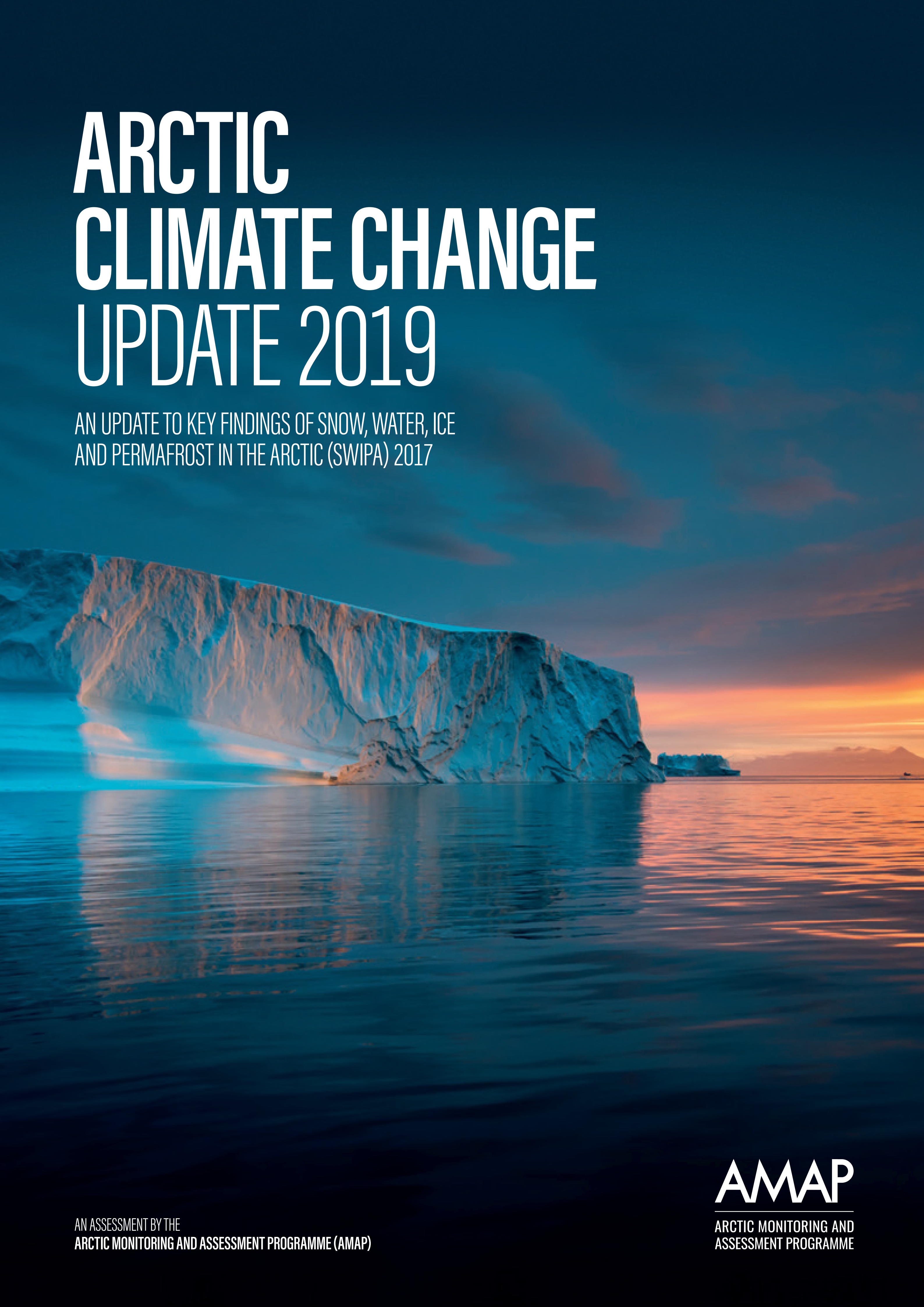


ARCTIC CLIMATE CHANGE UPDATE 2019

AN UPDATE TO KEY FINDINGS OF SNOW, WATER, ICE AND PERMAFROST IN THE ARCTIC (SWIPA) 2017

AN ASSESSMENT BY THE
ARCTIC MONITORING AND ASSESSMENT PROGRAMME (AMAP)

AMAP
ARCTIC MONITORING AND ASSESSMENT PROGRAMME

UPDATES AT A GLANCE

1. Observed and projected annual average warming in the Arctic continues to be more than twice the global mean, with higher increases in winter.

