Environment and Global Climate Change

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Key Terms and Concepts

- Chloroflourocarbons
- Climate change
- Environmental impact
- Ozone depletion
- Persistent organic pollutants (POPs)

Learning Objectives/Outcomes

Upon completion of this module students will:

- Be able to explain the terms aerosols, albedo, anthropogenic, chloroflourocarbons (CFCs), cryosphere, ozone, persistent organic pollutants (POPs);
- Have a broad understanding of the nature of climate change and its potential impacts;
- Understand and be able to describe the effects of radiation imbalance in the Arctic;
- Understand albedo and the ways it can increase or decrease;
- Be able to describe some ecological consequences of decreasing albedo in the Arctic;
- Understand how changes in sea ice formation affect deep water currents;
- Be able to define an ozone hole;
- Be able to describe the consequences of decreasing stratospheric ozone;
- Be able to describe potential hazards of POPs entering Arctic food chains; and
- Be able to describe the possible impacts of physical environment changes on traditional lifestyles in the Arctic.

Acknowledgements

We would like to express our sincere thanks to UNEP/GRID-Arendal and AMAP for permission to use their graphics.

Overview

This module builds on material presented in Module Two and gives a general overview of environmental issues that affect the Arctic, including climate change related themes. The module is based mainly on the circumpolar priorities described in the Arctic Council's Arctic Monitoring and Assessment Program (AMAP) and Conservation of Arctic Flora and Fauna (CAFF) working groups, and in the Arctic Sections of the Intergovernmental Panel on Climate Change (IPCC) reports supported by work presented in the scientific literature of the International Arctic Science Committee (IASC) and the United Nations Environment Programme (UNEP) GEO reports.

Lecture

Main Environmental Features

Meteorological Features

Air Temperature

The Arctic receives less heat energy as solar radiation than it emits into space as long-wave radiation. This net loss of energy produces low temperatures. It is balanced by a redistribution of heat from southern latitudes through air and ocean currents. Topography and the distribution of land and sea create significant temperature differences at similar latitudes. For example, at a station in the Canadian Arctic Archipelago, the average January temperature is approximately 20° C lower than the temperature at a station at the same latitude on Svalbard.

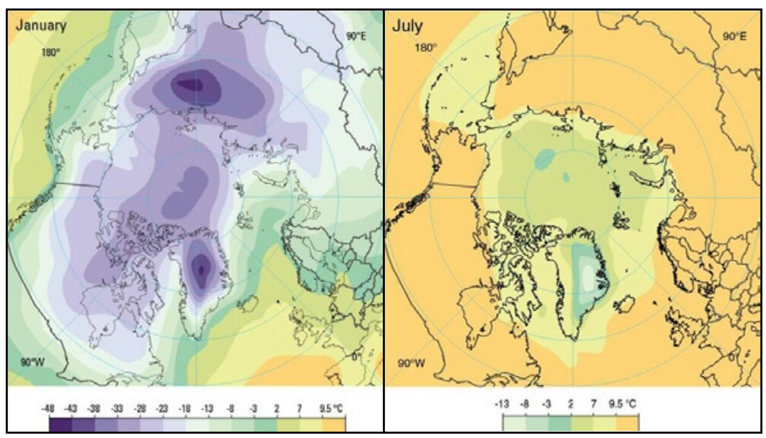


Figure 1 A. January temperature averages. B. July temperature averages.
Graphics production: GRID-Arendal.

Climate is divided into maritime and continental subtypes. Maritime areas have moderately cold, stormy winters. Summers are cloudy, with mean temperatures of about 10°C. Continental climate is found in the interior of the larger land masses in the Arctic, where precipitation is lower than over maritime areas, and temperature differences are more significant (e.g., July mean temperatures of +5°C to +10°C; January mean temperatures of -20°C to -40°C) (see Figures 1 A and 1 B).

Precipitation

On average, the annual precipitation in the Arctic is less than 500 mm, typically between 200 and 400 mm. Cold air can hold less moisture than warmer air, and although the frequency of precipitation may be high, the overall intensity is low. This explains why the accumulation of snow is relatively low in winter in much of the Arctic.

Cloud Cover

Persistent and extensive cloud cover is an important feature over polar oceans. The cloud cover varies from 70 to 90 per cent in summer to 40 to 60 per cent in winter. During periods of cold air outbreaks from the Arctic Basin, clouds are formed by cooling of the warmer boundary layer air.

Fog

Another characteristic feature of Arctic weather is fog. Some areas have, on average, more than 100 foggy days per year. In summer, the ice retreats northward, exposing open water, and warm air moves in over the ice and cold water, resulting in fog. In winter "sea smoke" or steam fog forms over open water leads in the pack ice.

Winds

The generally open landscape of the Arctic region means that winds are not greatly slowed by friction at ground level. Wind is an important factor in snow distribution, causing scouring in exposed areas and deposition in sheltered locations. It also augments the chilling effect of low temperatures. Wind also affects sea surface stability, increases mixing in the water column, and it influences ice drift.

The Arctic Landscape

Fresh Water

The Arctic landscape is dominated by fresh water in the form of rivers, lakes, glaciers, permafrost, and wetlands. Glaciers in Greenland and other parts of North America contain a noteworthy proportion of the world's fresh water. Cold winters convert most fresh water to ice, which has had a significant impact on the shape of the landscape (as we have seen in Module 2). Glacier-formed valleys and **moraines**, outwash plains, **polygon tundra**, and **pingos**, as well as river and coastal erosion, all result from endless seasonal cycles of ice freeze and thaw.

Arctic Rivers

Each year, Arctic rivers (see Figure 2) carry about 4200 km^3 of water into the Arctic Ocean along with a calculated 221 million tons of sediments. The landscape determines how much sediment each river carries. Those crossing flat, frozen **tundra** generally carry small amounts of sediment. Fast-moving rivers that flow through

Figure 2. The Arctic watershed. Graphic production by UNEP/GRID-Arendal.

landscapes with less permafrost and with soils that are easily eroded, Canada's Mackenzie River for example, carries large amounts of sediment.

Permafrost

When ground is frozen year round, for more than two years, a typical feature of the Arctic, it is called **permafrost** (see Figure 3). As we saw in Module 2, permafrost may be anything from a couple of metres to one kilometre deep. Normally, only the uppermost, active layer (down to one metre) thaws during summer.

The permafrost in northern Siberia and northern North America is deep and continuous. Further south the permafrost is discontinuous and restricted to mountain areas. Permafrost stores large amounts of ancient carbon and methane, both global warming gases. Thawing permafrost is likely to release some of this stored carbon and methane back into the atmosphere, increasing the risk of further climate change.

Figure 3. Permafrost. Graphic by UNEP/GRID-Arendal. *The extent of permafrost could be reduced by up to 22 per cent as a result of global warming, according to the IPCC 2000 report.*

The Arctic Ocean

The Arctic Ocean is the smallest of the world's five oceans. Most of the water flowing into the Arctic Ocean comes from the Atlantic Ocean through the North Greenland Sea and the Barents Sea (see Figure 4). Each year, approximately two per cent of its water comes from rivers of the Arctic region (see Figure 2). Nearly half of the ocean floor is continental shelf, the highest percentage among all oceans. These shelves are the primary areas of ice formation and ice melt.

