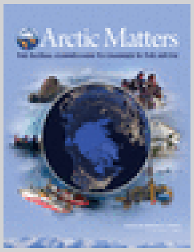

Arctic Matters: The Global Connection to Changes in the Arctic

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Arctic Matters

THE GLOBAL CONNECTION TO CHANGES IN THE ARCTIC

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE ARCTIC

NORTH PACIFIC OCEAN
Bering Sea
Sea of Okhotsk
50° N
60° N
70° N
80° N
Arctic Circle
UNITED STATES (Alaska)
CANADA
Chukchi Sea
Wrangel Island
East Siberian Sea
Beaufort Sea
New Siberian Islands
Banks Island
Laptev Sea
Victoria Island
ARCTIC OCEAN
RUSSIA
Queen Elizabeth Islands
Severnaya Zemlya
North Pole
Ellesmere Island
Kara Sea
80° W
Franz Josef Land
Baffin Island
Baffin Bay
Novaya Zemlya
Greenland (DENMARK)
Svalbard (NORWAY)
Barents Sea
60° W
Greenland Sea
Labrador Sea
Jan Mayen (NORWAY)
FINLAND
SWEDEN
Norwegian Sea
ICELAND
Faroe Islands (DENMARK)
NORWAY
EST.
Shetland Islands
LAT.
NORTH ATLANTIC OCEAN
LITH.
North Sea
BELARUS
DENMARK
UNITED KINGDOM
UKRAINE
POLAND
IRELAND
NETH.
GERMANY
MOL.
CZECH REP.
BEL.
SLOV.
ROMANIA
HUN.
AUS.
FRANCE
0 250 500 mi
0 250 500 km
Scale accurate at 81° N

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Introduction

Viewed in satellite images as a jagged white coat draped over the top of the globe, the high Arctic appears distant and isolated. Its vast expanses of ice and sky, blinding summer sun and frigid, foreboding winters, and the swirling aurora borealis give it an almost otherworldly air. But even if you don't live there, don't do business there, and will never travel there, you are closer to the Arctic than you think.

Wherever you are, you are connected to the Arctic through Earth itself.
The Arctic region includes the Arctic Ocean and parts of Alaska, Canada, Finland, Greenland, Iceland, Norway, Russia, and Sweden. Although remote to most of Earth's inhabitants, the Arctic is tied to every point on the globe through land, sea, or air. Our daily weather, what we eat, and coastal flooding are all tied to the future of the Arctic.

Wherever you are, you are connected to the Arctic through the ecosystems that sustain life.
Plants and animals observe no borders. As the Arctic changes, the availability of many of the resources on which we depend will also change. The physical, ecological, and human realms of the Arctic are inextricably linked. And in all three dimensions, what happens in the Arctic affects the rest of the world.

The Aurora Borealis, or Northern Lights, shines above Bear Lake, Eielson Air Force Base, Alaska.
Source: U.S. Air Force/Senior Airman Joshua Strang

The 8th Arctic Council Ministerial Meeting, Kiruna, Sweden, May 2013. *Source: The Arctic Council.*

What is the Arctic Council?

The Arctic Council is an intergovernmental forum representing eight member states (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden, and the United States) and six Arctic indigenous groups. Since its establishment in 1996, the Council has promoted cooperation, coordination, and interaction among its member states and partner communities. By engaging governments, indigenous groups, and other Arctic inhabitants, the Council advances awareness and action on issues such as sustainable development and environmental protection in the Arctic. The United States serves as Chair of the Council for the 2015–2017 term.

Finally, wherever you are, you are connected to the Arctic through human beings.
People have lived in the Arctic for millennia, and today the region is home to some four million people. These people contribute to society's cultural heritage diversity, and provide a historical record of the region. Increasingly, the Arctic serves as a source of natural resources and a place to visit, study, and travel through.

This booklet is intended to introduce the Arctic to those unfamiliar with the importance of this remarkable place in the past, present, and future of our planet. It draws from a collection of peer-reviewed reports of the National Research Council, the operational arm of the non-profit U.S. National Academy of Sciences and U.S. National Academy of Engineering that provides independent advice on issues of science and technology, as well as from other national and international reports. These reports collectively represent authoritative assessments prepared and reviewed by independent experts, including leaders in climate and atmospheric sciences, environmental science, oceanography, ecology, defense, business, anthropology, and many other fields.

The National Research Council developed this booklet, in recognition of the United States becoming Chair of the Arctic Council for the 2015–2017 term, to provide a primer on the complex ways in which the Arctic and its diverse people, resources, and environment affect us all — in short, *why the Arctic matters.*

The Arctic

Dispatches from the Front Lines of Climate Change

By definition, global climate change is reflected in a host of changes all over the planet. But changes do not occur uniformly across the globe. Changes in the Arctic have been generally more rapid than those anywhere else on Earth. Strange sights — such as forests of "drunken trees" loosened by thawing permafrost — provide dramatic visual evidence of this rapid change (Figure 1).

Why is Earth Warming?

Greenhouse gases such as carbon dioxide and methane absorb heat emitted from Earth's surface. Increases in the atmospheric concentrations of these gases cause Earth to warm by trapping more of this heat. Human activities — especially the burning of fossil fuels — have increased atmospheric carbon dioxide concentrations by about 40 percent, with more than half the increase occurring since 1970. Since 1900, the global average surface temperature has increased by about 0.8°C (1.4°F).

Figure 1. This forest of "drunken trees" in Alaska is a clear sign of thawing permafrost. When permafrost thaws it can make the ground buckle, causing trees to lose their footing and tip over at odd angles. *Source: National Snow and Ice Data Center, University of Colorado, Boulder/Tingjun Zhang*

Arctic Ocean Acidification

As well as warming the atmosphere, excess carbon dioxide is also absorbed by the ocean, forming carbonic acid that makes seawater more acidic (lower pH), a phenomenon called ocean acidification. Ocean acidification threatens the health of marine organisms, such as corals and some shellfish, which have shells composed of calcium carbonate—a material that dissolves at lower pH. As the pH of sea water decreases, it will become more difficult for these organisms to form or maintain their shells, with impacts that ripple throughout the marine ecosystem.

The Arctic Ocean is particularly sensitive to ocean acidification: frigid Arctic waters absorb more carbon dioxide than temperate waters. Additionally, declines in the extent of summer sea ice will expose more ocean area, allowing for greater transfer of carbon dioxide from the atmosphere into the ocean.

Tiny sea snails called pteropods are one example of an Arctic marine species at risk from ocean acidification. Pteropods swim near the ocean surface and provide food for a variety of fish. Healthy pteropods have smooth, transparent shells (top). In lower pH conditions, pteropod shells can start to dissolve and appear cloudy, ragged, and pockmarked (bottom). *Source: NOAA*

TEMPERATURES ARE RISING.

Temperatures are rising twice as fast in the Arctic as compared to the average global temperature rise (Figure 2). The most dramatic manifestation of this warming is seen during the Arctic winters, which are becoming milder. The temperature of the Arctic Ocean is also increasing, a pattern that is exacerbated as sea ice melts, leaving more of the water's surface exposed and allowing more heat to be taken up by the open water during the summer months.

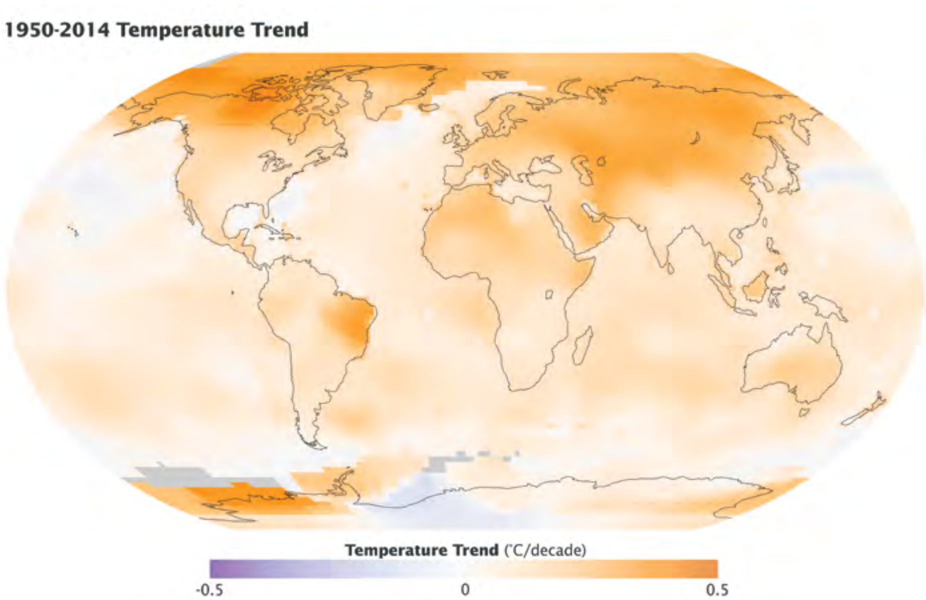


Figure 2. Temperatures have risen faster in the Arctic than elsewhere on the globe. This map depicts the temperature trend from 1950 to 2014. This analysis was assembled using publicly available data from roughly 6,300 meteorological stations around the world; ship-based and satellite observations of sea surface temperature; and Antarctic research station measurements. *Source: NASA Earth Observatory/ NASA Goddard Institute for Space Studies (GISS)/ Kevin Ward*

SEA ICE IS MELTING.

