

# ARCTIC CLIMATE CHANGE UPDATE 2021: KEY TRENDS AND IMPACTS

**SUMMARY FOR POLICY-MAKERS**

ARCTIC MONITORING & ASSESSMENT PROGRAMME



ARCTIC COUNCIL


AMAP

# KEY FINDINGS

The Arctic environment continues to change at a rapid pace—with some indicators changing even faster than previously reported by AMAP in 2019.




## 1 The physical drivers of Arctic change continue to change rapidly

 Key indicators such as temperature, precipitation, snow cover, sea ice thickness and extent, and permafrost thaw show rapid and widespread changes underway in the Arctic. An important update is that the increase in Arctic annual mean surface temperature (land and ocean) between 1971 and 2019 was three times higher than the increase in the global average during the same period. This is higher than reported in previous AMAP assessments.




## 2 Extreme events in the Arctic are changing in frequency and intensity

 The Arctic is experiencing an increase in extreme events. New findings include recent increases in the frequency and/or intensity of rapid sea ice loss events, melt events on the Greenland ice sheet, and wildfires. There has been an increase in extreme high temperatures and a decline in extreme cold events. Cold spells lasting more than 15 days have almost completely disappeared from the Arctic since 2000.




## 3 Climate change is having major impacts on Arctic communities

 Climate change is affecting the subsistence harvest-based livelihoods and food security of small Arctic communities—especially Indigenous communities. Arctic climate change is also posing widespread risks to safety, health, and well-being; damaging infrastructure; and causing economic impacts to many sectors. Commercial fisheries, aquaculture, and cruise tourism are expanding in the Arctic, with implications for coastal communities and livelihoods, vulnerable ecosystems, and demand for search-and-rescue services.



## 4 Arctic ecosystems are experiencing rapid, transformational changes

 The rapidly changing cryosphere is affecting ecosystems throughout the Arctic, changing the productivity, seasonality, distribution, and interactions of species in terrestrial, coastal, and marine ecosystems. Changes in sea ice type, extent, and seasonality, and snow cover on land and sea ice; and the rapid loss of perennial ice and the Greenland ice sheet are causing fundamental changes in ecosystems that affect the cycling of carbon and greenhouse gases. Unique ecosystems, such as those associated with multi-year sea ice or millennia-old ice shelves, are at risk and some are vanishing.

## IMPACTS OF COVID-19 ON ARCTIC RESEARCH


The COVID-19 pandemic has affected communities across the Arctic, with more than 400,000 cases and 6,600 deaths reported as of February 2021. The pandemic also exposed and exacerbated existing vulnerabilities, especially among Indigenous Peoples.

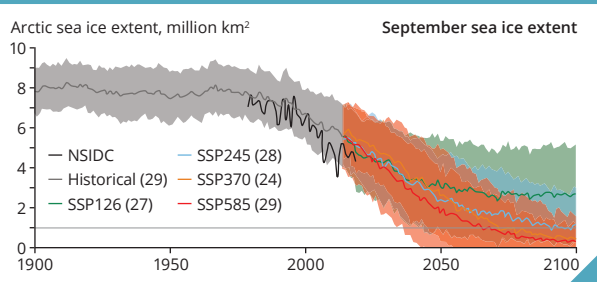
Based on multiple communications, the COVID-19 pandemic has had a major impact on Arctic research, leading to many delays, logistical challenges, cancellations, and postponement of expeditions and other field work. The resulting disruption of monitoring and research efforts is expected to lead to data gaps in 2020–2021, including gaps in some long-term data sets that are key to understanding Arctic climate change. Some research projects were able to proceed despite the pandemic, particularly those co-developed with northern and Indigenous communities, demonstrating the resilience of projects that are Arctic-led, co-developed, and/or well-partnered with local communities.

*Note: The information in this box is based on new material not included in the underlying technical report.*




### 5 Changes in the Arctic have global consequences

 The effects of Arctic change are felt far beyond the Arctic, including the impacts of global sea-level rise, the opportunities and risks associated with the opening of new shipping routes and improved access to fossil fuel reserves, and the potential for feedbacks that affect atmospheric greenhouse gas concentrations. Although studies have demonstrated connections between Arctic change and mid-latitude weather patterns, the linkages are complex and inconsistent.



### 6 The latest climate models continue to project that the Arctic will warm rapidly over the course of this century

 The newest generation of coupled global climate model projections (CMIP6) show that annual mean surface air temperatures in the Arctic will rise to 3.3–10°C above the 1985–2014 average by 2100, depending on the course of future emissions. Under most emission scenarios, the vast majority of CMIP6 models project the first instance of a largely sea-ice-free Arctic in September occurring before 2050. The probability of an ice-free Arctic summer is 10 times greater under a 2°C global warming scenario compared with a 1.5°C scenario.