The Arctic Ocean features an enormous ice pack of some 8 million km^2 in late summer, which nearly doubles in size at its peak between March and May (AMAP 1997). The ice pack is surrounded by open seas during the summer months. The ocean is almost entirely

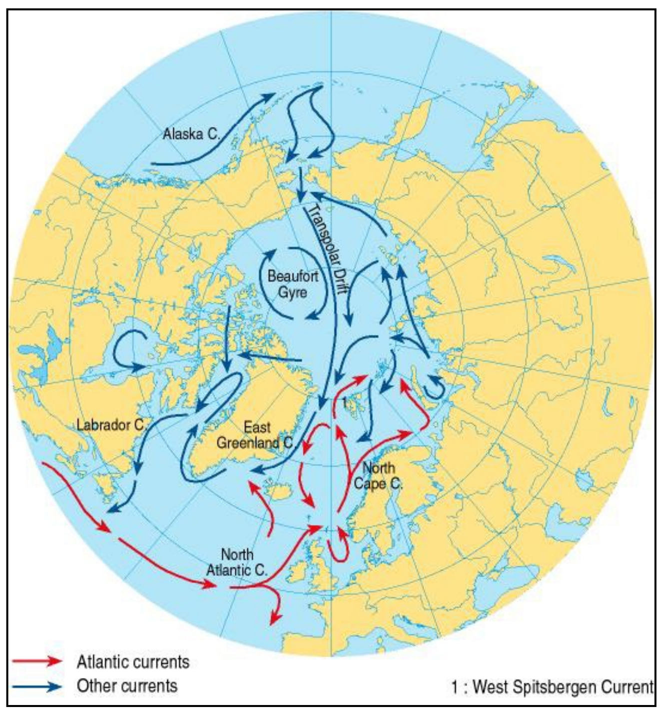


Figure 4. Arctic Ocean currents. Graphic by UNEP/GRID Arendal.

ice locked from October to June. The Arctic Ocean ice is not a monolithic cap, but moves, changes, breaks up, and reforms. It has an average thickness of approximately three metres with pressure ridges as much as three to five times thicker.

Ocean Currents

As in the atmosphere, there are both annual and inter-annual variabilities in ocean temperature, most pronounced in the relatively warmer water masses. In the North Atlantic, the ocean appears to alternate between warm and cold states, with fluctuation periods of three to five years as the most frequent.

Signs of Climate Change

The Greenhouse Effect

The temperature of the earth is controlled by the presence of water vapour, carbon dioxide (CO_2), ozone, methane, nitrous oxide, and other naturally occurring atmospher-

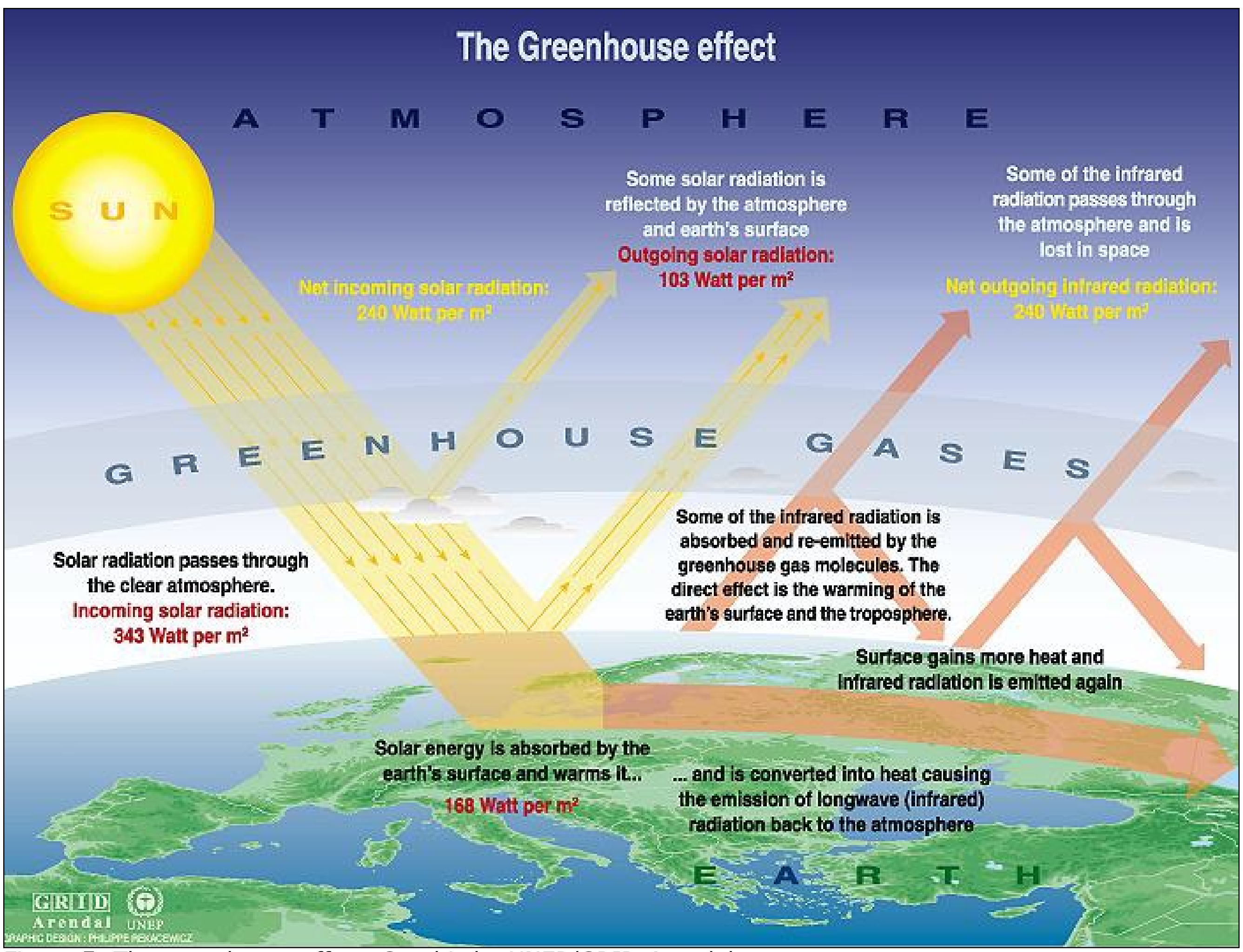


Figure 5: The greenhouse effect. Graphic by UNEP/GRID-Arendal.

icgases. These gases block outgoing, long-wave (heat) radiation from leaving the earth, thus warming the atmosphere (see Figure 5). This effect has given birth to the common name greenhouse gases.

On average, about one third of the solar radiation that hits the earth is reflected back to space. Of the remainder, some is absorbed by the atmosphere but most is absorbed by the land and oceans. The earth's surface becomes warm and, as a result, emits infrared radiation. Greenhouse gases mixed throughout the atmosphere trap the infrared radiation, thus warming the atmosphere. Naturally occurring greenhouse gases create a natural greenhouse effect. However, human activities are causing greenhouse gas levels in the atmosphere to increase.

Cooling Effects

The amount of **aerosols** (suspended particles) in the air has a direct effect on the amount of solar radiation that can reach the earth's surface. Aerosols may have significant local or regional impact on temperatures (see Figure 6).

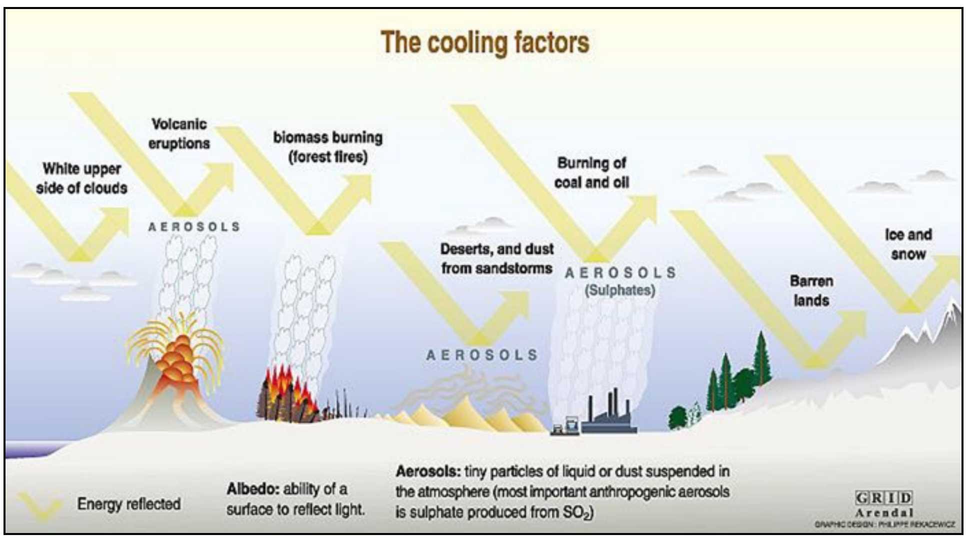


Figure 6: Cooling Factors. Graphic by UNEP/GRID-Arendal. *Aerosols directly affect the amount of solar radiation hitting the Earth and may have significant impacts on temperature. Water vapour is a greenhouse gas but the upper white surface of clouds reflects solar radiation.* ***Albedo***—*reflection of solar radiation from Earth surfaces—creates difficulties in exact calculations. If, for example, the polar ice cap melts, the albedo will be reduced. Open water absorbs heat, while white ice and snow reflect it.*

Increase in Atmospheric Carbon Dioxide

Concerns about climate change stem from the increasing concentration of CO_2 and other greenhouse gases). Atmospheric CO_2 has increased from a pre-industrial concentration of about 280 ppmv (parts per million by volume) to about 367 ppmv at present. The rapid increase has been occurring since the onset of industrialization (see Figure 7), and has closely followed the increase in CO_2 emissions from burning fossil fuels.

