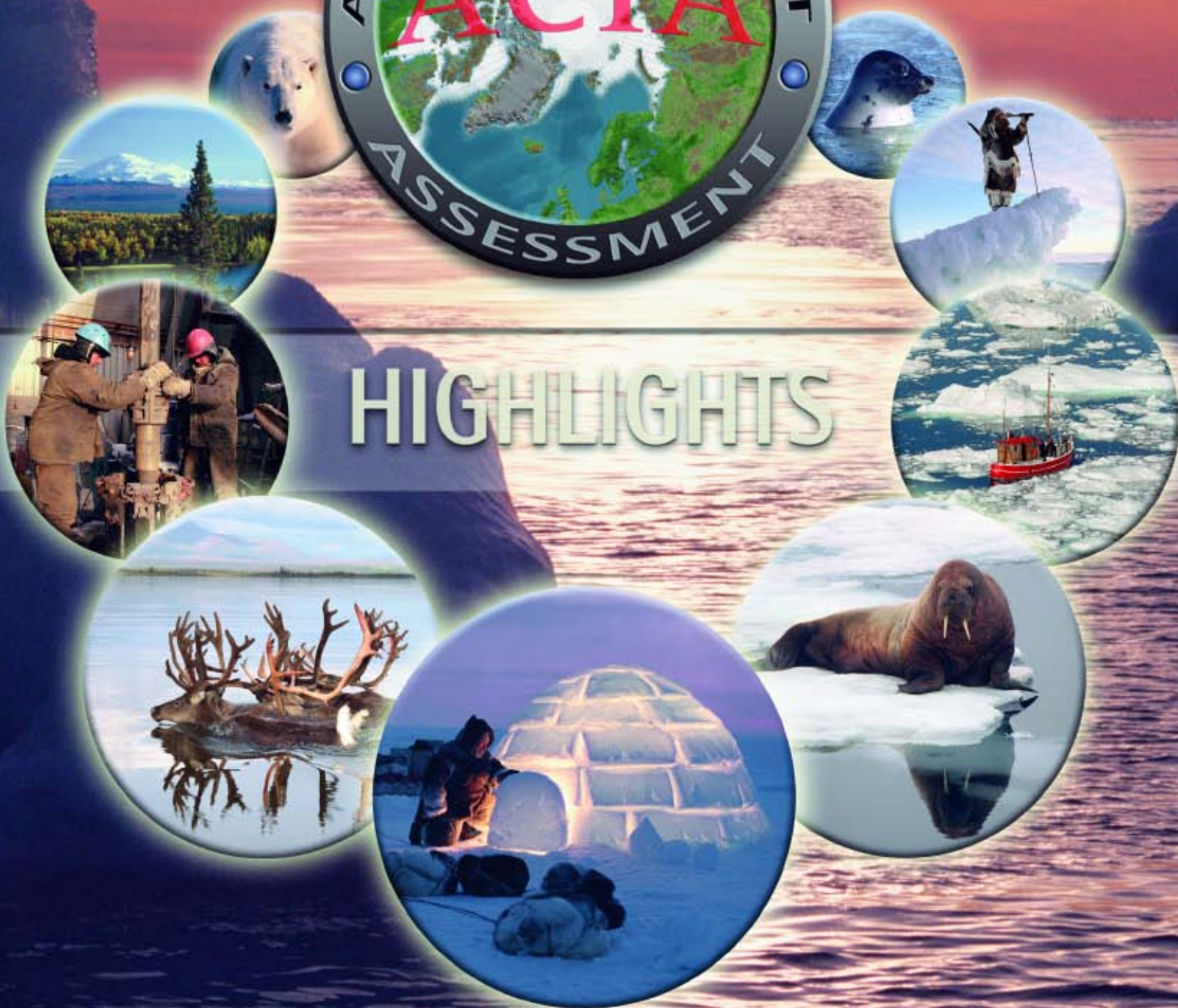


IMPACTS OF A WARMING ARCTIC



HIGHLIGHTS



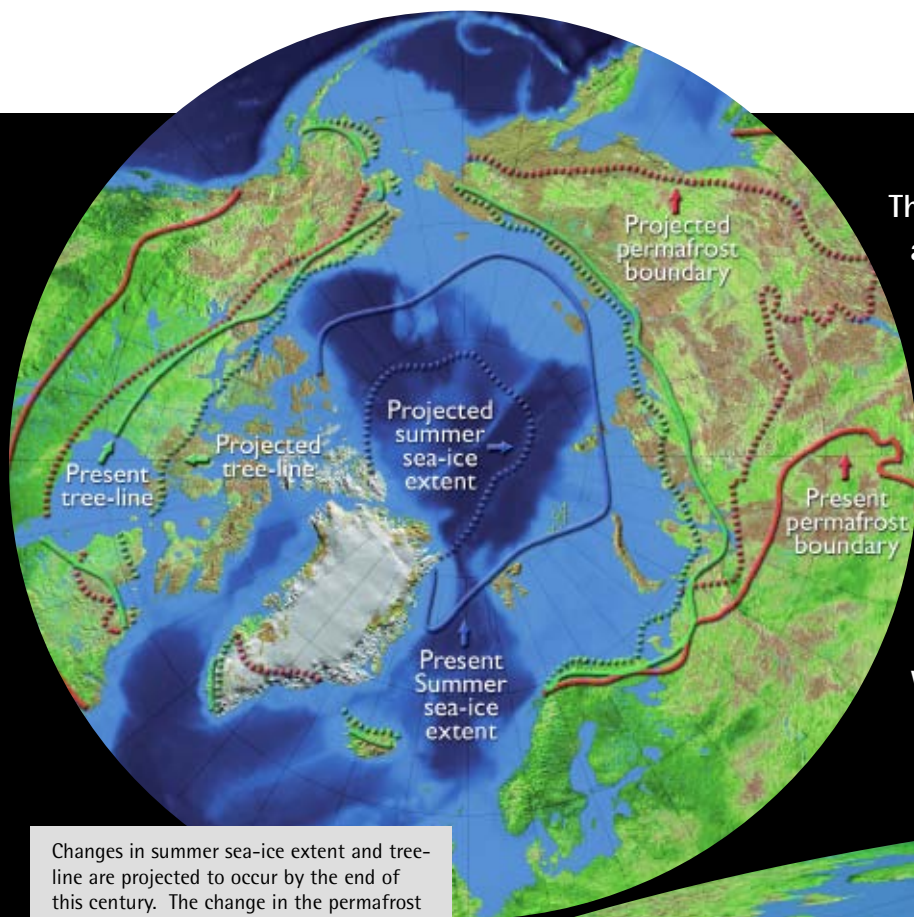


The Arctic is of special importance to the world and it is changing rapidly. This brochure is a brief presentation of highlights drawn from *Impacts of a Warming Arctic* the plain language synthesis report of the Arctic Climate Impact Assessment (ACIA). ACIA publications also include an extensive technical volume on which the synthesis report and these highlights are based.

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.

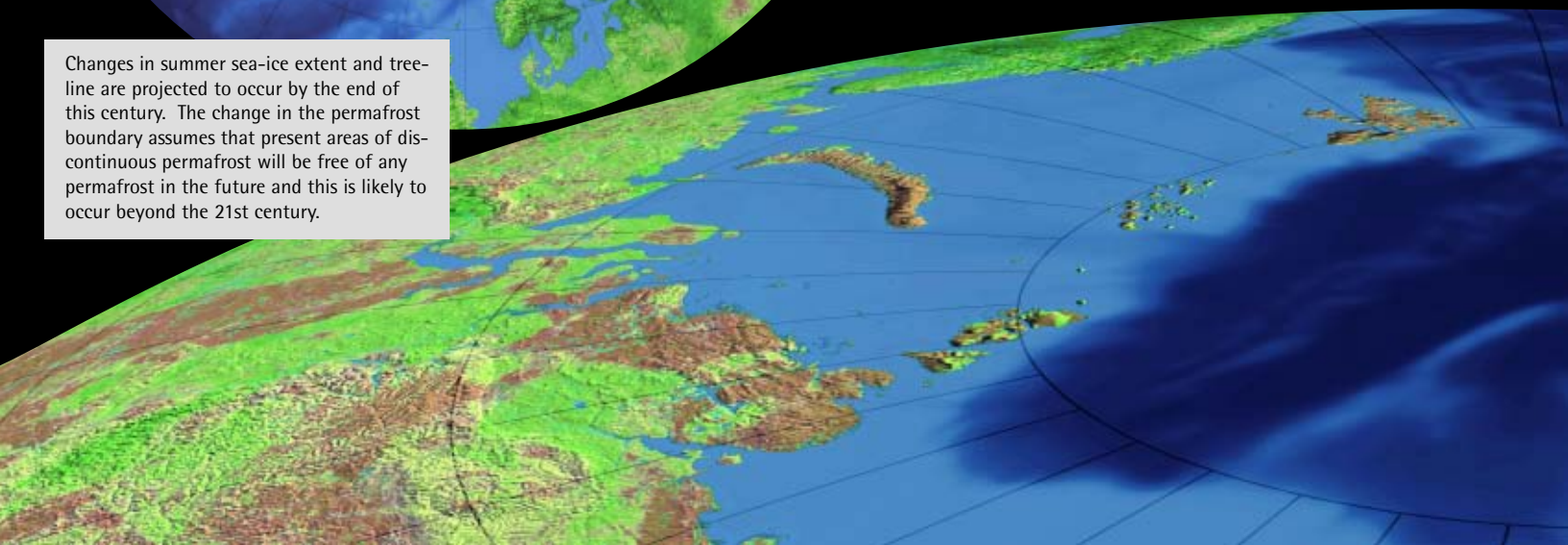
This assessment was called for by the Arctic Council and the International Arctic Science Committee (IASC). The Arctic Council is a high-level intergovernmental forum comprised of the eight arctic nations (Canada, Denmark/Greenland/Faroe Islands, Finland, Iceland, Norway, Russia, Sweden, and the United States of America) and six Indigenous Peoples organizations. IASC is an international scientific organization appointed by 18 national academies of science.