2. Arctic annual surface air temperatures in 2014, 2015, 2016, 2017, and 2018 exceeded those of any year since 1900.

3. Arctic winter sea ice maximums in 2015, 2016, 2017, and 2018 were at record low levels, and the volume of Arctic sea ice present in the month of September has declined by 75 percent since 1979.

4. Warming temperatures and extreme events are affecting the Arctic terrestrial landscape through expansion of shrubs into tundra, increased vulnerability to insect disturbances, regional declines in tundra vegetation, and increases in severe fire years. Marine environments are also affected: for example the loss of sea ice has triggered shifts in marine algal blooms, with potential impacts throughout the food web including krill, fish, birds, and mammals in marine ecosystems.

5. Arctic glaciers, led by the Greenland Ice Sheet, are the largest land-ice contributors to global sea level rise. Even if the Paris Agreement is successful, they will continue to lose mass over the course of this century.

OVERVIEW

Drawing and building on the findings of AMAP's *Snow, Water, Ice and Permafrost in the Arctic* (SWIPA) 2017 assessment, this document provides updated observations, information from other recent assessments, and conclusions from the latest reviews of Arctic trends and indicators. The pace of change in the Arctic is so rapid that new records are being set annually, and each additional year of data strengthens the already compelling evidence of a rapidly changing Arctic.

The updates focus on five broad topics of concern with practical relevance for policy, planning, and decision-making:

- Meteorological and climate trends;
- Sea ice;
- Impacts on terrestrial and marine ecosystems;
- Socioeconomic impacts and their implications;
- The contribution of Arctic glaciers to sea level rise.

The updated findings support the fundamental conclusions of the SWIPA 2017 report:

- The Arctic is rapidly shifting into a new state, driven by rising temperatures caused by increases in greenhouse gas concentrations in the atmosphere.
- Trends over the next few decades are largely determined by past, present, and near-future emissions, requiring planning for adaptation at local and global scales.
- Efforts to reduce greenhouse gas emissions over the coming years can limit the extent of Arctic climate change, especially after mid-century, but the Arctic of the future will certainly be very different regardless of the emissions scenario.
- Arctic glaciers, ice caps, and the Greenland Ice Sheet would continue to melt even under ambitious emissions reductions, contributing significantly to long-term sea level rise.

The sections below describe new observations and findings in each of these areas and explain their implications for the Arctic and the rest of the world.

Alaska Wildfire. Photo: PJF Military Collection / Alamy Stock Photo.