If you were to stand at the North Pole, the snow and ice under your boots would feel rock-solid, and its white expanse might extend as far as you could see. But you would not be standing on land, because Earth's North Pole is in the middle of the Arctic Ocean. You would be standing on sea ice — ice floating on the ocean's surface.

Each summer, as temperatures rise above freezing, the ice begins to melt and the area covered by sea ice shrinks (Figure 3). In winter, sea ice coverage expands again as sea water freezes.

But over the past several decades, warmer temperatures have meant there is less sea ice left at the end of the summer. Using satellites, scientists have found that the area of sea ice coverage each September has declined by more than 40 percent since the late 1970s, a trend that has accelerated since 2007.

In fact, by the end of each of the eight summers from 2007–2014, Arctic sea ice extended over less area than at any time in the preceding three decades — the time period for which we have satellite observations. In 2012, the ice shrank to its smallest extent ever recorded by satellites, with the ice covering only half the area covered just 30 years earlier.

This striking decrease in summer ice has also caused winter ice to become thinner and less stable. Even a few decades ago, a large core of sea ice survived the summer and beyond, thickening and hardening over many winters to become multiyear ice (generally 3–4 meters [10–13 feet] thick). But now, more summer melting means an increasing fraction of winter sea ice cover is first-year sea ice (generally only 1–2 meters [3–7 feet] thick) that melts more quickly and breaks up more easily in the summer, contributing to the overall trend of sea ice loss (Figure 4).

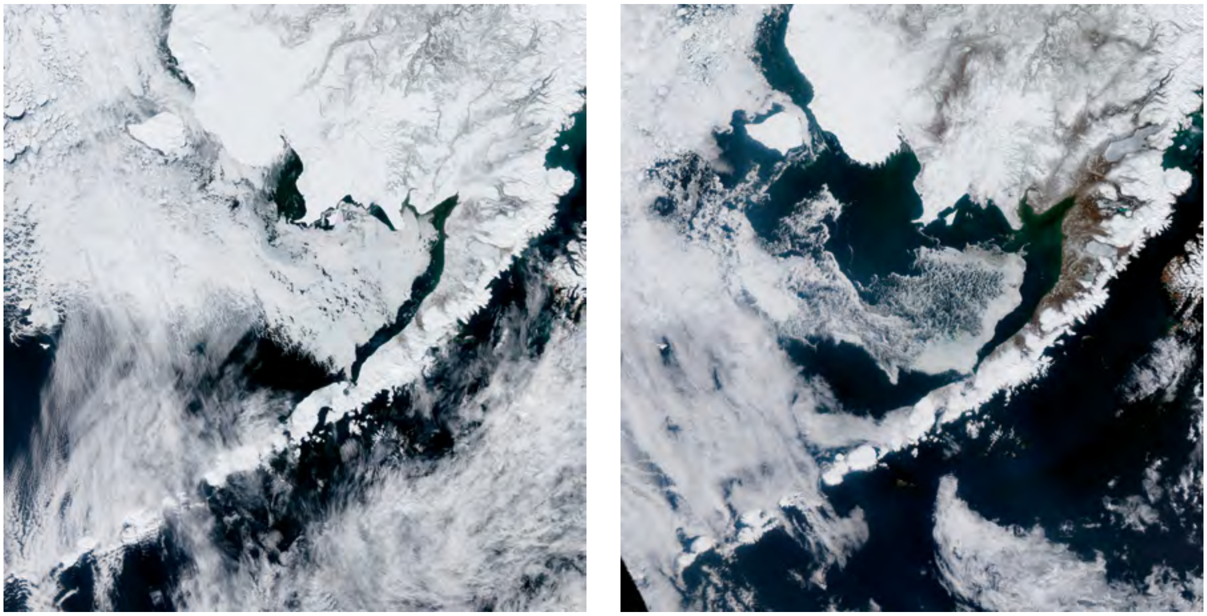


Figure 3. These images of Alaska's Bristol Bay, taken by the Moderate Resolution Imaging Spectroradiometer (MODIS) on the NASA Aqua satellite, illustrate the thinning and thawing of arctic sea ice each spring. The image on the left was taken on April 11 2012, and shows sea ice hugging the shore. Two weeks later, on April 24, the ice had retreated (right). *Source: NASA Earth Observatory/ Jesse Allen*

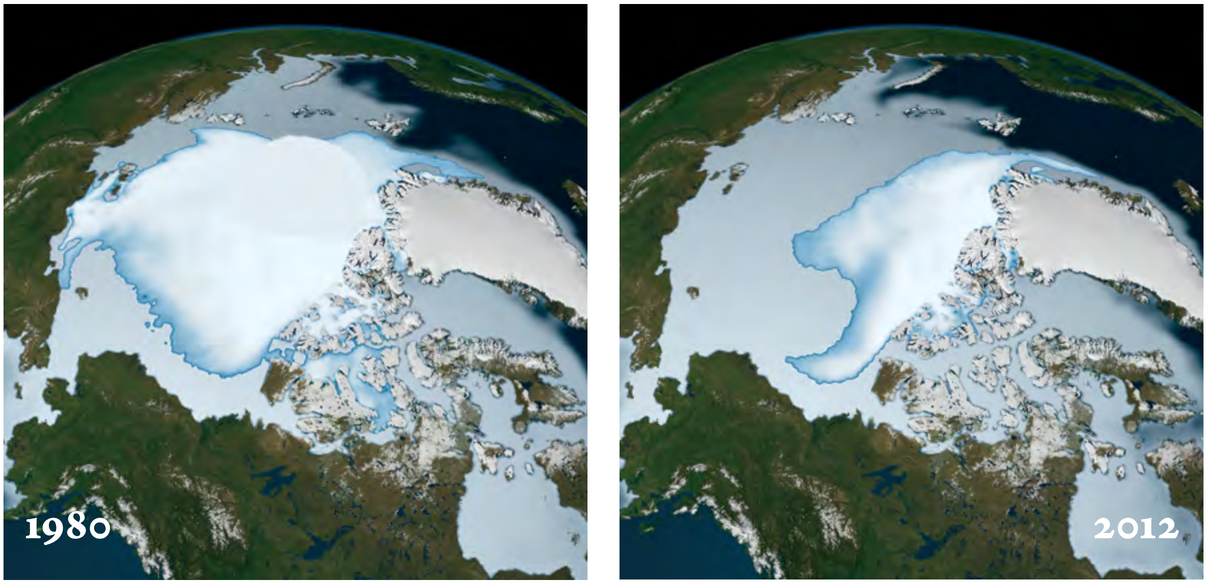


FIGURE 4. The extent of multi-year ice is decreasing rapidly. These visualizations show sea ice coverage in 1980 (left) and 2012 (right). Multi-year ice is shown in bright white, while younger sea ice is shown in light blue to milky white. The data show the ice cover for the period of November 1 through January 31 in their respective years. *Source: NASA Earth Observatory*

The Science of Predicting Sea Ice

Accurate sea ice predictions are crucial to modeling atmospheric and oceanographic processes, understanding ecological changes, and helping people know what to expect when venturing into the area to extract resources or transport goods. Scientists use satellites, ships, and airplanes to measure the areal extent of ice covering the Arctic Ocean, the thickness of the ice, and other characteristics. These measurements are then integrated with computer models to project what could happen in the future.

Despite sophisticated measurements and computer models, our prediction capability is limited. For example, seasonal forecasts from 21 research groups all underestimated the record-setting summer sea ice loss of 2012. The 2012 National Research Council report *Seasonal-to-Decadal Predictions of Arctic Sea Ice: Challenges and Strategies* offers strategies to improve sea ice projections.

The blanket of ice coating Earth's northernmost seas is thin and ragged by summer. This photo shows scientists treading carefully over ice in the Canada Basin of the Arctic in July 2005. *Source: NOAA/OAR/OER/Jeremy Potter*

LAND ICE IS MELTING.

Ice is melting at a rapid pace on the land masses that encircle the Arctic Ocean.

Glaciers, many of which have endured since the last Ice Age or longer, are becoming smaller (Figure 5). Those that border bodies of water are increasingly breaking off into icebergs, a process called calving. The icebergs then float away and gradually melt into the sea.

