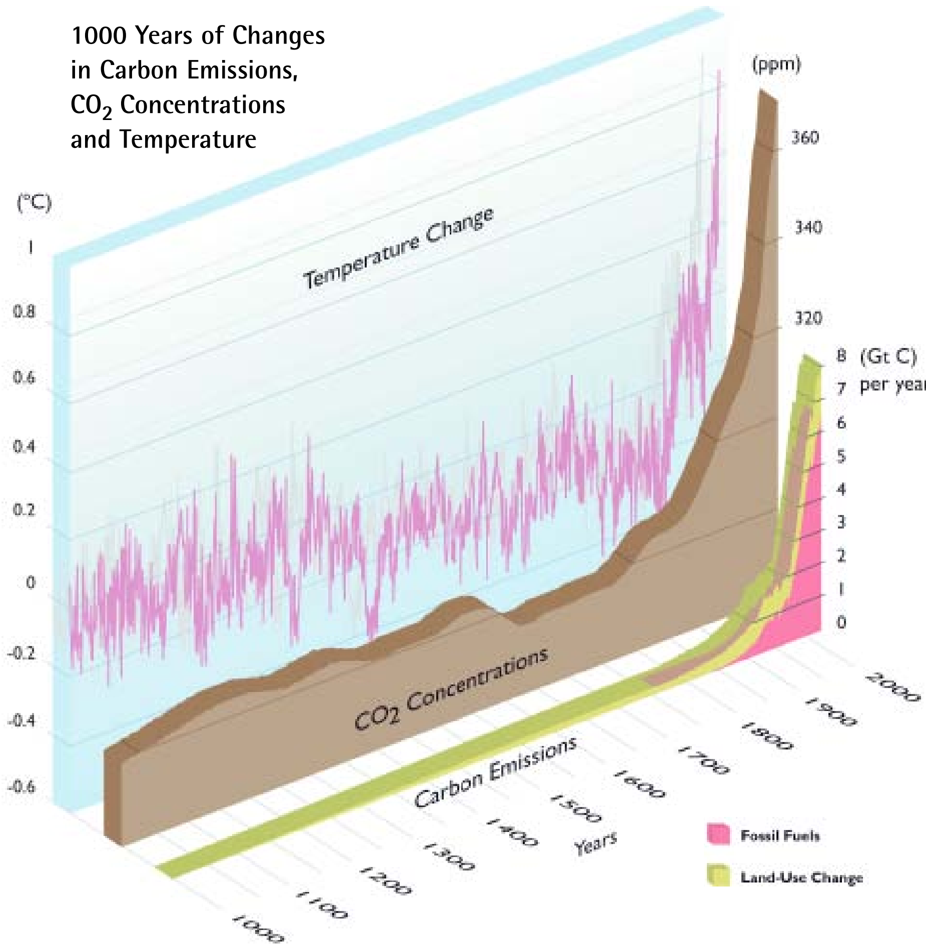
Altering the warming trend will be a long-term process, and the world will face some degree of climate change and its impacts for centuries.

The science suggests that responding to this challenge will require two sets of actions: one, called mitigation, to slow the speed and amount of future climate change by reducing greenhouse gas emissions; and the other, called adaptation, to attempt to limit adverse impacts by becoming more resilient to the climate changes that will occur while society pursues the first set of actions. The scope of this assessment did not include an evaluation of either of these sets of actions. These are being addressed by efforts under the auspices of the United Nations Framework Convention on Climate Change and other bodies.

Stratospheric Ozone Depletion is Another Issue

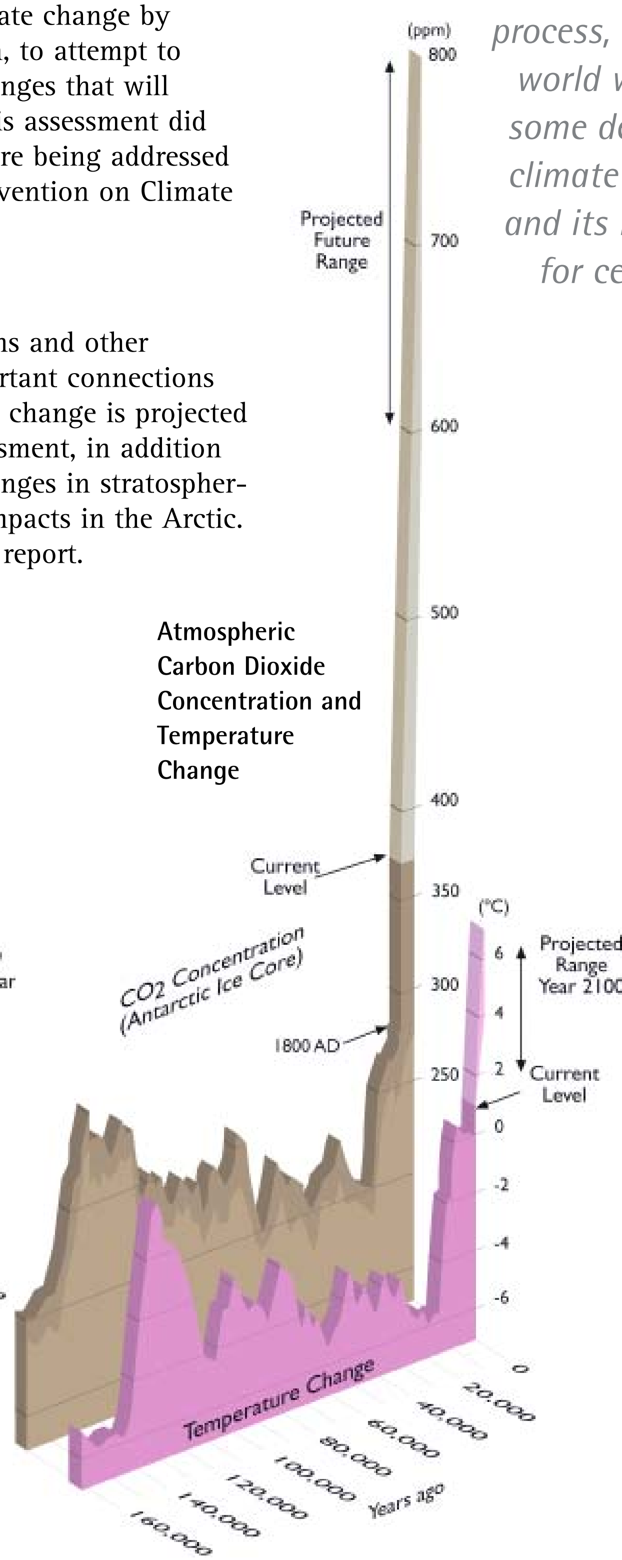
Depletion of the stratospheric ozone layer due to chlorofluorocarbons and other manmade chemicals is a different problem, although there are important connections between ozone depletion and climate change. For example, climate change is projected to delay recovery of stratospheric ozone over the Arctic. This assessment, in addition to its principal focus on climate change impacts, also examined changes in stratospheric ozone, subsequent changes in ultraviolet radiation, and related impacts in the Arctic. A summary of these findings can be found on pages 98-105 of this report.

1000 Years of Changes in Carbon Emissions, CO_2 Concentrations and Temperature



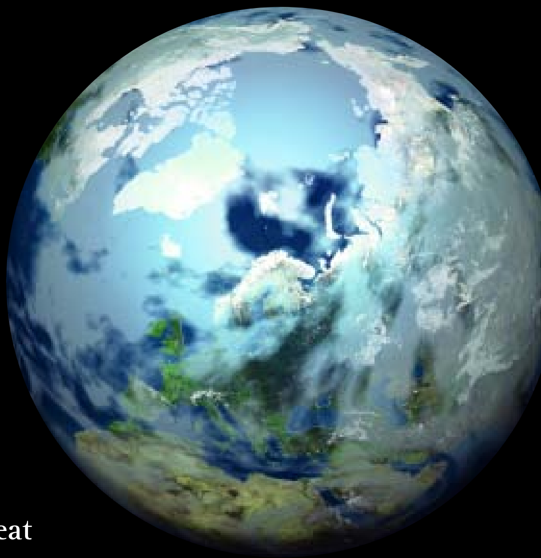
This 1000-year record tracks the rise in carbon emissions due to human activities (fossil fuel burning and land clearing) and the subsequent increase in atmospheric carbon dioxide concentrations, and air temperatures. The earlier parts of this Northern Hemisphere temperature reconstruction are derived from historical data, tree rings, and corals, while the later parts were directly measured. Measurements of carbon dioxide (CO_2) in air bubbles trapped in ice cores form the earlier part of the CO_2 record; direct atmospheric measurements of CO_2 concentration began in 1957.

Atmospheric Carbon Dioxide Concentration and Temperature Change



This record illustrates the relationship between temperature and atmospheric carbon dioxide concentrations over the past 160 000 years and the next 100 years. Historical data are derived from ice cores, recent data were directly measured, and model projections are used for the next 100 years.

The Arctic Region



Polaris, the North Star, is located almost directly above the North Pole. Around it are the stars that form the constellation known as Ursa Major, the Great Bear. The term Arctic comes from the ancient Greek word *Arktikós*, the country of the Great Bear.

Earth's northern polar region consists of a vast ocean surrounded by land, in contrast to the southern polar region in which an ice-covered continent is surrounded by ocean. Perhaps the most striking features are the snow and ice that cover much of the arctic land and sea surface, particularly in the high Arctic. And draped like a pair of great green shawls over the shoulders of the two facing continents are the boreal (meaning northern) forests. A wide expanse of tundra – treeless plains over frozen ground – lies between the icy high north and the forested sub-arctic.

