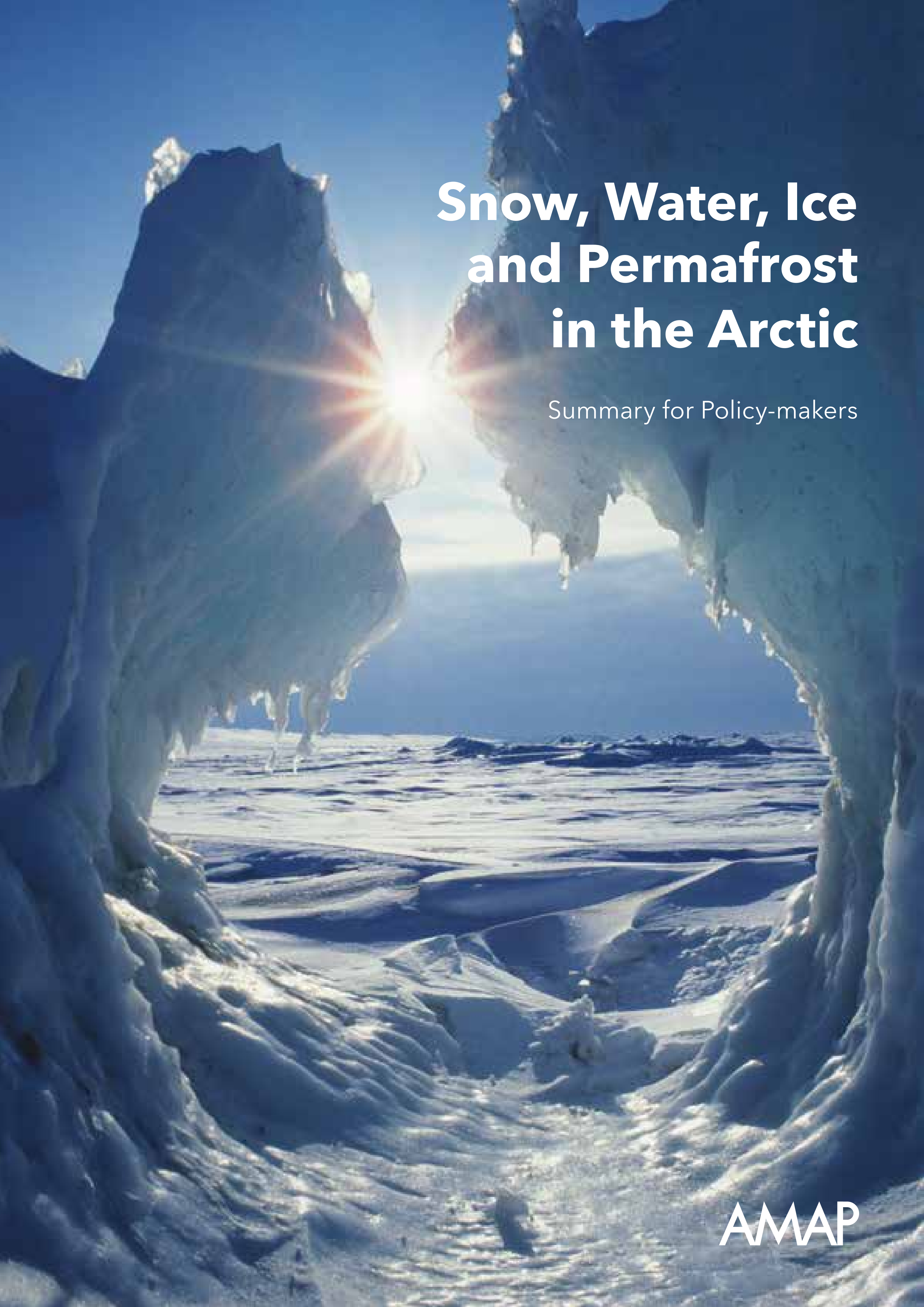
Snow, Water, Ice and Permafrost in the Arctic

Summary for Policy-makers



AMAP

Photo: Søren Rysgaard

This Summary for Policymakers presents key findings and implications of the second SWIPA assessment, conducted from 2010 to 2016 and published in 2017. More than 90 scientists contributed to the assessment, which was peer-reviewed by 28 experts in a rigorous quality control process. More details on the SWIPA process and findings are available in the full SWIPA report, available at www.amap.no/swipa.

The Snow, Water, Ice and Permafrost in the Arctic (SWIPA) assessment is a periodic update to the Arctic Climate Impact Assessment, published in 2005 by the Arctic Monitoring and Assessment Programme (AMAP), the Conservation of Arctic Flora and Fauna (CAFF), and the International Arctic Science Committee (IASC). SWIPA focuses on changes to the Arctic cryosphere (the portion of Arctic land and water that is seasonally or perennially frozen), and the implications of those changes. The first SWIPA assessment was conducted between 2008 and 2010, and was published in 2011.