Surface Air Temperature Changes

Surface air temperatures seem to be increasing by about 1.5°C per decade over continental central Siberia and over continental North America. In Fennoscandia, the records do not indicate any significant changes, whereas Baffin Bay is cooling by 1.5°C

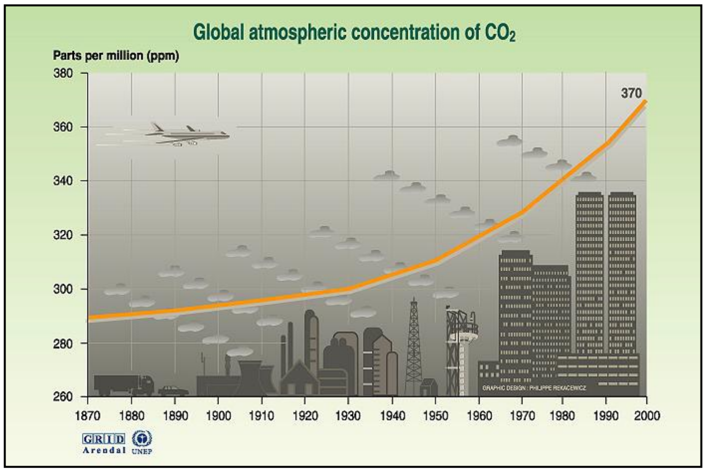


Figure 7: Global atmospheric concentrations of CO_2. Graphic by UNEP/GRID-Arendal.

Atmospheric CO_2 has increased from a pre-industrial concentration of about 280 ppmv (parts per million by volume) to about 367 ppmv at present. CO_2 concentration data from before 1958 are from ice-core measurements taken in Antarctica and from 1958 onwards are from the Mauna Loa measurement site. The smooth curve is based on a hundred-year running mean. It is evident that the rapid increase in CO_2 concentrations has been occurring since the onset of industrialization. The increase has closely followed the increase in CO_2 emissions from fossil fuels.

per decade. North of 70°N, temperature observations are sparse. There are indications, however, of warming around the northern continental rims of central and western North America and central Asia over the past century. Increasing air temperatures are evident at both sea and land surfaces. Indirect indicators, such as borehole temperatures and glacier shrinkage, provide independent support for the observed warming. It should be noted that the warming has not been globally uniform. For eastern North America through the North Atlantic, there is a cooling trend.

Increased Precipitation

During the past 40 years, precipitation has increased by up to 15 percent in high latitudes. On the North American tundra, there is a trend toward earlier spring snowmelt. Changes in snow cover may have profound impacts on plant and animal life in the Arctic.

Changes in Permafrost

Much of the permafrost in the Arctic is close to 0°C and particularly sensitive to temperature changes. Measuring temperature profiles in permafrost can provide a climate record that goes back hundreds of years at a particular site. Such measurements from Alaska (see Figure 8) indicate a warming of 2°C to 4°C over the past

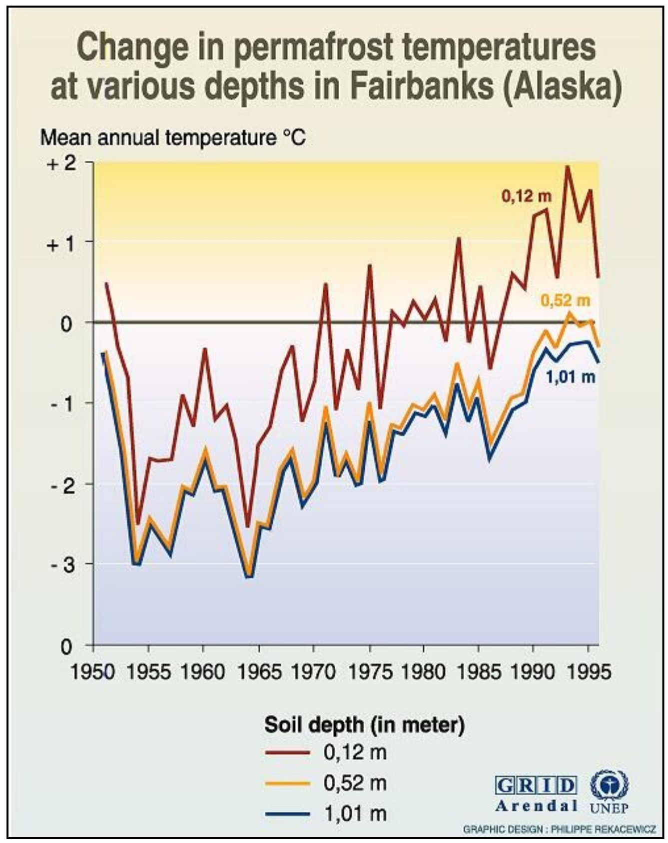


Figure 8: Change in permafrost temperatures at various depths in Fairbanks (Alaska). Graphic by UNEP/GRID-Arendal. *With a doubling of atmospheric CO_2, it is likely that there will be increases in the thickness of the active layer of permafrost and the disappearance of most of the ice-rich discontinuous permafrost over a century. This figure provides a good example of changes already observed in Alaska.*

hundred years. This warming has been confirmed by observations that the discontinuous permafrost in Alaska is thawing. Inuit in Barrow, Alaska, have seen their ice cellars, which are dug into the permafrost, drip water for the first time in living memory. Widespread loss of discontinuous permafrost will trigger erosion or subsidence of ice-rich landscapes, and change hydrologic processes. Large-scale thawing of permafrost will make the Arctic tundra into a major source of carbon dioxide and methane—two important greenhouse gases. In addition, changes in the **cryosphere** will reduce slope stability and increase incidence of natural hazards for people, structures, and communication links. Buildings, roads, pipelines, and communication links will be threatened or destroyed.

Examples of infrastructure damage caused by permafrost melting.

Observed Thinning of Sea Ice

Sea ice plays a critical role in the energy budget of the Arctic and thus in the region's climate. Snow-covered ice is highly reflective, so decreasing sea-ice cover will enhance a warming trend. Sea ice is also a physical barrier between the ocean and the atmosphere. Less ice and warmer air would allow the air to pick up moisture from the water, which might make the Arctic cloudier. This would probably change regional weather patterns. Sea ice limits the exchange of carbon dioxide between water and air and the penetration of light into the water, which in turn affects the productivity of algae in the ocean.

The thickness of the part of the ice that is submerged is its **draft**. Comparison of **sea-ice draft** data acquired on submarine cruises between 1993 and 1997 with similar data acquired between 1958 and 1976 indicates that the mean ice draft at the end of the melt season has decreased by about 1.3 m in most of the deep water portion of the Arctic Ocean, from 3.1 m in the period 1958 to 1976 to 1.8 m in the 1990s (see Figure 9). In summary: ice draft in the 1990s was over a metre thinner than two to four decades