THE ARCTIC'S CLIMATE AND WEATHER PATTERNS ARE CHANGING

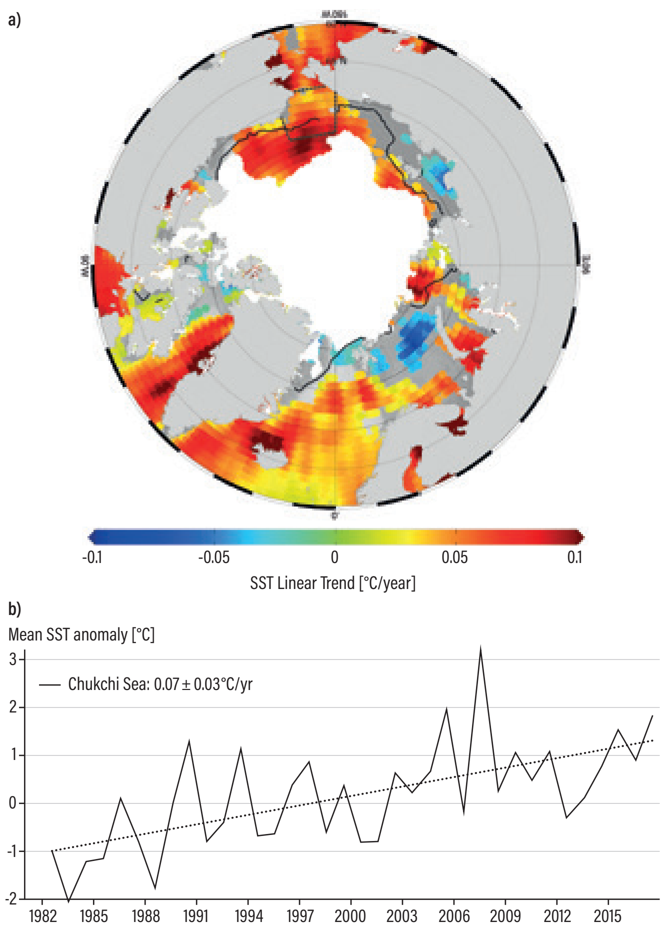
WHAT'S HAPPENING

The rapid warming trends and other climatic changes reported in SWIPA 2017 continue and in some cases appear to be strengthening.

TEMPERATURE

Arctic annual surface air temperatures in 2014, 2015, 2016, 2017, and 2018 were all greater than in any year since observational records began in 1900, and the average Arctic surface air temperature for October 2017–September 2018 was the 2nd warmest (after 2015–2016) since 1900. The annual average Arctic surface air temperature rose by 2.7°C from 1971 to 2017, with a 3.1°C increase during the cold season and a 1.8°C increase during the warm season.

Observed and projected annual average warming in the Arctic continues to be more than twice the global mean, with higher increases in winter. From 1971–2017, Arctic annual surface air temperatures rose 2.4 times faster than the Northern Hemisphere average.



Sea-surface temperatures are also increasing over much of the Arctic Ocean. August sea-surface temperatures in the Chukchi Sea, between Siberia and Alaska, rose at a rate of 0.7°C per decade from 1982–2017.

PRECIPITATION AND HUMIDITY

Annual precipitation appears to be increasing in the Arctic, by an estimated 1.5–2.0 percent per decade, with the strongest increase occurring during the October–May cold season. Some regions such as Scandinavia and the Baltic Sea basin are seeing less precipitation falling as snow and more as rain.

Humidity is increasing at the surface and in the atmosphere of the Arctic, due in part to longer open-water seasons and the inflow of moist air from mid-latitudes.

WHY IT'S IMPORTANT

Changes in temperature are the underlying driver for many of the changes underway in the Arctic. Rising air, surface, and ocean temperatures accelerate the melting of snow and ice (including glaciers) and affect the Arctic's interconnected physical, chemical, and biological systems in direct and indirect ways. Arctic warming can also have effects far beyond the region: for example, the recent rapid warming of the Arctic appears to have created conditions favoring a persistent pattern in the jet stream that provokes unusual extreme temperature events in the Northern Hemisphere. Increases in precipitation and humidity are also important drivers of Arctic change. Changes in precipitation patterns (including changes in frequency, intensity, and distribution) can affect freshwater flow into the Arctic Ocean, which in turn affects ocean circulation, nutrient levels, acidification, and biological productivity, and can influence weather patterns far to the south. Increases or decreases in precipitation can affect soil moisture, which in turn can affect the growth of vegetation—including plants used by northern animals for food. Higher humidity in the atmosphere contributes to amplified warming and snowmelt in the Arctic.

Arctic sea-surface temperature (SST) trend for August of each year, 1982–2017. White shading is the August 2017 mean sea ice extent. The graph on the bottom shows August trends for the Chukchi Sea relative to the 1982–2010 August mean. Source: NOAA Arctic Report Card 2017.

ARCTIC SEA ICE IS INCREASINGLY VULNERABLE

WHAT'S HAPPENING

Arctic winter sea ice maximums in 2015, 2016, 2017, and 2018 were at record low levels, and the 12 lowest minimum extents in the satellite record have all occurred in the last 12 years. The volume of Arctic sea ice present in the month of September has declined by 75 percent since 1979.