One line often used to define the region is the Arctic Circle, drawn at the latitude north of which the sun does not rise above the horizon at winter solstice and does not set below it at summer solstice – "the land of the midnight sun". Other boundaries used to define the Arctic include treeline, climatic boundaries, and permafrost extent on land and sea-ice extent on the ocean. For the purposes of this assessment, the boundary will be more flexible, also encompassing sub-arctic areas integral to the functioning of the arctic system.

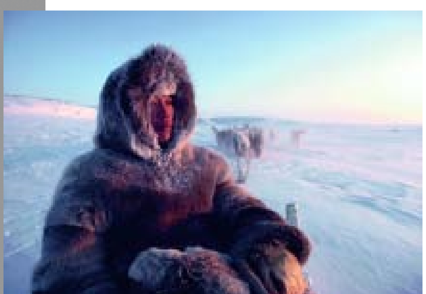
High arctic lands and seas are home to an array of plants, animals, and people that survive in some of the most extreme conditions on the planet. From the algae that live on the underside of sea ice, to the polar bears that hunt on top of the ice, to the indigenous human societies that have developed in close connection with their environment, these communities are uniquely adapted to what many outside the region would view as a very severe climate.

Life in the Arctic has historically been both vulnerable and resilient. Factors that contribute to the Arctic's vulnerability include its relatively short growing season and smaller variety of living things compared to temperate regions. In addition, arctic climate is highly variable, and a sudden summer storm or freeze can wipe out an entire generation of young birds, thousands of seal pups, or hundreds of caribou calves. Yet some arctic species have also displayed remarkable resilience to historic extremes, as evidenced by the recovery of populations that have occasionally been decimated by climatic variations.

The increasingly rapid rate of recent climate change poses new challenges to the resilience of arctic life. In addition to the impacts of climate change, many other stresses brought about by human activities are simultaneously affecting life in the Arctic, including air and water contamination, overfishing, increasing levels of ultraviolet radiation due to ozone depletion, habitat alteration and pollution due to resource extraction, and increasing pressure on land and resources related to the growing human population in the region. The sum of these factors threatens to overwhelm the adaptive capacity of some arctic populations and ecosystems.

The increasingly rapid rate of recent climate change poses new challenges to the resilience of arctic life.






People of the Arctic

Almost four million people live in the Arctic today, with the precise number depending on where the boundary is drawn. They include indigenous people and recent arrivals, hunters and herders living on the land, and city dwellers. Many distinct indigenous groups are found only in the Arctic, where they continue traditional activities and adapt to the modern world at the same time. Humans have long been part of the arctic system, shaping and being shaped by the local and regional environment. In the past few centuries, the influx of new arrivals has increased pressure on the arctic environment through rising fish and wildlife harvests and industrial development.

The Arctic includes part or all of the territories of eight nations: Norway, Sweden, Finland, Denmark, Iceland, Canada, Russia, and the United States, as well as the homelands of dozens of indigenous groups that encompass distinct sub-groups and communities. Indigenous people currently make up roughly 10% of the total arctic population, though in Canada, they represent about half the nation's arctic population, and in Greenland they are the majority. Non-indigenous residents also include many different peoples with distinct identities and ways of life.

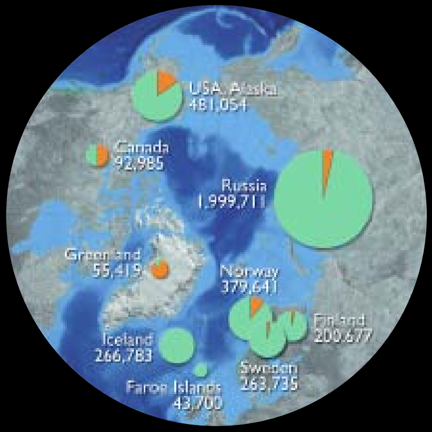
People have occupied parts of the Arctic since at least the peak of the last ice age, about 20 000 years ago, and recent studies suggest a human presence up to 30 000 years ago. In North America, humans are believed to have spread across the Arctic in several waves, reaching Greenland as many as 4500 years ago before abandoning the island for a millennium or more. Innovations such as the harpoon enabled people to hunt large marine mammals, making it possible to inhabit remote coastal areas in which the land offered scant resources. The development of reindeer husbandry in Eurasia allowed human populations to increase dramatically owing to a reliable food source. In Eurasia and across the North Atlantic, new groups of people moved northward over the past thousand years, colonizing new lands such as the Faroe Islands and Iceland, and encountering indigenous populations already present in West Greenland, and northern Norway, Sweden, Finland, and Russia.

In the 20th century, immigration to the Arctic increased dramatically, to the point where the non-indigenous population currently outnumbers the indigenous population in most regions. Many immigrants have been drawn by the prospect of new opportunities such as developing natural resources. Conflicts over land and resource ownership and access have been exacerbated by the rise in population and the incompatibility of some aspects of traditional and modern ways of life. In North America, the indigenous struggle to re-establish rights to land and resources has been addressed to some extent in land claims agreements, the creation of largely self-governed regions within nation-states, and other political and economic actions. In some areas, conflicts remain, particularly concerning the right to use living and mineral resources. In Eurasia, by contrast, indigenous claims and rights have only begun to be addressed as matters of national policy in recent years.

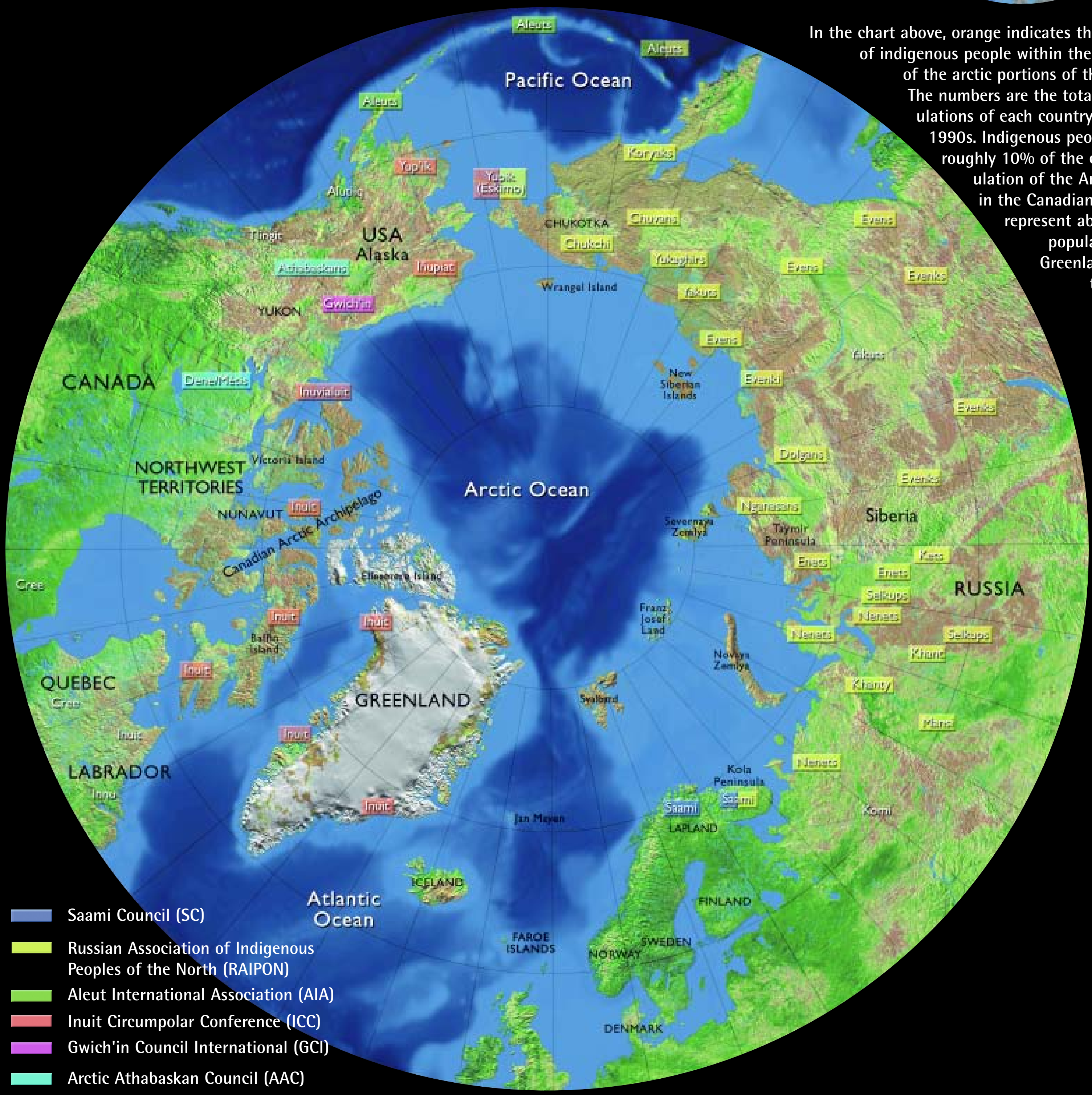
Populations are changing and northern regions are becoming more tightly related economically, politically, and socially to national mainstreams. Life expectancy has increased greatly across most of the Arctic in recent decades. The prevalence of indigenous language use, however, has decreased in most areas, with several languages in danger of disappearing in coming decades. In some respects, the disparities between northern and southern arctic communities in terms of living standards, income, and education are decreasing, although the gaps remain large in most cases.