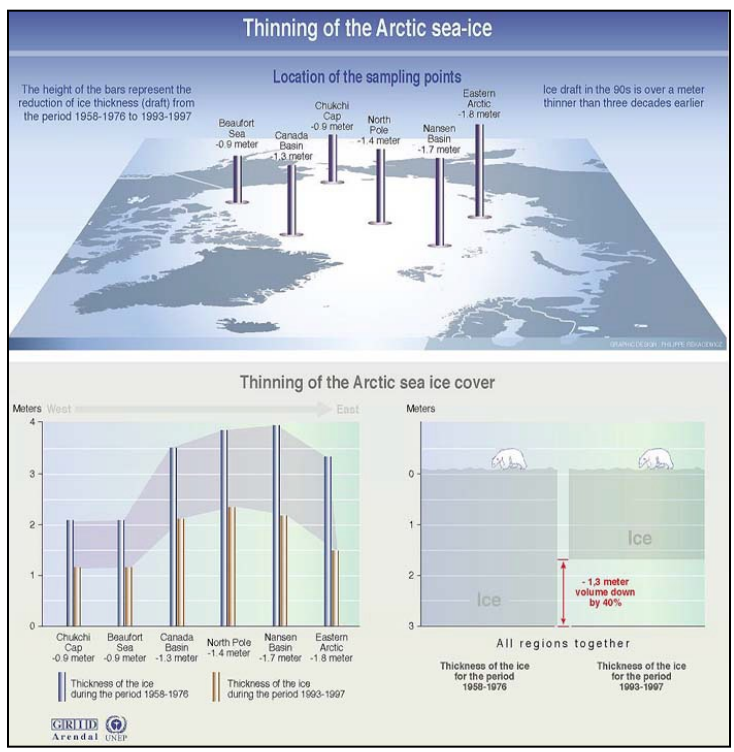


Figure 9: Thinning of the Arctic sea ice. Graphic by UNEP/GRID-Arendal.

earlier. The main draft has decreased from over 3 metres to under 2 metres, and the volume is down by some 40 per cent. During the last half of the 20th century, sea ice in the region has been disappearing at a rate of nearly three per cent per decade. In the Arctic, the extent of sea ice has declined by nearly one third over the past 130 years.

Predictions on Global Warming

According to the **Intergovernmental Panel on Climate Change (IPCC)**, a continued increase of greenhouse gases at current rates could raise the average global air temperature by 1°C to 3.5°C by 2100. The average rate of warming would likely be greater than ever in the past 10,000 years. Another prediction is that there will be more extremely warm days and fewer extremely cold days. The probability of both droughts and floods is expected to increase.

Current understanding of global climate patterns is still regarded as insufficient for making reliable regional predictions. Most studies suggest that the Arctic, as a whole, will warm more than the global mean. Current understanding is that greenhouse-induced warming will cause substantial decreases in the extent of snow and sea ice and in the thickness of the ice. Such changes will, in turn, affect local weather patterns, the distribution of clouds, ocean circulation, and global climate.

Average surface temperatures have increased (see Figure 10). Warming is evident in both sea-surface and land-surface air temperatures. Urbanization in general and desertification could have contributed only a small fraction of the overall global warming, although urbanization may have been an important influence in some regions. Indirect indicators such as borehole temperatures and glacier shrinkage provide independent

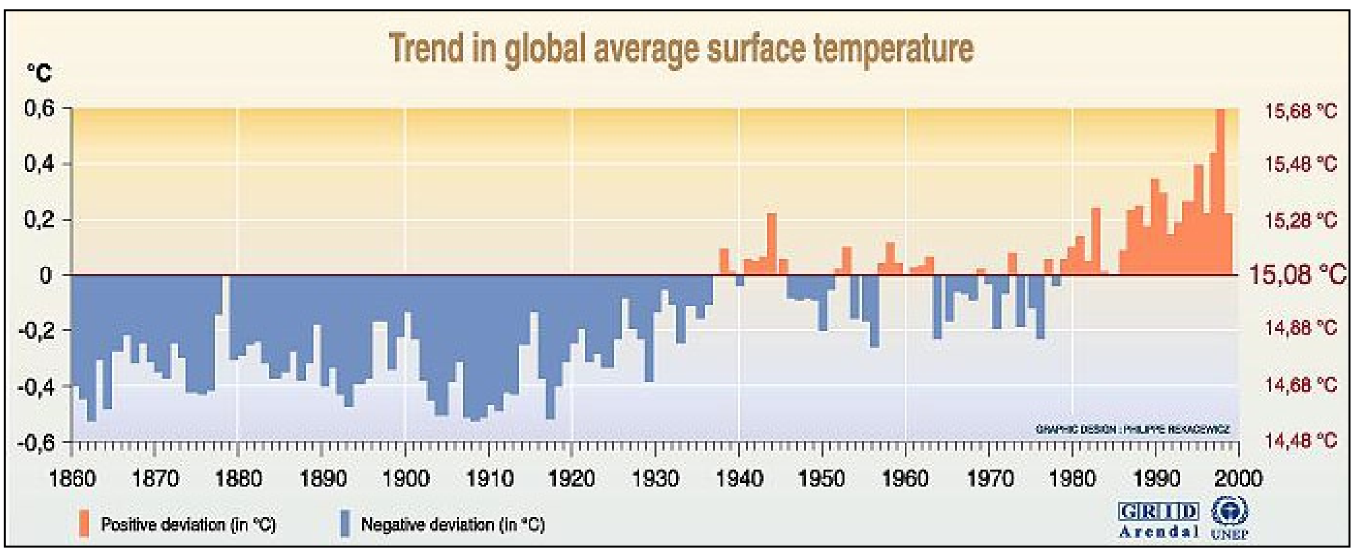


Figure 10. Trend in global average surface temperature. Graphic by GRID-Arendal. *The figure shows the combined land-surface and sea-surface air temperatures between 1861 and 1998, relative to the average temperature between 1961 and 1990. The mean global surface temperature has increased by about 0.3 to 0.6°C since the late 19th century and by about 0.2 to 0.3°C over the last 40 years, which is the period with the most reliable data. Recent years have been among the warmest since 1860, the period for which records are available.*

support for the observed warming. It should also be noted that the warming has not been globally uniform. The recent warming has been greatest between 40°N and 70°N latitude, though some areas, such as the North Atlantic Ocean, have cooled in recent decades.

Rising Sea Levels

According to IPCC, the sea level will rise somewhere between 15 and 95 centimetres by 2100. In the Arctic, many smaller glaciers have been shrinking during the past century and global warming will accelerate their demise. The mass balance of glaciers is controlled not only by temperature but also by snowfall and the physical processes of ice motion. Therefore, changes in glacier size typically lag behind climate changes, by years to decades for mountain glaciers and by longer periods for larger ice sheets.

Higher Water Temperatures

Sea levels will rise further because water expands when it warms up. Moreover, the huge amount of fresh water from melting glaciers is likely to affect seawater salinity, which will, in turn, affect the mixing of water masses and ocean currents. Changes in the formation of sea ice, which leads to salty, heavy water sinking down deep into the ocean, also plays a key role in driving deepwater currents, which, in turn, affect weather patterns and climate around the globe.

Coastal erosion, Beaufort Sea, caused by rising water levels and melting permafrost. Photo courtesy of Northern Climate ExChange, Yukon College.

Open water during part of the year over the shallow continental shelf of the Arctic Ocean will also allow exchange of contaminants between water and air, and high biological productivity will provide routes for contaminants to enter the food chain (see Module 3 for a description and discussion of food chains).

Ozone Depletion: The Thinning Ozone Layer

Ozone is an atmospheric gas that plays a critical role in blocking harmful ultraviolet (UV) radiation from reaching the Earth. The amount of ozone in the **stratosphere** (the layer in the atmosphere above the troposphere that extends to about 50 km above the earth's suface) is decreasing, which has raised concern about increased ultraviolet (UV) radiation. Decreasing ozone also affects the temperature structure of the atmosphere and has implications for climate. Also, climate change may enhance ozone depletion by cooling the stratosphere and by changing circulation patterns in a way that will bring low-ozone air into the Arctic.

Ozone-depleting chemicals are spread globally in the atmosphere, but ozone depletion is more severe in the polar areas than closer to the Equator. The extreme case is in Antarctica, where an ozone hole appears every spring over a large area that includes the southern end of South America.

The Arctic, while similar in general climate, does not exhibit the same sort of distinctive yearly ozone hole. The most common form of Arctic ozone depletion can better be described as a Swiss cheese, where smaller holes occur from time to time, especially during the late winter and early spring (see Figure 11). The ozone depletion in these holes can be severe, up to 40 per cent, but they are normally only a few hundred kilometres in diameter and last only a few days. There is, however, also a general downward trend in ozone levels in the Arctic. In the early 1990s, the average yearly levels of ozone in the Arctic were 10 per cent lower than in the late 1970s.

This trend raises questions about how the environment in the Arctic is changing and how this, in turn, may affect the health of people and ecosystems. New snow can reflect as much as 90 per cent of all the incoming UV radiation, and a thin cloud cover can cause UV rays to bounce back and forth between the snow and the clouds, increasing the UV dose in all directions.