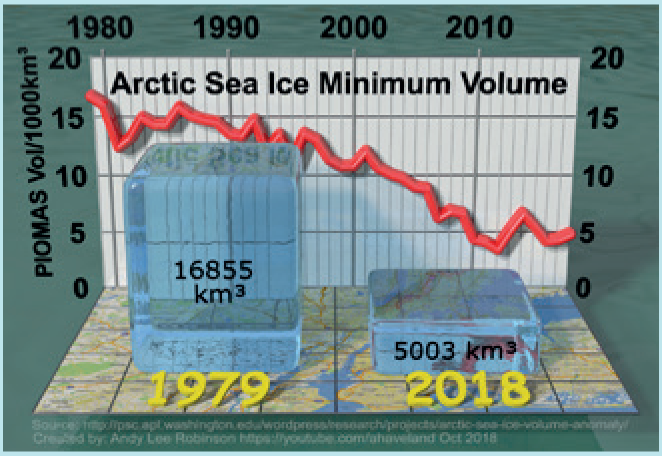
Sea ice has gone through a transition from mostly thick multi-year sea ice to younger and thinner seasonal sea ice. If global warming is stabilized at 1.5°C, the probability of an ice-free summer occurring in any given year would be roughly 2 percent; at 2°C, the probability would rise to 19–34 percent. Some models suggest the Arctic Ocean could be seasonally ice-free within the next few decades. The reductions in sea ice are caused by a combination of atmospheric warming and the influx of warmer waters from the south.

WHY IT'S IMPORTANT

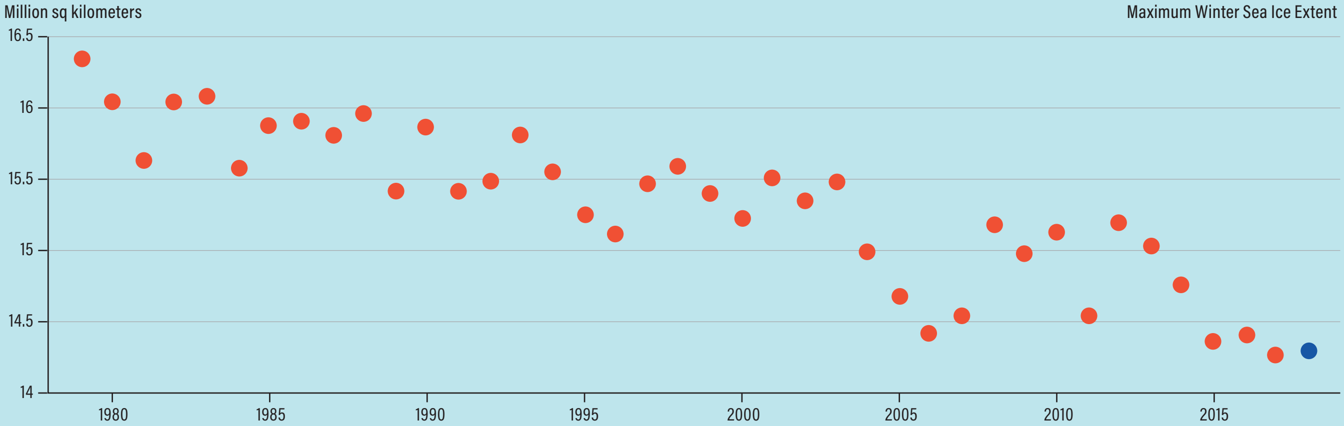
The coverage, extent, and thickness of multi-year sea ice reflect climate conditions over years to decades, making its loss an indicator of Arctic and global climate change. The later freeze-up of sea ice contributes to the rise in cold-season Arctic temperatures and affects the Arctic system's overall condition, which in turn can have far-reaching consequences for Arctic ecosystems, human communities and economies, and weather conditions in mid-latitudes. For example, sea ice declines in the Bering Sea—including a persistently low winter ice extent in 2017–2018—may be linked to dramatic changes in fish populations, seabird die-offs, and localized die-offs of marine mammals such as seals and walrus. Research also suggests that Arctic sea-ice declines are affecting ocean circulation in the North Atlantic.