The economy of the region is based largely on natural resources, from oil, gas, and metal ores to fish, reindeer, caribou, whales, seals, and birds. In recent decades, tourism has added a growing sector to the economies of many communities and regions of the Arctic. Government services including the military are also a major part of the economy in nearly all areas of the Arctic, responsible in some cases for over half of the available jobs. In addition to the cash economy, traditional subsistence and barter economies make a major contribution to the overall well-being of parts of the region, producing significant value that is not recorded in official statistics.

Total and Indigenous Populations of the Arctic



In the chart above, orange indicates the proportion of indigenous people within the populations of the arctic portions of the countries. The numbers are the total arctic populations of each country in the early 1990s. Indigenous people make up roughly 10% of the current population of the Arctic, though in the Canadian Arctic, they represent about half the population, and in Greenland, they are the majority.



Executive Summary

> *"Changes in climate that have already taken place are manifested in the decrease in extent and thickness of Arctic sea ice, permafrost thawing, coastal erosion, changes in ice sheets and ice shelves, and altered distribution and abundance of species."*
>
> *IPCC, 2001*

Arctic Climate Change and Its Impacts

Earth's climate is changing, with the global temperature now rising at a rate unprecedented in the experience of modern human society. While some historical changes in climate have resulted from natural causes and variations, the strength of the trends and the patterns of change that have emerged in recent decades indicate that human influences, resulting primarily from increased emissions of carbon dioxide and other greenhouse gases, have now become the dominant factor.

These climate changes are being experienced particularly intensely in the Arctic. Arctic average temperature has risen at almost twice the rate as the rest of the world in the past few decades. Widespread melting of glaciers and sea ice and rising permafrost temperatures present additional evidence of strong arctic warming. These changes in the Arctic provide an early indication of the environmental and societal significance of global warming.

An acceleration of these climatic trends is projected to occur during this century, due to ongoing increases in concentrations of greenhouse gases in the earth's atmosphere. While greenhouse gas emissions do not primarily originate in the Arctic, they are projected to bring wide-ranging changes and impacts to the Arctic. These arctic changes will, in turn, impact the planet as a whole. For this reason, people outside the Arctic have a great stake in what is happening there. For example, climatic processes unique to the Arctic have significant effects on global and regional climate. The Arctic also provides important natural resources to the rest of the world (such as oil, gas, and fish) that will be affected by climate change. And melting of arctic glaciers is one of the factors contributing to sea-level rise around the globe.

Climate change is also projected to result in major impacts inside the Arctic, some of which are already underway. Whether a particular impact is perceived as negative or positive often depends on one's interests. For example, the reduction in sea ice is very likely to have devastating consequences for polar bears, ice-dependent seals, and local people for whom these animals are a primary food source. On the other hand, reduced sea ice is likely to increase marine access to the region's resources, expanding opportunities for shipping and possibly for offshore oil extraction (although operations could be hampered initially by increasing movement of ice in some areas). Further complicating the issue, possible increases in environmental damage that often accompanies shipping and resource extraction could harm the marine habitat and negatively affect the health and traditional lifestyles of indigenous people.

Another example is that increased areas of tree growth in the Arctic could serve to take up carbon dioxide and supply more wood products and related employment, providing local and global economic benefits.

On the other hand, increased tree growth is likely to add to regional warming and encroach on the habitat for many birds, reindeer/caribou, and other locally beneficial species, thereby adversely affecting local residents. Potential complications include projected increases in forest disturbances such as fires and insect outbreaks that could reduce expected benefits.

Climate change is taking place within the context of many other ongoing changes in the Arctic, including the observed increase in chemical contaminants entering the Arctic from other regions, overfishing, land use changes that result in habitat destruction and fragmentation, rapid growth in the human population, and cultural, governance, and economic changes. Impacts on the environment and society result not from climate change alone, but from the interplay of all of these changes. This assessment has made an initial attempt to reveal some of this complexity, but limitations in current knowledge do not allow for a full analysis of all the interactions and their impacts.

Unless we change our direction, we are likely to end up where we are headed.

One of the additional stresses in the Arctic that is addressed in this assessment results from increasing levels of ultraviolet radiation reaching the earth's surface due to stratospheric ozone depletion. As with many of the other stresses mentioned, there are important interactions between climate change and ozone depletion. The effects of climate change on the upper atmosphere make continued ozone depletion over the Arctic likely to persist for at least a few more decades. Thus, ultraviolet radiation levels in the Arctic are likely to remain elevated, and this will be most pronounced in the spring, when ecosystems are most sensitive to harmful ultraviolet radiation. The combination of climate change, excess ultraviolet radiation, and other stresses presents a range of potential problems for human health and well-being as well as risks to other arctic species and ecosystems.

The impacts of climate change in the Arctic addressed in this assessment are largely caused from outside the region, and will reverberate back to the global community in a variety of ways. The scientific findings reported here can inform decisions about actions to reduce the risks of climate change. As the pace and extent of climate change and its impacts increase, it will become more and more important for people everywhere to become aware of the changes taking place in the Arctic, and to consider them in evaluating what actions should be taken to respond.

Are These Impacts Inevitable?

Carbon dioxide concentrations in the atmosphere, which have risen rapidly due to human activities, will remain elevated above natural levels for centuries, even if emissions were to cease immediately. Some continued warming is thus inevitable. However, the speed and amount of warming can be reduced if future emissions are limited sufficiently to stabilize the concentrations of greenhouse gases. The scenarios developed by the IPCC assume a variety of different societal developments, resulting in various plausible levels of future emissions. None of these scenarios assume implementation of explicit policies to reduce greenhouse gas emissions. Thus, atmospheric concentrations do not level off in these scenarios, but rather continue to rise, resulting in significant increases in temperature and sea level and widespread changes in precipitation. The costs and difficulties of adapting to such increases are very likely to increase significantly over time.

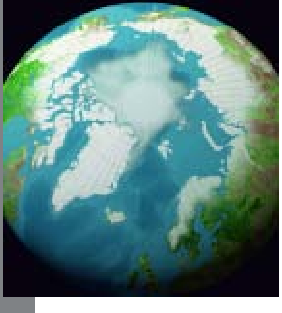
If, on the other hand, society chooses to reduce emissions substantially, the induced changes in climate would be smaller and would happen more slowly. This would not eliminate all impacts, especially some of the irreversible impacts affecting particular species. However, it would allow ecosystems and human societies as a whole to adapt more readily, reducing overall impacts and costs. The impacts addressed in this assessment assume continued growth in greenhouse gas emissions. Although it will be very difficult to limit near-term consequences resulting from past emissions, many longer-term impacts could be reduced significantly by reducing global emissions over the course of this century. This assessment did not analyze strategies for achieving such reductions, which are the subject of efforts by other bodies.

Key Findings

The Arctic is extremely vulnerable to observed and projected climate change and its impacts. The Arctic is now experiencing some of the most rapid and severe climate change on earth. Over the next 100 years, climate change is expected to accelerate, contributing to major physical, ecological, social, and economic changes, many of which have already begun. Changes in arctic climate will also affect the rest of the world through increased global warming and rising sea levels.

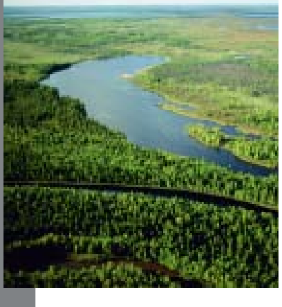
1. Arctic climate is now warming rapidly and much larger changes are projected.

- Annual average arctic temperature has increased at almost twice the rate as that of the rest of the world over the past few decades, with some variations across the region.
- Additional evidence of arctic warming comes from widespread melting of glaciers and sea ice, and a shortening of the snow season.
- Increasing global concentrations of carbon dioxide and other greenhouse gases due to human activities, primarily fossil fuel burning, are projected to contribute to additional arctic warming of about 4-7°C over the next 100 years.
- Increasing precipitation, shorter and warmer winters, and substantial decreases in snow cover and ice cover are among the projected changes that are very likely to persist for centuries.
- Unexpected and even larger shifts and fluctuations in climate are also possible.



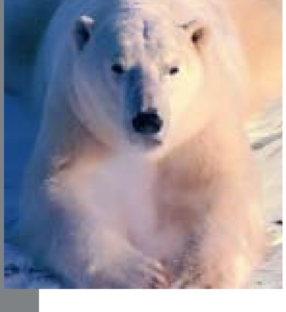
2. Arctic warming and its consequences have worldwide implications.

- Melting of highly reflective arctic snow and ice reveals darker land and ocean surfaces, increasing absorption of the sun's heat and further warming the planet.
- Increases in glacial melt and river runoff add more freshwater to the ocean, raising global sea level and possibly slowing the ocean circulation that brings heat from the tropics to the poles, affecting global and regional climate.
- Warming is very likely to alter the release and uptake of greenhouse gases from soils, vegetation, and coastal oceans.
- Impacts of arctic climate change will have implications for biodiversity around the world because migratory species depend on breeding and feeding grounds in the Arctic.