Impacts of a Warming Arctic is published by Cambridge University Press with copies available at <http://www.cambridge.org>



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.

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.



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. 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.

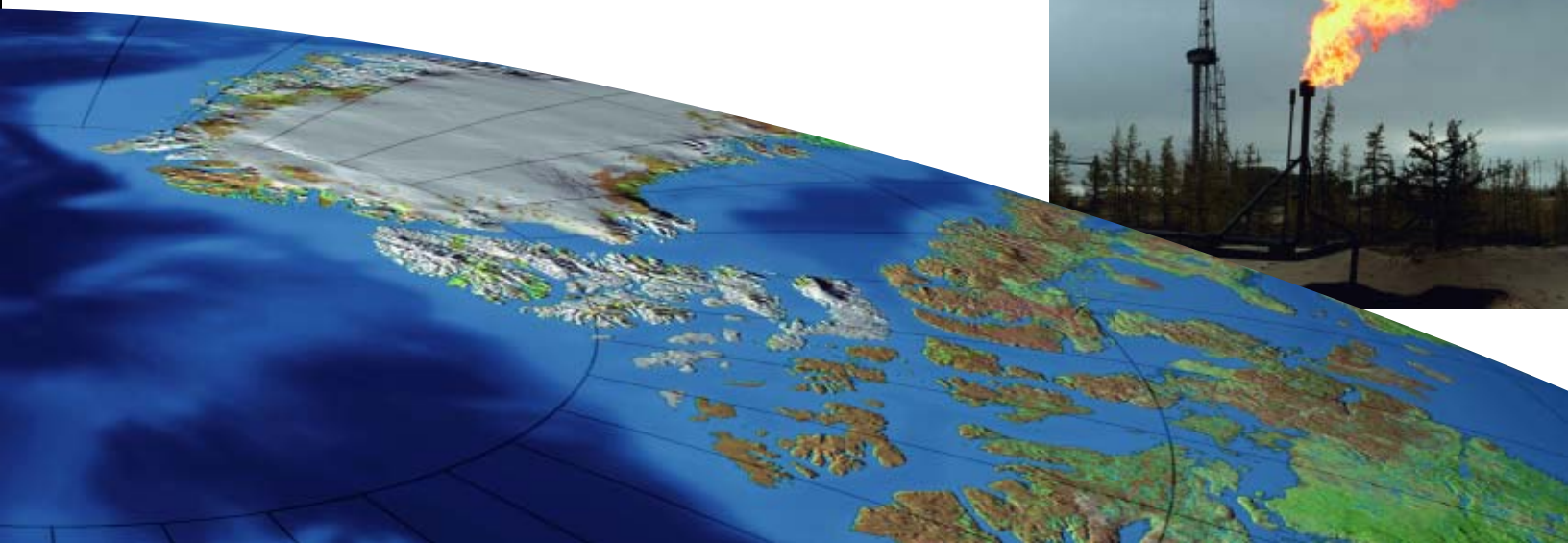
Are These Impacts Inevitable?

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 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.

"There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities."

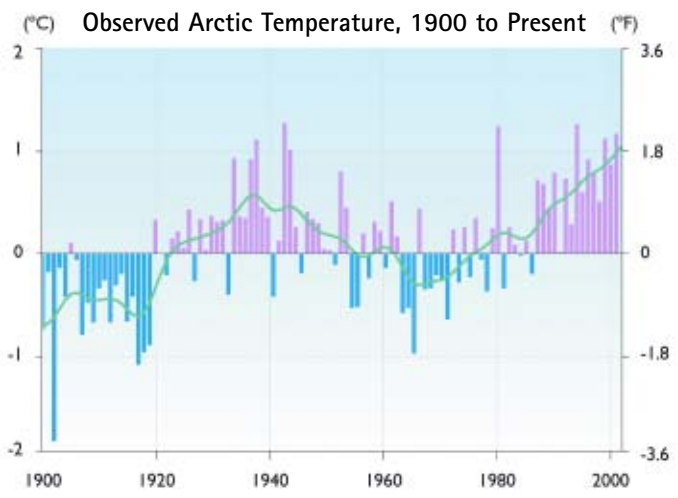
Intergovernmental Panel on Climate Change (IPCC), 2001



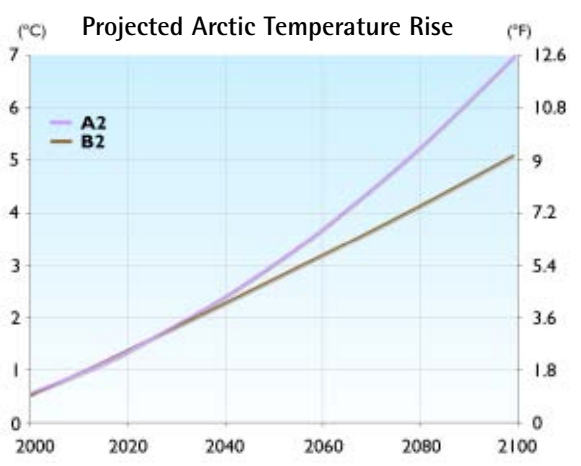
Arctic climate is now warming rapidly and much larger changes are projected

Rising Arctic Temperatures

Records of increasing temperatures, melting glaciers, reductions in extent and thickness of sea ice, thawing permafrost, and rising sea level all provide strong evidence of recent warming in the Arctic. There are regional variations due to atmospheric winds and ocean currents, with some areas showing more warming than others and a few areas even showing a slight cooling; but for the Arctic as a whole, there is a clear warming trend. There are also patterns within this overall trend; for example, in most places, temperatures in winter are rising more rapidly than in summer. In Alaska and western Canada, winter temperatures have increased as much as 3-4°C (5-7°F) in the past 50 years. Over the next 100 years, under a moderate emissions scenario, annual average temperatures are projected to rise 3-5°C (5-9°F) over land and up to 7°C (13°F) over the oceans. Winter temperatures are projected to increase by 4-7°C (7-13°F) over land and 7-10°C (13-18°F) over the oceans.



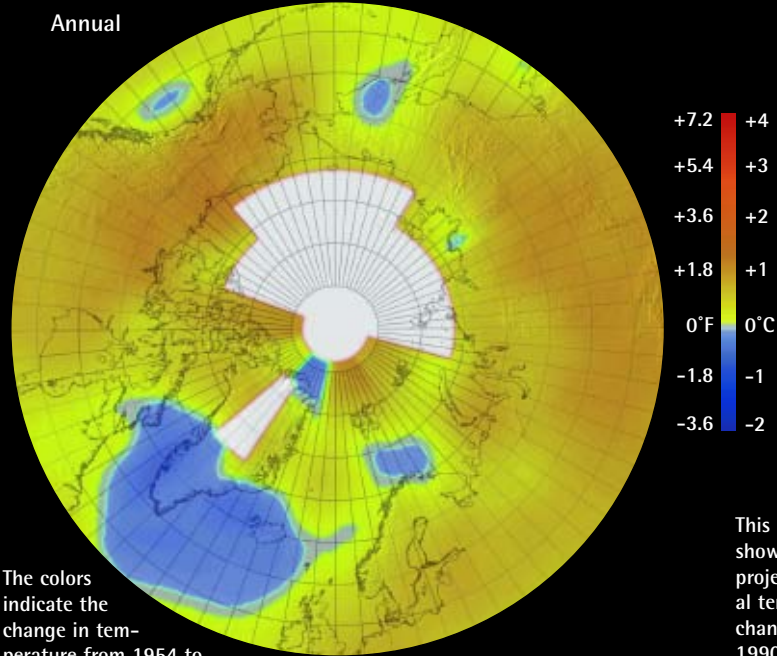
Annual average change in near surface air temperature from stations on land relative to the average for 1961-1990, for the region from 60 to 90°N.



Increases in annual average arctic temperature (for 60°-90°N) projected by an average of ACIA models for the A2 and B2 emissions scenarios, relative to 1981-2000.

Observed Surface Air Temperature Changes: 1954 - 2003

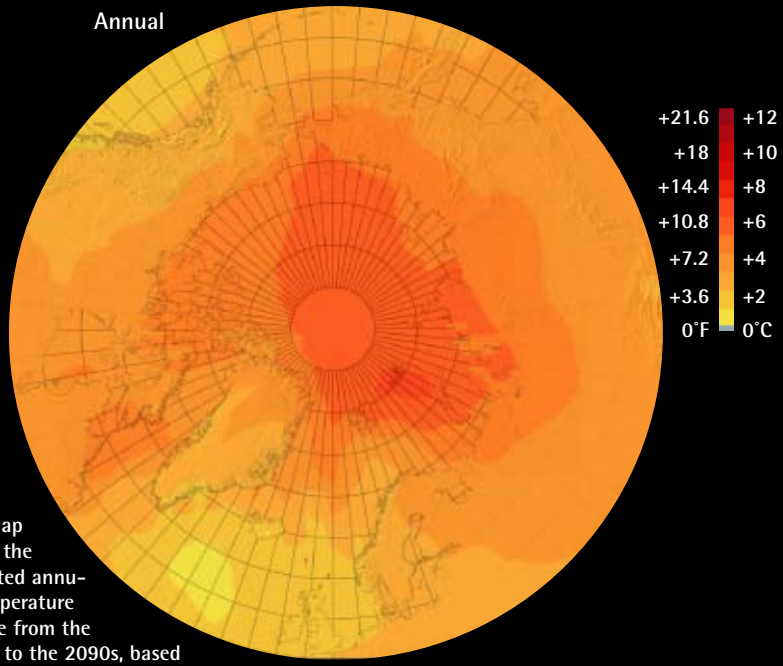
Annual



The colors indicate the change in temperature from 1954 to 2003. The map above indicates annual average temperature change, which ranges from a 2-3°C (3.6-5.5°F) warming in Alaska and Siberia to a cooling of up to 1°C in southern Greenland.