The major emissions responsible for depleting the ozone layer are **chlorofluorocarbons** (CFCs), but there are several other man-made compounds that contribute. The production and use of such substances is controlled by an international agreement: the Montreal Protocol on Substances that Deplete the Ozone Layer. It is expected that the maximum ozone depletion will occur within the current or next two decades. The estimates of the ozone recovery are, however, uncertain (WMO 1998).

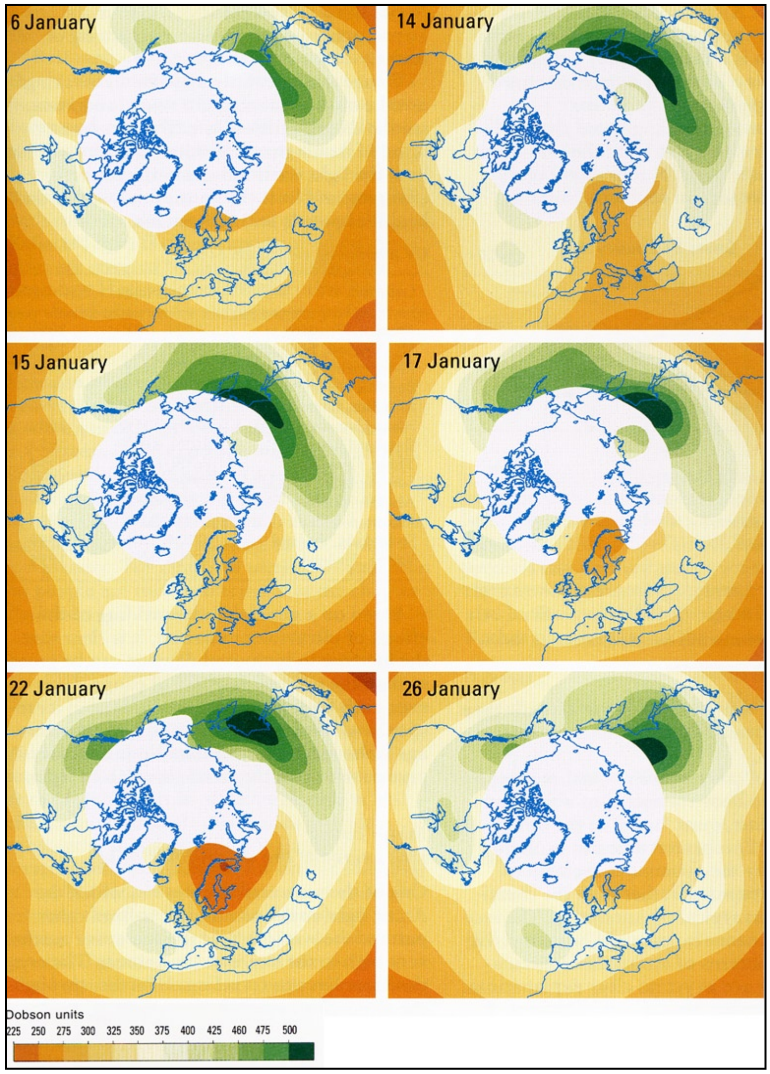


Figure 11. Arctic ozone map. Graphic by GRID-Arendal. *This ozone hole (shown in oranges over Scandinavia and northwestern Russia) in January, 1996 evolved in just a few days and was primarily caused by the dynamic atmospheric circulation and then augmented by chemical reactions. January 6: normal Arctic ozone pattern as measured in Dobson units showing lower ozone values in green. Light grey area indicates no data. January 14-15: influx of low-ozone air from lower latitudes after which this air starts to be pinched off by the strong winds of the developing polar vortex. January 17: The polar vortex isolates the low-ozone air. January 22: Chemical reactions enhance ozone depletion in the isolated hole. January 26: The ozone hole dissipates.*

Other Pollution Issues

Arctic Haze

The term Arctic haze was coined in the 1950s to describe an unusual reduction in visibility observed in the High Arctic. The haze is seasonal, with a peak in the spring. It is caused by human activity; the main source are sulfate emissions from coal burning, mostly in Eurasian countries. Further information on Arctic haze can be found at the web sites noted in the Supplementary Readings/Materials section below.

Hazardous Chemicals

Due to global atmospheric and ocean transportation patterns, many chemicals, released into air or water by human activities, may accumulate in the Arctic in concentrations that have ecological impacts on humans, fauna and flora. Damages, to human beings and animals, from hazardous substances may include physical genetic defects, metabolic changes, reduced fertility, and cancer. Nervous system and muscle functions may also be affected. These impacts could lead to loss of habitat and may be detrimental to the health and welfare of entire populations.

Examples of such hazardous substances are heavy metals (e.g., mercury), **persistent organic pollutants** (POPs) and radioactive materials. Several of these substances can accumulate in food chains until toxic levels are reached. Top predators are particularly vulnerable to such **bioaccumulation**. Combined effects of various environmental contaminants have produced unforeseen problems.

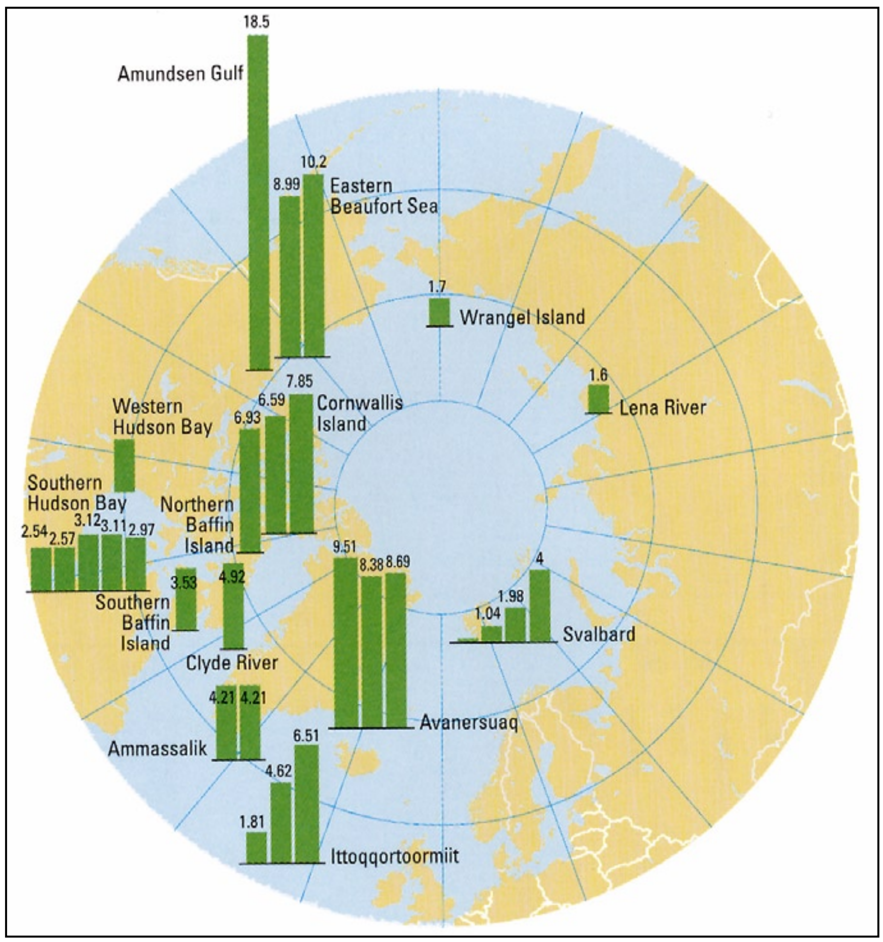


Figure 12. Mercury in polar bears. Graphic by GRID-Arendal. Observed distribution of mercury levels in polar bear hairs. The measurements from various parts of the Arctic are micrograms of mercury per gram of hair.

Mercury

The levels of mercury in peat bogs in southern Greenland have increased tenfold during the 20th century, reflecting changes in atmospheric deposition. The pattern of decreasing heavy metal emissions in Europe and North America has been offset by increased emissions associated with the growing demand for electricity in Asia. Globally, emissions of heavy metals from stationary fossil fuel combustion have not changed significantly since the beginning of the 1980s.