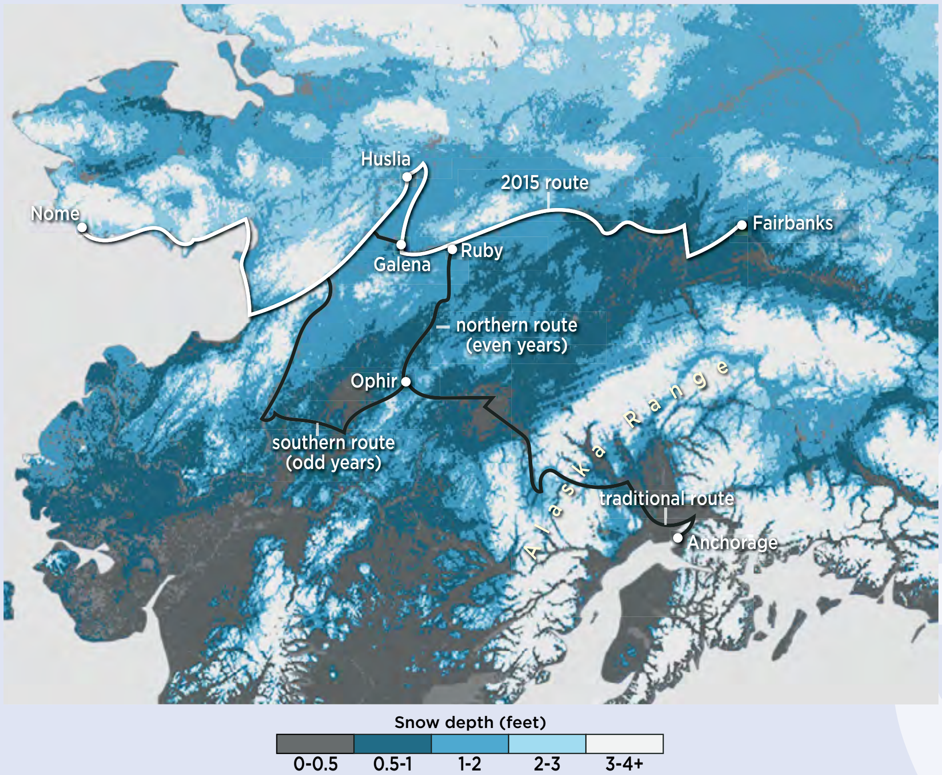
The Greenland ice sheet is essentially an enormous glacier that extends about 1,699,000 square kilometers (656,000 square miles) and covers most of the island of Greenland. In recent decades, this ice sheet has begun to decrease in size and mass as a result of warmer summer temperatures melting ice at the surface, and increased calving of ice at the island's edges.

Snow cover has also decreased as temperatures rise and snow melts off more quickly in the spring and summer. For example, snow cover in June 2012 was 40 percent below the average from 1971–2000 — the baseline period of observations — in many areas of the Arctic.

This loss of ice from Arctic land masses contributes to sea level rise, alters the way water moves over and through the land, and could affect the circulation of the oceans and atmosphere globally.

Figure 5. Recent losses of land ice are illustrated by comparing a 1976 photograph of Muir Glacier in Glacier Bay National Park and Preserve, Alaska (left) with a 2003 photograph of the same glacier (right). The 1976 photograph shows the calving edge of Muir Glacier (where icebergs break off) extending the width of the fiord, and aside from algae growing on a lighter colored dike, there is no vegetation visible in the photograph. The 2003 photograph documents the disappearance of Muir Glacier from the field of view, and shows vegetation beginning to develop. *Source: USGS/Bruce F. Molnia.*

Snow largely a no-show for 2014 Iditarod Trail Sled Dog Race



Source: NOAA Climate.gov/ NWS NOHRSC

On March 1, 2014, 65 mushers and their teams of dogs left Anchorage, Alaska, on a quest to win the Iditarod—a race covering 1,000 miles of mountain ranges, frozen rivers, dense forest, tundra and coastline. According to local news reports, a lack of snow covering the trail's harsh terrain made the race especially challenging, and many mushers pulled out of the race due to injuries and broken sleds. This map shows model-estimated snow depth across Alaska as of March 5, 2014. Historical Iditarod trail routes are shown in black. Snow depth increases from gray (one foot or less), to blue, to white (3 feet or more).

PERMAFROST IS THAWING.

Although permafrost derives its name from the word "permanent," it is becoming markedly less so.

Defined as soil, rock, and any other subsurface earth material that exists at or below freezing for two or more consecutive years, permafrost thaws when ground temperatures increase. Permafrost ranges from solid to sporadic, depending on temperature and soil type. Discontinuous (patchy) permafrost is particularly susceptible to thawing. Scientists have seen declines in permafrost over the past 30 years and predict that discontinuous permafrost will likely disappear across much of the Arctic, where ground temperatures are now within 1–2° C (1.8–3.6° F) of thawing.

The effects of changes in permafrost are complex because each area has a unique geological, chemical, atmospheric, and biological environment. When permafrost thaws, it can have significant impacts on an area's landscape, ecosystem, hydrology, and infrastructure, for example by causing the collapse of roads, bridges, runways and buildings (Figure 6).

Figure 6. Ocean waves erode coastlines the world over, but in parts of Alaska coastal erosion has accelerated due to two climate-driven phenomena: declining sea ice and thawing permafrost. Arctic sea ice absorbs wave energy, dampening the waves that beat against the shoreline, but declines in summertime sea ice cover are creating expanses of open ocean that allow storms to stir up waves. At the same time, thawing permafrost means that land is becoming softer and more vulnerable to erosion. Taken near Drew Point, along Alaska's northern coast, the photo on the left shows how ocean waves have undercut the land nearest the shore. The photo on the right, taken about a year later, shows chunks of coastline tumbling into the sea. *Source: Stratus Consulting/University of Colorado; NOAA Climate.gov*

The distribution of permafrost in the Arctic. *Source: Philippe Rekacewicz, UNEP/GRID-Arendal*

How Do You Measure Permafrost?

To directly measure permafrost, scientists drill into the ground, measure the temperature, and analyze samples to see how long the ground has been frozen. But this approach can only be deployed in a tiny fraction of places where permafrost exists. To determine the extent of permafrost across the entire Arctic—and track its disappearance—scientists use a variety of measurements.

For example, sophisticated sensors on ground-based equipment, aircraft, and satellites provide information about ice and snow on the ground, topography and shifts in the landscape over time, soil characteristics and chemistry, vegetation, and many other factors. These factors can be used to monitor permafrost indirectly.

A 2014 National Research Council workshop summarized in the report *Opportunities to Use Remote Sensing in Understanding Permafrost and Related Ecological Characteristics* explored how remote sensing technologies could be harnessed to advance knowledge about permafrost.

ARCTIC ECOSYSTEMS ARE CHANGING.

The Arctic is home to living creatures found nowhere else on Earth. Many are highly specialized, having evolved in response to the unique Arctic environment over millions of years. As ice melts and temperatures change, these species face mounting challenges — including the possibility of extinction.

Some of the most recognizable Arctic animals, such as polar bears, seals, and walruses, rely on sea ice as a platform for resting and hunting. Like the Arctic's human residents, these animals face the loss of habitat and drastically reduced hunting ranges as sea ice recedes.

For example, in past years walruses in the Chukchi Sea (between Alaska and the Russian Far East) would have been found scattered across a large area of sea ice overhanging the shallow waters of the continental shelf, using the ice as a resting platform between dives to forage for clams and worms in the seabed. In recent years, however, that sea ice has largely been confined to the deeper waters of the far north, forcing tens of thousands of walruses to come ashore in Alaska and Russia (Figure 7). From land, the walruses must travel farther to reach their prey, forcing them to expend extra energy and making them more vulnerable to illness, competition, and trampling.

Figure 7. In September 2014, an estimated 35,000 walrus came ashore in Point Lay, Alaska. *Source: NOAA*
Inset: A female walrus and pup rest on an ice floe. *Source: U.S. Geological Survey/Sarah Sonsthagen*

As the Arctic grows more temperate, some species are seizing the opportunity to expand into new territory. The melting of sea ice has created new expanses of open ocean, allowing large populations of phytoplankton to bloom and causing shifts in the marine food chain. On land, shrubs are expanding in the tundra and invasive insects are sweeping across the forests (Figure 8). As Arctic summers warm and the ice-free season lengthens, more species from the south could begin to spread northward. Competition from these species for food and other resources could potentially lead to major ecosystem reorganization and even extinctions.

Arctic ecologists are particularly concerned about "tipping points" — thresholds where a small change in climate could have major, irreversible ecological impacts. Scientists are investigating how to predict tipping points in the hope of developing strategies to minimize their impacts. The 2011 National Research Council report *Frontiers in Understanding Climate Change and Polar Ecosystems* identifies key research questions to better understand the ecological impacts of climate change in the Arctic.