#### KEY TO SYMBOLS:



OBSERVED



PROJECTED



NEW FINDING



UPDATED FINDING



KNOWLEDGE GAP



REINFORCING MESSAGE

# CONTEXT AND SCOPE

Climate change is a global problem, but many of its impacts are being felt now and most strongly in the Arctic. Extensive evidence shows that Indigenous communities in the Arctic bear substantial impacts from climate change.

Over the past 49 years, the Arctic has warmed three times faster than the world as a whole, leading to rapid and widespread changes in sea ice, land ice (glaciers and ice sheets), permafrost, snow cover, and other physical features and characteristics of the Arctic environment. These changes are transforming the Arctic, with far-reaching consequences.

This Summary for Policy-makers is an overview of key findings in the *AMAP Arctic Climate Change Update 2021: Key Trends and Impacts. Summary for Policy-makers* report, which provides updates on key issues and changes since the *Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017* assessment and the *Arctic Climate Change Update 2019* report. The report summarizes the latest findings on extreme events; connections between Arctic change and mid-latitude weather; ecosystem-climate connections, including impacts and feedbacks; and observed (and in some cases projected) societal impacts of Arctic climate change. The report also provides updated projections of Arctic climate change from the next generation of climate models and scenarios that will be evaluated as part of the Intergovernmental Panel on Climate Change's Sixth Assessment Report.

Each chapter of *Arctic Climate Change Update 2021: Key Trends and Impacts. Summary for Policy-makers* was written by experts from relevant scientific disciplines and was subjected to anonymous peer review. The underlying report is fully referenced and is based on the peer-reviewed scientific literature or on new results obtained using well-documented

observations or models. The peer-reviewed observations, methods, and studies used in the report in a few cases include contributions from Indigenous Knowledge as well as traditional and local knowledge. However, it is recognized that a holistic understanding of the changes occurring in the Arctic requires equitable inclusion of Indigenous Knowledge and local and Indigenous Peoples in assessment processes.

## WHY THIS IS IMPORTANT

Climate change is the dominant driving force in many of the environmental, economic, and societal transitions in the Arctic today. Along with its direct impacts, climate change acts as an additional stressor on top of existing challenges faced by Arctic communities, industries, and ecosystems.


Changes in the Arctic have global implications. The rapid mass loss of the Greenland ice sheet and other Arctic land ice contributes more to global sea level rise than does the melting of ice in Antarctica. Changes in Arctic ecosystems can induce feedbacks to the global climate system, although the future direction and magnitude of these feedbacks remain unclear. Wildfires in the Arctic result in carbon emissions to the atmosphere. The availability of new shipping routes; access to oil, gas, and mineral resources; and changes in Arctic fisheries have economic consequences within and outside the Arctic. Climate change also affects species that migrate between the Arctic and southern latitudes.




# THE PHYSICAL DRIVERS OF ARCTIC CHANGE CONTINUE TO CHANGE RAPIDLY

Climate change is a here-and-now problem in the Arctic, where temperatures are rising far faster than the global average and widespread changes in precipitation, snow cover, sea and land ice, permafrost, and extreme events are transforming the Arctic environment.


## LATEST FINDINGS ON KEY INDICATORS

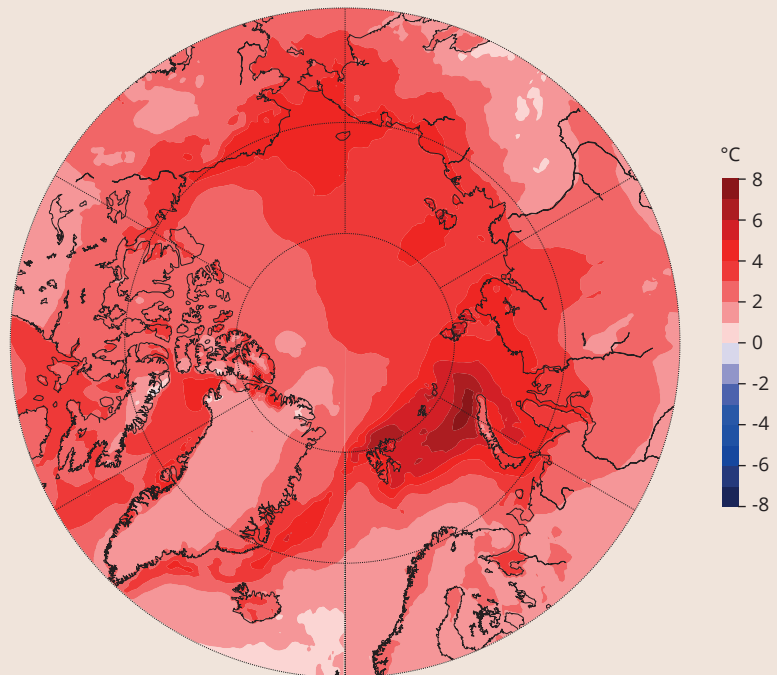
 The following updates to climate indicators focus on the 49-year period beginning in 1971 and ending in 2019 unless otherwise indicated. The starting date of 1971 was chosen because it is the oldest date for which many of the most reliable records for Arctic temperature and other Arctic indicators are available.