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

- Treeline is expected to move northward and to higher elevations, with forests replacing a significant fraction of existing tundra, and tundra vegetation moving into polar deserts.
- More-productive vegetation is likely to increase carbon uptake, although reduced reflectivity of the land surface is likely to outweigh this, causing further warming.
- Disturbances such as insect outbreaks and forest fires are very likely to increase in frequency, severity, and duration, facilitating invasions by non-native species.
- Where suitable soils are present, agriculture will have the potential to expand northward due to a longer and warmer growing season.



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

- Reductions in sea ice will drastically shrink marine habitat for polar bears, ice-inhabiting seals, and some seabirds, pushing some species toward extinction.
- Caribou/reindeer and other land animals are likely to be increasingly stressed as climate change alters their access to food sources, breeding grounds, and historic migration routes.
- Species ranges are projected to shift northward on both land and sea, bringing new species into the Arctic while severely limiting some species currently present.
- As new species move in, animal diseases that can be transmitted to humans, such as West Nile virus, are likely to pose increasing health risks.
- Some arctic marine fisheries, which are of global importance as well as providing major contributions to the region's economy, are likely to become more productive. Northern freshwater fisheries that are mainstays of local diets are likely to suffer.

5. Many coastal communities and facilities face increasing exposure to storms.

- Severe coastal erosion will be a growing problem as rising sea level and a reduction in sea ice allow higher waves and storm surges to reach the shore.
- Along some arctic coastlines, thawing permafrost weakens coastal lands, adding to their vulnerability.
- The risk of flooding in coastal wetlands is projected to increase, with impacts on society and natural ecosystems.
- In some cases, communities and industrial facilities in coastal zones are already threatened or being forced to relocate, while others face increasing risks and costs.

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

- The continuing reduction of sea ice is very likely to lengthen the navigation season and increase marine access to the Arctic's natural resources.
- Seasonal opening of the Northern Sea Route is likely to make trans-arctic shipping during summer feasible within several decades. Increasing ice movement in some channels of the Northwest Passage could initially make shipping more difficult.
- Reduced sea ice is likely to allow increased offshore extraction of oil and gas, although increasing ice movement could hinder some operations.
- Sovereignty, security, and safety issues, as well as social, cultural, and environmental concerns are likely to arise as marine access increases.

7. Thawing ground will disrupt transportation, buildings, and other infrastructure.

- Transportation and industry on land, including oil and gas extraction and forestry, will increasingly be disrupted by the shortening of the periods during which ice roads and tundra are frozen sufficiently to permit travel.
- As frozen ground thaws, many existing buildings, roads, pipelines, airports, and industrial facilities are likely to be destabilized, requiring substantial rebuilding, maintenance, and investment.
- Future development will require new design elements to account for ongoing warming that will add to construction and maintenance costs.
- Permafrost degradation will also impact natural ecosystems through collapsing of the ground surface, draining of lakes, wetland development, and toppling of trees in susceptible areas.

8. Indigenous communities are facing major economic and cultural impacts.

- Many Indigenous Peoples depend on hunting polar bear, walrus, seals, and caribou, herding reindeer, fishing, and gathering, not only for food and to support the local economy, but also as the basis for cultural and social identity.
- Changes in species' ranges and availability, access to these species, a perceived reduction in weather predictability, and travel safety in changing ice and weather conditions present serious challenges to human health and food security, and possibly even the survival of some cultures.
- Indigenous knowledge and observations provide an important source of information about climate change. This knowledge, consistent with complementary information from scientific research, indicates that substantial changes have already occurred.

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

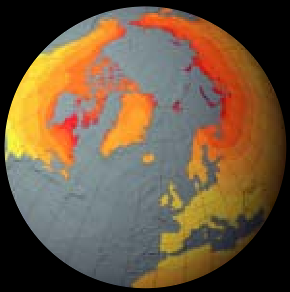
- The stratospheric ozone layer over the Arctic is not expected to improve significantly for at least a few decades, largely due to the effect of greenhouse gases on stratospheric temperatures. Ultraviolet radiation (UV) in the Arctic is thus projected to remain elevated in the coming decades.
- As a result, the current generation of arctic young people is likely to receive a lifetime dose of UV that is about 30% higher than any prior generation. Increased UV is known to cause skin cancer, cataracts, and immune system disorders in humans.
- Elevated UV can disrupt photosynthesis in plants and have detrimental effects on the early life stages of fish and amphibians.
- Risks to some arctic ecosystems are likely as the largest increases in UV occur in spring, when sensitive species are most vulnerable, and warming-related declines in snow and ice cover increase exposure for living things normally protected by such cover.

10. Multiple influences interact to cause impacts to people and ecosystems.

- Changes in climate are occurring in the context of many other stresses including chemical pollution, overfishing, land use changes, habitat fragmentation, human population increases, and cultural and economic changes.
- These multiple stresses can combine to amplify impacts on human and ecosystem health and well-being. In many cases, the total impact is greater than the sum of its parts, such as the combined impacts of contaminants, excess ultraviolet radiation, and climatic warming.
- Unique circumstances in arctic sub-regions determine which are the most important stresses and how they interact.

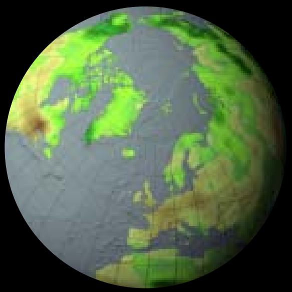
Arctic Climate Trends

Warming in the Arctic is causing changes in nearly every part of the physical climate system. Some of these changes are highlighted below and explored in further detail throughout this report.



Rising Temperatures

Temperatures have increased sharply in recent decades over most of the region, especially in winter. Winter increases in Alaska and western Canada have been around 3-4°C over the past half century. Larger increases are projected this century.



Increasing Precipitation

Arctic precipitation has increased by about 8% on average over the past century. Much of the increase has come as rain, with the largest increases in autumn and winter. Greater increases are projected for the next 100 years.

Rising River Flows

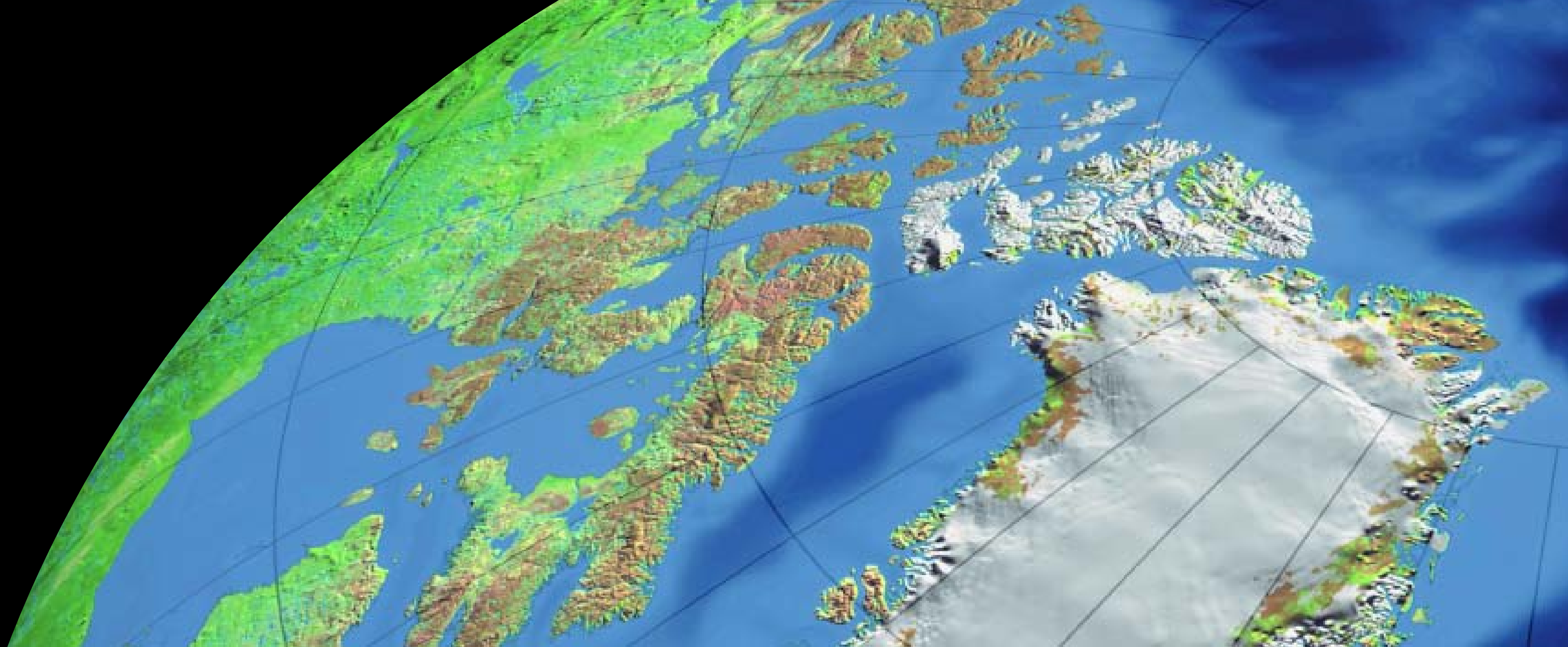
River discharge to the ocean has increased over much of the Arctic during the past few decades and spring peak river flows are occurring earlier. These changes are projected to accelerate.

Thawing Permafrost

Permafrost has warmed by up to 2°C in recent decades, and the depth of the layer that thaws each year is increasing in many areas. Permafrost's southern limit is projected to shift northward by several hundred kilometers during this century.