As climate warms, shrubs have started to grow in areas previously dominated by tundra vegetation such as lichens, an important winter food source for caribou. The loss of lichens can lead to declines in the growth and abundance of caribou, which in turn, are an important food source for hunters from the Arctic's indigenous communities as well as for predators such as bears and wolves. *Source: U.S. Fish and Wildlife Service/Dean Biggins*

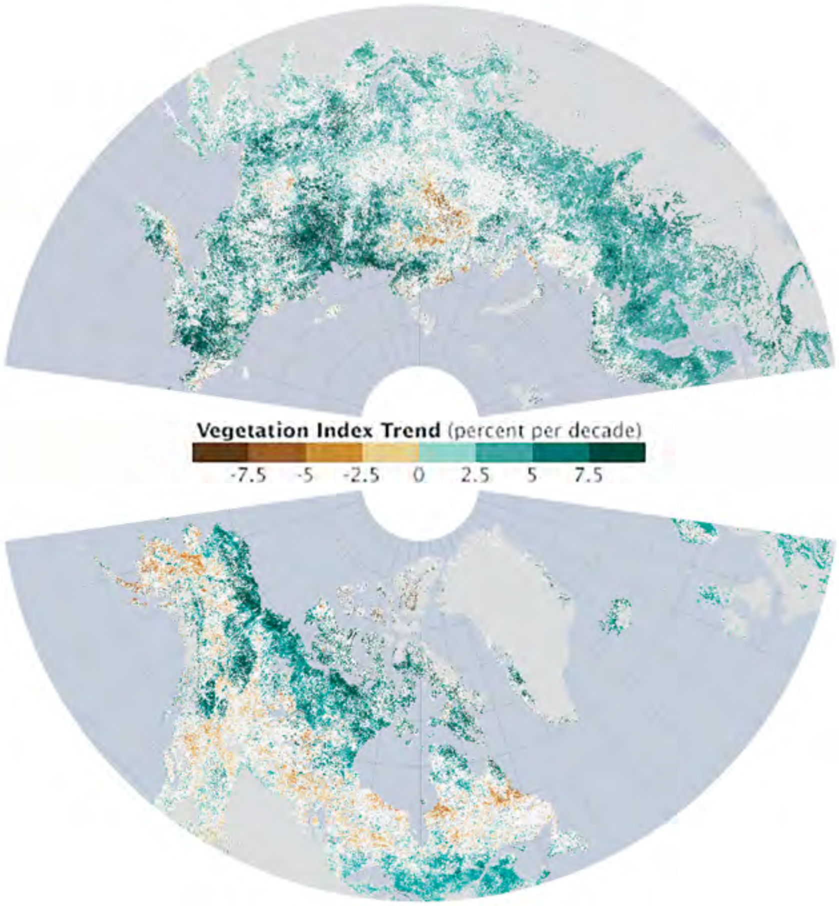


Figure 8. As temperatures have risen in the Arctic, the growing season has got longer in the far northern latitudes, bringing major changes to Arctic ecosystems. Instruments on NASA and NOAA satellites have continuously monitored the growth of vegetation from space since the late 1970s. Scientists use that information to calculate the Normalized Difference Vegetation Index (NDVI), an indicator of photosynthetic activity, or the "greenness" of the landscape. These maps show NDVI trends between July 1982 and December 2011 for the northern portions of North America and Eurasia. Shades of green depict areas where plant productivity and abundance increased; shades of brown show where photosynthetic activity declined. There was no significant trend in areas that are white, and areas that are gray were not included in the study. The maps show a ring of greening in the treeless tundra ecosystems of the circumpolar Arctic — the northernmost parts of Canada, Russia, and Scandinavia. Tall shrubs and trees started to grow in areas that were previously dominated by tundra grasses. The researchers concluded that plant growth had increased by 7 to 10 percent overall. *Source: NASA Earth Observatory*

As Permafrost Thaws, Ancient Treasures are Exposed

As temperatures warm, artifacts and biological specimens that have been frozen in place for thousands of years have begun to emerge from thawing permafrost and eroding coastlines, bearing profound messages about human history and the evolution of life on Earth.

Scientists are racing to take advantage of these great opportunities to understand the region's rich human history through archaeological discovery—but as these artifacts are exposed to the air, many culturally and historically significant sites will start to decompose and will be lost forever.

A nearly century-old whaling boat along the Beaufort Sea coast near Lonely, Alaska. The boat washed away to sea just a few months later due to erosion, an example of how rapid change can lead to the loss of historical sites. *Source: USGS/ Benjamin Jones*

LIFE IS CHANGING FOR THE PEOPLE OF THE ARCTIC.

The Arctic is home to about 4 million people. They range from city dwellers to oil prospectors to hunters and herders living on the land. Many are members of indigenous groups whose ancestors have lived in the Arctic for millennia. They are citizens of eight different countries who speak dozens of distinct languages.

These unique and diverse Arctic communities face an uncertain future. Thawing permafrost poses particularly significant problems. As permafrost thaws, the shape of the land changes and streams or bodies of water can form in areas that were previously dry. Resulting erosion wreaks havoc on buildings, roads, pipes, and other infrastructure, costing communities hundreds of millions of dollars as they struggle to make repairs and keep up with changing conditions.

Towns situated along the coasts are especially vulnerable. Historically, large swaths of sea ice forming along the shoreline have provided a buffer against coastal storms and waves. As sea ice declines, coastal communities face the full brunt of increasingly strong storms. In addition, sea-level rise threatens low-lying communities, and advancing seas and stronger storms may force some communities to relocate.

The 2014 National Research Council report *The Arctic in the Anthropocene: Emerging Research Questions* explores the need for actionable Arctic science to better understand how environmental and societal changes will affect the Arctic and the rest of the world.

Threats to an Ancient Way of Life

A family with a traditional qamutik (sled) in Cape Dorset, an Inuit hamlet in Nunavut, Canada. *Source: Ansgar Walk*

The Arctic's indigenous communities exist at the intersection of the modern world and a cultural history thousands of years old. Changes in the Arctic environment—combined with broad political, economic, and cultural shifts—are putting new strains on ancient traditions.

Many Arctic indigenous groups have traditionally moved between seasonal camps and settlements to optimize opportunities for hunting, fishing, herding, and farming. This way of life has faded with the advent of property ownership, government regulations, and housing developments. In addition, melting snow and ice poses problems for subsistence hunters, who typically rely on over-ice forms of transportation such as dog sleds and snow machines to reach animals like seals, walruses, and caribou. Reductions in ice or snow reduce hunters' range and make travel riskier.

Global Impacts

What Happens in the Arctic Doesn't Stay in the Arctic

The area encompassed by the Arctic Circle is approximately 6 percent of Earth's surface area, about the same as the area covered by the African continent. Yet, no part of the planet is untouched by this unique and rapidly-changing region.

Figure 9. During Superstorm Sandy in 2012, storm surges brought water inland and flooded the coastline of New Jersey, causing billions of dollars in damages. *Source: U.S. Air Force/Master Sgt. Mark C. Olsen*

MELTING LAND ICE CAUSES SEA LEVELS TO RISE.

The Arctic's melting land ice and glaciers contribute to the sea-level rise happening around the world. As this ice melts, much of it ultimately flows into the sea, adding volume to the world's oceans.

According to measurements from a variety of sources, the average global sea level has risen about 20.3 cm (about 8 inches) since 1901. The pace of sea level rise is increasing. Over the past two decades, sea level has risen globally at a rate of 3.1 mm (0.12 inches) per year on average. Between 2003 and 2008, melting Arctic glaciers, ice caps, and the Greenland Ice Sheet contributed 1.3 mm (0.05 inches) — more than 40 percent — of the total global sea level rise observed each year.

If greenhouse gas emissions continue to increase on their current trajectories, scientists project

that global sea level may rise by an additional 0.3–1.3 m (1 to 4 feet) by 2100. About 40 percent of the world's population lives within 100 km of the world's coasts. Sea-level rise (and associated storm surges) poses significant threats to human lives and infrastructure, especially in these vulnerable and densely-populated coastal areas. Many places are already experiencing its effects. For example, storm surge associated with Superstorm Sandy resulted in billions of dollars of damage to coastal homeowners, businesses, and transportation infrastructure (Figure 9).

ARCTIC CHANGES RIPPLE THROUGH THE OCEANS AND ATMOSPHERE.

Although the movement of wind and water around Earth may seem random to the untrained eye, there are actually patterns and processes that influence our weather and climate in relatively predictable ways. Recent changes in the Arctic, however, may be disrupting those patterns, making weather and climate harder to predict.

Which way does the wind blow?

Changes in the Arctic have the potential to affect weather thousands of miles away.

One of the most prominent factors influencing weather in the Northern Hemisphere is the jet stream, a meandering air current that flows around the globe in a generally eastward direction (Figure 10). It results from the collision of colder air masses from the Arctic with warmer air masses from the tropics.

Because temperatures are increasing faster in the Arctic than at the tropics, the temperature gradient that drives the jet stream is becoming less intense. Some scientists have suggested that this could cause the jet stream to become weaker and more meandering, causing weather patterns to become more persistent — that is, to stick around longer — in the mid-latitudes. This could result in longer droughts, heat waves, and cold snaps in many heavily-populated areas of North America and Europe.