### AIR TEMPERATURE

 From 1971–2019, the annually averaged Arctic near-surface air temperature increased by 3.1°C, three times faster than the global average. This finding is based on instrumental data, with interpolation applied over the Arctic Ocean where observations are sparse, and is higher than the increase reported in previous AMAP reports. The largest change in air temperature over this 49-year period was over the Arctic Ocean during the months of October through May, averaging 4.6°C with a peak warming of 10.6°C occurring over the northeastern Barents Sea.

### PRECIPITATION

 Total annual precipitation in the Arctic (rain and snow combined) increased by more than 9% from 1971–2019, based on a combination of observed and modeled data. Rainfall increased by 24% during that period, with no net overall Arctic trend in snowfall. The largest increase in precipitation is during the cold season, from October through May.



### PERMAFROST TEMPERATURE

Arctic permafrost has warmed by 2–3°C since the 1970s. At many colder permafrost sites, rates of warming over the past 20 years have been greater than any since 1979. The seasonally thawed active layer has grown deeper at many sites since the 1990s, and landscape observations indicate permafrost thaw across the Arctic.

Figure 1. Arctic annual surface temperature trend patterns, 1971–2019, based on combined observed and modeled data.

### TERRESTRIAL SNOW COVER

Arctic snow cover extent during the months of May through June declined by 21% from 1971–2019, with a larger decrease (25%) over Eurasia compared with North America (17%).

## RIVER ICE AND WATER VOLUME

Arctic rivers are freezing up later in the autumn and their ice is breaking up earlier in springtime. Ice thickness is decreasing on most northern rivers, based on data from Russia, Canada, and Alaska, reducing the risk of spring ice-jam floods. The volume of freshwater flowing through the eight major Arctic rivers to the Arctic Ocean increased by 7.8% between 1971 and 2019.

## SEA ICE

The extent of Arctic sea ice in September declined by 43% between 1979 and 2019, and—with the exception of the Bering Sea—sea ice extent and area are declining throughout the Arctic in all months. Sea ice cover also continues to be younger and thinner than during the 1980s, 1990s, and early 2000s. Over the last 30 years, snow depth on sea ice has declined by more than 33% in the western Arctic. Although thick snow has been observed in some years in the Atlantic sector of the Arctic, data gaps make it difficult to draw conclusions about changes in snow depth there.

## LAND ICE

All regions of the Arctic are now experiencing net loss of land ice, with the rate of loss increasing in recent decades for several regions (see Figure 2). Greenland is the largest regional source of land ice loss, accounting for 51% of the Arctic total, and land ice loss in the Arctic is a major contributor to global sea level rise.

## TRENDS IN EXTREME EVENTS

Extreme climate and weather events affect ecosystems, infrastructure, and people. They can also push conditions over thresholds for potentially irreversible change: for example, extreme precipitation following a low but consistent rate of long-term permafrost warming can trigger thermokarst erosion, with potential for the release of carbon dioxide and methane.

Strong evidence shows that warm extremes are increasing and cold extremes are decreasing in the Arctic. Widespread decreases in extreme cold spells<sup>1</sup> occurred in the Arctic during 1979–2013, although some areas of Siberia experienced increases in cold spells. Cold spells lasting more than 15 days have almost completely disappeared from the Arctic since 2000.

Evidence for increases in heavy precipitation and inland flooding is much less clear. Similarly, although increases in rain-on-snow and freezing rain events have been reported in some parts of the Arctic, data for the Arctic as a whole are limited and there is not enough information to discern whether widespread changes have occurred.

Coastal erosion is accelerating in many parts of the Arctic, which has some of the highest rates of erosion on Earth. As much as 5 metres of coastline are disappearing annually in some areas of Alaska. The combined impacts of long-term warming (increasing water temperatures, longer ice-free seasons, permafrost thaw) and extreme events (storm-driven waves and swell) are causing the increase.