Projected Surface Air Temperature Change: 1990s - 2090s

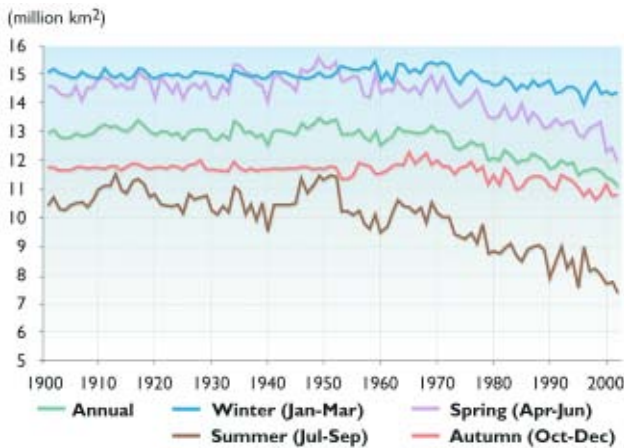
Annual



This map shows the projected annual temperature change from the 1990s to the 2090s, based on the average change calculated by five climate models using the lower of the two emissions scenarios (B2) considered in this assessment. For example, the orange area is projected to warm by about 6°C (11°F) from the 1990s to the 2090s.

Declining Sea Ice: A Key Climate Change Indicator

Observed Seasonal Arctic Sea-ice Extent (1900–2003)

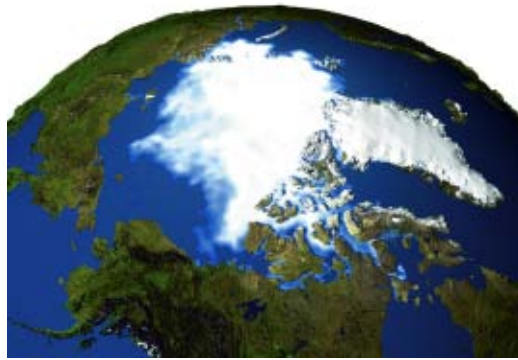


Over the past 30 years, the annual average sea-ice extent has decreased by about 8%, or nearly one million square kilometers (386,100 square miles), an area larger than all of Norway, Sweden, and Denmark (or Texas and Arizona) combined, and the melting trend is accelerating. Sea-ice extent in summer has declined more dramatically than the annual average, with a loss of 15–20% of the late-summer ice coverage. Additional declines of 10–50% in annual average sea-ice extent are projected by 2100. Loss of sea ice during summer is projected to be considerably greater, with a 5-model average projecting more than a 50% decline by late this century, and some models showing near-complete disappearance of summer sea ice.

Observed Sea Ice September 1979



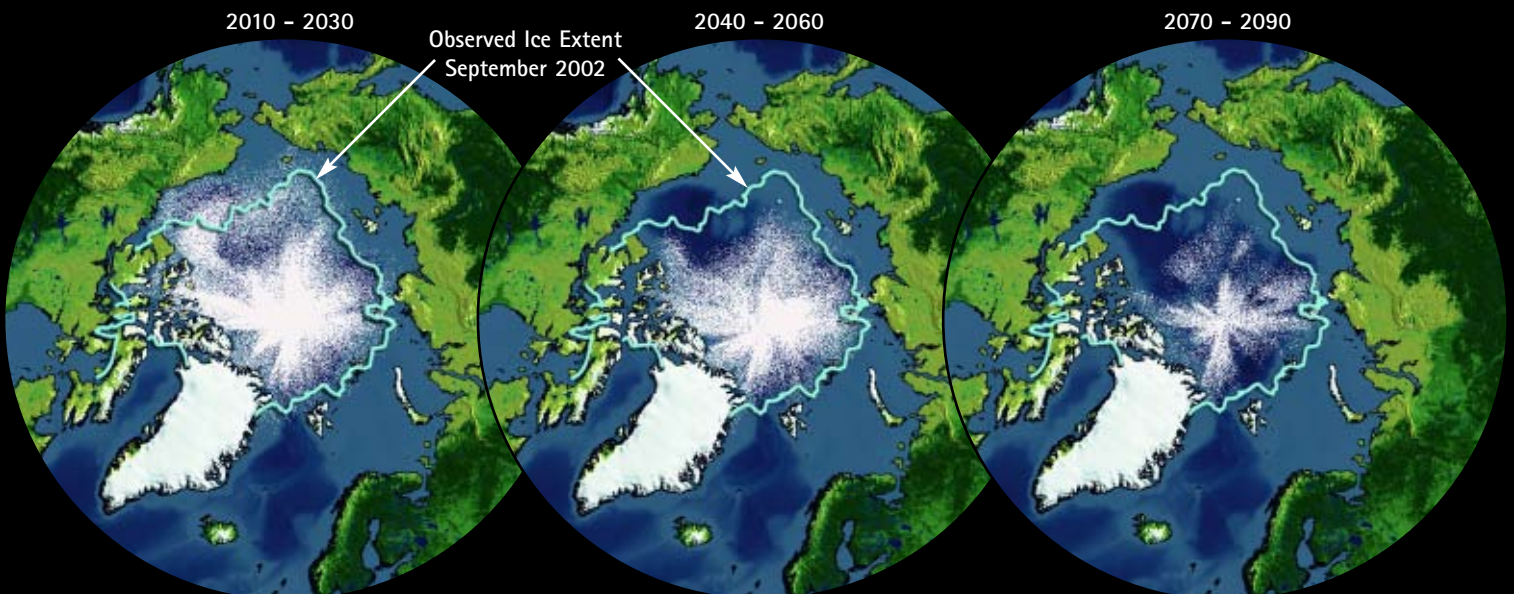
Observed Sea Ice September 2003



Just as miners once had canaries to warn of rising concentrations of noxious gases, researchers working on climate change rely on arctic sea ice as an early warning system.

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.

Projected Sea Ice Extent



September sea-ice extent, already declining markedly, is projected to decline even more rapidly in the future. The three images above show the average of the projections from five climate models for three future time periods. As the century progresses, sea ice moves further and further from the coasts of arctic land masses, retreating to the central Arctic Ocean. Some models project the nearly complete loss of summer sea ice in this century.

Greenland Ice Sheet Melt Extent



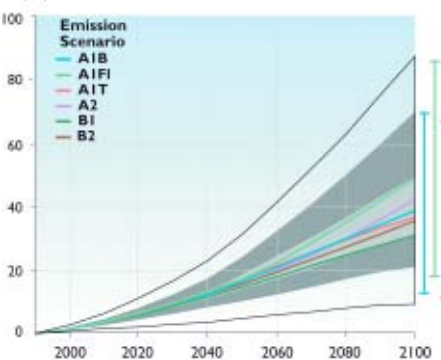
Seasonal melt extent on the surface of the Greenland Ice Sheet has been observed by satellite since 1979 and shows an increasing trend. The melt zone, where summer warmth turns snow and ice around the edges of the ice sheet into slush and ponds of meltwater, has been expanding inland and to record high elevations in recent years. When the meltwater seeps down through cracks in the ice sheet, it may accelerate melting and, in some areas, allow the ice to slide more easily over the bedrock below, speeding its movement to the sea. In addition to contributing to global sea-level rise, this process adds freshwater to the ocean, with potential impacts on ocean circulation and thus regional climate.

Melting Arctic Glaciers and Global Sea Level Rise

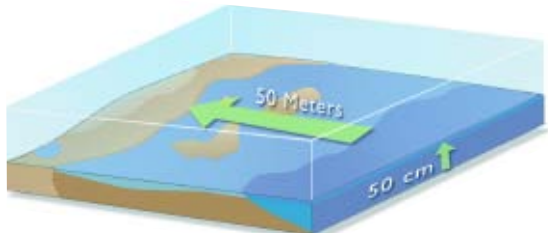
The Greenland Ice Sheet dominates land ice in the Arctic. Maximum surface-melt area on the ice sheet increased on average by 16% from 1979 to 2002, an area roughly the size of Sweden, with considerable variation from year to year. The total area of surface melt on the Greenland Ice Sheet broke all records in 2002, with extreme melting reaching up to a record 2000 meters (6600 feet) in elevation. Satellite data show an increasing trend in melt extent since 1979. This trend was interrupted in 1992, following the eruption of Mt. Pinatubo, which created a short-term global cooling as particles spewed from the volcano reduced the amount of sunlight that reached the earth's surface.

Global average sea level rose by about eight centimeters (three inches) in the past 20 years and the rate of rise has been increasing. The primary factors contributing to this rise are thermal expansion due to ocean warming and melting of land-based ice that increases the total amount of water in the ocean. Global average sea level is projected to rise 10 to 90 centimeters (four inches to three feet) during this century, with the rate of rise accelerating as the century progresses. Models indicate that warming over Greenland is likely to be of a magnitude that would eventually lead to a virtually complete melting of the Greenland Ice Sheet, with a resulting sea-level rise of about seven meters (23 feet).

Projected Global Sea Level Rise

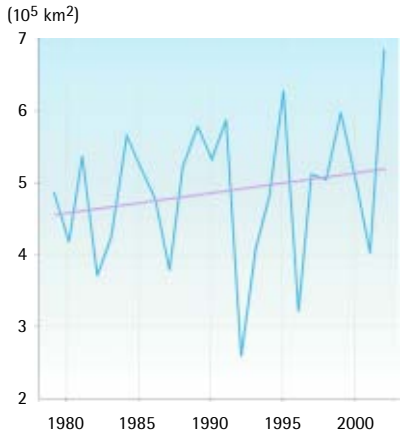


Future increases in global average sea level in centimeters as projected by a suite of climate models using six IPCC emissions scenarios.



A 50-cm (1.5 feet) rise in sea level will typically cause a shoreward retreat of coastline of 50 meters (150 feet) if the land is relatively flat (like most coastal plains), causing substantial economic, social, and environmental impacts.