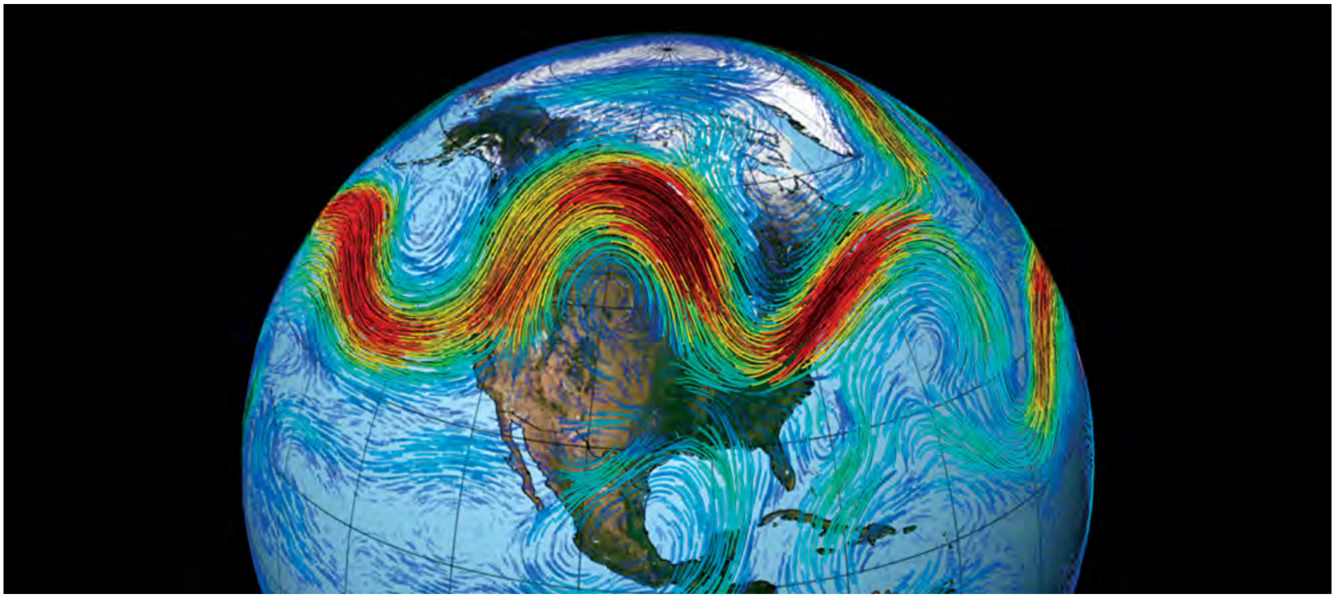
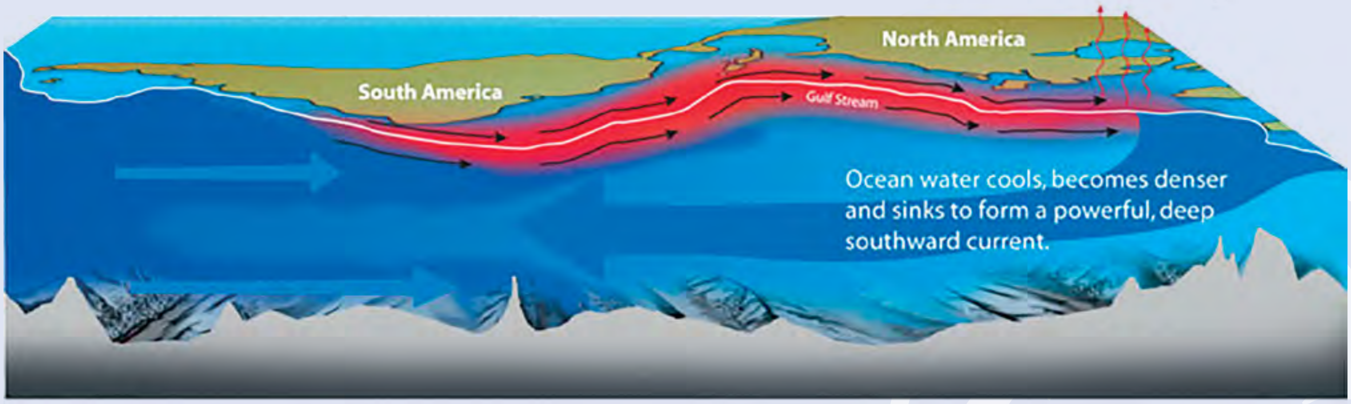


Figure 10. The jet stream — an air current generated when colder air masses from the Arctic meet warmer air masses from the tropics — is a major influence on weather in the Northern Hemisphere. *Source: NASA*

North Atlantic Ocean Circulation Today



The Atlantic meridional overturning circulation (AMOC) carries a tremendous amount of heat from the tropics northward, warming the North Atlantic region. When the surface water cools at high latitudes, this large volume of cold, salty water sinks and flows southward, filling up the deep Atlantic Ocean basin and eventually spreading into the deep Indian and Pacific Oceans. Change within the Arctic could influence ocean circulation—and in turn, affect global climate. Examples of such impacts include sea level rise in the North Atlantic, a southward shift of tropical rain belts, restructuring of local marine ecosystems, ocean and atmospheric temperature and circulation changes, and changes in the ocean's ability to store heat and carbon. *Source: E. Paul Oberlander, Woods Hole Oceanographic Institution*

The 2014 National Research Council workshop report *Linkages Between Arctic Warming and Mid-Latitude Weather Patterns* summarizes presentations by meteorologists and climate scientists about how climate change in the Arctic might affect weather elsewhere in the world.

Side effects of a large dose of fresh water

Changes in the Arctic could affect the ocean's regular currents.

As Arctic ice melts, the Arctic Ocean is being flooded with fresh water. Because the circulation of ocean water is acutely affected by water temperature and salinity (saltiness), scientists believe this freshwater influx could have profound impacts on the circulation of ocean water worldwide. Ocean circulation, in turn, is a major driver for weather patterns, both in the Arctic and around the world.

Scientists cannot currently predict with a high degree of certainty exactly how climate change will affect ocean circulation. One possibility researchers are studying is whether changes in the Arctic Ocean might slow a major current in the Atlantic Ocean called the Atlantic meridional overturning circulation (AMOC). Some scientists believe that the AMOC is beginning to slow. Current models predict that the AMOC will slow, but not stop, during the 21^{st} century. A significant change in the strength of the AMOC would alter winds, temperatures, and precipitation patterns around the globe, with potentially strong local effects along the east coast of the United States and the west coast of northern European countries.

Large-scale changes in ocean currents are not unprecedented. About 12,000 years ago, scientists believe a massive increase in freshwater influx from melting Arctic ice caused the AMOC to shut down entirely, contributing to a major shift of Earth's climate.

Norwegian fishing boat. *Source: Cliff Hellis*
Inset: Supermarket fish counter. *Source: Shutterstock/ Goran Bogicevic*

THE ARCTIC'S LIVING RESOURCES AFFECT GLOBAL HEALTH AND WELL-BEING.

If you eat seafood, it's likely that at some point you've enjoyed the resources of the Arctic marine ecosystem. Ten percent of the world's fish catch comes from Arctic and subarctic waters, and about half of the U.S. fish catch comes from subarctic waters. Changes in the Arctic marine environment could have important implications for this global food source, with potential effects on local communities, regional labor markets, and international trade.

On one hand, some changes in the Arctic could improve the outlook for fishermen. As sea routes open earlier in the spring and freeze later in the fall, it gets easier for fishing boats to access the Arctic's marine bounty. In addition, some favorite southern species are becoming more common farther north. For example, as populations of Pacific salmon have moved into Arctic waters, they may become an important food source for subsistence fishermen along Alaska's north coast.

On the other hand, new species entering an existing ecosystem may threaten existing populations. Atlantic cod, for example, have been displacing the endemic polar cod in the waters surrounding the Norwegian archipelago Svalbard. In addition, rising temperatures and an influx of fresh water from melting ice can cause rippling effects through the marine food chain. In the North Atlantic, for example, scientists project that ocean warming will cause shifts in the spawning and feeding grounds of several economically-important fish populations, including Arctic cod, herring, and capelin.

The fishing industry has long grappled with fluctuations in fish stocks. But some of the adaptations that have worked to keep up with ecological changes in the past and in other places — such as flexibility in fishing location, timing, and species — may be more challenging to employ in the Arctic due to environmental, economic, and management constraints.

In addition to their contributions to the global food supply, Arctic ecosystems are valuable for the biodiversity they represent. When species become extinct and the world's biodiversity decreases, we may lose the opportunity to benefit from important biological resources that could yield benefits in medicine, engineering, materials design, and other applications. Some areas of the Arctic are so remote and inaccessible that their ecosystems have not been studied at all. As the Arctic continues to warm and ecosystems reorganize, it is quite possible that unique Arctic species could disappear without our even knowing it.

FEEDBACK LOOPS ACCELERATE THE PACE OF CHANGE.

Many of the shifts underway in the Arctic are likely to contribute to further climate changes — both in the Arctic and around the globe. Positive feedback loops can amplify the initial temperature change, causing further warming.