Declining land-fast sea ice results in greater coastal erosion due to the effects of warmer air and water combined with increasing storm, wave, and tidal activity. Because sea ice acts as a barrier to marine transport and commercial activities such as shipping and the extraction of natural resources, the loss of sea ice is expected to open new economic activities.

The decline of sea ice in the Arctic appears to be linked to a loss of biodiversity in sea ice habitats, although observations also show that some species (e.g., a variety of whales, including Orcas, blue whales, right whales, fin whales, and white whales) are expanding their ranges or are present during a longer portion of the year.



Arctic sea ice minimum volumes, 1979–2018. Visualization by Andy Lee Robinson using data from Pan-Arctic Ice Ocean Modeling and Assimilation System, University of Washington, Polar Science Center. Animated version available at https://youtu.be/GZzEUJ86PCg.



Arctic winter seasonal maximum sea ice extents, 1979-2018. Source: Overland et al. 2019.

CLIMATE CHANGE IS AFFECTING THE ARCTIC'S TERRESTRIAL AND MARINE ENVIRONMENTS

WHAT'S HAPPENING

The changes underway in the Arctic have altered fundamental characteristics of Arctic ecosystems and in some cases are causing the loss of entire habitats, with consequences for people who rely on and benefit from Arctic ecosystems. Warming temperatures are affecting the Arctic terrestrial landscape through expansion of shrubs into tundra, increased vulnerability to insect disturbances, and increases in severe fire years. Many permafrost observatories have recorded new record-high average temperatures in the upper 10–20 meters of the ground in recent years, with the greatest increases occurring in colder permafrost of the northern Arctic.

Wildfires occurred in western Greenland in 2017, including an unusually large fire that lasted several weeks and burned at least 1,200 hectares of tundra. In 2018, Sweden experienced its hottest May on record followed by an unusually heavy wildfire season. The number of wildfires ignited by lightning has risen in Canada's Northwest Territories and in interior Alaska since 1975. Increases in temperature and precipitation correlate with increases in the number of lightning-caused wildfire ignitions.

Summer warming trends are causing key plant species to flower earlier in the season and for a shorter time, affecting pollinators and species that prey on them. The density of midsummer tundra biomass has been increasing since the early 1980s, although more recently tundra vegetation has shown some decline in many areas due to water or nutrient limitation, permafrost degradation, or extreme winter events. Air temperature and tundra biomass are correlated, with biomass increasing during warmer summers, and there is some evidence that methane emissions from tundra ecosystems increase with temperature.

Wildfire at Nordre Strømfjord in West Greenland, August 2017.
Photo from Sentinel-2B satellite, edited by Pierre Markuse.

Evidence also shows that Arctic climate change is affecting the distribution and demographics of some animal species, such as muskox. Rain-on-snow events have become more frequent and intense in autumn and winter across the northwestern Russian Arctic—a trend that has been linked to the loss of sea ice in the Barents and Kara Seas—leading to mass starvation among reindeer herds due to heavy ice cover on pastures. Warmer and wetter winters have also increased mortality among wild reindeer populations in Svalbard, and populations of caribou and wild reindeer across the Arctic have declined by almost 50% over the past 20 years.

Marine environments are also being affected. An increase in river discharges has led to a corresponding increase in the delivery of carbon and nutrients near Arctic coastlines. Primary production (the conversion of light energy into organic matter) was up to 500% higher than normal in the Bering Sea region in 2018 in response to record low sea ice extent in 2017–2018.

The loss of sea ice has triggered shifts in the timing and intensity of marine algal blooms, with potential impacts throughout the food web including krill, fish, birds, and mammals in marine ecosystems. Areas experiencing double blooms (one in spring and one in autumn) have increased in regions with the greatest loss of sea ice. Some algal blooms produce toxins that have subsequently been observed in shellfish and in the bodies of marine mammals, raising public health concerns in the Arctic. Sea ice loss also has direct impacts on species such as polar cod, whales, seals, and polar bears.

Ocean acidification, which is caused primarily by rising CO_2 concentrations in the atmosphere, may also affect marine ecosystems, including fish species such as pink salmon, sole, and herring. The ranges of some marine fish species are shifting northward in response to warmer ocean waters; 20 new species and 59 range changes have been confirmed in the Chukchi and Beaufort Seas in the past 15 years.