Greenland Ice Sheet Melt Extent (Maximum melt extent 1979 - 2002)



Areas in Florida Subject to Inundation with 100 Centimeter (3.3 ft) Sea Level Rise



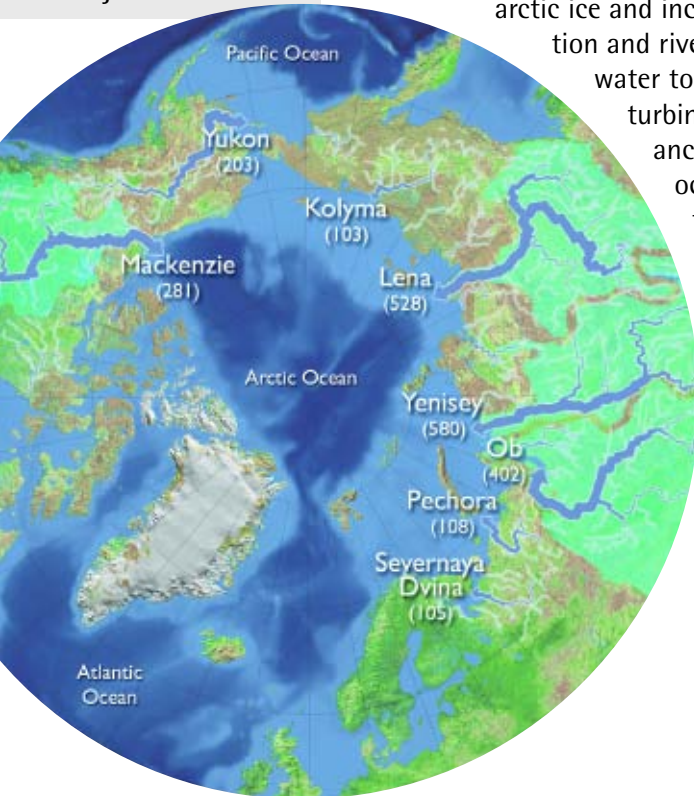
Arctic Changes Impact Global Climate

There are several major mechanisms by which arctic processes can cause additional climate change for the planet. One involves changes in the reflectivity of the land and ocean surface as snow and ice melt and vegetation cover changes. As the surface becomes darker, it absorbs more of the sun's energy, amplifying global warming.

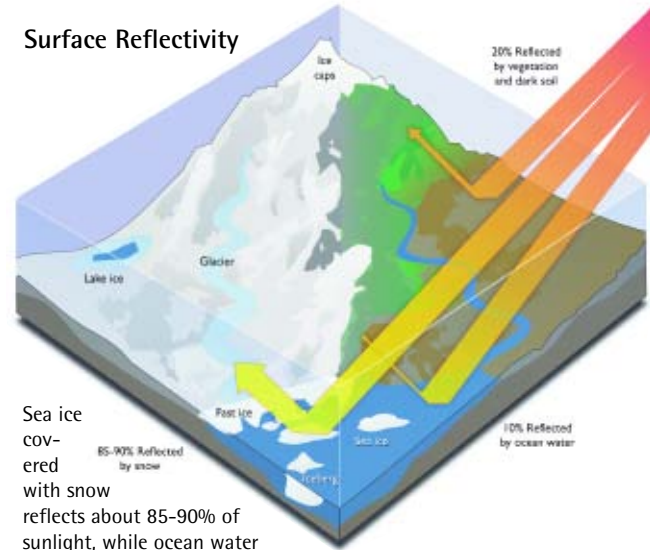
Another mechanism involves potential changes to the global ocean circulation that can cause large scale climatic changes. Such

changes can be brought about as melting arctic ice and increasing precipitation and river runoff add freshwater to the oceans, disturbing the salinity balance that sustains the ocean circulation pattern that carries warmth from the tropics northward.

Major Arctic Rivers

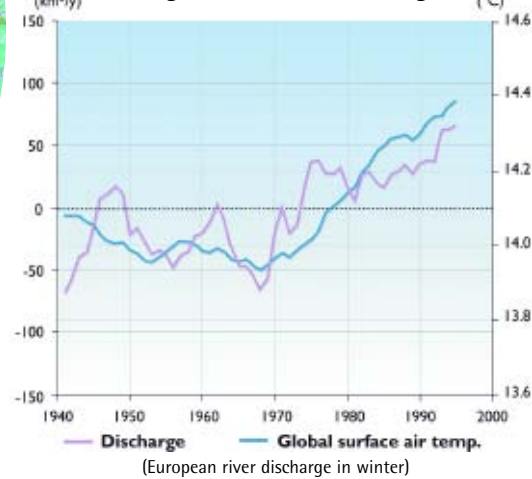


Surface Reflectivity



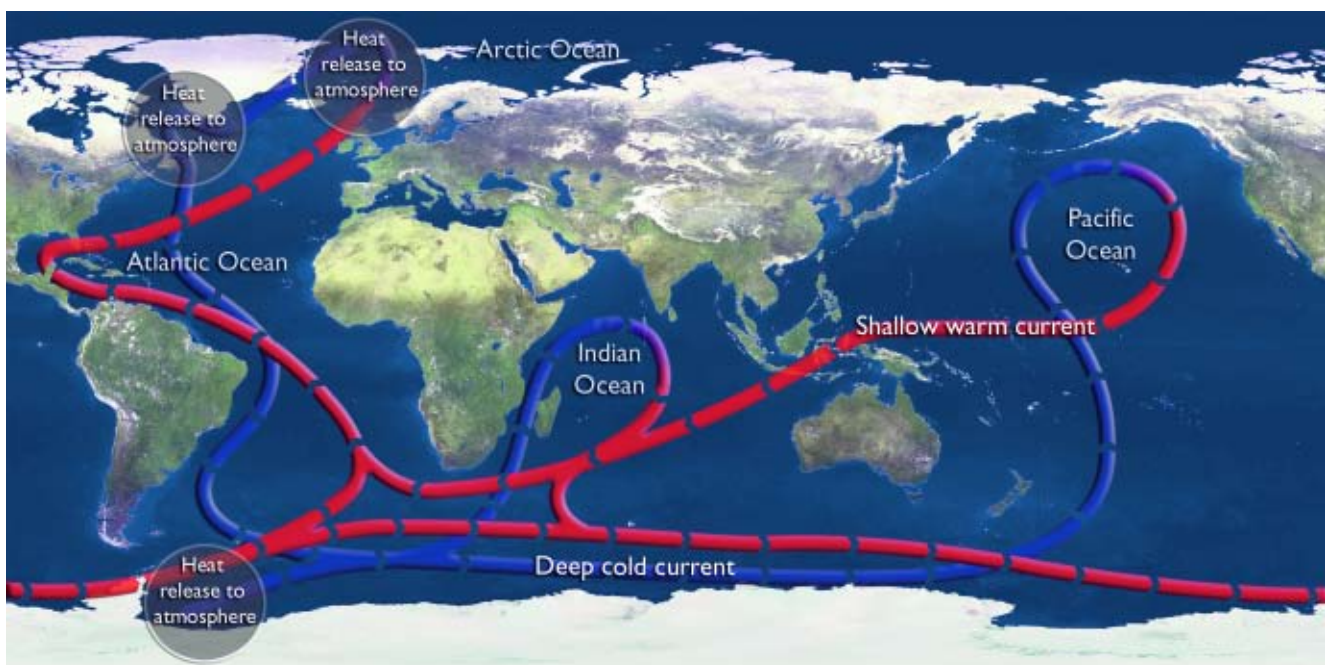
Sea ice covered with snow reflects about 85-90% of sunlight, while ocean water reflects just 10%. Similar differences in reflectivity exist between snow- and ice-covered land areas and the ground beneath them. Thus, as sea ice and land-based snow and ice melt, revealing more and more of the ocean or land beneath them, the increasing absorption of solar radiation adds to global warming, which causes more melting, which in turn causes more warming, and so on...

Rising Winter River Discharge



The map shows the major river networks of the Arctic. The thickness of the blue lines represents the relative river discharge (the numbers are cubic kilometers of discharge per year). As the line chart shows, rising air temperatures lead to rising river discharge as glaciers melt and precipitation increases. As more freshwater enters the ocean, it has the potential to slow or even shut down the oceanic overturning (sometimes called the conveyor belt circulation) that carries warmth from the tropics northward. The illustration below shows how this circulation functions, with red representing warm surface waters that carry heat poleward, and blue representing cold deep waters that return towards the tropics.

Global Ocean Circulation



Climate Impacts on Animals and their Habitats



Polar Bears

Polar bears are dependent on sea ice, where they hunt ice-living seals and use ice corridors to move from one area to another. Polar bears are unlikely to survive as a species if there is an almost complete loss of summer sea-ice cover, which is projected to occur before the end of this century by some climate models. The loss of polar bears is likely to have significant and rapid consequences for the ecosystems that they currently occupy.



Ice-dependent Seals

Ice-dependent seals, including the ringed seal, ribbon seal, and bearded seal, are particularly vulnerable to the observed and projected reductions in arctic sea ice because they give birth to and nurse their pups on the ice and use it as a resting platform. They also forage near the ice edge and under the ice. Adapting to life on land in the absence of summer sea ice seems highly unlikely for these species.



Global Impacts on Migratory Birds

Several hundred million birds migrate to the Arctic each summer and their success in the Arctic determines their populations at lower latitudes. Important breeding and nesting areas are projected to decrease sharply as treeline advances northward, encroaching on tundra, and because the timing of bird arrival in the Arctic might no longer coincide with the availability of their insect food sources. At the same time, sea-level rise will erode tundra extent from the north in many areas, further shrinking important habitat for many living things. A number of bird species, including several globally endangered seabird species, are projected to lose more than 50% of their breeding area during this century.



Caribou/Reindeer

Caribou and reindeer herds depend on the availability of abundant tundra vegetation and good foraging conditions. Climate-induced changes to arctic tundra are projected to cause vegetation zones to shift significantly northward, reducing the area of tundra and the traditional forage for these herds. Freeze-thaw cycles and freezing rain are also projected to increase. These changes will have significant implications for the ability of caribou and reindeer populations to find food and raise calves. Future climate change could thus mean a potential decline in caribou and reindeer populations, threatening human nutrition for many indigenous households and a whole way of life for some arctic communities.

Climate Impacts on Indigenous People

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. For Inuit, for example, 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.