Tracing the albedo effect

Walk barefoot across asphalt on a hot summer day and you'll quickly find that dark surfaces trap more heat than light-colored surfaces. That principle plays out on an enormous scale in the Arctic. As the area covered by reflective, white snow and ice shrinks, darker surfaces like tundra and water — which absorb much more sunlight — are left behind. As a result, the reflectivity, or *albedo*, of the region decreases, causing more heat to be absorbed and the surface and air temperature to rise. In turn, these rising temperatures cause more snow and ice to melt, and the cycle begins again (Figure 11).

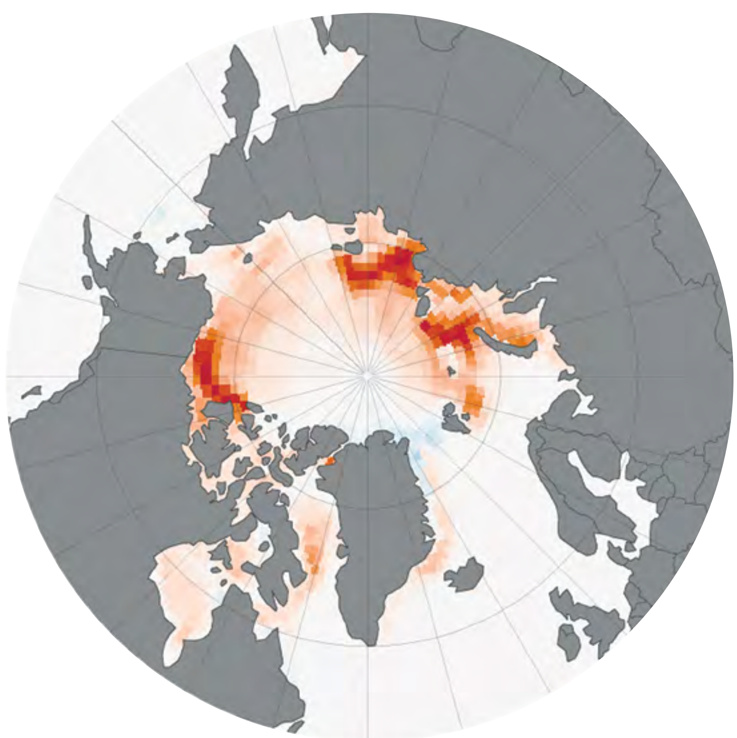


Figure 11. While sea ice is mostly white and reflects sunlight, ocean water is darker and absorbs more of the Sun's energy. A decline in Arctic albedo (reflectivity) has been a key concern among scientists since summer Arctic sea ice cover began shrinking in recent decades. As more solar energy is absorbed by the ocean, air, and icy land masses, it enhances the ongoing warming in the Arctic region, which is more pronounced than anywhere else on the planet. This map shows the net change in sea ice cover from 2000 to 2014. Shades of red depict areas with less ice cover.
Source: NASA Earth Observatory

Thawing permafrost has the potential to release huge quantities of carbon into the atmosphere in the form of carbon dioxide (typically from dry environments) and methane (typically from wet environments). *Source: NASA Earth Observatory.*

Scientists believe the albedo effect is one of the major reasons why the Arctic is warming more quickly than the rest of the planet. Some scientists have suggested that this effect may be exacerbated by soot from burning fuels and vegetation in the Arctic, as well as in the lower latitudes, which finds its way into the Arctic, and darkens the remaining snow and ice. In addition, warmer air holds more water vapor, which traps even more heat in the lower atmosphere.

The 2013 National Research Council report *Abrupt Impacts of Climate Change: Anticipating Surprises* explores the potential for the albedo effect and other climate factors to contribute to rapid changes in physical, biological, and human systems around the globe.

Releasing ancient stores of greenhouse gases

Locked within the Arctic's ancient ice and permafrost are vast quantities of carbon, frozen as either plant matter or within icy crystals of methane gas. If warming temperatures were to release these ancient carbon stores into the atmosphere, they would exacerbate the greenhouse effect and have a potentially massive impact on the Earth's climate.

The carbon stores in Arctic soil are there due to the enterprising plants that grow in the thin layer of unfrozen soil atop permafrost. Plants are essentially made of carbon. When a plant dies in a temperate area, it decomposes, releasing some of its carbon into the air and some into the soil. But when a plant dies in a place too cold for decomposition, it simply stays put, locking its carbon in place. Plant by frozen plant, that carbon adds up. If large areas of permafrost were to thaw, all of that previously-frozen plant matter would begin to decompose, releasing huge quantities of carbon into the atmosphere in the form of carbon dioxide or methane.

Scientists think that much of the carbon stored in the Arctic is frozen within icy crystals called methane clathrate. These crystals form under specific conditions of high pressure and low temperature that can occur either deep in Earth or under water. Scientists are not sure how much clathrate is in the Arctic, but as ice and permafrost continue to degrade and collapse, the clathrates could release more of this methane into the atmosphere.

Although both carbon dioxide and methane are greenhouse gases, they behave differently in the atmosphere. Carbon dioxide persists for a long time in Earth's atmosphere and is the major driver of long-term, irreversible climate change. Methane is many times more potent as a greenhouse gas than carbon dioxide over short time scales. Thus an abrupt release of a large quantity of methane could cause larger, more rapid climate changes, but the magnitude of the effect would taper gradually as the methane breaks down in the atmosphere to form carbon dioxide.

Wildfire on frozen ground

Wildfires can and do happen in the Arctic. In recent years, scientists and Arctic residents have watched with alarm as wildfires have begun spreading into some permafrost regions. Studies suggest these fires, which are made possible by the increasingly dry conditions resulting from local climatic changes, are unprecedented over the past 10,000 years.

Wildfires could exacerbate climate change in three ways. First, because they burn plant material, they release carbon. Second, the dark, charred ground they leave behind increases warming because of the albedo effect. Finally, if a fire is severe enough to burn the surface organic layer of soil, it can speed the thawing of permafrost below, accelerating the release of carbon from the previously frozen soil.

Wildfire burns near Currant Creek in Lake Clark National Park, Alaska. *Source: National Park Service, Alaska Region*

Into the Future

Managing Change

Much of the Arctic's future is uncertain, but one thing seems sure: change will continue for the people, plants, and animals that make the Arctic their home. Dramatic change has become their way of life. Responding to and managing this change has become a new, all-encompassing focus for the region. The challenge is both daunting and exciting, but it is not optional.

Shipping traffic in the Arctic is increasing. *Source: istock/Eretmochelis*

A MORE ACCESSIBLE ARCTIC OPENS OPPORTUNITIES —AND RISKS.

As sea ice diminishes, large areas of open ocean are becoming newly accessible to shipping. Melting ice and snow has changed the ways that people drive across and dig into the land. These changes are transforming the Arctic: some formerly isolated and pristine areas are now more accessible, but at the same time the diminishing seasonal duration of ice roads can limit travel for subsistence hunting and mineral development.

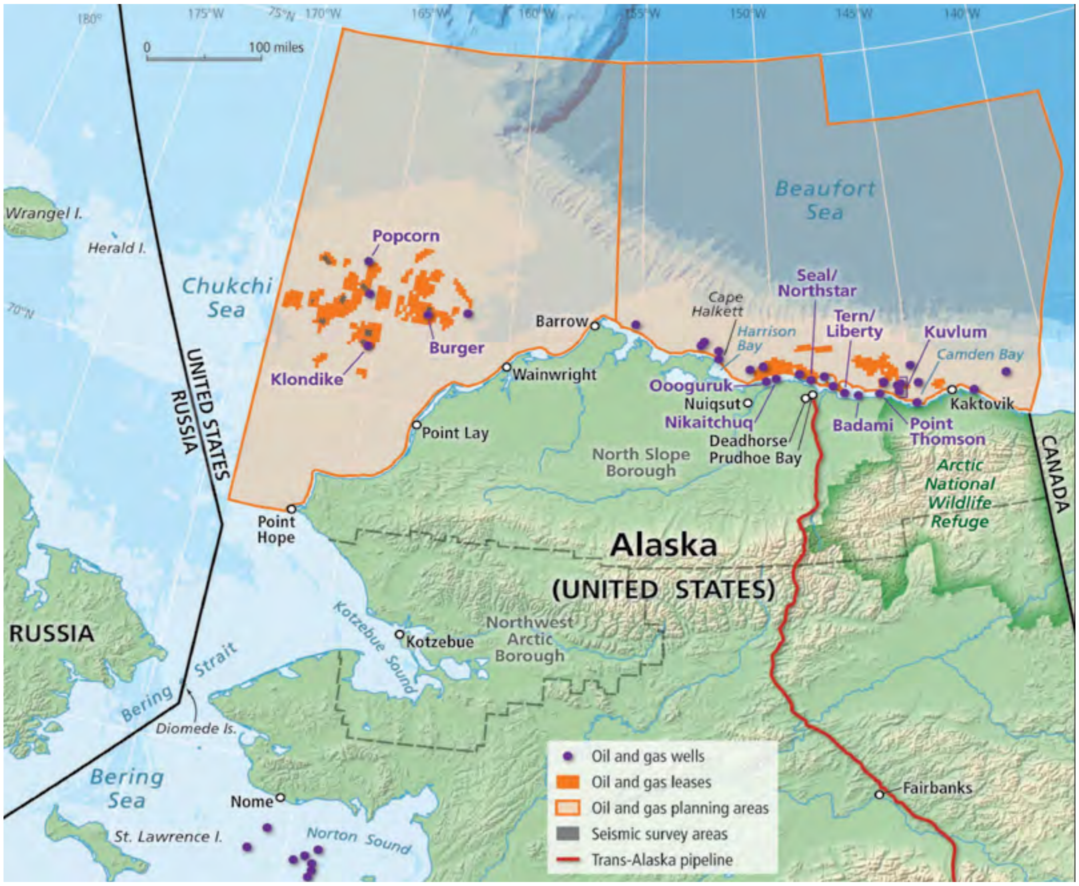


Figure 12. Planned areas for oil and gas exploration in the U.S. Arctic. *Source: National Research Council*