Declining Snow Cover

Snow cover extent has declined about 10% over the past 30 years. Additional decreases of 10-20% by the 2070s are projected, with the greatest declines in spring.



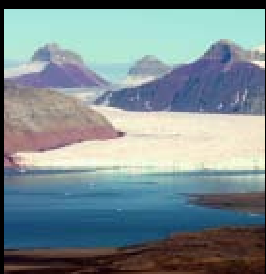
"The world can tell us everything we want to know. The only problem for the world is that it doesn't have a voice. But the world's indicators are there. They are always talking to us."

Quitsak Tarkiasuk

Ivujivik, Canada

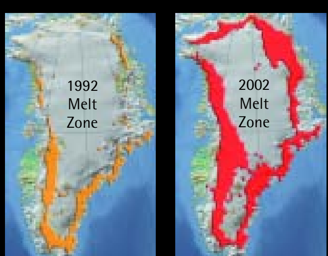
Diminishing Lake and River Ice

Later freeze-up and earlier break-up of river and lake ice have combined to reduce the ice season by one to three weeks in some areas. The strongest trends are over North America and western Eurasia.



Melting Glaciers

Glaciers throughout the Arctic are melting. The especially rapid retreat of Alaskan glaciers represents about half of the estimated loss of mass by glaciers worldwide, and the largest contribution by glacial melt to rising sea level yet measured.



Melting Greenland Ice Sheet

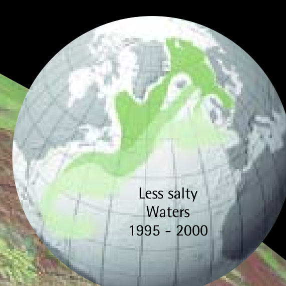
The area of the Greenland Ice Sheet that experiences some melting has increased about 16% from 1979 to 2002. The area of melting in 2002 broke all previous records.

Retreating Summer Sea Ice

The average extent of sea-ice cover in summer has declined by 15-20% over the past 30 years. This decline is expected to accelerate, with the near total loss of sea ice in summer projected for late this century.

Rising Sea Level

Global and arctic sea level has risen 10-20 centimeters in the past 100 years. About an additional half meter of sea-level rise (with a range of 10 to 90 cm) is projected to occur during this century. The increase in the Arctic is projected to be greater than the global average. The slope of the land and whether the coastline is rising or falling also affects the relative sea-level rise in each location.



Ocean Salinity Change

Reduced salinity and density have been observed in the North Atlantic Ocean as melting ice and increasing river runoff have added more freshwater to the ocean. If this trend persists, it could cause changes in ocean circulation patterns that strongly affect regional climate.

Impacts on Natural Systems

The climate trends highlighted on the previous pages affect natural ecosystems. Some of these impacts are highlighted below and explored throughout this report.

Wetland Changes

Permafrost thawing will cause lakes and wetlands to drain in some areas, while creating new wetlands in other places. The balance of these changes is not known, but as freshwater habitats are thus modified, major species shifts are likely.

Vegetation Shifts

Vegetation zones are projected to shift northward, with forests encroaching on tundra, and tundra encroaching on polar deserts. Limitations in amount and quality of soils are likely to slow this transition in some areas.

Increasing Fires and Insects

Forest fires, insect infestations, and other disturbances are projected to increase in frequency and intensity. Such events can subject habitats to invasion by non-native species.

Northward Species Shifts

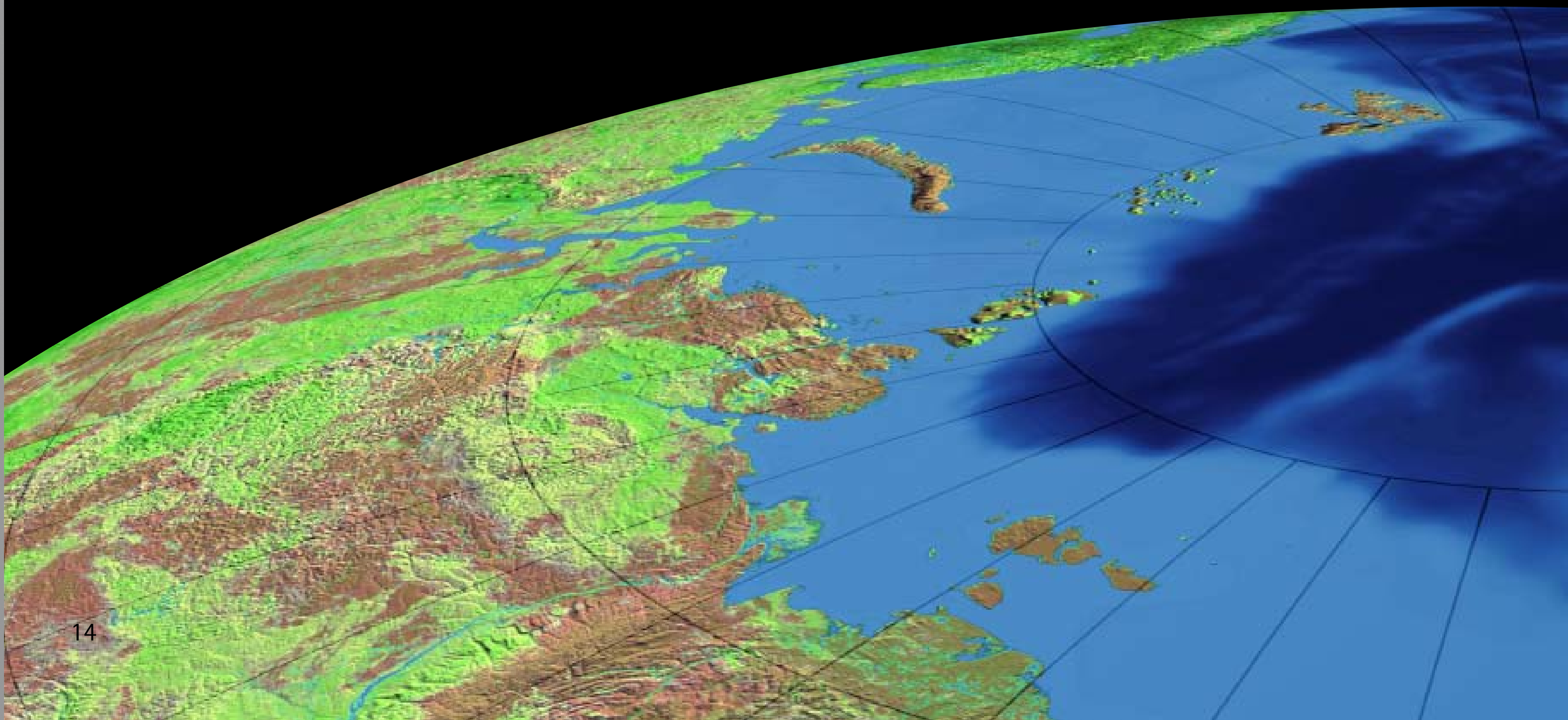
The ranges of many plant and animal species are projected to shift northward, resulting in an increased number of species in the Arctic. Some currently widespread arctic species are likely to suffer major declines.

Marine Species at Risk

Marine species dependent on sea ice, including polar bears, ice-living seals, walrus, and some marine birds, are very likely to decline, with some species facing extinction.

Land Species at Risk

Species quite specifically adapted to the arctic climate are especially at risk including many species of mosses and lichens, lemmings, voles, arctic fox, and snowy owl.

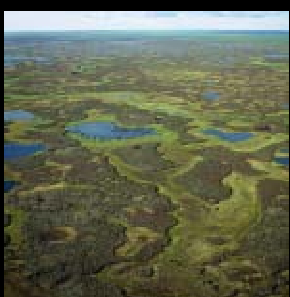


UV Impacts

Increased ultraviolet radiation reaching the earth's surface as a result of stratospheric ozone depletion and the reduction in spring snow and ice cover will impact ecosystems on land and in water.

Old-growth Forest Loss

Old-growth forest is rich in species of lichens, mosses, fungi, insects, woodpeckers, and birds that nest in tree cavities. Climate warming would increase forest fires and insect-caused tree death, further reducing this valuable habitat which is already declining due to other human activities.