WHY IT'S IMPORTANT

The changes underway are leading to range expansions of some species, contractions of others, loss of habitats, and a wide range of other impacts on the Arctic's interconnected ecosystems and the services they provide. Many Arctic countries depend heavily on fisheries, which are being affected by changes in both terrestrial and marine ecosystems. Changes in the frequency and intensity of wildfires may affect the distribution of caribou and reindeer, with implications for livestock husbandry and subsistence in northern communities.

Permafrost thaw can have major implications for hydrology, vegetation, biogeochemical cycling, and human settlements and infrastructure. Wildfires can release large amounts of CO_2 and black carbon. Arctic browning, caused by extreme events such as extreme winter warming and desiccation, can significantly reduce the carbon sink capacity of northern ecosystems even when vegetation is not killed.

Separately and together, these and other impacts of climate change in the Arctic have consequences for the entire global climate system and pose fundamental risks to many ecosystem services, affecting the livelihoods of Indigenous Peoples and other inhabitants of the High North.

Canadian Coast Guard icebreaker and Arctic research ship CCGS Amundsen in the Amundsen Gulf in spring-time ice. Photo: Lee Thomas / Alamy Stock Photo.

Saami reindeer herders in Sweden with their flock. Wildfires in northern Sweden in summer 2018 destroyed large areas of reindeer pasture land, particularly affecting winter feeding grounds and impacting half of the Saami communities in Sweden. Restoration of the damaged ecosystem will take decades. Photo: Jannie Staffansson.

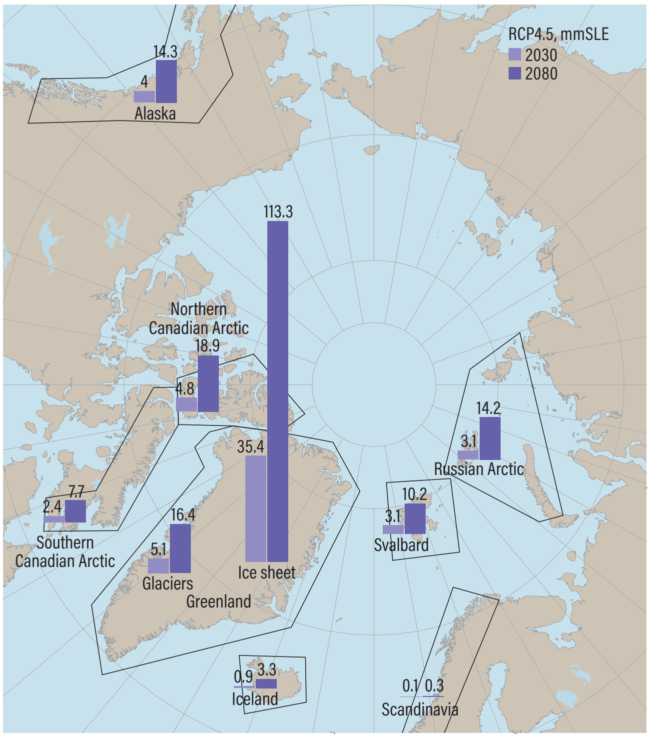
ARCTIC GLACIERS ARE IMPORTANT CONTRIBUTORS TO GLOBAL SEA LEVEL RISE

WHAT'S HAPPENING

Recent studies show that Arctic glaciers, led by the Greenland Ice Sheet, are the largest land-ice contributors to global sea level rise. The Arctic accounts for 48 percent (10 cm) of the total global sea level rise that occurred from 1850–2000 and 30 percent of the total sea level rise that occurred from 1992–2017.

The loss of ice from Arctic glaciers has been accelerating with climate change over the past several decades, with the loss from the Greenland Ice Sheet in particular expected to accelerate further in the decades ahead. Scientists estimate that human-induced climate change was responsible for 70 percent of the global loss of glacier mass between 1991 and 2010.