COASTAL EROSION



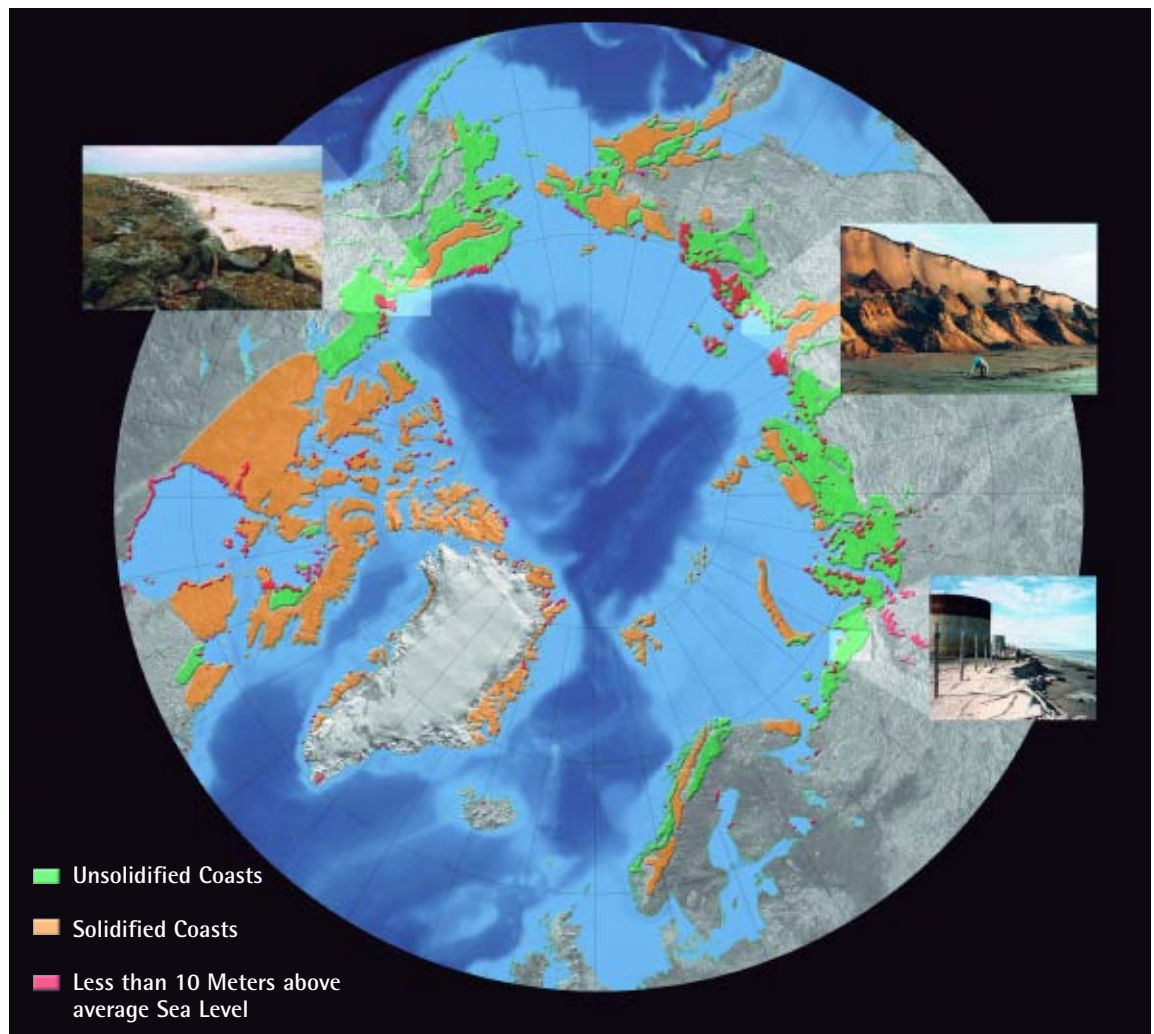
Coastal Erosion and Thawing Permafrost

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. Some communities and industrial facilities in coastal zones are already threatened or being forced to relocate, while others face increasing risks and costs.

"Some of our communities are eroding into the ocean in front of our eyes because of the decrease in the multi-layered ice, which is allowing for larger storms to roll in."

*Duane Smith
Inuit Circumpolar
Conference, Canada*

Arctic Coastal Areas Susceptible to Erosion



The vulnerability of a coastline to erosion depends on sea level, the properties of the coastal materials, wave action, and tectonic forces. Unsolidified arctic coasts (in green) containing variable amounts of ground ice, are more susceptible to erosion than solidified coasts (in orange). Some unstable coastal environments are shown in the inset photographs. Areas (in red) in which elevation is less than 10 meters (33 feet) above average sea level are particularly vulnerable.

Thawing ground will disrupt transportation, buildings and infrastructure

Thawing Permafrost

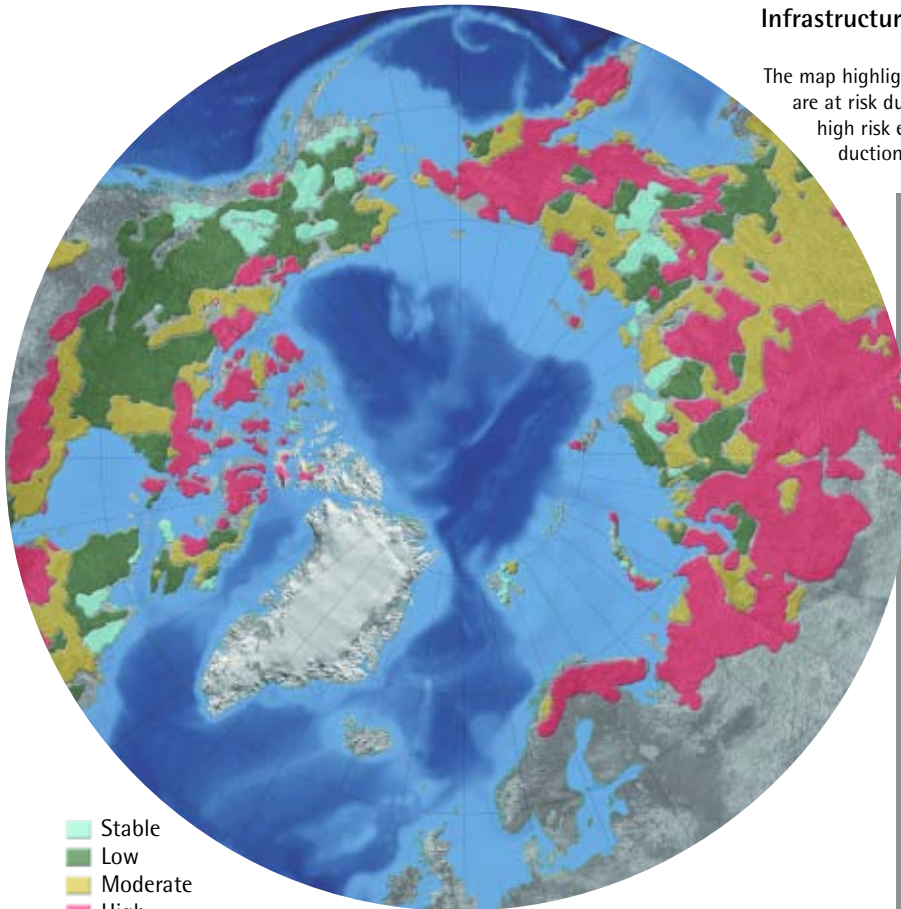
Transportation and industry on land, including oil and gas extraction and forestry, will increasingly be disrupted by the shortening of the periods during which ice roads and tundra are frozen sufficiently to permit travel.

As frozen ground thaws, many existing buildings, roads, pipelines, airports, and industrial facilities are likely to be destabilized.

The projected rate of warming and its effects will need to be taken into account in the design of all new construction.

Infrastructure at Risk by 2050 Due to Permafrost Thaw

The map highlights areas in which buildings, roads, and other infrastructure are at risk due to permafrost thaw by the middle of this century. Areas at high risk encompass population centers, oil pipelines, natural gas production facilities, railroads, and a nuclear power plant.

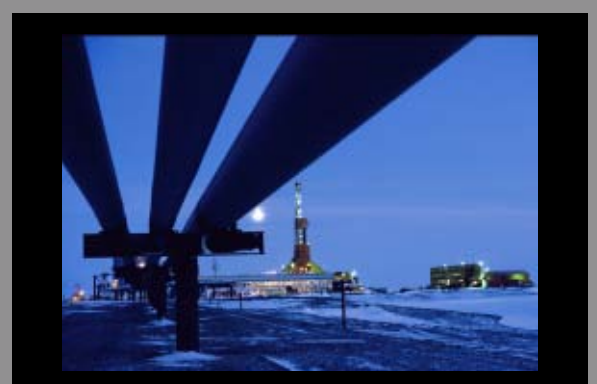


Alaska Winter Tundra Travel Days (1970-2002)

The number of days in which oil exploration activities on the tundra are allowed under Alaska Department of Natural Resources standards has been halved over the past 30 years due to climate warming. The standards are based on tundra hardness and snow conditions and are designed to protect the tundra from damage.