About the Arctic Council

The Arctic Council is the leading intergovernmental forum promoting cooperation, coordination, and interaction among the Arctic States, Arctic indigenous peoples, and other Arctic inhabitants on common Arctic issues, in particular on issues of environmental protection and sustainable development in the Arctic. Established in 1996, the Arctic Council is composed of eight Member States (Canada, the Kingdom of Denmark, Finland, Iceland, Norway, the Russian Federation, Sweden, and the United States). It also includes six organizations representing Arctic indigenous peoples: the Aleut International Association, the Arctic Athabaskan Council, Gwich'in Council International, the Inuit Circumpolar Council, the Russian Association of Indigenous Peoples of the North, and the Saami Council.

About AMAP

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.

Key Findings

Key findings of the SWIPA 2017 assessment include:

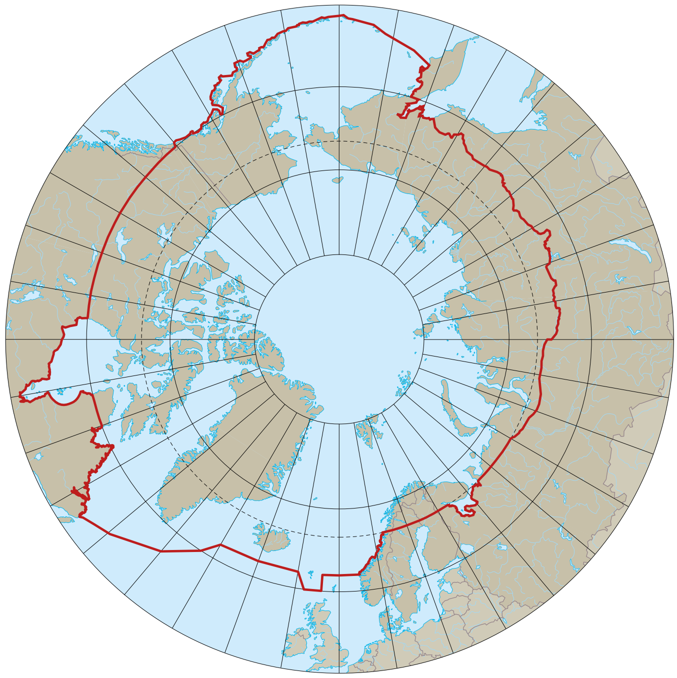
1 The Arctic's climate is shifting to a new state

Rising concentrations of greenhouse gases are driving widespread changes in the Arctic's sensitive climate, hydrological, and ecological systems. Since 2011, downward trends have continued in sea ice thickness and extent, land ice volume, and spring snow cover extent and duration, while near-surface permafrost has continued to warm.

With each additional year of data, it becomes increasingly clear that the Arctic as we know it is being replaced by a warmer, wetter, and more variable environment. This transformation has profound implications for people, resources, and ecosystems worldwide.

While SWIPA 2017 includes many important new findings, summarized below, three points in particular deserve special emphasis:

- The Arctic Ocean could be largely free of sea ice in summer as early as the late 2030s, only two decades from now.
- The recent recognition of additional melt processes affecting Arctic and Antarctic glaciers, ice caps, and ice sheets suggests that low-end projections of global sea-level rise made by the Intergovernmental Panel on Climate Change (IPCC) are underestimated.
- Changes in the Arctic may be affecting weather in mid-latitudes, even influencing the Southeast Asian monsoon.



AMAP Assessment Area

THE ROLE OF ARCTIC GLACIERS AND ICE CAPS IN GLOBAL SEA-LEVEL RISE

Scientific advances since 2011 show that while Arctic glaciers and ice caps represent only a quarter of the world's land ice area, meltwater from these sources accounts for 35% of current global sea-level rise.

2 Climate change in the Arctic has continued at a rapid pace

- **Arctic temperatures are rising faster than the global average**. The Arctic was warmer from 2011 to 2015 than at any time since instrumental records began in around 1900, and has been warming more than twice as rapidly as the world as a whole for the past 50 years. January 2016 in the Arctic was 5°C warmer than the 1981–2010 average for the region, a full 2°C higher than the previous record set in 2008, and monthly mean temperatures in October through December 2016 were 6°C higher than average for these months. Sea temperatures are also increasing, both near the surface and in deeper water.
- **The frequency of some extreme events is changing**. Recent observations include a widespread decline in periods of extreme cold during both winter and summer, and increases in extreme warm periods in some areas, such as northern Alaska and northeastern Russia in autumn and spring.

TRADITIONAL AND LOCAL KNOWLEDGE

The SWIPA scientific assessment is based primarily on peer-reviewed observations, methods, and studies, which in many cases include contributions from traditional and local knowledge. However it is recognized that this approach does not necessarily capture all relevant knowledge held by Indigenous and local communities.