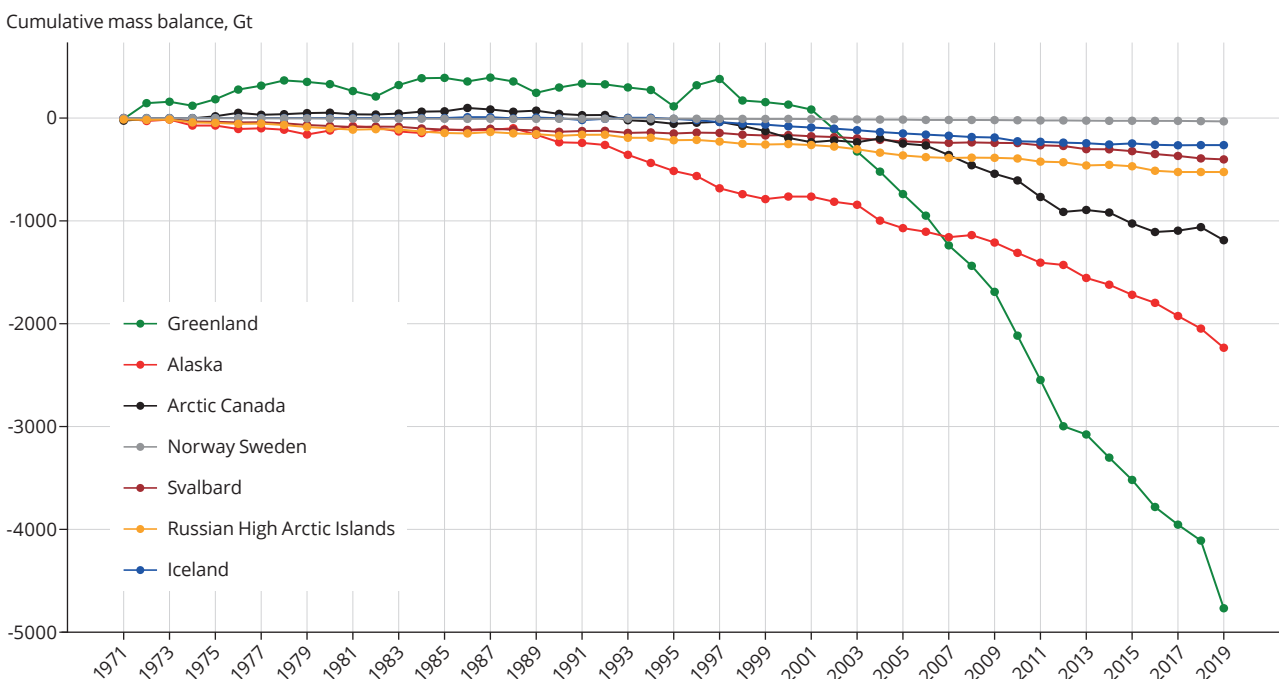


Figure 2. Arctic land ice mass balance changes, 1971–2019.



## WILDFIRE

Climate warming is associated with an increase in boreal forest and tundra wildfires, which are also a large and increasing source of black carbon and particulate emissions to the atmosphere. In most years, the area burned by wildfires in northern forests is greater than that in mid-latitudes. The frequency of extreme wildfires in Alaska has increased since 1950, and records for Siberia show an increase between 1996 and 2015. Trends elsewhere are less clear, and wildfires have become less frequent in areas where they are actively monitored and suppressed, such as Fennoscandia, due to the economic importance of forestry.

## UPDATED CLIMATE MODEL PROJECTIONS FOR THE ARCTIC

According to the CMIP6 ensemble of climate models, which are being used in the Intergovernmental Panel on Climate Change's Sixth Assessment Report, the Arctic's annual mean surface air temperature will rise to 3.3–10.0°C above the 1985–2014 average by the end of this century, depending on the course of future emissions. The first ice-free September in the Arctic could occur as early as the 2040, and the probability of an ice-free Arctic summer would be 10 times larger under a global warming of 2°C compared with a warming of 1.5°C.

## CONNECTIONS BETWEEN ARCTIC CHANGE AND MID-LATITUDE WEATHER

Although some studies have identified potential relationships between the warming Arctic climate and mid-latitude weather, there is currently no agreement in the science community on the degree to which observed changes in the Arctic are directly connected to mid-latitude extreme weather events such as droughts, cold air outbreaks, and stalled severe weather systems.

<sup>1</sup> Cold spells in this case are defined as at least six consecutive days in which the daily minimum temperature is below the 10th percentile, calculated from a five-day running mean of the daily minimum temperature over a 1980–2010 reference period.

# CLIMATE CHANGE IS HAVING MAJOR IMPACTS ON ARCTIC COMMUNITIES



Climate change is driving rapid changes in the Arctic that affect people—especially Indigenous Peoples—living in the Arctic and beyond. Changing environmental and ecological conditions are having negative impacts on health and well-being, food security, transportation, livelihoods, industries, infrastructure, and the availability of safe drinking water.