THAWING PERMAFROST



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

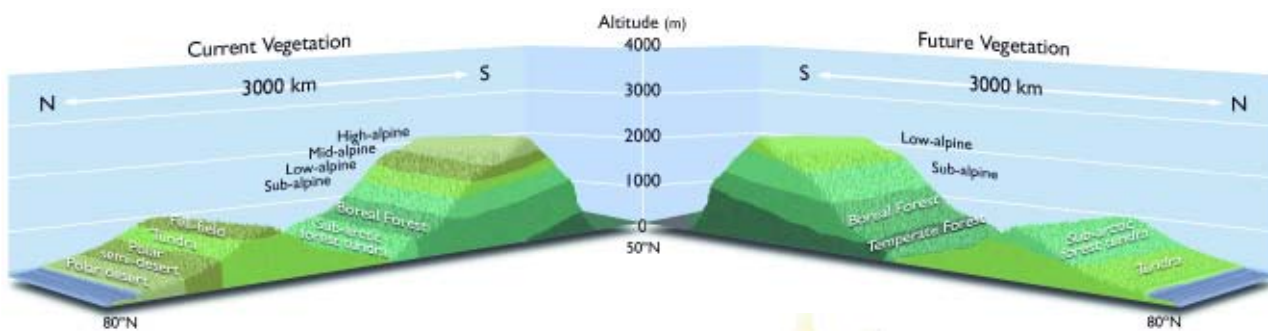
Shifting Vegetation Zones

Climate change is projected to cause vegetation shifts because rising temperatures favor taller, denser vegetation, and will thus promote the expansion of forests into the arctic tundra, and tundra into the polar deserts. The timeframe of these shifts will vary around the Arctic. Where suitable soils and other conditions exist, changes are likely to be apparent in this century. Where they do not, the changes can be expected to take longer. These vegetation changes, along with rising sea levels, are projected to shrink tundra area to its lowest extent in at least the past 21 000 years, greatly reducing the breeding area for many birds and the grazing areas for land animals that depend on the open landscape of tundra and polar desert habitats. Not only are some threatened species very likely to become extinct, some currently widespread species are projected to decline sharply.

Studies suggest that the increase in absorption of solar radiation will dominate over the increase in carbon storage, resulting in a net increase in warming.

The projected reduction in tundra and expansion of forest will cause a decrease in surface reflectivity, amplifying global warming because the newly forested areas are darker and more textured and thus will absorb more solar radiation than the lighter, smoother tundra. For example, black spruce is the least reflective of any vegetation type and is likely to be a large part of the mix of new trees in North America. In addition, expanding forests will mask highly reflective snow. The darkening of the surface that results from these changes will create a feedback loop whereby more warming will lead to more tree establishment and forest cover, which will cause more warming, and so on.

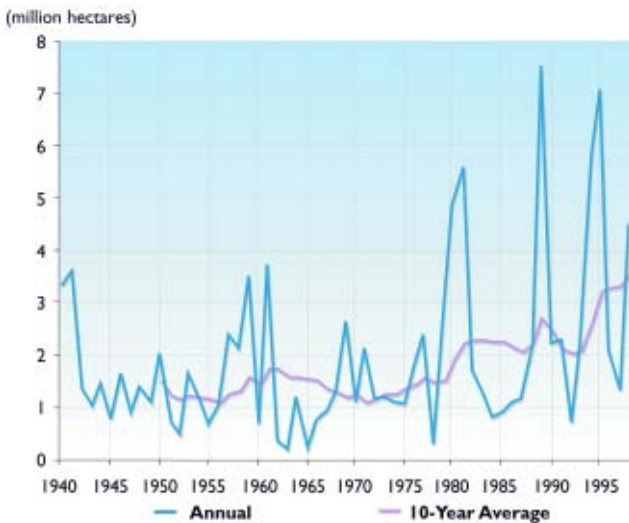
This schematic illustrates the projected upslope and northward displacement of vegetation zones in the Arctic as a result of future warming. Note the difference in altitude of vegetation boundaries on north and south facing slopes. The altitudinal and latitudinal zones are analogous, but not identical.



Increasing Fires and Insect Outbreaks

Forest fires, insect infestations, and other disturbances are projected to continue to increase in frequency and intensity in a warming climate.

Boreal Forest Burned in North America



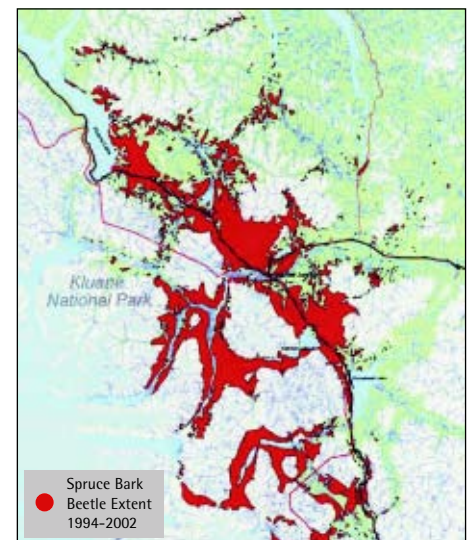
The graph shows the area of North American boreal forest that burned each year, in millions of hectares. The average area burned has more than doubled since 1970, coinciding with climatic warming in the region.



Birch forest destroyed by autumn moths in Abisko, Sweden, 2004.

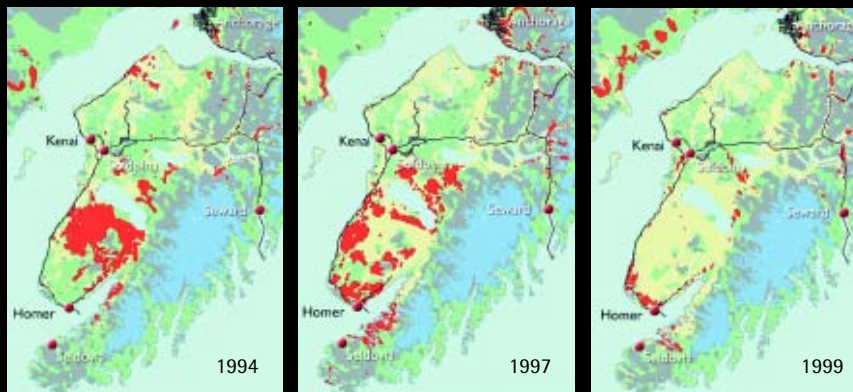


Spruce Beetle Infestations in the Yukon, 1994-2002



The spruce bark beetle has killed trees on about 300,000 hectares in the Alsek River corridor in Kluane National Park and in the Shakwak Valley north of Haines Junction since an outbreak was first identified in 1994. This is the largest and most intense outbreak of spruce bark beetle ever to affect Canadian trees.

Spruce Beetle Activity, Kenai Peninsula 1994-1999



During the 1990s the Kenai Peninsula in Alaska experienced the world's largest outbreak of spruce bark beetles (SBB). Since 1989, more than 1.6 million hectares of mature white spruce and Sitka/Lutz spruce forest in south-central Alaska have been affected with at least 10% to 20% tree mortality, the threshold level for aerial mapping detection.

- Tree Mortality due to SBB
- Past Tree Mortality due to SBB
- Forest
- Non-Forest
- Glacier

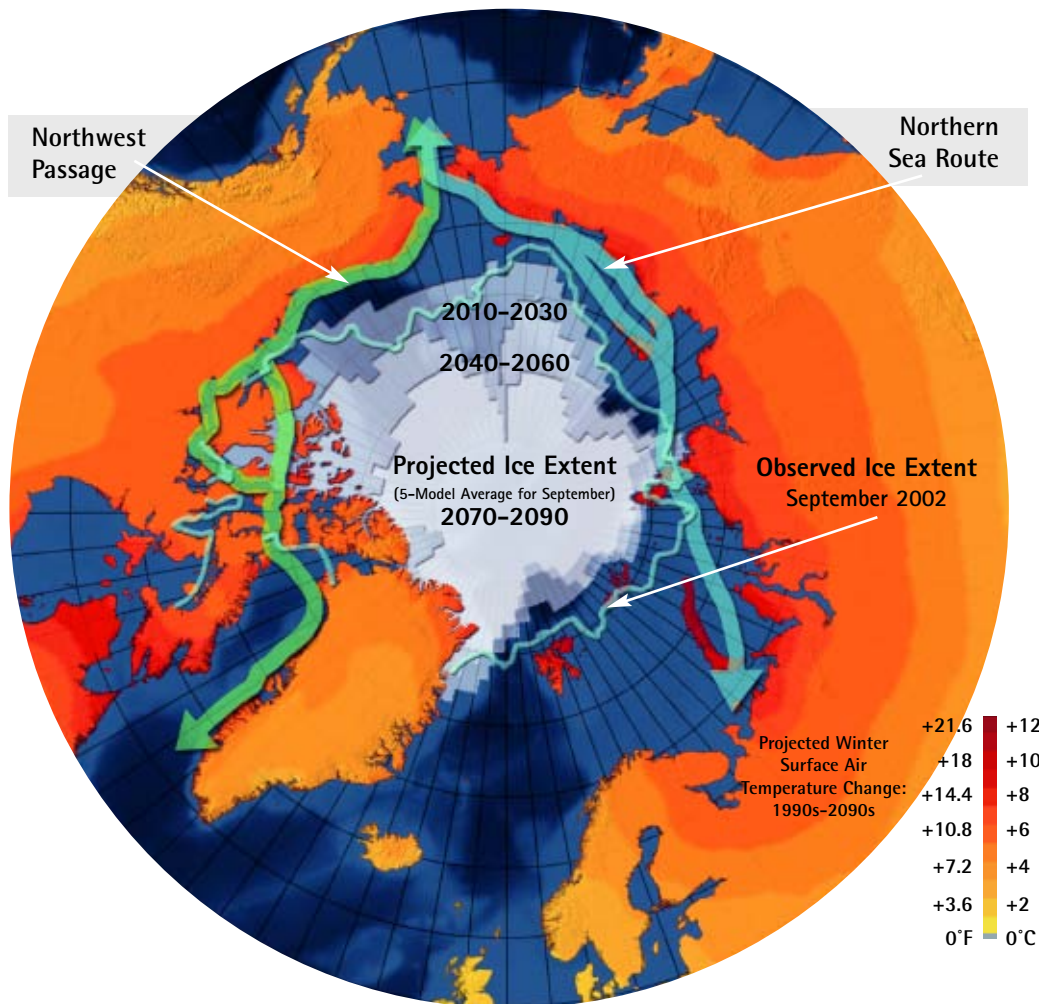


Impacts of Opening Sea Routes

Observations over the past 50 years show a decline in arctic sea-ice extent in all seasons, with the most prominent retreat in summer. Climate models project an acceleration of this trend, with periods of extensive melting spreading progressively further into spring and autumn. Model projections suggest that sea ice in summer will retreat further and further away from most arctic landmasses, opening new shipping routes and extending the period during which shipping is feasible.