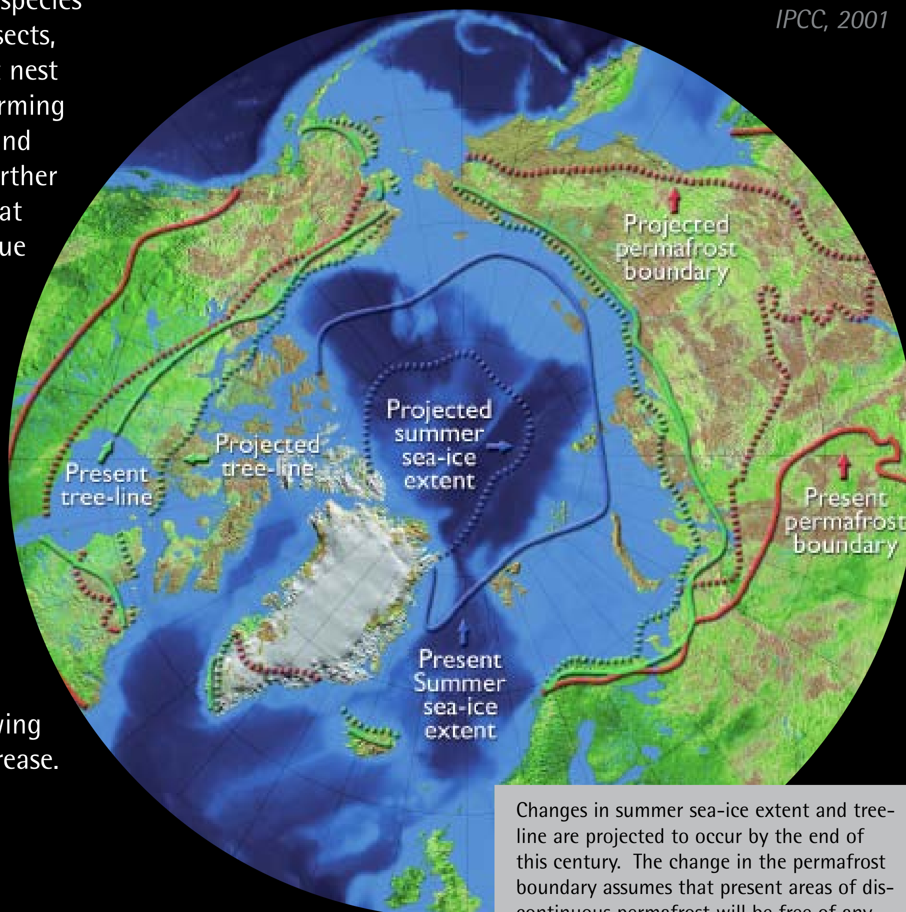


Carbon Cycle Changes

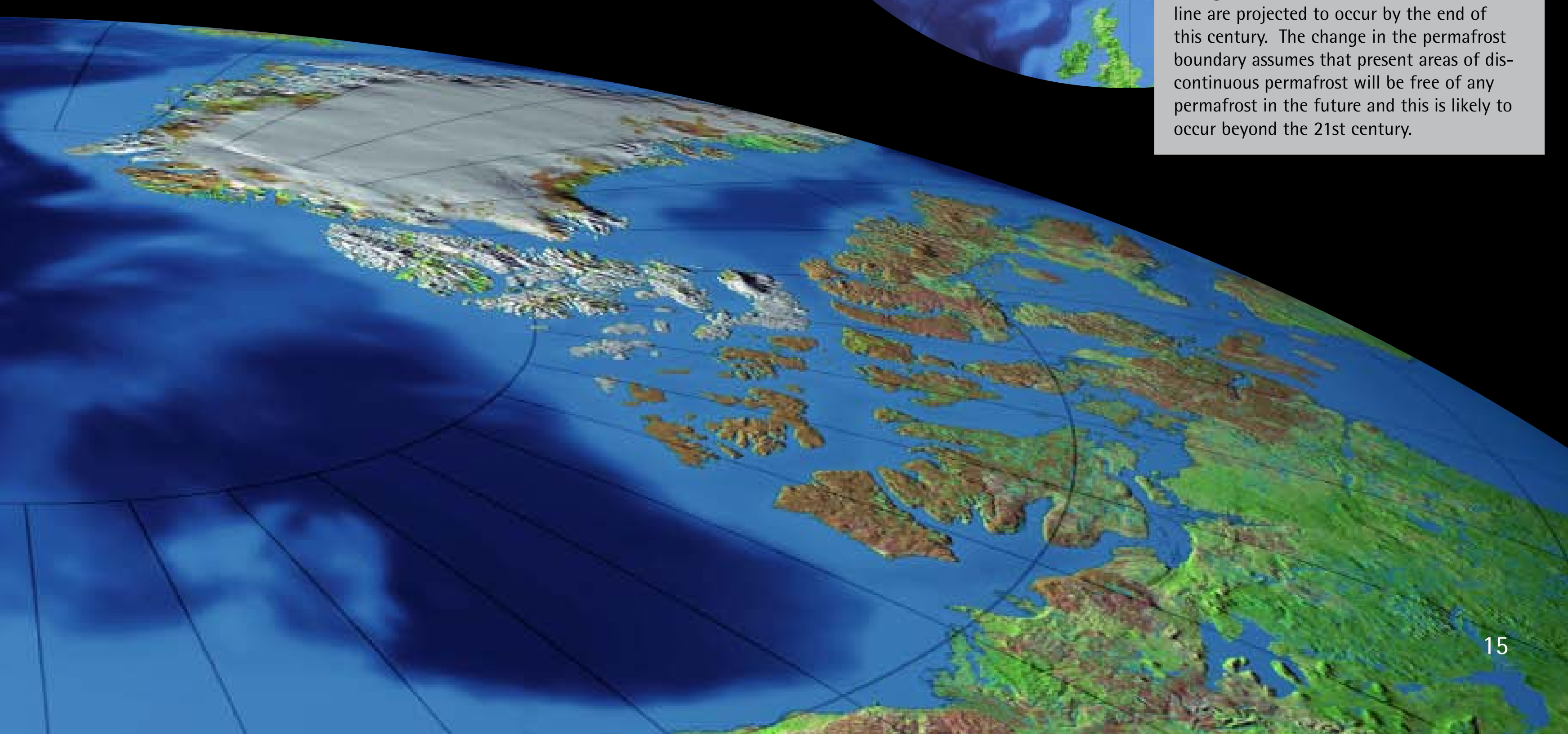
Over time, replacement of arctic vegetation with more productive vegetation from the south is likely to increase carbon dioxide uptake. On the other hand, methane emissions, mainly from warming wetlands and thawing permafrost, are likely to increase.

"Climate change in polar regions is expected to be among the largest and most rapid of any region on the Earth, and will cause major physical, ecological, sociological, and economic impacts, especially in the Arctic..."

IPCC, 2001



Changes in summer sea-ice extent and tree-line are projected to occur by the end of this century. The change in the permafrost boundary assumes that present areas of discontinuous permafrost will be free of any permafrost in the future and this is likely to occur beyond the 21st century.



Impacts on Society

The changes in climate and natural systems highlighted on the previous pages are projected to lead to numerous impacts on society throughout the Arctic.

Loss of Hunting Culture

For Inuit, warming is likely to disrupt or even destroy their hunting and food-sharing culture as reduced sea ice causes the animals on which they depend to decline, become less accessible, and possibly become extinct.

Declining Food Security

Access to traditional foods including seal, polar bear, caribou, and some fish and bird species is likely to be seriously impaired by climate warming. Reduced quality of food sources, such as diseased fish and dried up berries, are already being observed in some locations. Shifting to a more Western diet carries risks of increased diabetes, obesity, and cardiovascular diseases.

Human Health Concerns

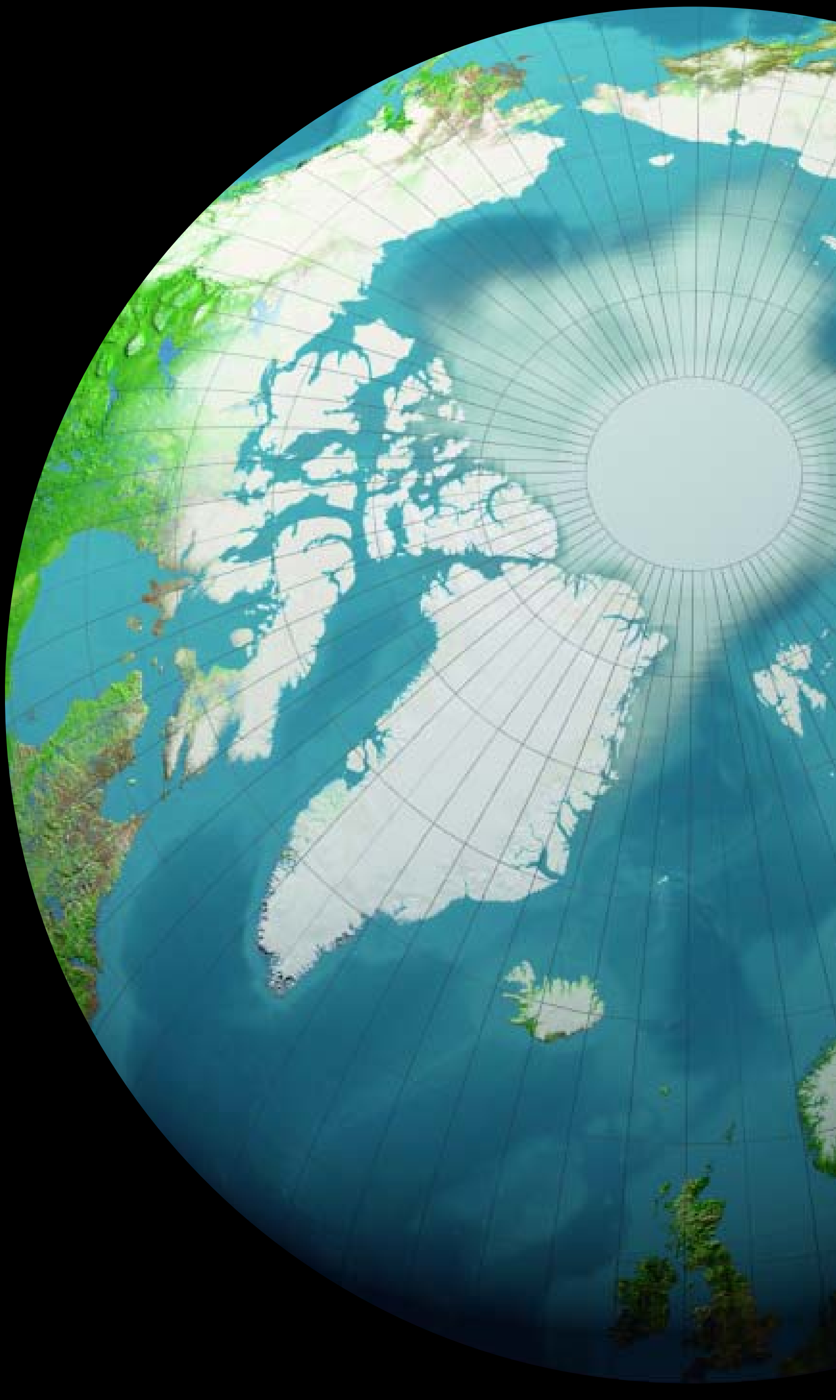
Human health concerns also include increased accident rates due to environmental changes such as sea ice thinning, and health problems caused by adverse impacts on sanitation infrastructure due to thawing permafrost.