- **The decline in sea ice continues, with variation from year to year.** Sea ice thickness in the central Arctic Ocean declined by 65% over the period 1975–2012. Sea ice extent has varied widely in recent years, but continues a long-term downward trend. A record low minimum sea ice extent occurred in 2012 and a record low maximum sea ice extent occurred in 2016.

  Older ice that has survived multiple summers is rapidly disappearing; most sea ice in the Arctic is now 'first year' ice that grows in the autumn and winter but melts during the spring and summer.

  Except for the coldest northern regions of the Arctic Ocean, the average number of days with sea ice cover in the Arctic declined at a rate of 10–20 days per decade over the period 1979–2013, with some areas seeing much larger declines. Warm winds during the autumn of 2016 substantially delayed the formation of sea ice.

  Sea ice is becoming more mobile as its extent and thickness decrease, increasing ice-related hazards.

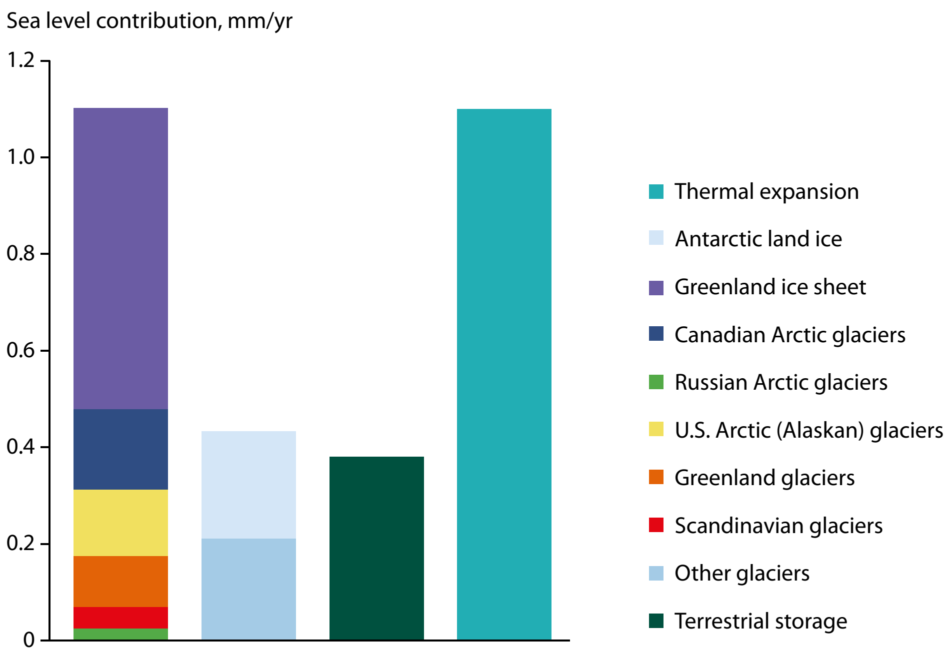
  More open water occurs in all months of the year compared with observations reported in 2011.

- **The area and duration of snow cover are decreasing**. Snow cover has continued to decline in the Arctic, with its annual duration decreasing by 2–4 days per decade. In recent years, June snow area in the North American and Eurasian Arctic has typically been about 50% below values observed before 2000.

- **Permafrost warming continues**. Near-surface permafrost in the High Arctic and other very cold areas has warmed by more than 0.5°C since 2007–2009, and the layer of the ground that thaws in summer has deepened in most areas where permafrost is monitored.

- **The loss of land-based ice has accelerated in recent decades**. Since at least 1972 the Arctic has been the dominant source of global sea-level rise. Seventy percent of the Arctic's contribution to sea-level rise comes from Greenland, which on average lost 375 gigatons of ice per year—equivalent to a block of ice measuring 7.5 kilometers or 4.6 miles on all sides—from 2011 to 2014. This is close to twice the rate over the period 2003–2008.

- **Freshwater storage in the Arctic Ocean has increased**. Compared with the 1980–2000 average, the volume of freshwater in the upper layer of the Arctic Ocean has increased by 8,000 cubic kilometers, or more than 11%. This volume equals the combined annual



During the period 2004–2010, melting Arctic land ice accounted for more than 1/3 of global sea-level rise, while thermal expansion caused by warming water contributed another 1/3 and contributions from Antarctica, other glaciers and changes in terrestrial storage contributed less than 1/3.

discharge of the Amazon and Ganges rivers, and could—if it escapes the confines of the Arctic Ocean—affect circulation in the Nordic Seas and the North Atlantic.

- **Ecosystems are changing**. The decline in sea ice thickness and extent, along with changes in the timing of ice melt, are affecting marine ecosystems and biodiversity; changing the ranges of Arctic species; increasing the occurrence of algal blooms; leading to changes in diet among marine mammals; and altering predator-prey relationships, habitat uses, and migration patterns. Terrestrial ecosystems are feeling the effects of changes in precipitation, snow cover, and the frequency or severity of wildfires. The occurrence of rain-on-snow and winter thaw/refreezing events affects grazing animals such as caribou, reindeer, and muskox by creating an ice barrier over lichens and mosses. While many tundra regions have become greener over the past 30 years, reflecting an increase in plant growth and productivity, recent satellite data show shifts toward browning (indicating a decrease in plant cover and productivity) over large areas of the Arctic, particularly in Eurasia.