## TRANSPORTATION

The warming climate has affected transportation over snow, ice, and permafrost in many parts of the Arctic. For example, hunters in northwest Greenland report that the period when travel by dogsled on sea ice is possible has decreased from 5 to 3 months. Permafrost degradation and local increases in rain events have affected local travel by all-terrain vehicles as well as road infrastructure in some remote settlements in Canada and Russia. The accessibility of some remote settlements with limited transportation options, such as those in northern Russia whose only access in winter is via ice roads, is projected to decline in the future. Changes in sea-ice cover pose risks to transportation over ice. A study in Canada's Nunavut territory, for example, found that ice conditions (thickness and variation in types of ice) are predictive of the probability of a search and rescue taking place on any given day. The longer period of ice-free open water may expand the boating season, although this benefit may be offset in some areas by increases in high winds leading to rougher seas, as has been observed in some Alaskan coastal communities.

## TRADITIONAL FOODS AND LIVELIHOODS

The safety of food stored in ice cellars has been affected in some areas by permafrost thaw and higher temperatures. The warming and freshening of the ocean provides more suitable conditions for the development of toxic algal blooms, which pose risks to food security and potentially health as well. Periods of heavy rainfall and rapid snowmelt

may transport pathogens, posing risks to the safety of drinking water—especially when people drink untreated water from streams, rivers, and lakes on harvesting trips. Thawing permafrost can release contaminants, such as mercury, that can make their way into aquatic ecosystems.

Changing sea ice, precipitation, snow regimes, temperatures, and tundra productivity are affecting the availability of traditional foods such as whales, walrus, seabirds, seals, and reindeer/caribou. In some areas, populations of moose are increasing, and tundra greening is changing the ranges of wildlife species available to hunters. Reindeer herders in Fennoscandia and Russia have experienced major losses in their herds due to extreme snowfall and rain-on-snow events, the latter of which are projected to increase in the future.

The general trend toward warmer springs and earlier greening of pastures can have positive impacts on reindeer production, but the combination of climate impacts on wildfire, forage, and predators, along with industrialization (which shifts lands to other uses and creates barriers to migration routes), pose many challenges to reindeer pastoralism as a livelihood.

Communities in Alaska, northern Canada, and Finland have reported changes in the abundance and quality of berries. Indigenous hunters and fishers in Canada and Russia have reported thinner seals, decreased health of wildlife, and a greater prevalence of worms in fish and sea mammals.







Carsten-Egevang / Arctic Arts Project

## FISHERIES, CRUISE TOURISM, AND RESOURCE EXTRACTION

The increasing influence of warmer Atlantic and Pacific waters and reduced sea-ice cover are associated with an observed northward expansion of sub-Arctic fish and marine mammal species. Although the ecosystem interactions are complex and mediated by policy and management decisions, these range expansions could increase opportunities for commercial fishing in some regions of the Arctic (e.g., the northern Barents Sea, northern Bering Sea, and Sea of Okhotsk), with potential economic benefits for some coastal Arctic communities. Salmon farming and other forms of aquaculture are also expanding northward in parts of the North Atlantic Arctic, creating additional economic opportunities, although aquaculture also brings societal and environmental costs such as competition with local fisheries and the spread of parasites such as salmon lice to local wild fish populations.

Arctic cruise tourism has increased in parts of the Arctic, with documented benefits to local economic development in some areas as well as risks to marine ecosystems, infrastructure costs, congestion, and potential cultural impacts.

Climate change is expected to increase access to resources such as oil, gas, and minerals in the Arctic. However, the potential for expansion of these industries is tempered by efforts to limit greenhouse gas emissions and achieve goals established under the Paris Agreement. Furthermore, the environmental implications of a major oil spill in the Arctic would be significant. Oil deposits take longer to decompose in the Arctic than in warmer environments, resulting in longer-lasting impacts.

## ARCTIC DEMOGRAPHICS

The Arctic is home to approximately 4 million people. Indigenous Peoples, with distinct, unique cultures and representing more than 40 ethnic groups, account for 9% of this total. Although more than 74% of the Arctic population is concentrated in a few large settlements with populations of 5,000 or more, over 90% of Arctic settlements are small (fewer than 5,000 in population). More than 66% of Arctic settlements are located on permafrost, and nearly half (46%) of those permafrost settlements are coastal.

## ARCTIC CRUISE TOURISM HAS INCREASED

The number of cruise ship visitors to Iceland rose from 265,935 in 2015 to 402,834 in 2017, a 66% increase. Ports in northern Norway experienced a 33% increase in cruise passenger visits between 2014 and 2019.