As the decline in arctic sea ice opens historically closed passages, questions are likely to arise regarding access to shipping routes and seabed resources. Issues of security and safety could also arise. One impact of the projected increase in marine access for transport and offshore development will be requirements for new and revised national and international regulations focusing on marine safety and environmental protection.

Along with increasing access to shipping routes and resources comes an increasing risk of environmental degradation caused by these activities. One obvious concern involves oil spills and other industrial accidents. A recent study suggests that the effects of oil spills in a high-latitude, cold ocean environment last much longer and are far worse than first suspected.

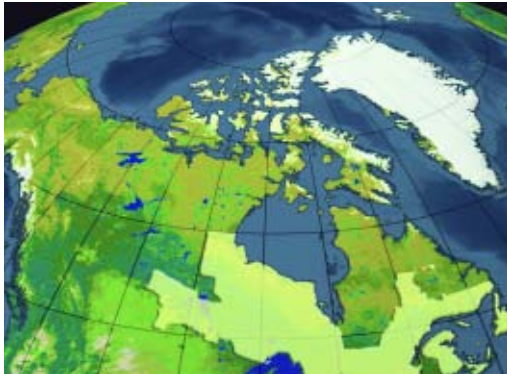


Impacts on Human Health

Climate change will continue to affect human health in the Arctic. The impacts will differ from place to place due to regional differences in climate change as well as variations in health status and adaptive capacity of different populations. Rural arctic residents in small, isolated communities with a fragile system of support, little infrastructure, and marginal or non-existent public health systems appear to be most vulnerable. People who depend upon subsistence hunting and fishing, especially those who rely on just a few species, will be vulnerable to changes that heavily affect those species (for example, reduced sea ice and its impact on ringed seals and polar bears). Climate stress and shifting animal populations also create conditions for the spread of infectious diseases in animals that can be transmitted to humans, such as West Nile virus.

West Nile Virus Change in Canada

2001



2002



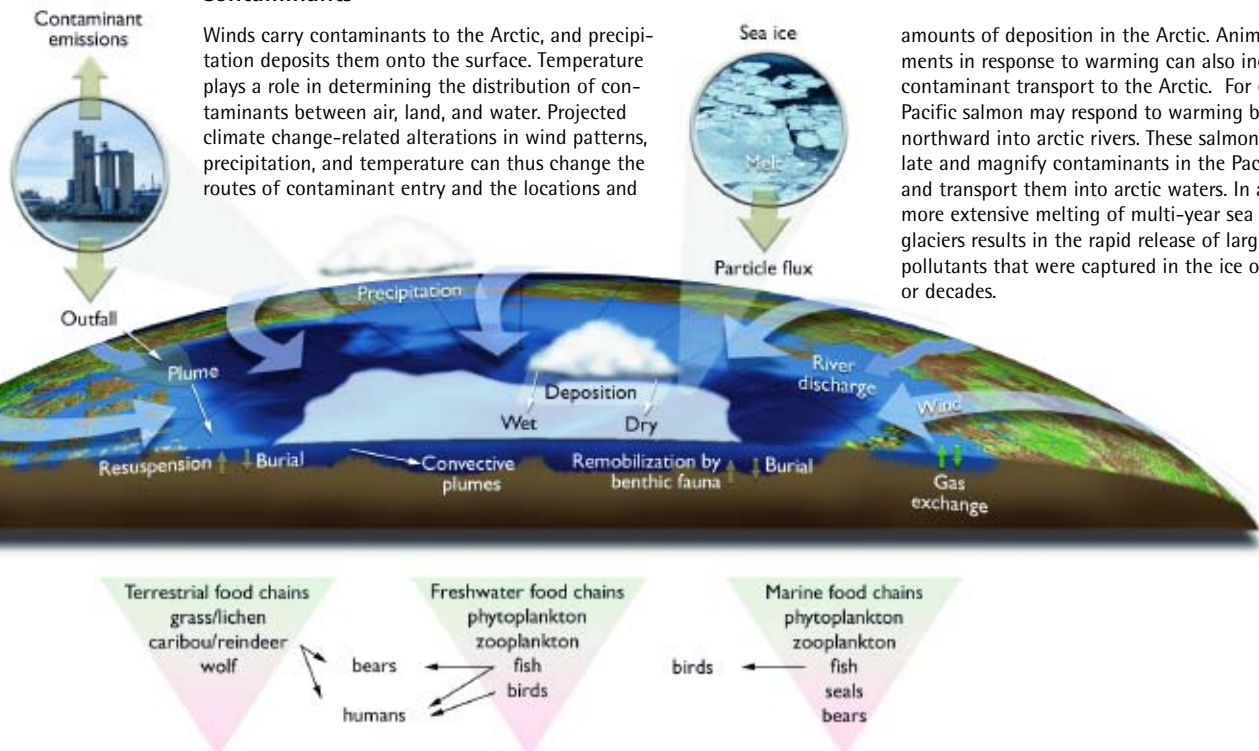
2003



The West Nile encephalitis virus is a recent example of how far and fast a disease can spread once it becomes established in a new region. The West Nile virus can infect many bird and mammal species (including humans) and is transmitted by mosquitoes. It was first identified on the East Coast of North America in 1999 and spread to 43 states and six Canadian provinces by 2002. Migratory birds are responsible for its spread to other regions. Mosquitoes spread the virus to other birds (as well as to other animals and humans) within a region. Although the virus originated in tropical Africa, it has adapted to many North American mosquitoes, and so far, to over 110 species of North American bird, some of which migrate to the Arctic. Mosquito species known to transmit the virus are also found in the Arctic. Climate has historically limited the range of some insect-borne diseases, but climate change and adaptive disease agents such as the West Nile virus tend to favor continued northerly expansion. Some arctic regions, such as the State of Alaska, have initiated West Nile virus surveillance programs.

Dead Birds Submitted for Testing
 Tested Positive for West Nile Virus

Contaminants



Global Climate Change

The earth is projected to warm more than twice as much in this century as it warmed over the past century.

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 (1°F). 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 (2.5 to 10.4°F) (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 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.



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.

Why Does the Arctic Warm Faster than Lower Latitudes?

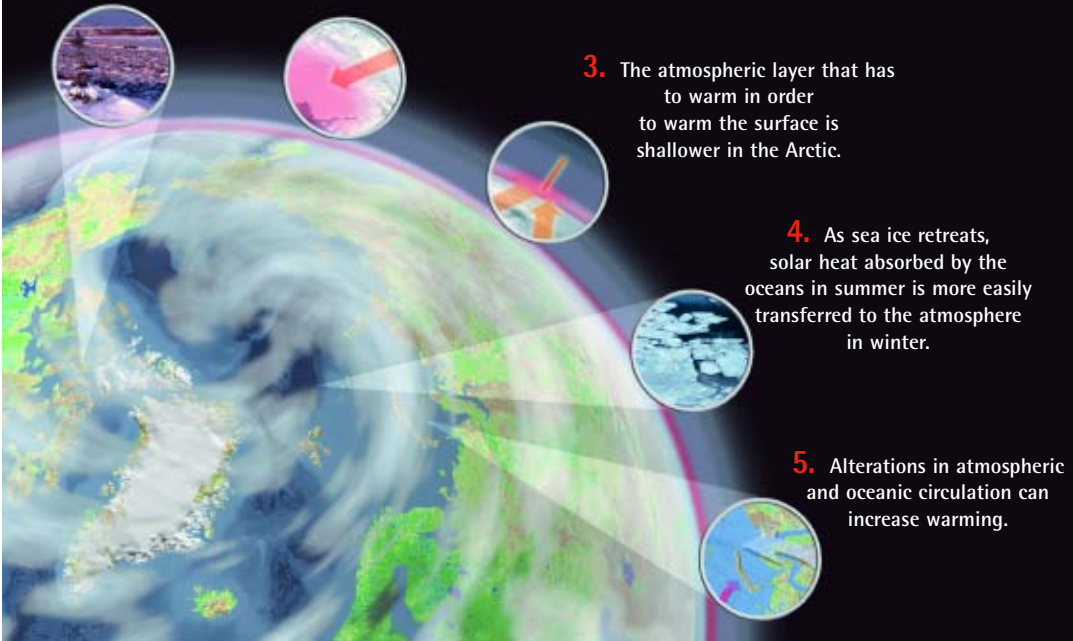
1. As snow and ice melt, darker land and ocean surfaces absorb more solar energy.

2. More of the extra trapped energy goes directly into warming rather than into evaporation.

3. The atmospheric layer that has to warm in order to warm the surface is shallower in the Arctic.

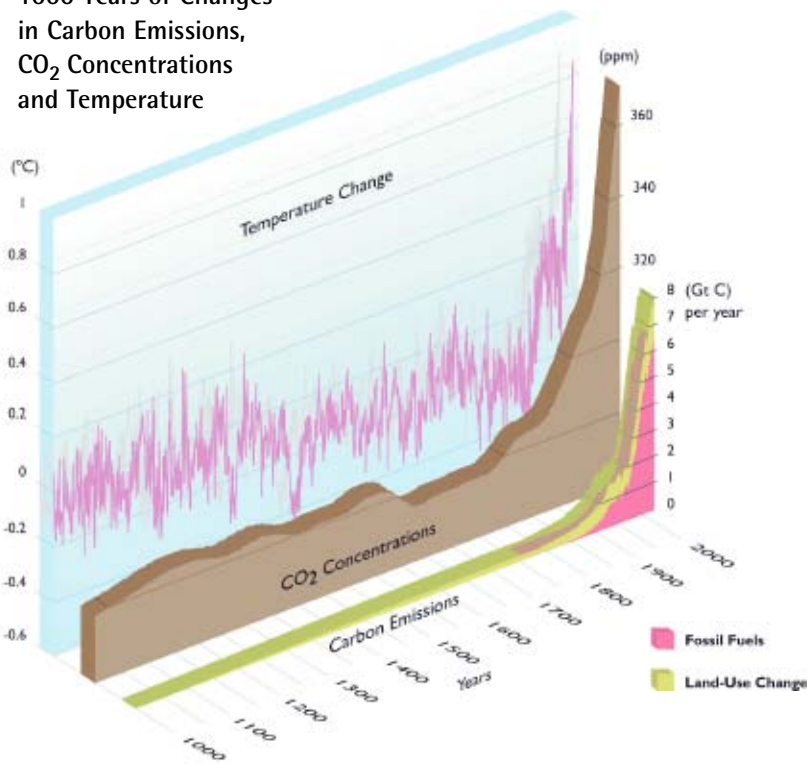
4. As sea ice retreats, solar heat absorbed by the oceans in summer is more easily transferred to the atmosphere in winter.