Wildlife Herd Impacts

Caribou and reindeer herds will face a variety of climate-related changes in their migration routes, calving grounds, and forage availability as snow and river ice conditions change, thus affecting the people who depend on hunting and herding them.

Expanding Marine Shipping

Shipping through key marine routes, including the Northern Sea Route and the Northwest Passage, is likely to increase. The summer navigation season is projected to lengthen considerably as the century progresses, due to the decline of sea ice. Expansion of tourism and marine transport of goods are likely outcomes.



Increasing Access to Resources

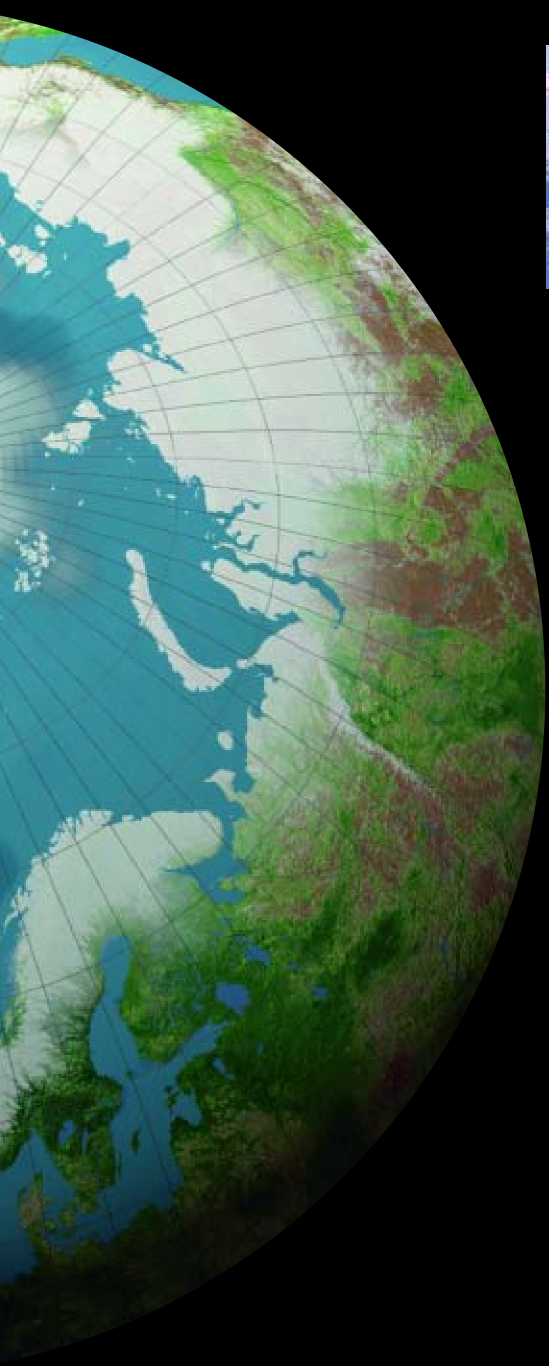
Marine access to some arctic resources, including offshore oil and gas and some minerals, is likely to be enhanced by the reduction in sea ice, bringing new opportunities as well as environmental concerns. Increased ice movement could initially make some operations more difficult.

Enhanced Marine Fisheries

Some major arctic marine fisheries, including those for herring and cod, are likely to become more productive as climate warms. Ranges and migration patterns of many fish species are very likely to change.

"Nowadays snows melt earlier in the springtime. Lakes, rivers, and bogs freeze much later in the autumn. Reindeer herding becomes more difficult as the ice is weak and may give way... Nowadays the winters are much warmer than they used to be. Occasionally during wintertime it rains. We never expected this; we could not be ready for this. It is very strange... The cycle of the yearly calendar has been disturbed greatly and this affects the reindeer herding negatively for sure."

Larisa Avdeyeva
Lovozero, Russia

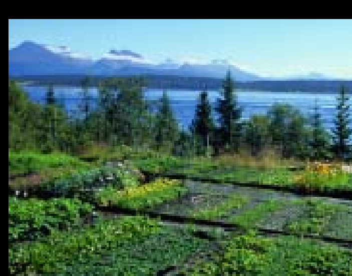


Disrupted Transport on Land

Transportation routes and pipelines on land are already being disturbed in some places by thawing ground, and this problem is likely to expand. Oil and gas extraction and forestry will be increasingly disrupted by the shrinking of the period during which ice roads and tundra are sufficiently frozen to allow industrial operations. Northern communities that rely on frozen roadways to truck in supplies are also being affected.

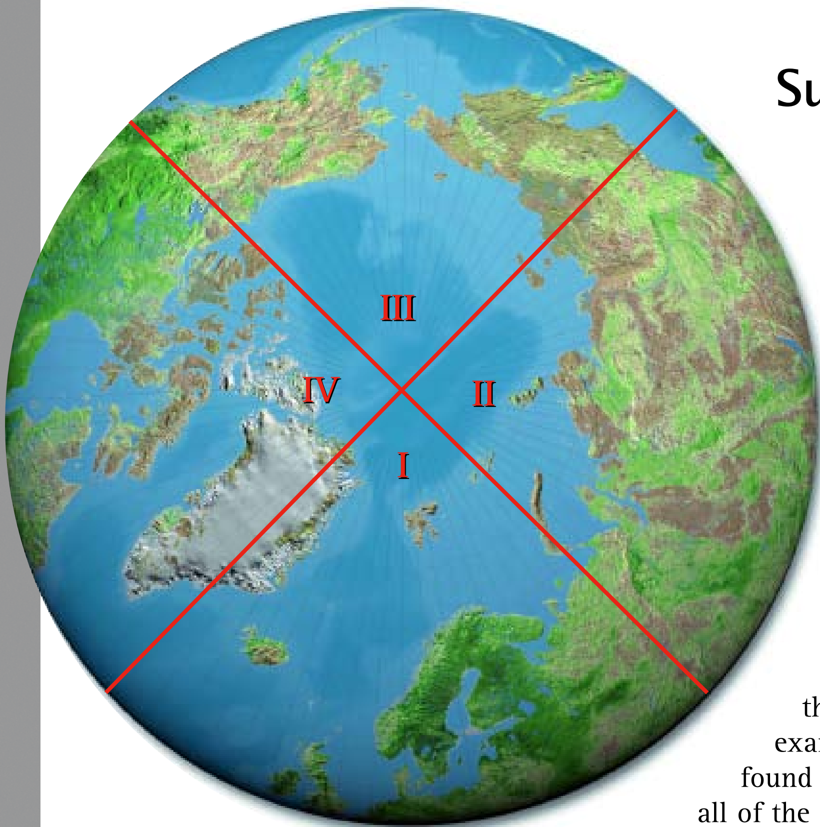
Decline in Northern Freshwater Fisheries

Decreased abundance and local and global extinctions of arctic-adapted fish species are projected for this century. Arctic char, broad whitefish, and Arctic cisco, which are major contributors to the diets of local people, are among the species threatened by a warming climate.



Enhanced Agriculture and Forestry

Agricultural and forestry opportunities are likely to increase as potential areas for food and wood production expand northward due to a longer and warmer growing season and increasing precipitation.