- **Arctic climate trends affect carbon storage and emissions**. New estimates indicate that Arctic soils hold about 50% of the world's soil carbon. While thawing permafrost is expected to contribute significantly to future greenhouse gas emissions, the amount released over the past 60 years has been relatively small.

- **The impacts of Arctic changes reach beyond the Arctic**. In addition to the Arctic's role in global sea-level rise and greenhouse gas emissions, the changes underway appear to be affecting weather patterns in lower latitudes, even influencing Southeast Asian monsoons.

3 Changes will continue through at least mid-century, due to warming already locked into the climate system

- **Warming trends will continue**. Models project that autumn and winter temperatures in the Arctic will increase to 4–5°C above late 20th century values before mid-century, under either a medium or high greenhouse gas concentration scenario. This is twice the increase projected for the Northern Hemisphere. These increases are locked into the climate system by past emissions and ocean heat storage, and would still occur even if the world were to make drastic near-term cuts in emissions.

- **The Arctic Ocean may be ice-free sooner than expected**. Extrapolations of recent observed data suggest a largely ice-free summer ocean by the late 2030s, which is earlier than projected by most climate models. Natural variability and model limitations make precise predictions impossible.

- **Declines in snow and permafrost will continue**. The duration of snow cover is projected to decrease by an additional 10–20% from current levels over most of the Arctic by mid-century under a high emissions scenario, and the area of near-surface permafrost is projected to decrease by around 35% under the same scenario.

- **The melting of land-based ice will contribute significantly to sea-level rise**. If increases in greenhouse gas concentrations continue at current rates, the melting of Arctic land-based ice would contribute an estimated 25 centimeters to sea-level rise between 2006 and 2100. Many of the smallest glaciers across the Arctic would disappear entirely by mid-century.

- **The Arctic water cycle will intensify**. Climate models project increases in cold-season precipitation of 30–50% over the Arctic Ocean toward the end of this century, with an increasing portion of that precipitation falling as rain instead of snow.

- **Arctic ecosystems will face significant stresses and disruptions**. Changes in sea ice are expected to affect populations of polar bears, ice-dependent species of seals and, in some areas, walrus, which rely on sea ice for survival and reproduction. There will also be losses of ice-associated algae. Physical disturbance arising from an increasing frequency of wildfire and abrupt thawing of permafrost could accelerate ecological shifts, such as the expansion of tall shrubs and trees into tundra. Boreal forests will be affected by thawing permafrost, increases in wildfires, insect pest outbreaks, and climate zone shifts.

- **Arctic changes will affect sources and sinks of important greenhouse gases**. The amount of atmospheric carbon dioxide absorbed by the Arctic Ocean may be significantly affected by changes in sea-ice cover, the structure and functioning of marine ecosystems, and the hydrological cycle. Thawing permafrost is expected to increase emissions of methane.

4 Substantial cuts in global greenhouse gas emissions now can stabilize impacts after mid-century

- **Reducing concentrations of greenhouse gases in the atmosphere will make a difference**. While the changes underway in the Arctic are expected to continue through at least mid-century, substantial global reductions in net greenhouse gas emissions can begin to stabilize some trends (albeit at higher levels than today) after that. Reversing trends would require reductions in atmospheric greenhouse gas concentrations.
- **Compliance with the Paris Agreement will stabilize snow and permafrost losses, but there will still be much less snow and permafrost than today**. Climate models show that reducing greenhouse gas emissions and stabilizing concentrations, under a scenario roughly consistent with the Paris Agreement, could stabilize the further loss of snow cover and permafrost after mid-century. In contrast, higher emissions would result in continued losses.
- **Efforts to control greenhouse gas emissions can have a major impact on sea-level rise after mid-century**. For example, a scenario roughly consistent with the Paris Agreement would reduce end-of-century sea-level rise by 43% compared with that projected to occur under a business-as-usual emissions scenario.
- **However, the Arctic will not return to previous conditions this century under the scenarios considered in the SWIPA 2017 assessment**. The near-future Arctic will be a substantially different environment from that of today, and by the end of this century Arctic warming may exceed thresholds for the stability of sea ice, the Greenland ice sheet, and possibly boreal forests.

5 Adaptation policies can reduce vulnerabilities

- **Adaptation at the community and regional levels, both in the Arctic and globally, is essential**. The near inevitability of accelerating impacts in the Arctic and globally between now and mid-century reinforces the urgent need for local and regional adaptation strategies that can reduce vulnerabilities and take advantage of opportunities to build resilience.