The number of cruise ship visitors to Svalbard rose from 39,000 in 2008 to 63,000 in 2017; Greenland experienced an increase from 20,000 to 30,000 visitors over the same period. Overall, the number of visitors to the High Arctic grew from 67,752 in 2008 to 98,238 in 2017, a 57% increase.

The COVID-19 pandemic disrupted these trends in 2020, with more than 50% of Arctic cruises being cancelled or postponed.



Eyal Barrov / PhotoStock-Israel / Alamy Stock Photo



## INFRASTRUCTURE

Buildings, roads, and other infrastructure are suffering damage from the thawing of ice-rich permafrost in many regions of the Arctic; some of this damage may be directly related to infrastructure design or the impacts of the construction process rather than climate change. The stability of permafrost support for buildings and infrastructure has declined in Arctic Russia compared with the 1970s; up to 50% of buildings in Pevek, the northernmost town in Russia,

have been damaged by permafrost thaw and nearly all infrastructure in most settlements on the Taimyr Peninsula has been affected. Permafrost slumping as it thaws also poses risks to transportation infrastructure.

Coastal erosion rates in the Arctic are among the highest in the world, with impacts to communities, property, infrastructure, and livelihoods.

Total acres burned each year

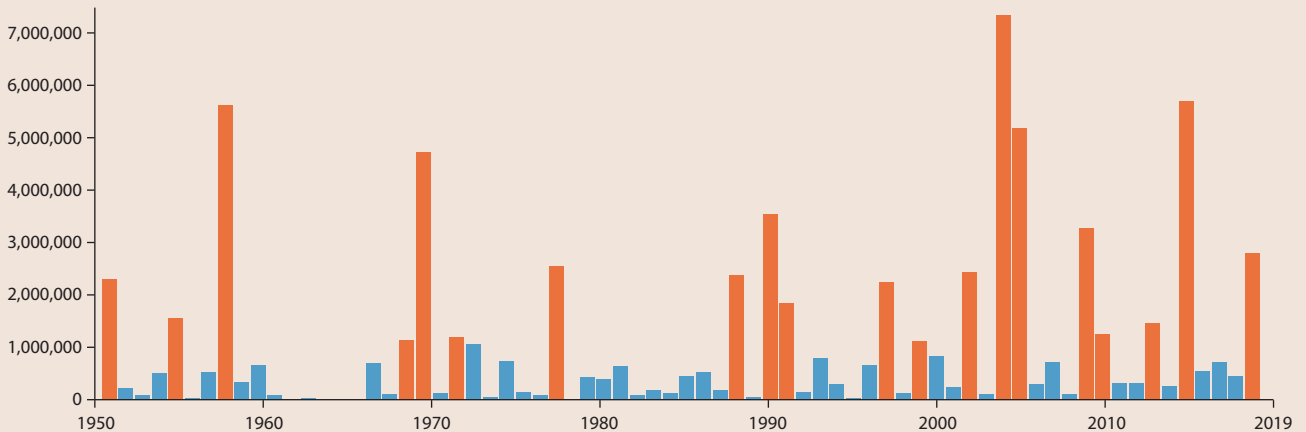


Figure 3. Annual acres burned by wildfires in Alaska, 1950–2019. Orange bars denote values of more than 1 million acres (404,686 hectares).



## EXTREME EVENTS


Wildfires, inland and coastal flooding, and extreme temperature and precipitation events already have major socioeconomic impacts in the Arctic and are expected to become more frequent and/or severe in the years ahead. For example, more than 85% of Alaska native villages currently experience some level of flooding and erosion; severe floods pose particular risks for remote communities since the availability of search and rescue operations may be limited. Heavy snowfall and rainstorms, combined with high winds, have induced avalanches, slush flows, and landslides on the Svalbard Archipelago over the past decade.

The incidence of wildfire has increased in some parts of the Arctic, such as Alaska and Siberia. Wildfire has a wide range of impacts, including risks to life and property, the economic costs of damages and fire suppression efforts, health impacts from smoke and related toxins, public anxiety and personal stress, and ecosystem impacts. The potential for wildfires to affect mental health is illustrated by a non-Arctic assessment of mental health status among young adolescents following a large wildfire in Fort McMurray (northeastern Alberta, Canada) in 2016, which found more than a tripling in the rate of depression, a doubling in the rate of anxiety, and more than a doubling in the incidence of post-traumatic stress disorder compared with pre-fire assessments. Sweden experienced an unprecedented wildfire season in 2018, which among other impacts burned 81,000 hectares of critical reindeer pasture. The Swedish Sámi Parliament estimated the cost to reindeer herders at €64 million. Although longer and warmer summers are expected to increase the risk of wildfire activity in the future, climate models also project increases in annual mean precipitation and a decrease in the number of consecutive dry days in the Arctic. Future trends in wildfire incidence and severity are thus unclear.