Oil and mineral extraction in the Arctic

There are an estimated 30 billion barrels of technically recoverable, undiscovered oil in the U.S. Arctic alone, constituting 13 percent of the world's remaining oil reserves (Figure 12). The Arctic also contains valuable mineral deposits, including some rare minerals critical to making electronics. Rising demand for these raw materials, combined with the Arctic's increasing accessibility, make it possible that the region will become more highly developed as these reserves are explored and tapped. Increasing exploration and development in the Arctic can lead to a number of opportunities and risks. There is potential for economic benefits and increased opportunities for access, but this needs to be balanced with increased scientific knowledge of the Arctic physical, ecological, social, political, and economic systems to support sound management decisions.

Increased oil activities open the region to increased risk of oil spills. Managing an oil spill is extremely challenging even in temperate and calm conditions, but the remoteness and harsh conditions of the Arctic make it particularly difficult to mount a speedy and effective response when something goes wrong. Responders can easily become blocked by severe storms or water routes that suddenly freeze over. In the winter, reduced daylight poses special challenges. Communications infrastructure and response equipment are limited in many areas of the Arctic, hindering responders' ability to effectively coordinate their efforts.

The presence of sea ice and other environmental variables like rapidly changing weather and dense fog can complicate oil spill response, and no single technique applies in all situations. Operators working in the Arctic need to be ready to assess

Oil rig in the Arctic Ocean.
Source: Shutterstock/vitstudio
Inset: Gas station.
Source: Shutterstock/Carolyn Franks

the environmental tradeoffs associated with different response options and deploy any, all, or, when warranted, none of the measures available to them to most effectively reduce the impacts to the ecosystem.

Oil spills can be harmful to ecosystems and societies anywhere, but communities in the Arctic are particularly vulnerable. Many Arctic residents rely on hunting and fishing to feed their families, so even temporary damage to the ecosystem can be catastrophic for these communities, not only because of the loss of sustenance, but also the customs that go along with the practices and preparation. The Arctic's wild animals and ecosystems are similarly vulnerable to spill-related toxins and food chain disruptions.

The 2014 National Research Council report *Responding to Oil Spills in the U.S. Arctic Marine Environment* identifies priorities for improving the ability to respond to a serious oil spill in the Arctic.

The northern route: shipping and transportation

In the past, few ships ventured into the perilous waters of the Arctic Ocean or its various straits and seas. Those that passed through were primarily there to service oil production facilities, transport mining products, and deliver supplies to coastal communities.

That situation is changing rapidly. In the summer of 2012, the U.S. Coast Guard estimated 480 ships transited the Bering Strait between Alaska

and Russia, an area that would have seen much less vessel traffic 10 years earlier. More and more ships are coming to the Arctic to explore for oil and gas, conduct research missions, and transport oil and other commodities. Tourism vessels are also on the rise.

With increased vessel traffic comes greater risks to people and the environment. Although sea ice is shrinking, the Arctic remains a harsh and dangerous environment for navigation, especially because remnant sea ice can pose hazards, particularly with changing weather and sea conditions. In the fall, open routes can freeze solid in a matter of days. Many areas are poorly charted and have limited communications infrastructure, making navigation and emergency response exceedingly difficult. Ports of refuge are few and far between, and many emergency response capabilities that exist in the U.S. Arctic are limited and restricted to southern Alaska. These rapid changes also may have an impact on subsistence hunting and migratory patterns of marine mammals.

The U.S. Coast Guard is the lead federal agency in matters relating to safe navigation in U.S. waters and works with other nations to support maritime safety in international waters. One critical new technology the Coast Guard is using to make Arctic shipping safer is the automatic identification system (AIS). Almost all commercial vessels operating in U.S. waters are now equipped with AIS transponders that continuously transmit information about the vessel and its route, allowing the Coast Guard to convey warnings, monitor ships' positions, and send help when needed.

Though technology is improving, communication and international cooperation remain crucial to ensuring the safety and security of ships navigating the Arctic. The 2013 Transportation Research Board conference summary *Safe Navigation in the U.S. Arctic* explores challenges and needs related to vessel traffic in U.S. Arctic waters.

U.S. Coast Guard icebreaker *Healy* and the Canadian Coast Guard icebreaker *Louis S. St-Laurent* side by side.
Source: U.S. Coast Guard

Tourism at the ends of Earth

Warm or cold, one thing about the Arctic remains the same: it's extraordinary. Tourists and adventurers have long been drawn to its stunning landscapes, fascinating wildlife, and unique cultures. As Arctic waters and land become easier to navigate, the number of people with the means and motivation to tour the Arctic is rapidly increasing.

Cruise ships and small personal vessels are venturing farther into the Arctic each year, and tourists have become the largest human presence in many Arctic regions. For Arctic communities, a steady flow of tourists can be a boon to local economies, creating local jobs in shops, restaurants, hotels, and tour companies. But tourism also has downsides for indigenous communities, such as the risk that tourists may violate traditional customs or damage cultural sites and artifacts. Tourism and cruise ships also can have impacts on traditional hunting and fishing, as the ships are typically present in the summer months, when obtaining subsistence resources that last through the winter is important.

Tourism also increases the pressure on land, water, wildlife, and other natural resources. Large cruise ships visit during the Arctic summer, when many animals are at their most vulnerable as they feed, mate, and tend their young. Ships may intentionally or inadvertently discharge sewage, oil, invasive species, and debris into sensitive Arctic environments. Increased tourism traffic through Arctic land and water also increases safety risks and adds to the burden on limited emergency support personnel when problems arise.

Tourists explore the ice in the Canadian Arctic in August 2013. *Source: Alain A Grenier*

A CHANGING ARCTIC RAISES NEW CHALLENGES FOR COMMUNITIES AND GOVERNMENTS.

The increasing exploration and exploitation of Arctic resources has important geopolitical and economic ramifications far beyond the Arctic Circle. In addition to the nations that have territory in the Arctic, many other countries are increasing their presence in the Arctic through tourism, research, and commercial development. As an illustration of the level of interest in the Arctic among more southern countries, the Arctic Council now includes China, Japan, South Korea, Singapore, India, and Italy as "Arctic observer states," a status that allows them to participate in the Arctic Council but not to vote on Council decisions (Figure 13).