6 Effective mitigation and adaptation policies require a solid understanding of Arctic climate change

- **Reducing knowledge gaps will improve our ability to respond to current and future changes in the Arctic**. Efforts are needed to increase the geographic coverage of observations, improve local-level projections, and reduce uncertainties.
- **Coordination across monitoring efforts, modeling studies, and international assessments can facilitate information-sharing and avoid duplication of effort**. As international attention becomes increasingly focused on Arctic climate change and its impacts, the need to coordinate among assessment processes and studies becomes greater.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The Arctic Transformed

The Arctic is still a cold place, but it is warming faster than any other region on Earth. Over the past 50 years, the Arctic's temperature has risen by more than twice the global average. Increasing concentrations of greenhouse gases in the atmosphere are the primary underlying cause: the heat trapped by greenhouse gases triggers a cascade of feedbacks that collectively amplify Arctic warming.

As a result, the Arctic of today is different in many respects from the Arctic of the past century, or even the Arctic of 20 years ago. Many of the changes underway are due to a simple fact: ice, snow, and frozen ground—the components of the Arctic cryosphere—are sensitive to heat. As the cryosphere changes, so do the Arctic's physical, chemical, and biological systems, with complex consequences within and beyond the region.

Since 2011, evidence for the Arctic's evolution toward a new state has grown stronger. Additional years of data show continued or accelerating trends in record warm temperatures, changes in sea ice and snow, melting of glaciers and ice sheets, freshening and warming of the Arctic Ocean, thawing of permafrost, and widespread ecological changes.

Beyond the trends, new data also show stronger evidence for fundamental shifts in some elements of the cryosphere, the ocean, and ecosystems. Sea ice in the Arctic is entering a new regime in which vast areas of ocean that used to be covered by ice throughout the year are now seasonally ice-free and dominated by younger, thinner ice. The composition of many boreal forests is changing: coniferous trees are increasingly being replaced by deciduous species normally found farther south.

Together, these findings portray a system whose component parts are changing at different speeds, affecting the Arctic's role as a regulator of global temperature and its influence on Northern Hemisphere weather, its contribution to sea-level rise, the livelihoods of those who live and work in the Arctic, and the habitats of Arctic species. Today's Arctic is a new environment, evolving rapidly and in unexpected ways.

Despite the many changes already underway or projected, some of which appear irreversible (such as thawing permafrost and melting of the Greenland ice sheet), climate models show that a scenario roughly equivalent to that under the 2015 Paris Agreement of the United Nations Framework Convention on Climate Change would slow or stop some trends, especially after the middle of this century, with the Arctic's average temperature stabilizing at a new, higher level. These findings offer encouragement for the long term, although the Arctic environment will continue to undergo significant changes far into the future, requiring northern countries, communities, and operators in the Arctic to focus on adaptation.

The Importance of Feedbacks

A number of feedback mechanisms, some of them unique to the Arctic, are responsible for the more rapid warming observed over the Arctic compared with the rest of the world. These feedbacks amplify warming well beyond the effects caused by increasing greenhouse gas concentrations alone. By analyzing climate models, scientists have identified the relative contribution of the different feedbacks to warming in the Arctic.

The largest feedbacks, according to climate models, are related to the Arctic's inefficiency at radiating heat. Cold regions radiate heat slowly, so the warmth trapped by greenhouse gases tends to build up. Furthermore, warming in the Arctic is concentrated close to the Earth's surface, slowing the rate at which heat is lost to space from the top of the atmosphere.

WATER IN THE ARCTIC

While liquid water and water vapor might seem irrelevant in a region where so much water is frozen, water in all its forms plays key roles in Arctic processes and ocean systems. For example, the increase in freshwater flow to the ocean from rivers and melting glaciers has implications for ocean circulation and climate that extend far beyond the Arctic.

The next-largest warming feedback comes from changes in surface reflectivity due to the melting of snow and ice. As reflective surfaces are replaced by darker surfaces such as open water or land, less energy is radiated back to space and the region warms further, leading to still more melting. Water vapor (a powerful greenhouse gas) also provides a warming feedback. Warmer temperatures increase evaporation, and a warmer atmosphere can hold more water vapor.