The combined impacts of multiple extreme events occurring simultaneously or successively can also have significant impacts on Arctic livelihoods and communities, such as extreme rain and snow events that lead to flooding, or multiple simultaneous wildfires that strain fire suppression and safety services.



## THE COSTS OF THAWING PERMAFROST

 In Alaska, permafrost thaw will increase cumulative maintenance costs of public infrastructure by an estimated 10% (US \$5.5 billion) by 2100 under a high greenhouse gas concentrations scenario (RCP 8.5).

One study estimated that more than 36,000 buildings, 13,000 kilometres of roads, and 100 airports in the Arctic could be at risk of damage from near-surface permafrost thaw by 2050, although the actual risks at individual sites will depend on local ground conditions and infrastructure design.



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## ARCTIC ECOSYSTEMS ARE EXPERIENCING RAPID, TRANSFORMATIONAL CHANGES



Many of the socioeconomic impacts described above are driven by effects of climate change on Arctic ecosystems. Ecosystems across the Arctic are undergoing fundamental changes in their structure and functioning, affecting traditional foods, livelihoods, commercial fisheries, and—through feedbacks in the climate system—global climate change.

The warming and freshening of the Arctic Ocean directly and indirectly affect the lifecycles of marine species, leading to changes in seasonality, range shifts, and broad changes in ocean ecosystems. The decline in sea ice affects marine ecosystems through changes in the open water areas and increases in the length of the open water period (both of which affect phytoplankton and ice algae, including the timing of phytoplankton blooms), as well as under-ice productivity and diversity. These changes are having cascading effects through ecosystems, with

widespread impacts on the distribution, seasonality, and abundance of a variety of species.


Satellite data show an increasing trend in primary production in all regions of the Arctic Ocean over the past two decades, explained by complex changes in light and nutrient conditions. The consequences of warming near the ocean surface on primary producers in the surface and subsurface ocean layers are still poorly understood, and there is new evidence that dominant Arctic phytoplankton species may be able to adapt to higher temperatures.



Arctic tundra greenness increased overall by 10% between 1982 and 2019, related to longer and warmer summers. A limited area has “browened” instead, indicating a decrease in vegetation cover and productivity, including the Canadian Arctic Archipelago, southwestern Alaska, and parts of northwestern Siberia. Causes of browning include extreme winter weather events and pest outbreaks; other possible contributing factors include delays in the onset of snowmelt and increases in standing surface water. Arctic vegetation plays an important role in exchanges of energy and carbon between the land and atmosphere: changes in Arctic vegetation can cause ecosystem-climate feedbacks that exacerbate climate change, but changes in vegetation can also lead to increases in carbon uptake, at least partly offsetting this impact.

Extreme events can exacerbate transitions already underway from climate warming and sea ice changes, triggering further impacts on terrestrial, freshwater, and coastal ecosystems. For example, more frequent extreme precipitation events, along with a generally increasing rain-to-snow ratio, affect the structure and function of terrestrial ecosystems.

## CHANGES IN THE ARCTIC OCEAN GATEWAYS

 Warmer waters from the Pacific and Atlantic are pushing farther into the Arctic Ocean, with widespread impacts on ocean ecosystems. The composition of Arctic plankton communities that form the basis of marine food webs is changing, as are the distribution and abundance of a variety of invertebrate, fish, and marine mammal species.

# RECOMMENDATIONS

On the basis of this update, AMAP emphasizes the need for action to both limit future warming and to understand better the consequences of future warming for the Arctic. To ensure the future vitality and resilience of Arctic peoples, communities, and ecosystems, AMAP emphasizes the need to:

## 1 LIMIT FUTURE CHANGE

Because the buildup of greenhouse gases in the atmosphere, and some emissions of short-lived climate forcers, are driving Arctic climate change, the Arctic States, Permanent Participants, and observers to the Arctic Council should individually and collectively lead sustained, ambitious, and global efforts to reduce these emissions and fully implement the Paris Agreement.

## 2 EXPAND MONITORING AND DOCUMENTATION OF ARCTIC CHANGE

The rapid pace of change in Arctic ecosystems calls for immediate action to document what is being lost and what is being created as unique ecosystems are disappearing and the cryosphere is shrinking. Unique ecosystems of the remaining perennial sea ice cover, ice shelves and epishelf lakes, and the Greenland ice sheet are among the priorities for documentation.

AMAP emphasizes the need for Arctic and international science institutions and governments to address key data gaps. The use of satellites, autonomous vehicles, and other emerging technologies, along with community-based monitoring to gather data from difficult-to-reach areas of the Arctic, is encouraged.