5. Alterations in atmospheric and oceanic circulation can increase warming.



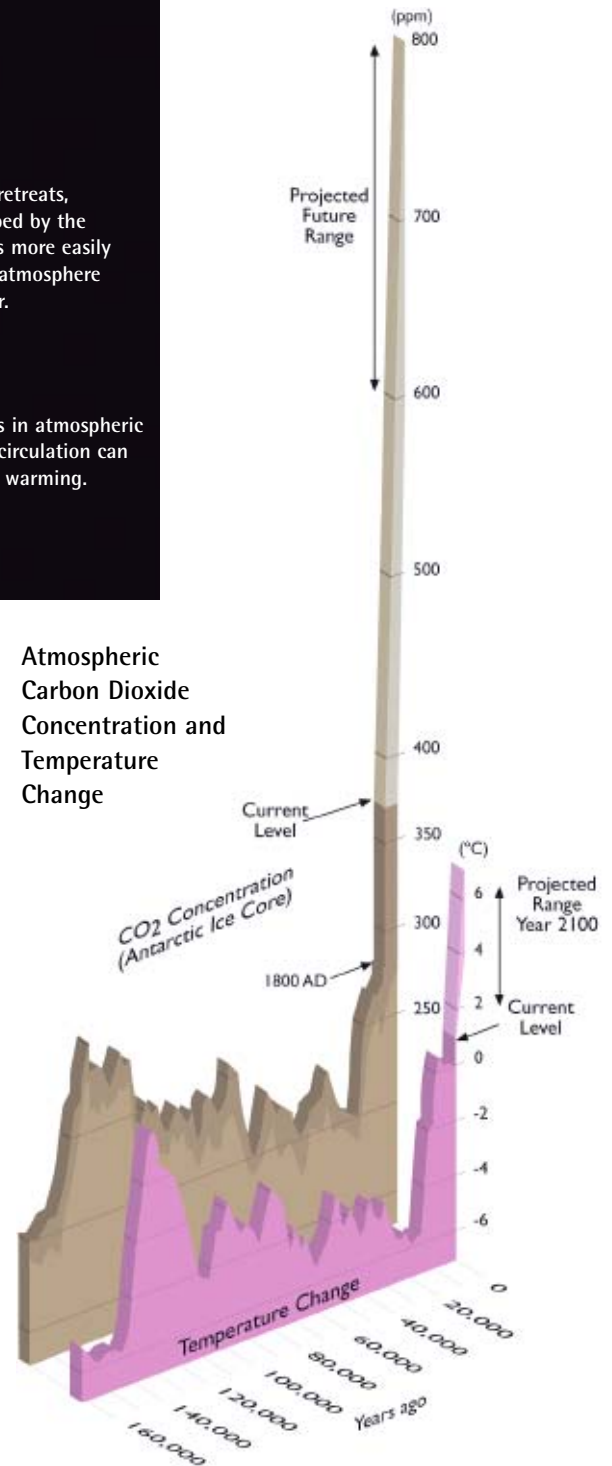
Altering the warming trend will be a long-term process, and the world will face some degree of climate change and its impacts for centuries.

1000 Years of Changes in Carbon Emissions, CO₂ 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 (CO₂) in air bubbles trapped in ice cores form the earlier part of the CO₂ record; direct atmospheric measurements of CO₂ concentration began in 1957.

Atmospheric Carbon Dioxide Concentration and Temperature Change



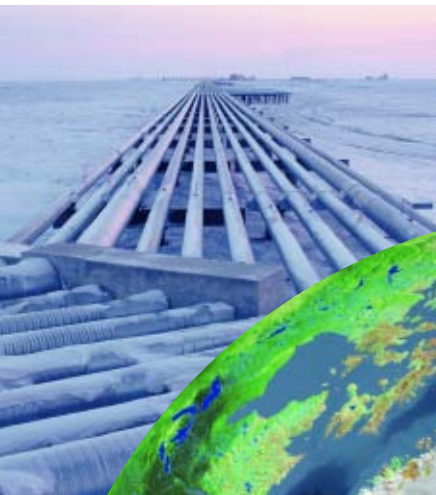
This record illustrates the relationship between temperature and atmospheric carbon dioxide concentrations over the past 160,000 years and the next 100 years. Historical data are derived from ice cores, recent data were directly measured, and model projections are used for the next 100 years.



Concluding Thoughts

Climate change presents a major and growing challenge to the Arctic and the world. Some of the climate-related changes in the arctic environment that are most likely to occur are expected to have major impacts; these include the decline in sea ice, the increase in coastal erosion, and the thawing of permafrost. In addition, other concerns emerge from possible outcomes that appear to have only a low likelihood, but the occurrence of which would have very large impacts - so-called "surprises".

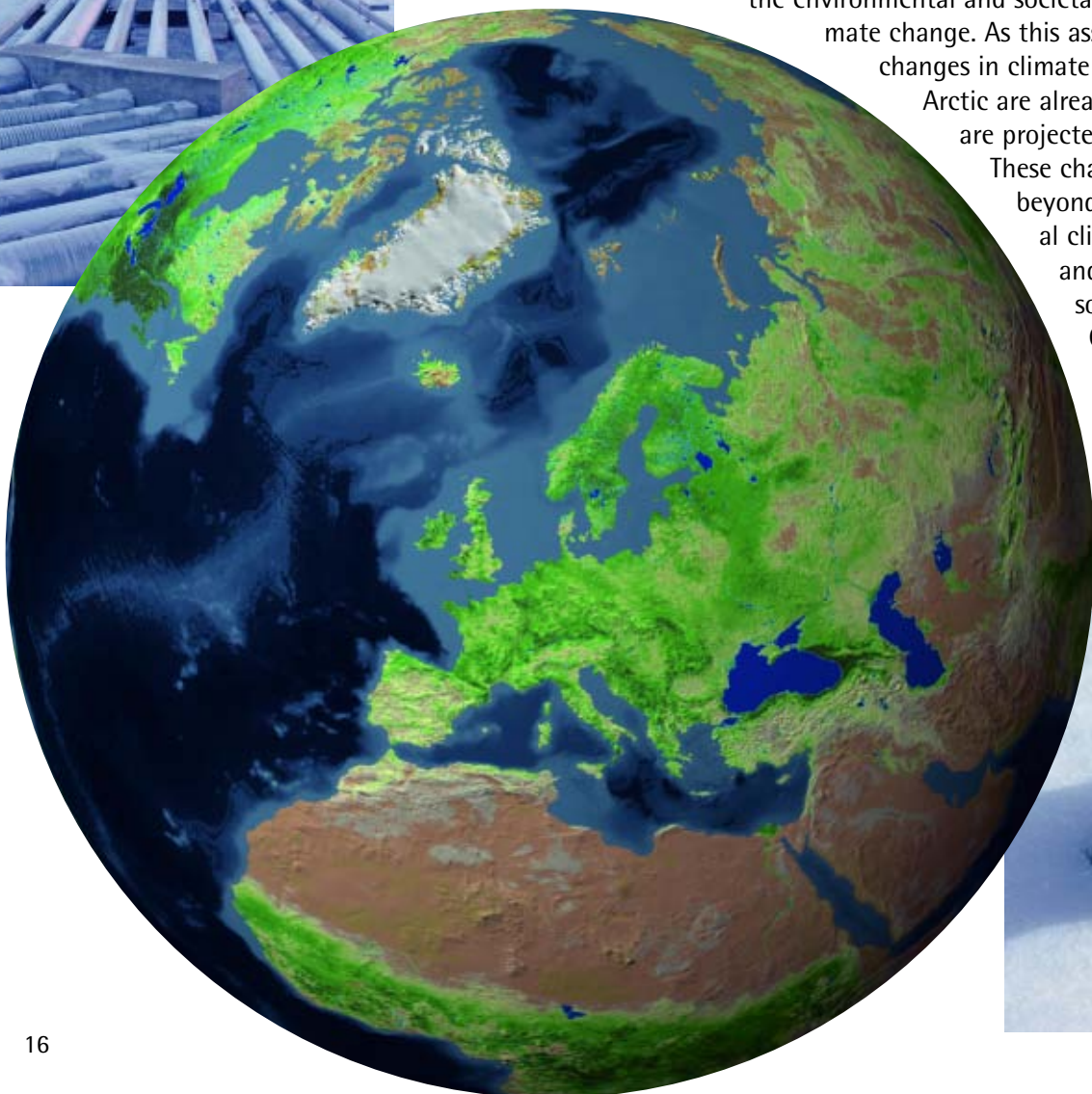
Due to the complexity of the earth system, it is possible that climate change will evolve differently than the gradually changing scenarios used in this assessment. For example, storm intensities and tracks could change in unforeseen ways or temperatures could rise or fall abruptly due to unexpected disturbances of global weather systems. Possible changes in the global oceanic circulation and widespread ramifications of such changes provide another example of a potential climate surprise. Although such changes could cause major impacts, very little information is currently available for considering such possibilities.



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 assessment illustrates,

changes in climate and their impacts in the Arctic are already being widely felt, and are projected to become much greater.

These changes will also reach far beyond the Arctic, affecting global climate, sea level, biodiversity, and many aspects of human social and economic systems. Climate change in the Arctic thus deserves and requires urgent attention by decision makers and the public worldwide.



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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.

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AMAP
Arctic Monitoring and
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CAFF
Conservation of Arctic Flora and Fauna