Chief Kristina Kane speaks at an Arctic Council meeting.
Source: Arctic Council

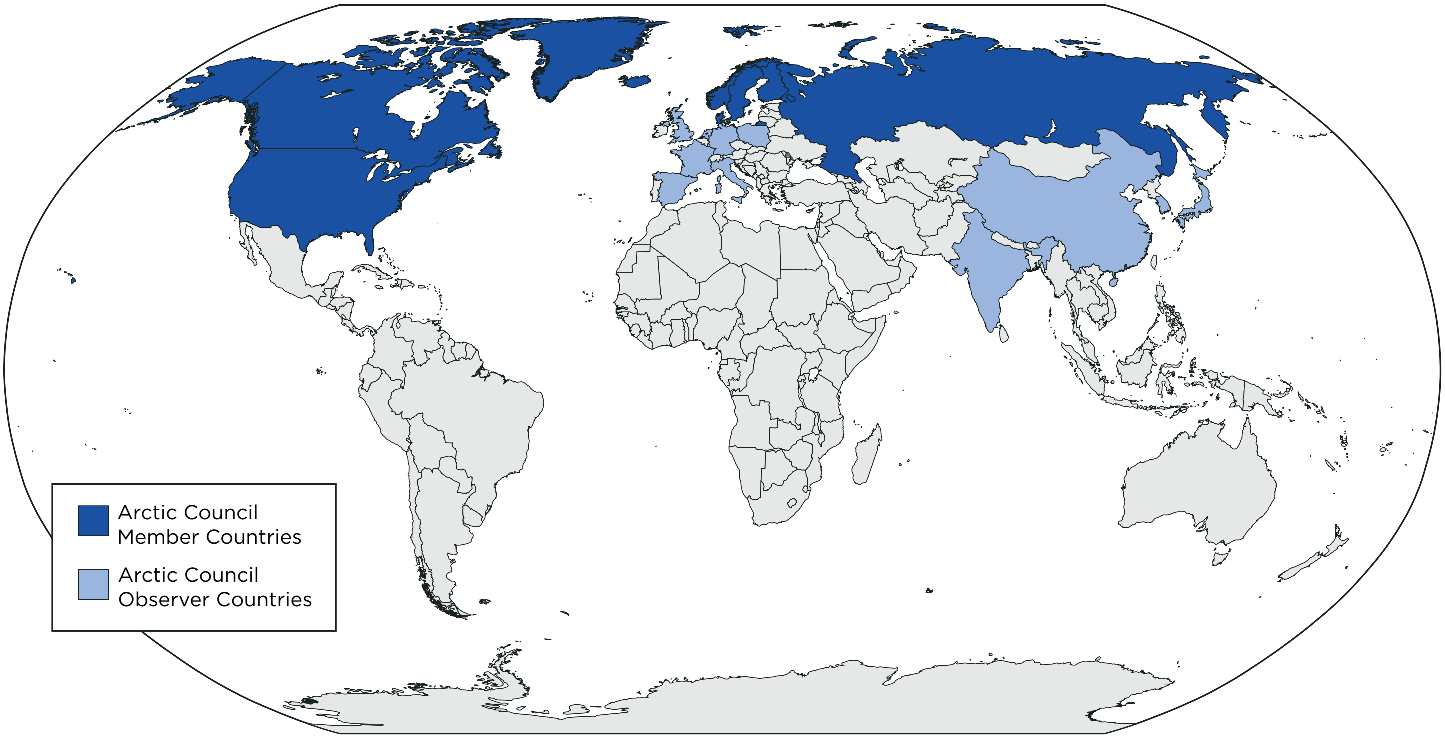


FIGURE 13. Map of Arctic Council member countries (dark blue) and Observer countries (light blue).
Source Data: Arctic Council

Arctic Residents as Research Partners

Source: Henry Huntington

The need for actionable Arctic research has never been greater than it is today. From providing logistical support and safety in the field to offering insights from generations of observations and experience, Arctic people have a great deal to offer as partners in the research endeavor. They also have a great deal to gain from sound scientific research, which can play an important role in addressing the effects of the region's rapid environmental and social change.

Even with recent advances in science and new observational tools on land, sea, air, and space, understanding Arctic ecosystems is no easy task. Understanding how shifting weather and climate are affecting the region's flora and fauna will require in-depth knowledge about the environment. Traditional knowledge—insight about the environment built through many years of observations, experiences, and lessons and passed on through generations of longtime residents—is an invaluable resource to help build that understanding.

There is room for improvement in the involvement of local Arctic residents in all stages of research. Bringing local communities into the discussion in the early stages of research development can help foster improved partnerships and could help scientists better refine their methods and research questions. Although there are many good examples of effective community-researcher collaborations, residents can also experience "research fatigue" if they have been involved in many studies without seeing follow up from researchers after the studies conclude. For the people who are living the reality of the changing Arctic every day, it is crucial to be able to act on what is learned from research. Making connections between research activities and real-world decisions requires the involvement of residents, researchers, and leaders.

The important role of Arctic residents as research partners is discussed in the 2014 National Research Council report, *The Arctic in the Anthropocene: Emerging Research Questions*.

New roles for Arctic residents

Arctic residents — both indigenous and non-indigenous — are most directly affected by the environmental changes happening in the Arctic and are most acutely affected by the region's increase in human activity. At the same time, growing interest in the Arctic from the south is bringing an influx of new people, new cultures, new ideas, and new opportunities.

Many Arctic indigenous groups are experiencing greater political autonomy and influence. Although most are located within the legal jurisdiction of the Arctic nations, these groups have benefitted from an increasing level of involvement in decision making. Many are now part of processes that review proposed developments such as mines or oil drilling operations and influence the way the economic benefits of such developments are distributed.

Although the numerous groups in the Arctic often have differing views, Arctic communities continue to exercise their influence to balance cultural, economic, and environmental needs. Their experiences can be valuable for other indigenous and remote cultures facing increasing stresses including climate change.

National security in the far north

Melting sea ice makes the Arctic more accessible to commercial and military interests alike. In addition, the growing interest in exploiting the region's rich natural resources could spark disputes over territory and transit rights among countries bordering the Arctic and those pursuing business interests there.

Although the likelihood of conflict in the Arctic is low, it cannot be ruled out. The relationships among Arctic nations could become more strained in the future as the stakes rise in the competition for Arctic resources. Experts have raised concerns about the U.S. Navy's limited surface capability and operational infrastructure in the region, suggesting the United States re-institute a cold-weather training program and work to improve mapping, communications infrastructure, and navigation charts for the region. In addition, the U.S. fleet of icebreakers — vessels capable of clearing a path through ice-covered water — is badly in need of updating to boost the nation's ability to train, operate, and engage in the Arctic.

The 2011 National Research Council report *National Security Implications of Climate Change for U.S. Naval Forces* addresses the United States' preparedness for national security threats in the Arctic.

The U.S. Navy Los Angeles class Attack Submarine *USS Hampton* surfaced at the North Pole as part of an operational exercise beneath the polar ice cap. *Source: United States Navy/ JOC Kevin Elliott*

Conclusion

Resilience in the Face of Change

People living in the Arctic have a long history of adapting to fluctuations in their harsh environment. Even though this is a continuing challenge, especially given the increased pace and scale of recent changes, Arctic residents are finding new ways to survive and thrive.

Climate and environmental change can disrupt established ways of life, creating significant challenges for Arctic residents. For example, changes in vegetation and wildlife may make it more difficult for Sami reindeer herders in Sweden to earn a livelihood. *Source: Mats Andersson*

To take best advantage of the changes in resource availability and access, for example, residents are continuing to diversify their income sources and shift when and where they hunt, gather, herd, and fish. To make travel safer, residents are working to improve their communications infrastructure and increase the use of GPS and other specialized equipment to navigate treacherous terrain and assess sea ice conditions. At the community level, Arctic residents are investing in greater protection against extreme weather, such as flood and water management infrastructure. Despite these adaptations, Arctic residents will continue to face challenges as the region changes in the years to come.

Climate change and the realities of an uncertain future are affecting the Arctic at a more rapid pace than other places in the word. With rising sea levels, climate feedback loops, ecological changes, geopolitical shifts, new opportunities for resource extraction, and countless other ways, these changes will have immediate and lasting effects around the globe.

Summertime in Kulusuk, Greenland.
Source: NASA Earth Observatory, Andrew Bossi

FURTHER READING

This booklet is based on the following National Research Council reports:

- *The Arctic in the Anthropocene: Emerging Research Questions.* National Research Council, 2014.
- *Responding to Oil Spills in the U.S. Arctic Marine Environment.* National Research Council, 2014.
- *Linkages Between Arctic Warming and Mid-Latitude Weather Patterns: Summary of a Workshop.* National Research Council, 2014.
- *Opportunities to Use Remote Sensing in Understanding Permafrost and Related Ecological Characteristics: Report of a Workshop.* National Research Council, 2014.
- *Abrupt Impacts of Climate Change: Anticipating Surprises.* National Research Council, 2013.
- *Climate Change Evidence and Causes: An Overview from the Royal Society and the US National Academy of Sciences,* 2014.
- *Safe Navigation in the U.S. Arctic: Summary of a Conference.* Transportation Research Board, 2013.
- *Seasonal-to-Decadal Predictions of Arctic Sea Ice: Challenges and Strategies.* National Research Council, 2012.
- *Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future.* National Research Council, 2012.
- *Frontiers in Understanding Climate Change and Polar Ecosystems: Summary of a Workshop.* National Research Council, 2011.
- *National Security Implications of Climate Change for U.S. Naval Forces.* National Research Council, 2011.

Other relevant reports:

- *National Climate Assessment.* US Global Change Research Program, 2014.
- *Climate Change 2013: The Physical Science Basis.* Intergovernmental Panel on Climate Change (IPCC), 2014.
- *US Navy Arctic Roadmap: 2014–2030.* US Navy, 2014.

For more information, please visit http://nas-sites.org/arctic.

Source: National Park Service, Alaska Region

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Explore the Arctic Matters Web Interactive to see the Global Connection to Changes in the Arctic: http://nas-sites.org/arctic

You are closer to the Arctic than you think. What happens in this remote and remarkable region has profound effects on the rest of the planet. Climate changes currently underway in the Arctic are a main driver for global sea-level rise, offer new prospects for natural resource extraction, and have rippling effects through the world's weather, climate, food supply, and economy. Take an up-close look at the threats and opportunities of the Arctic's rapidly-changing environment and find out why the Arctic matters — *to all of us.*

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