The Arctic's contribution to future sea level rise depends strongly on current and future emissions, but the Arctic is expected to continue to dominate the global contribution of land ice to sea level rise in the future. Global mean sea level rise by 2100 would be approximately 10 centimeters lower under a global warming of 1.5°C compared with a warming of 2°C.



Projected mass loss from local glaciers, ice caps, and Greenland Ice Sheet for 2030 (pale bars) and 2080 (dark bars) (expressed in millimeters of sea level equivalence) under a moderate climate change scenario (RCP 4.5). Modified from SWIPA 2017.

Even if the Paris Agreement is successful in limiting warming to its target of well below 2°C, the Greenland and Antarctic ice sheets will continue to lose mass over the course of this century. It is important to recognize that predictions of future ice loss from both Greenland and Antarctica remain highly uncertain due to key knowledge gaps, and larger losses of ice are possible.

Climate change is also expected to affect the timing and magnitude of glacier runoff. Projections indicate an initial increase in runoff in early summer followed by a decline thereafter, with impacts on downstream watersheds.

WHY IT'S IMPORTANT

The Arctic plays an important role in sea level rise, which poses significant risks to coastal communities and ecosystems worldwide. Sea level rise increases coastal flooding, beach erosion, damage to infrastructure, environmental impacts on ecosystems, and saltwater intrusion into groundwater— effects that are exacerbated when combined with storm tides. While the contribution of glaciers to sea level rise is mainly from polar regions, the largest sea level rise will occur in the tropics due to gravitational and heat-related effects that focus sea level rise there. Increases in freshwater runoff from glaciers can have major impacts on downstream terrestrial and marine ecosystems in the Arctic, caused by factors such as changes in nutrients and contaminants.

THE GREENLAND ICE SHEET IN 2017 AND 2018

Based on modeled estimates the Greenland Ice Sheet lost little mass overall in 2017 and 2018, and may have actually gained a small amount. Both years saw unusually cold summers and heavy snowfalls in Greenland, despite warmer and drier conditions elsewhere in the Arctic and more generally at mid-latitudes. Satellite data are not yet available to calculate the ice sheet's total mass budget for 2018, so there is some uncertainty in the estimate.

These unusual conditions may be caused by rapid warming in the Arctic influencing the position of the jet stream, leading to unusual and persistent weather patterns over northern Europe and Greenland. Within the North Atlantic, the position of the jet stream is also known to vary with the North Atlantic Oscillation, influencing storm tracks.

Inuit fishermen longline fishing on Ilulissat Fjord, Greenland. Photo: Norbert Eisele-Hein / Alamy Stock Photo.

Inupiaq Eskimo hunters walking over the shore ice along the Chukchi Sea, Barrow, Alaska. Photo: Kevin G Smith / Alamy Stock Photo.

THE CHANGING CLIMATE AFFECTS ARCTIC COMMUNITIES, PUBLIC HEALTH, AND ECONOMIES

Climate change interacts with other environmental and health stressors (e.g., pollution, ocean acidification, erosion), along with a range of social, economic, and political factors (e.g., migration, resource extraction, local development, recreation and tourism) that are fundamentally changing the nature of the Arctic. These changes challenge the ability of Arctic communities to adapt and maintain resilience.

The trend toward shorter snow seasons in the Arctic affects traditional activities such as hunting and access to certain food sources, with implications for health, disposable income, and Indigenous cultures and economies. Many coastal communities in the Arctic are affected by the loss of sea ice (which serves as hunting and fishing platforms) as well as increasing exposure to storms, coastal erosion, and flooding of coastal wetlands.

Thawing permafrost disrupts transportation and affects buildings and infrastructure such as pipelines, airports, and industrial facilities, as well as water and wastewater distribution systems.

Wildfires accelerate the loss of natural resources, pose direct risks to human health and safety, can affect the health of downwind populations exposed to smoke, and can affect traditional land use by Indigenous Peoples and other residents.

The decline of sea ice makes way for new economic activities, particularly for shipping and resource extraction, and warmer winter temperatures have led to a documented reduction in demand for space heating in Alaska. Climate change will also bring many economic costs, however; such as those related to impacts on commercial fisheries, the increased costs of wildfire suppression, relocation costs for vulnerable communities and infrastructure, and costs related to impacts on public health, buildings, and transportation networks. For example, the projected cumulative cost of repair and replacement of public infrastructure in Alaska due to climate change ranges from US $3.7 billion to $4.5 billion by the end of this century, compared with $2.0 billion to $2.5 billion for proactive adaptation measures.