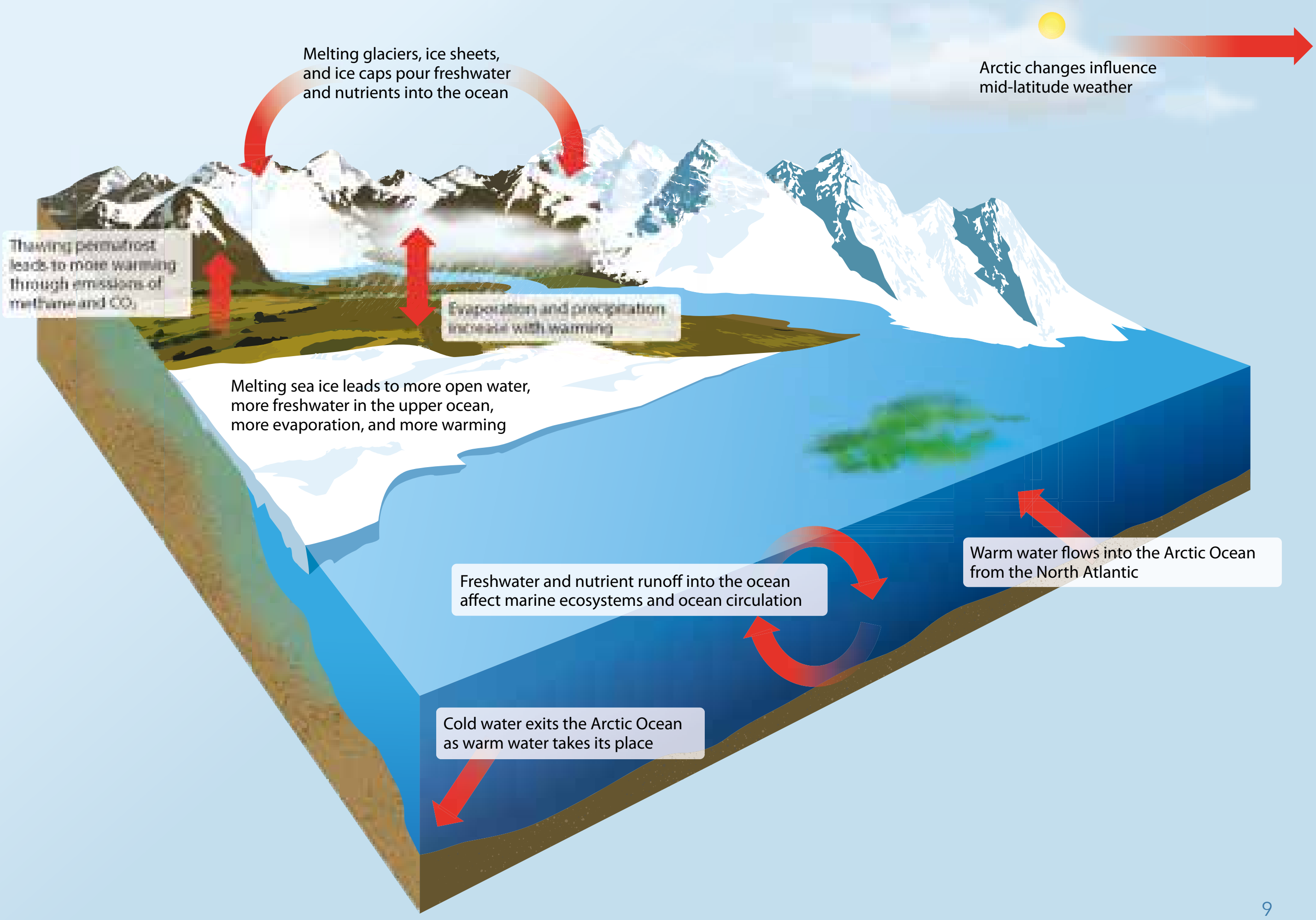
Follow the Water: The Changing Interactions between the Cryosphere and the Hydrosphere

The amplifiers of warming described above have contributed to an intensified water cycle in the Arctic, in which flows of freshwater between the land, the atmosphere, and the ocean are increasing. This pattern has important implications for human populations and ecosystems in the Arctic, as well as weather at lower latitudes.

For example, when precipitation increases in a warmer climate, much of that water ends up in rivers. As does the meltwater from snow, glaciers, and ice caps. The Arctic's rivers account for roughly 10% of the world's total river discharge, pouring enormous quantities of freshwater, sediment, nutrients, and organic carbon into the Arctic Ocean every year. Non-Arctic rivers, such as the St. Lawrence River in Canada, also contribute freshwater that ends up in the Arctic. Increases in freshwater flow into the ocean affect ocean circulation, ocean acidification (see AMAP's 2013 report on Arctic Ocean acidification), and biological productivity, and affect weather patterns far to the south. Melting sea ice also contributes to freshening of the ocean's surface. As the sea ice thins and shrinks it also becomes more mobile, creating hazards to shipping and other activities, while increasing the risk that currents will push it to warmer waters where it will melt.

Following the path of water through the hydrological cycle reveals many complex interactions between water and the cryosphere, some of which are illustrated in the figure below.

Key Interactions Between **Cryosphere** and **Hydrosphere**



The Decades Ahead

With the warming already committed in the climate system plus the additional warming expected from rising concentrations of greenhouse gases in the atmosphere, the Arctic will experience significant changes during this century even if greenhouse gas emissions are stabilized globally at a level lower than today's. If emissions continue to increase, future changes in the Arctic would be even more substantial and long-lasting.