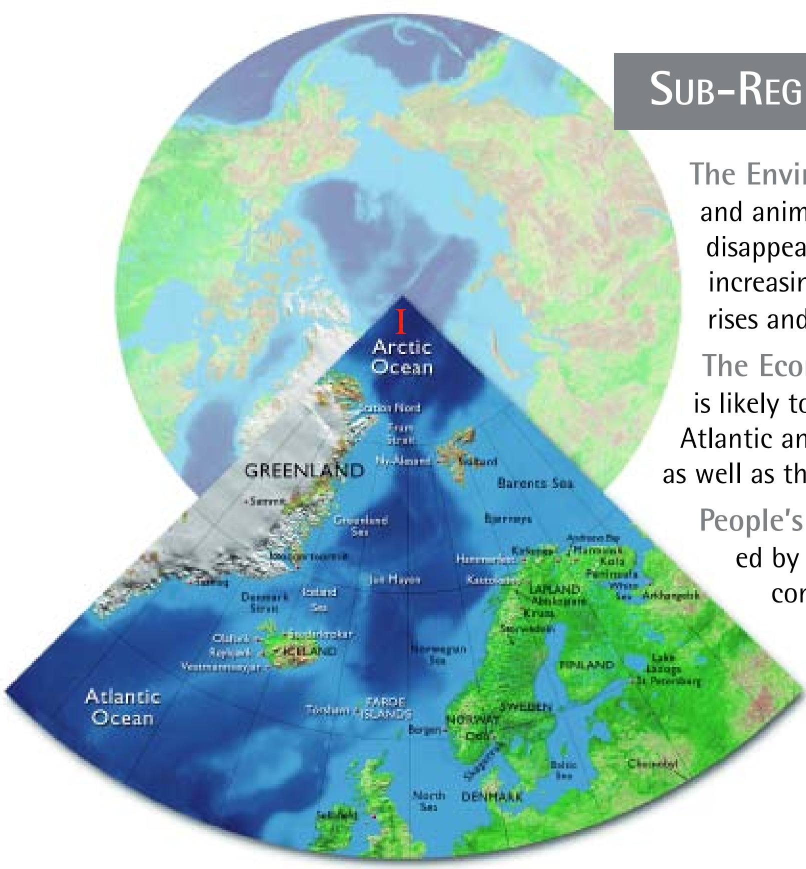


Sub-Regional Overview

In a region as large and diverse as the Arctic, there are significant sub-regional variations in climate. Recent warming has been more dramatic in some areas than others. A few places, such as parts of Canada and Greenland surrounding the Labrador Sea, have not yet experienced the widespread warming of the rest of the region, and have actually cooled. Regional variations in future climate change are also projected. Local features of the natural world and societies also create differences in what impacts will occur and which will be most significant in each sub-region.

For this assessment, four sub-regions were identified, and this report highlights selected impacts in each of these sub-regions. This is not a comprehensive evaluation of climate change impacts in these areas, nor an appraisal of which impacts are the most significant. Rather, it is a brief selection of important examples that emerged from this assessment. Further details can be found on pages 114-121 of this report. Some impacts are important in all of the sub-regions, but to avoid repetition, are not specifically discussed in each. Other assessments, some already underway, will examine the impacts of some specific activities, such as oil extraction, in these Arctic sub-regions.

In assessing future impacts in the sub-regions, projected changes in climate were primarily derived from global scale climate models. As regional scale climate models improve and become more widely available, future assessments may be capable of more precisely detailing the local and regional patterns of change. For this assessment, the patterns of climate change and their impacts should be viewed at a fairly broad regional scale, as they become less certain and less specific at smaller scales.



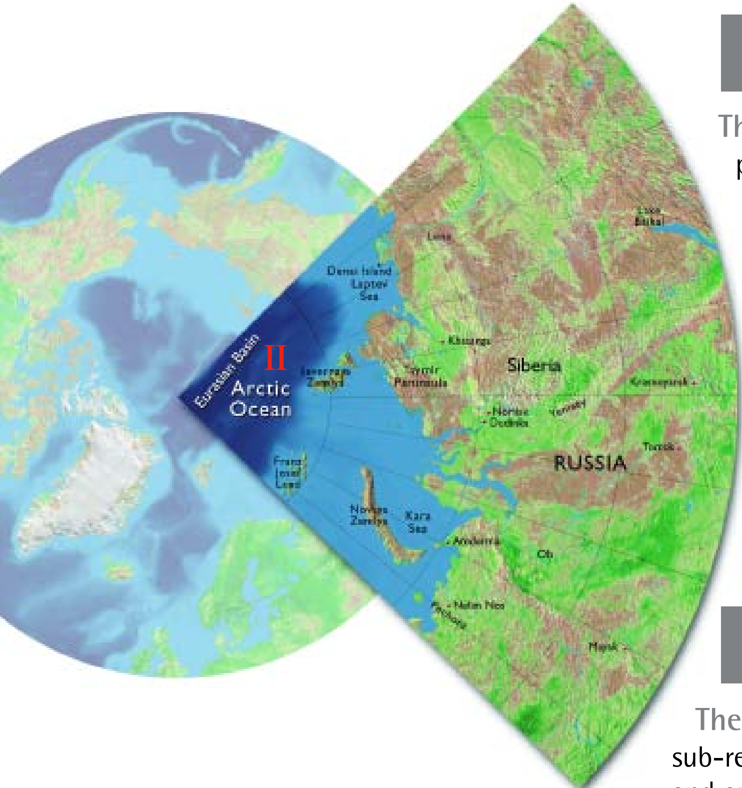
Sub-Region I

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

The Environment Northward shifts in the ranges of plant and animal species are very likely, with some tundra areas disappearing from the mainland. Low-lying coastal areas are increasingly likely to be inundated by storm surges as sea level rises and sea ice retreats.

The Economy Marine access to oil, gas, and mineral resources is likely to improve as sea ice retreats. A general increase in North Atlantic and Arctic fisheries is likely, based on traditional species as well as the influx of more southerly species.

People's Lives Reindeer herding is likely to be adversely affected by reduced snow cover and 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.



Sub-Region II — Siberia and adjacent seas

The Environment Forests are likely to change significantly as climate warms, permafrost thaws, and fire and insect disturbances increase. Forests and shrublands are very likely to replace tundra in many areas. Plant and animal species will shift northward. River discharge will increase.

The Economy Sea-ice retreat is very likely to increase the navigation season through the Northern Sea Route, presenting 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.

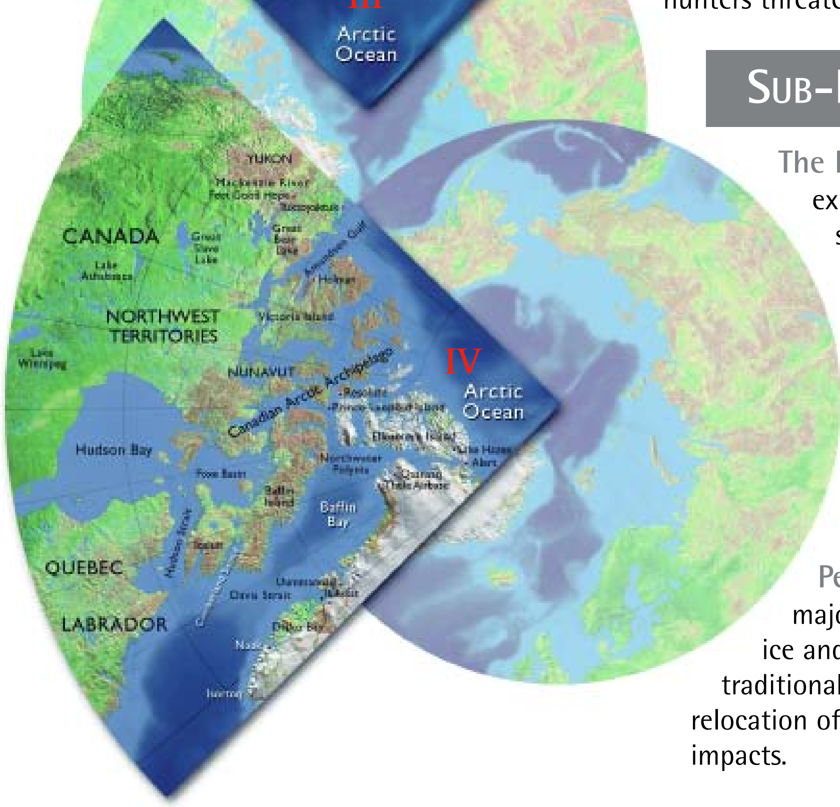
People's Lives Permafrost thawing is already causing serious damage to buildings and industrial facilities and is projected to continue. A shrinking river ice season and thawing permafrost are likely to hinder reindeer migration routes, affecting traditional livelihoods of indigenous people.

Sub-Region III — Chukotka, Alaska, Western Canadian Arctic, and adjacent seas

The Environment Biological diversity is most at risk from climate change in this sub-region because 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. Low-lying coastal areas will experience more frequent inundation.

The Economy Damage to infrastructure will result from permafrost thawing and coastal erosion. Reduced sea ice will enhance ocean access to northern coastlines. Thawing will hinder 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 warming.

People's Lives Coastal erosion due to sea-ice decline, sea-level rise, and thawing permafrost is very likely to force the relocation of some villages and create increasing stress on others. Declines in ice-dependent species and increasing risks to hunters threaten the food security and traditional lifestyles of indigenous people.



Sub-Region IV — Central and Eastern Canadian Arctic, West Greenland, and adjacent seas

The Environment The Greenland Ice Sheet is likely to continue to experience record melting, changing the local environment and raising sea levels globally. Low-lying coastal areas will be more frequently inundated due to rising sea levels and storm surges.

The Economy Sea-ice retreat is likely to increase shipping through the Northwest Passage, 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 sport fishing and tourism.

People's Lives 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 hinder 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.

Why Does the Arctic Warm Faster than Lower Latitudes?

First, as arctic snow and ice melt, the darker land and ocean surfaces that are revealed absorb more of the sun's energy, increasing arctic warming. Second, in the Arctic, a greater fraction of the extra energy received at the surface due to increasing concentrations of greenhouse gases goes directly into warming the atmosphere, whereas in the tropics, a greater fraction goes into evaporation. Third, the depth of the atmospheric layer that has to warm in order to cause warming of near-surface air is much shallower in the Arctic than in the tropics, resulting in a larger arctic temperature increase. Fourth, as warming reduces the extent of sea ice, solar heat absorbed by the oceans in the summer is more easily transferred to the atmosphere in the winter, making the air temperature warmer than it would be otherwise. Finally, because heat is transported to the Arctic by the atmosphere and oceans, alterations in their circulation patterns can also increase arctic warming.