RECOMMENDED ACTION STEPS

The recommendations presented in the 2017 SWIPA Summary for Policy-makers—which focused on limiting future change, adapting to near-term impacts, supporting the advancement of understanding, and building public awareness—remain robust and relevant. New findings and emerging priorities reinforce those recommendations and point toward action, as described below.

LIMITING CHANGE

- Policy actions taken today to reduce emissions of greenhouse gases will determine the actual scenario that unfolds over the remaining decades of this century and beyond.
- The need to limit future change in the Arctic is underscored not only by the serious implications for the Arctic and its inhabitants but also by the impacts of Arctic change on lower latitudes (e.g., through sea level rise, the release of greenhouse gases, and shifts in ocean and atmospheric circulation), and by the fact that Arctic temperature feedbacks may impede efforts to achieve a stabilized global climate.
- The Arctic Council should continue its efforts to identify opportunities to reduce emissions of short-lived climate forcers such as black carbon and methane. Progress in this area could help slow the current pace of change in the Arctic while work is underway to reduce longer-term impacts. Black carbon is currently considered one of the most important anthropogenic climate drivers after CO_2. In the Arctic its influence may be even stronger than elsewhere. To inform decision-making, AMAP is currently updating its impact estimates of black carbon to account for recent developments in air pollution legislation and climate policies globally.

ADAPTING TO IMPACTS

- Given the pace and magnitude of change in the Arctic, a growing number of countries, regions, and communities are performing risk assessments to help prioritize their adaptation activities. Risk assessments consider probabilities and consequences associated with potential impacts (e.g., permafrost thaw or extreme events such as heat waves or wildfires), with high-probability/high-consequence impacts ranked highest in priority. Risk assessments can be applied, for example, to a community's infrastructure base to help identify which assets should receive priority attention for adaptation.

Photo: Louise Murray / Alamy Stock Photo.

Melt water on the Greenland Ice Sheet near Camp Victor north of Ilulissat. Photo: Ashley Cooper pics / Alamy Stock Photo.

IMPROVING OUR UNDERSTANDING

- Arctic climate and weather extremes could have devastating consequences for Arctic societies, including significant economic costs. However, compared with other aspects of Arctic change, relatively little is known about climate and weather extremes in the Arctic. Similarly, relatively little is known about how climate change will affect Arctic ecosystems. Improving our understanding of these risks and their impacts is a fundamental requirement for effective adaptation to Arctic climate change.
- The impacts of Arctic changes on mid-latitude weather and climate are also poorly understood and represent another priority for improvements in scientific understanding.
- Arctic nations should ensure that the coverage of existing observational and community-based monitoring networks in the Arctic is at least maintained, and preferably enhanced. Gaps in the coverage of observational data limit scientists' ability to understand interactions among system components, identify current trends, and project future changes.

ADDITIONAL READING

SWIPA 2017, Summary for Policy-makers
https://www.amap.no/documents/doc/snow-water-ice-and-permafrost.-summary-for-policy-makers/1532

SWIPA 2017 Fact Sheets
https://www.amap.no/documents/doc/swipa-2017-press-material/1544

Overland, J. et. al., 2019. The Urgency of Arctic Change. *Polar Science*, ISAR5 Special Collection.
https://doi.org/10.1016/j.polar.2018.11.008

Box, J. et al., 2019. Key Indicators of Arctic Climate Change: 1971–2017. *Environmental Research Letters*.
https://doi.org/10.1088/1748-9326/aafc1b

NOAA Arctic Report Card 2018

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AMAP, established in 1991 under the eight-country Arctic Environmental Protection Strategy, monitors and assesses the status of the Arctic region with respect to pollution and climate change. AMAP produces science-based policy-relevant assessments and public outreach products to inform policy and decision-making processes. Since 1996, AMAP has served as one of the Arctic Council's six working groups.

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