Recent studies have identified a mechanism by which elemental mercury, previously thought to be of little biological significance, may be converted to a reactive form that accumulates in biota in the Arctic (AMAP 2003). On the Faeroe Islands, subtle effects have been observed on infant neurodevelopment and blood pressure due to exposure to mercury during pregnancy. The level of mercury observed in other populations implies that infants may be at risk of similar effects in several parts of the Arctic. The Arctic Council has identified mercury as an emerging issue and has requested UNEP to initiate a global assessment that could form the basis for appropriate international action.

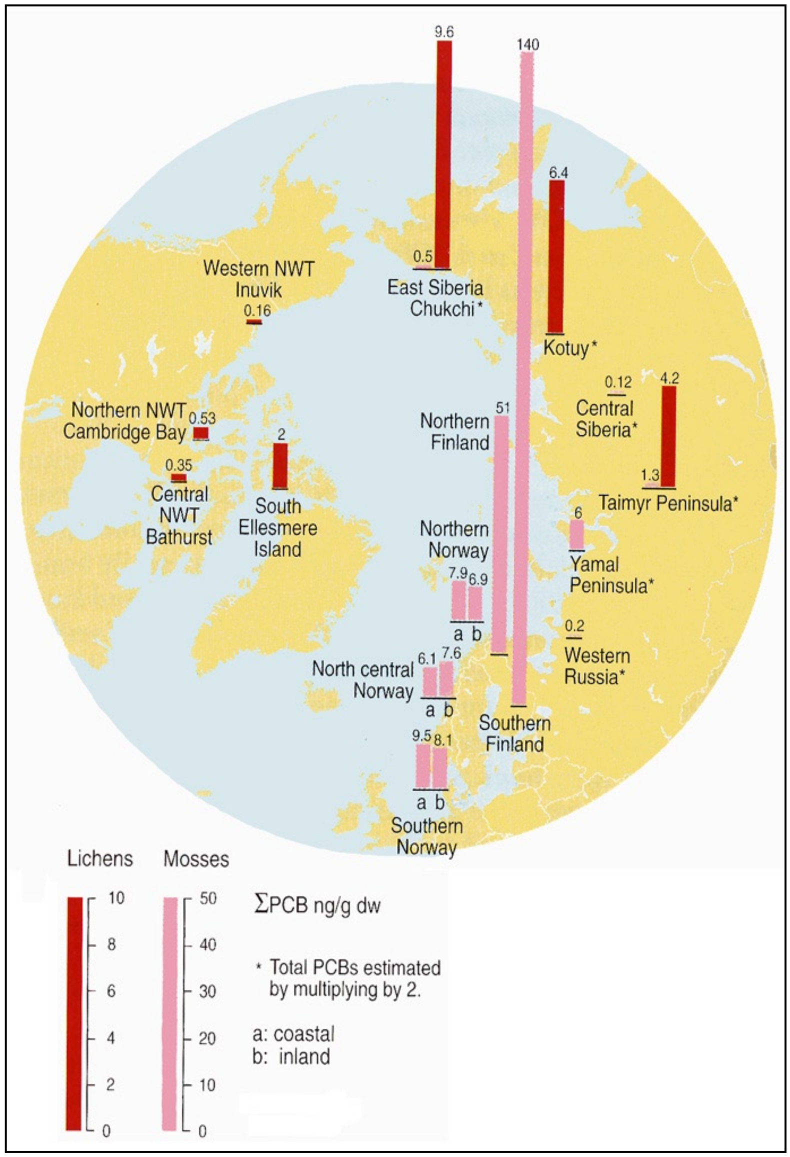


Figure 13. PCB levels in the Arctic. Graphic by GRID-Arendal. *PCB values in lichens and mosses stems from deposition of airborne PCBs. Like other persistent organic pollutants, PCBs accumulate in fatty tissue of animals. Sensitive targets for the toxic effects of PCBs include the developing nervous system and liver enzymes. Other effects on animals are related to the ability to conceive and raise young. One of the underlying causes of failure to reproduce is that some of the chemicals interfere with sex hormones. Another sensitive target for organic contaminants is the immune system, the body's primary defence against disease.*

Polar bears in northern Alaska have higher levels of mercury in liver and muscle tissue than do those in western Alaska (see Figure 12). Bears in western Arctic Canada seem to accumulate mercury faster in their livers than polar bears in eastern Arctic Canada. The eastward decreasing trend in mercury extends to Greenland and Svalbard (Eaton and Farant 1982, Renzoni and Nordstrom 1990, Born et al.1991).

The geographic difference found between western Arctic Canada and eastern Arctic Canada is most likely caused by higher level of mercury levels in the ringed seal food chain caused by higher natural levels in the sediments–and consequently in the lower food chain of the Melville Island area.

Mercury acts as a nerve toxin and the main health concern is its effect on the brain, particularly in the growing foetus and the young. Mercury can also damage reproduction in mammals by interfering with the formation of sperm. Neurological and reproductive effects have also been seen in birds. In fish, its effects include a decreased sense of smell, damage to the gills, blindness, and more.

Persistent Organic Pollutants (POPs)

The Arctic accumulates pollutants, including POPs like polychlorinated biphenols (PCBs) and the pesticide DDT that have been discharged from industry and agriculture around the globe. Large amounts of these "ghosts of the past" that are trapped in sea ice could be released and allowed to enter the food chain through atmospheric warming. This would pose a health threat to top predators such as humans and polar bears (see Figure 13).

Radioactive Pollutants

Strontium and cesium fallout—from the Chernobyl accident (25-26 April 1986) and past nuclear tests—accumulates in lichen, which is, in turn, eaten by reindeer and caribou, and then by humans. As a former playground of the Cold War, the Arctic faces the risk of radioactive contamination (see Figure 14) from leakage from old military installations, weapon storage sites, reprocessing plants, and ships carrying nuclear waste from Europe to central Siberia.

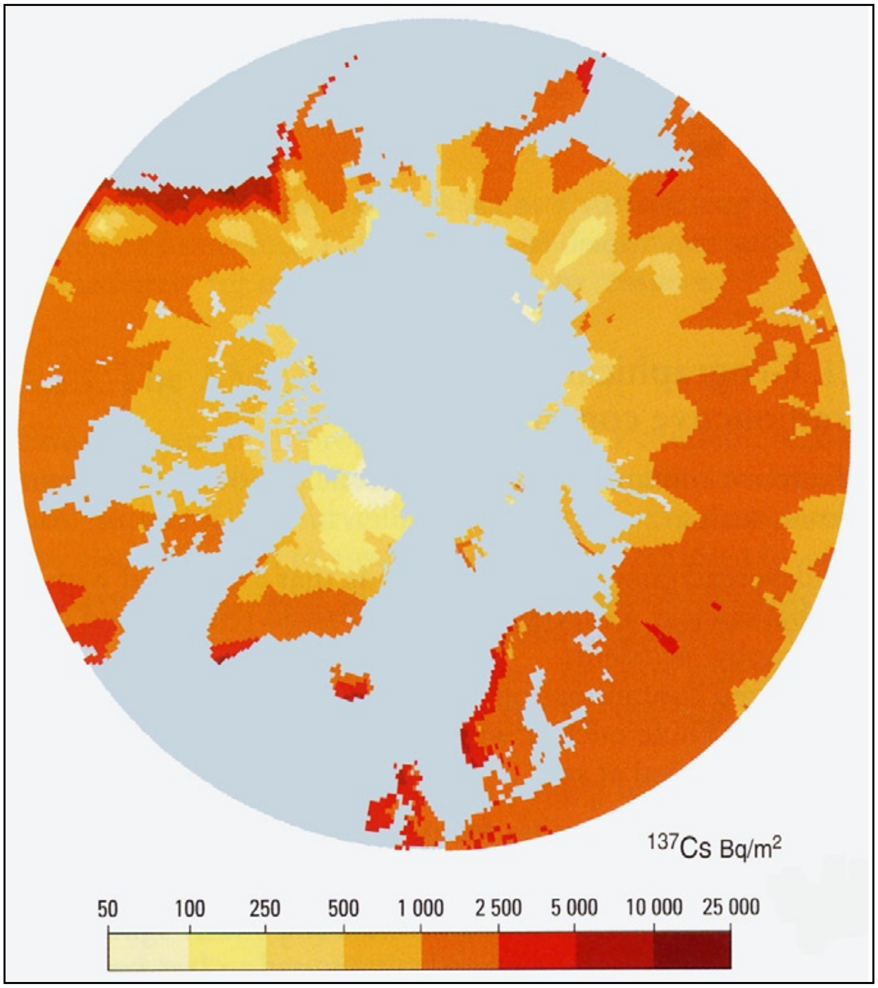


Figure 14. Radioactivity in the Arctic. Graphic by UNEP/GRID-Arendal. *Estimated averages of radioactive Cesium (137 Cs), measured as Becquerel per m². Radiation from radioactive sources is extremely energy-rich and can be harmful to cells and tissue in living organisms. Cesium is regarded as one of the most important man-made radioactive sources. From vegetation, or water, it may accumulate in animals and humans. If there are no new accidents, or no atomic weapons are tested or used, the effects of Chernobyl accident and previous military tests will gradually diminish.*

Acidification

Oxides of sulfur are the major acidifying compounds in the Arctic. They are formed when fossil fuels burn and when sulfide ores are smelted. Release of sulfur dioxide (SO_2) to the environment has risen with the growth in energy demand and industrial activity.