There is a need to sustain and enhance the development of pan-Arctic climate indicators, which are co-produced with Indigenous Knowledge holders, along with improvements in data sharing and availability, to assist researchers and policy-makers at national and regional scales.

Documentation of the impacts of extreme events on Arctic ecosystems and people can reveal priorities for further evaluation of changes in extreme events. In particular, there is a need for systematic assessments of socioeconomic impacts from extreme events in the context of environmental change in the Arctic.

Coordination of climate-ecosystem monitoring in regions of rapid change would benefit from comparable observations in regions less susceptible to change, to help constrain predictive ecosystem and resource management models.

Changes in coastal ecosystems, intensified by extreme events, affect coastal communities that are increasingly vulnerable to coastal erosion through wave and storm action. Adaptation requires sustained and coordinated climate-ecosystem monitoring at key locations in combination with community-driven monitoring that uses Indigenous Knowledge and local knowledge.



# 3



## ADDRESS INFORMATION GAPS

Large gaps remain in our understanding of the societal implications of climate change in the Arctic. There is a particular need for more integrated modeling and assessment of climate-related impacts on interconnected socioecological systems.

The impacts of climate change do not occur in isolation and may interact with each other. For example, the combination of rapid springtime warming and heavy precipitation on a deep snow pack triggered nearly 800 avalanches in Greenland in April of 2016. Understanding the impacts of these types of cumulative and compound effects is important for risk mitigation, hazard response, climate adaptation, and policy response to changing climatic conditions.

A better understanding of the potential links between Arctic change and mid-latitude weather could improve forecasters' ability to predict dangerous extreme weather events in regions far from the Arctic. More research is needed to clarify these linkages.

The perspectives of Indigenous Peoples are largely absent from assessments of Arctic

change. Efforts should be made to include information from those who have been most directly affected by climate change and who have the longest history of observations and knowledge with respect to climate change impacts, including extreme events.

Large uncertainties remain for projections of Arctic productivity. Predicting the future productivity of the Arctic Ocean requires a better understanding of the changing productivity associated with sea ice and in open waters, the cycling of nutrients and the adaptive capacity of primary producers to changing conditions.

Thresholds in Arctic ecosystems, such as seawater temperature limits for Arctic phytoplankton species or ocean acidification thresholds beyond which pteropods can no longer form shells, need more rigorous evaluation, especially with regard to potential ecosystem shifts. Few evaluations of extreme high temperatures, rapid sea ice loss events, widespread melt events on the Greenland Ice Sheet, and other extreme events in the Arctic have explored their effect on physical and ecological thresholds or tipping points.

# 4



## IMPROVE RELEVANCE AND AVAILABILITY OF SCIENTIFIC INFORMATION FOR DECISION MAKING

Arctic countries are devoting increasing attention to climate services, which translate climate data into relevant, timely information to support governments, communities, and industries in planning and decision making. Climate services can play a crucial role in the Arctic, enhancing safety and security in the face of climate-related risks as well as informing the activities of industries such as shipping, tourism, and fisheries, and there is a need for more data and work in this area. There is an opportunity to improve the flow of data and state-of-the-art climate predictive capacity to climate services organizations, and efforts are needed to develop additional and appropriate climate service products for Arctic communities.

Similarly, decision makers could benefit from additional climate information that is directly relevant for planning and decision making, documentation of climate models' ability

to capture extreme events, downscaling of model projections to identify community impacts, guidance for selecting models to use in analyses, and quantification of uncertainties in projections. Indigenous Knowledge should be considered as an input to decision making, and the participation and self-determination of Indigenous Peoples in research and decision-making processes is essential.

There is a need to further develop the understanding of future risks to Arctic ecosystems and communities, including economic costs and benefits, to inform effective and ambitious action by Arctic nations and the rest of world to limit Arctic warming and hasten the transformation toward a more resilient state.

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.

This document was prepared by the Arctic Monitoring and Assessment Programme (AMAP) and does not necessarily represent the views of the Arctic Council, its members or its observers.

The **AMAP Arctic Climate Change Update 2021: Key Trends and Impacts** is one of several reports and assessments published by AMAP in 2021. Readers are encouraged to review this, and the reports below, for more in-depth information on climate and pollution issues:

- *AMAP Assessment 2020: POPs and Chemicals of Emerging Arctic Concern: Influence of Climate Change*
- *AMAP Assessment 2021: Mercury in the Arctic*
- *AMAP Assessment 2021: Impacts of Short-lived Climate Forcers on Arctic Climate, Air Quality, and Human Health*
- *AMAP Assessment 2021: Human Health in the Arctic*

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