Climate models, using scenarios that depict plausible changes in future greenhouse gas emissions and concentrations over time, offer the following updated projections for the Arctic in SWIPA 2017:

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THE PARIS AGREEMENT AND ARCTIC CHANGE

Efforts to reduce emissions can have an impact in the later years of this century. Projections suggest that reducing greenhouse gas emissions under a scenario roughly similar to that under the Paris Agreement would have the following effects by the end of this century:

- Stabilize temperature at 5–9°C above the 1986–2005 average over the Arctic Ocean in winter.
- Reduce global sea-level rise from 2006–2100 by more than 20 centimeters.
- Stabilize the duration of snow cover at about 10% below current values.
- Stabilize near-surface permafrost extent at roughly 45% below current values.

While the Paris Agreement, if implemented, would limit the extent to which the Arctic climate changes, the Arctic environment in 2100 would still be substantially different from that of today.

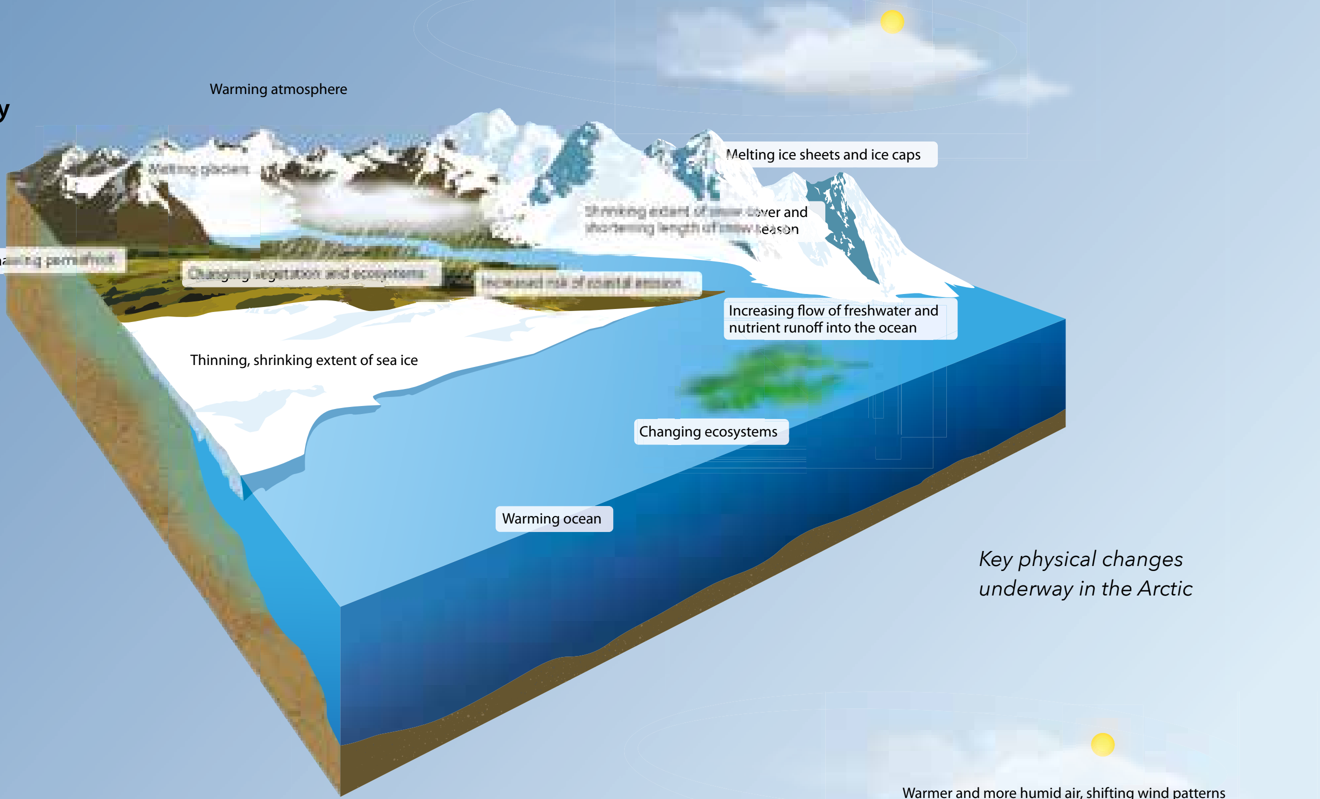
Temperature

Autumn and winter temperatures will increase by a regional average of 4°C over the next 30 years—twice the warming projected for the Northern Hemisphere as a whole—with new record temperatures observed in some regions and years. The strongest warming is projected to occur during the cold season, including spring and autumn for northern Eurasia. Even several years of cold weather due to natural variations are unlikely to affect the long-term trend, and efforts to reduce greenhouse gas emissions will not affect projected temperatures until the latter half of this century. The warming climate will increase the amount of freshwater in the Arctic, with important implications for people, industries, ecosystems, and infrastructure.