Most of the sulfur in Arctic air comes from industrial areas further south. Eurasia (40 per cent) and eastern North America (20 per cent) are the major global sources. A large part of the remaining global emissions occur in the Far East, particularly China. Emissions of SO_2 have decreased considerably in North America and Europe after peaking in the late 1970s and early 1980s.

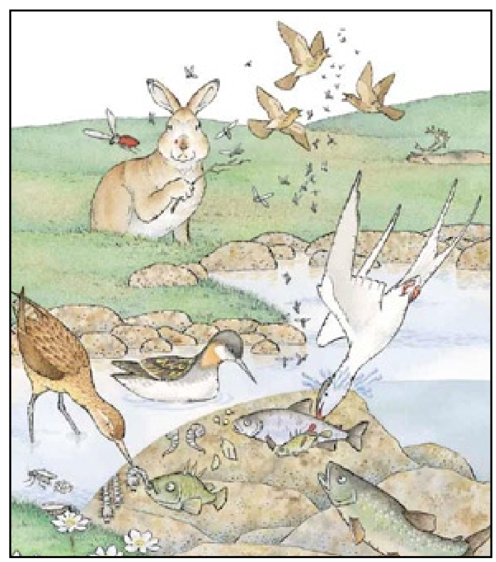
In the Arctic, production of copper, nickel, and other non-ferrous metals from sulfur-bearing ores creates the largest emissions of acidifying substances. Most smelter emissions come from the Nikel, Zapolyarnyy, and Monchegorsk complexes on the Kola Peninsula and from Noril'sk in northwestern Siberia. Compared with similar industries in other areas, emissions from these smelters are extremely high.

Environmental Impacts

Effects on Biodiversity

While it is one of the world's last, large, mainly undisturbed terrestrial ecosystems, the Arctic now faces problems due to climate change, ozone depletion, long-range transported pollution and unsustainable use. These **anthropogenic** risks loom as the greatest threats to the biodiversity of the Arctic (CAFF 2001, IPCC 2001). Seals, caribou, fish, whales, and polar bears may also pass along high levels of contaminants to human communities that subsist on marine mammals and wildlife (AMAP 1997).

The most biologically productive and diverse areas in the Arctic are along coasts and at the edges of the ice, where marine mammals are most abundance. These areas are some of the largest productive marine ecosystems on earth, and have, for this very reason, faced strong pressure from fisheries and hunting of marine mammals over the last decades. The Bering and Barents seas currently support the world's largest fisheries by tonnage.



Biodiversity. Painting by M. Rapeli, from CAFF, *Arctic Flora and Fauna*, 2001, Ch. 7, p. 162.

Shore birds, caribou, whales, polar bears, seals, and sea lions all can be found in abundance at the long polar coastline. These ecosystems are vulnerable to rapid changes, though there is a record of hardy species that can quickly recover. For the marine wildlife that depends on these areas for breeding and hunting—and Indigenous communities that still maintain a subsistence lifestyle—the earlier breakup, steady retreat, and later return of shorefast ice present critical challenges to survival (IPCC 2001).

Another threat to Arctic biodiversity is habitat fragmentation. While the Arctic does include some of the largest tracts of wilderness on the planet, infrastructure development, mainly due to presence of minerals and hydrocarbons, has, for decades, influenced even remote corners of the North. Thus, infrastructure development can be used as an indicator of human impacts in the Arctic (see Figure 15).

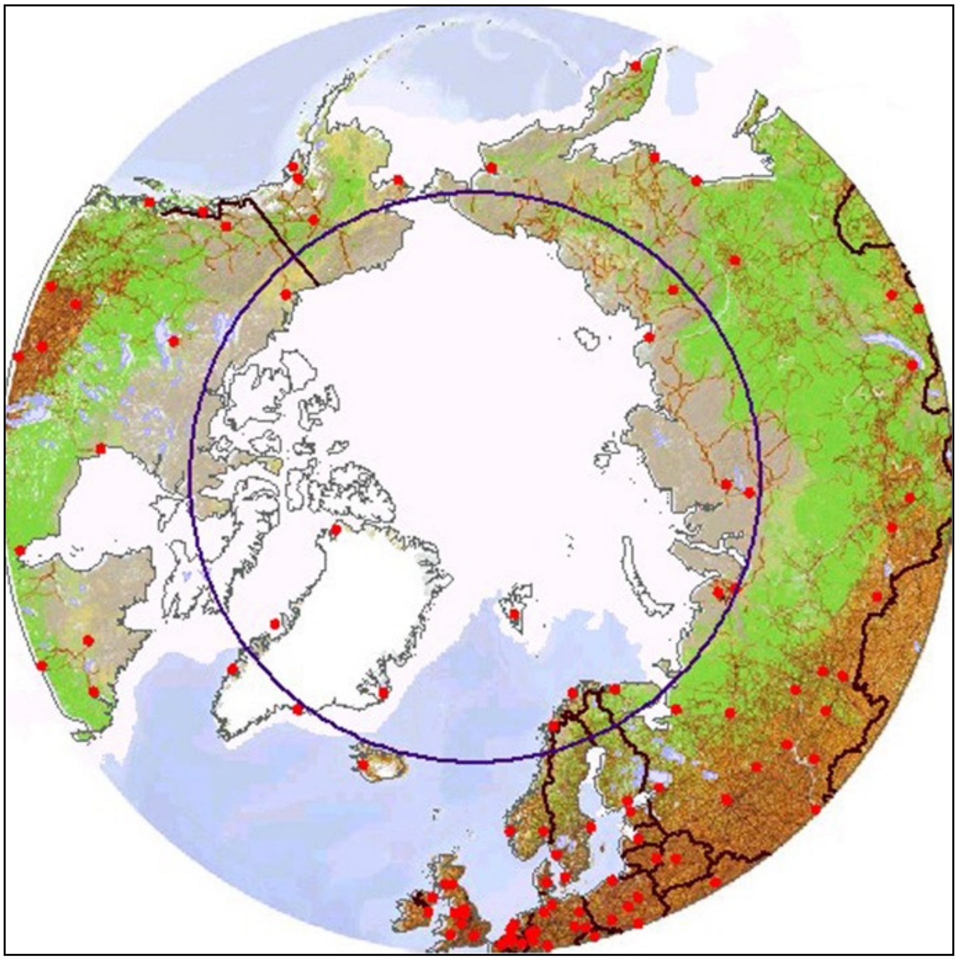


Figure 15. Infrastructure as indicator. *On this map, infrastructure development is used as an indicator of human impacts. By relating probability of impact on biodiversity and ecosystems to distance to infrastructure, based on existing impact assessment studies, a simple measure of a number of threats to nature is achieved. Infrastructure brings primary industrial development, but also secondary, more uncontrolled, development with increased human immigration and settlement, with greater risks of deforestation, overgrazing, desertification, social conflict, and water and land degradation. The map illustrates the degree of environmental impact on Circumpolar ecosystems, and clearly highlights the large tracts that remain of relatively undisturbed nature that have been the homelands for Indigenous peoples for thousands of years.*

Humans and Environmental Changes

While Indigenous human habitation in northern latitudes dates back several thousand years in most areas of the Arctic, those settlements have remained modest. Although non-Indigenous residents now outnumber Indigenous residents in much of the Arctic, Indigenous communities continue to redefine their relationship between living on the land using traditional means and adopting and taking advantage of modern approaches and technology. Steadily growing populations throughout the twentieth century attest to the continued vibrancy of Indigenous peoples of the North.

Dictated by topography and harsh climate, employment in the Arctic is mainly a mixture of nomadic animal husbandry, tourism, and natural-resource extraction. In the twentieth century, the Russian North has experienced a mass immigration due to resource extraction industries—coal, oil, gas, nickel, copper, gold, and diamonds. In a vast area with approximately 180,000 Indigenous people, over 6 million ethnic Russians have settled in northern urban centers. Some of these centers have from onequarter- million to one million residents. Since the demise of the Soviet Union, however, that influx has begun to reverse en masse.

The survival of Arctic peoples has always been intricately linked to climate. To the extent that people continue to harvest plants and animals and live permanently or seasonally on coastal spits or along riverbanks and lakeshores, climate change will directly impact their lives. Even if modern resources can mitigate some effects, climate change is likely to disrupt culturally important hunting and fishing activities.

Coastal erosion has forced some Aboriginal communities in Alaska to relocate. A rise in sea level would threaten many more communities, especially in Russia and Alaska where they are often located on low-lying coastal plains and on river deltas. Coastal erosion would also cause changes to the geography of river deltas.

Temperature and humidity changes will probably affect the local physical environment. Thawing permafrost represents a growing challenge with huge economic implications. On large areas of the coastal plains and wet tundra, an increase in precipitation could contribute to making the land unusable. It might also shift the migration patterns of terrestrial mammals and alter the breeding and molting areas of birds.

Changes in snow cover would alter travelling conditions over the tundra, making it potentially more difficult for hunters to reach inland locations in spring and fall. For communities on the coast, changes in sea ice might have dramatic impacts by shifting the migration routes of marine mammals. Even if animal life seems abundant, it is often made up of seasonal migrants on their way to specific feeding grounds where food production is intense but brief. The population density of seals, for example, is correlated with the distribution of coastal sea ice. Indigenous peoples and other northern residents depending on traditional food for all or part of their diet may be adversely affected by chronic exposure to long-distance pollutants.

While fragmented over three continents and two islands—North America, Europe, Asia, Greenland and Iceland—problems and concerns confronting the region in many ways share more in common across the Circumpolar North than between northern and southern regions of the same continent or nation state. Since the end of the Cold War, this sense of common history and purpose has led to a growing number of post-Cold-War avenues for Arctic cooperation. Among all collaborative efforts needed for sustainable development in the region, concerted action on environment and climate change issues will require top priority.

Supplementary Reading/Materials

Arctic Monitoring and Assessment Programme (AMAP). 1997. Arctic Pollution Issues: A State of the Arctic Environment Report. Oslo, NO: AMAP. Adobe pdf at http://www.amap.no/ (link to Popular (non-scientific) reports).

Arctic Monitoring and Assessment Programme (AMAP). 2002. Effects of Contaminants on Arctic Humans and Biota. AMAP fact sheet. October. Available in Adobe pdf at http://www.amap.no/ (link to Fact sheets).

Arctic Monitoring and Assessment Programme (AMAP). 2002. Mercury – An Increasing Threat? AMAP fact sheet. October. Available in Adobe pdf at http://www.amap.no/ (link to Fact sheets).

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Arctic Monitoring and Assessment Programme (AMAP). 2002. Transport of Contaminants to the Arctic, and their Fate. AMAP fact sheet. October. Available in Adobe pdf at http://www.amap.no/ (link to Fact sheets).

Arctic Monitoring and Assessment Programme (AMAP). 2003. AMAP Assessment 2002: Human Health in the Arctic. Oslo, NO: AMAP. xiii+137 pp. Available by chapters in Adobe pdf at http://www.amap.no/ (link to Scientific reports).

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Conservation of Arctic Flora and Fauna (CAFF). 2001. Arctic Flora and Fauna: Status and Conservation. Helsinki, FI: Edita. Available by chapters in Adobe pdf at http://www.caff.is/sidur/sidur.asp?id=18&menu=docs

Eaton, R.D.P. and J.P. Farant. 1982. Polar Bear as a Biological Indicator of the Environmental Mercury Burden. *Arctic* 35(3): 422-425.

Intergovernmental Panel on Climate Change. 2001. *Climate Change 2001: Impacts, Adaptation and Vulnerability*. Cambridge, UK: Cambridge UP for IPCC.

Renzoni, A. and R.J. Nordstrom. 1990. Mercury in the Hairs of Polar Bears *Ursus maritimus*. *Polar Record* 26(159): 326-328.

World Meteorological Organization (WMO). 1998. *Scientific Assessment of Ozone Depletion*. WMO Global Research and Monitoring Project Report No. 44.

Useful Websites

Climate Change

Vital Climate Graphics: The IPCC report in a nutshell
http://www.grida.no/climate/vital/index.htm

Kyoto protocol and emission map
http://maps.grida.no/kyoto/

Northern Climate ExChange
http://www.taiga.net/nce/

Permafrost

Background information
http://www.grida.no/inf/news/news01/news09b.htm

General

Arctic Region Resources
http://www.grida.no/arctic.htm

World Meteorological Organization
http://www.wmo.ch/indexflash.html

Essays on the Arctic
http://www.arctic.noaa.gov/essay.html

Toxicology

Definitions
http://www.grida.no/soeno98/contam/toxy.htm

Potential damages
http://www.grida.no/soeno98/contam/effects.htm

Arctic Haze

National Snow and Ice Data Center. n.d. "Arctic Haze: Facts from the Arctic Climatology and Meteorology Primer." *Arctic Climatology and Meteorology PRIMER for Newcomers to the North*. At http://www.nsidc.org/arcticmet/quickfacts/arctic_haze.html

These web links were last verified 21 June 2004.

Study Questions

1. Describe the effects of radiation imbalance in the Arctic.
2. What is albedo? In what ways can the albedo increase or decrease? Describe some ecological consequences of decreasing albedo in the Arctic.
3. How do changes in formation of sea ice affect deepwater currents?
4. What is meant by an "ozone hole"? Describe the consequences of decreasing stratospheric ozone.
5. Describe potential hazards of POPs entering Arctic food chains.

6. Describe the possible impacts of physical environment changes on wildlife distribution and traditional lifestyles in the Arctic.
7. What are the signs of climate change in the Arctic? Subarctic?
8. Why are circumpolar peoples and communities concerned about climate change and contaminants such as POPs?
9. What are some of the things northern peoples are doing in response to these threats?

Glossary

Aerosols: Tiny particles of liquid or dust suspended in the atmosphere. A colloidal suspension of particles dispersed in air or other gas.

Albedo: The ability of a surface to reflect light. The proportion of incident light or radiation reflected by a surface.

Anthropogenic: Caused by human activity.

Chloroflourocarbons (CFCs): Various man-made gaseous compounds of carbon, hydrogen, chlorine, and fluorine, used as refrigerants, propellants, etc. Because researchers generally agree that they destroy ozone in the atmosphere, their manufacture and use is restricted by international agreement.

Cryosphere: Areas where water is frozen. E.g., glaciers, snow, permafrost, etc.

Moraine: A ridge or mound of rock or earth carried and deposited by a glacier.

Ozone: A colourless, unstable gas formed from oxygen through electrical discharges or exposure to ultraviolet light. Chemical formula: O_3. In sufficient concentrations, ozone in the earth's atmosphere has the ability to block solar ultraviolet radiation.

Permafrost: The permanently frozen layer of soil and ice at and under the surface of Arctic land.

Persistent Organic Pollutants (POPs): Various man-made organic compounds that remain in the environment for a long time after their introduction and that may accumulate to toxic levels through bioaccumulation in the food chain.

Pingos: Dome-shaped mounds found in permafrost areas and consisting of a layer of soil covering a large core of ice.

Polygon tundra: Tundra with patterned ground features that form polygons.

Sea-ice draft: The thickness of the part of sea ice that is submerged.

Tundra: The vast, treeless, flat Arctic region, usually with a marshy surface and underlying permafrost.