Sea Ice

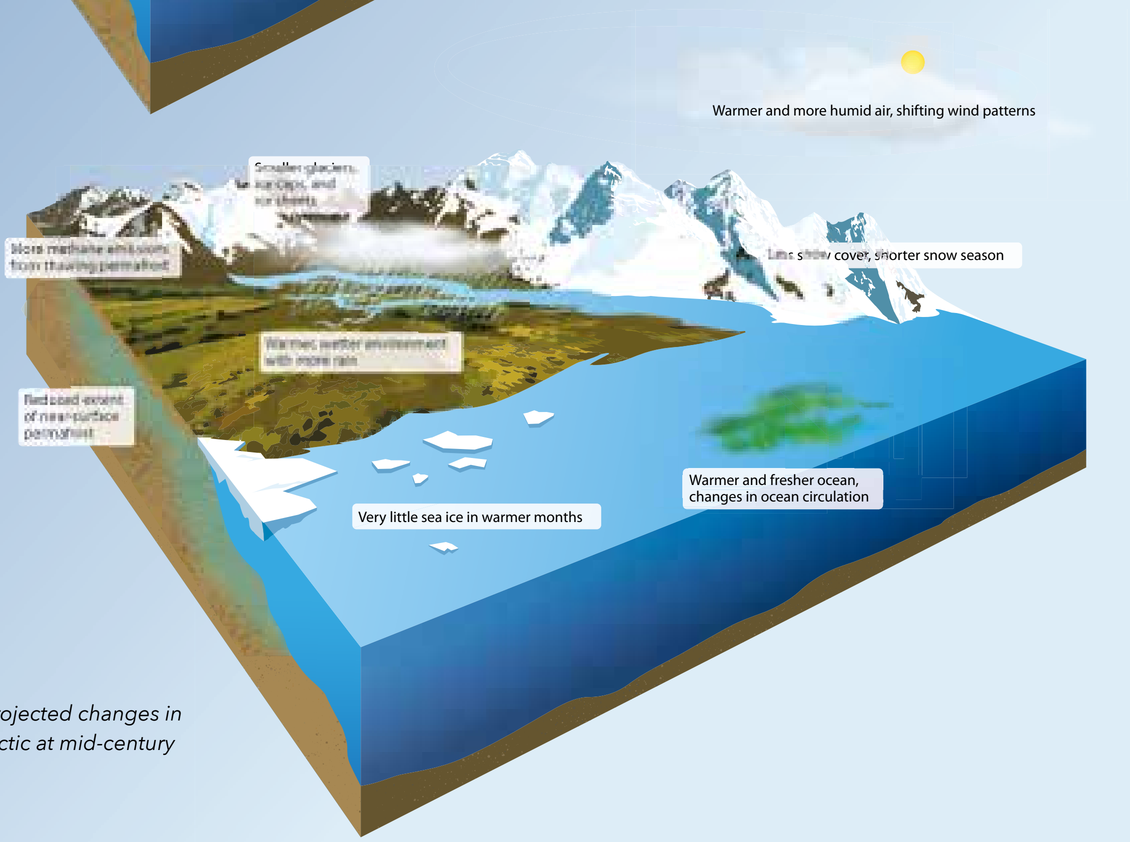
The Arctic is expected to be largely free of sea ice in late summer within the next few decades, possibly as early as the 2030s, although natural variability and other factors make it impossible to make precise predictions. The ice that appears in winter will be thinner, more salty, less rigid, and more mobile than today's sea ice. More open water is expected in winter, affecting temperature and the exchange of moisture

Today



Key physical changes underway in the Arctic

Mid-Century



Key projected changes in the Arctic at mid-century

SCENARIOS AND PROJECTIONS

Climate models project future conditions, based on scenarios. What does that mean?

Scenarios depict a range of plausible alternative futures, based on assumptions about future economic, social, technological, and environmental conditions that drive greenhouse gas emissions and their concentrations in the atmosphere.

Climate modelers use these scenarios to project, rather than predict, future climate under each scenario. Projections answer the question: if emissions and concentrations were to proceed along this pathway, what changes in climate would result?

SWIPA 2017 compared the outcomes of two different greenhouse gas concentration scenarios, RCP-4.5 and RCP-8.5. In the RCP-4.5 scenario, reductions in emissions lead to stabilization of greenhouse gas concentrations in the atmosphere by 2100 and a stabilized end-of-century global average temperature rise of 1.7–3.1°C above pre-industrial levels. RCP-8.5 is a high-emission business-as-usual scenario, leading to a global non-stabilized temperature rise of 3.8–6°C by 2100.

between the atmosphere and ocean, leading to more extreme weather locally and at lower latitudes. Sea ice is currently thinning and shrinking more rapidly than projected by most models.

Snow and Permafrost

Projected changes in snow cover and maximum accumulation vary widely over the Arctic. Warmer coastal areas such as those in Alaska and Scandinavia will see the fastest and largest declines. The cold high latitudes of the Arctic will experience an increase in the annual accumulation of snow. The largest reductions in snow cover are projected in the spring in most regions of the Arctic.

The area of near-surface permafrost in the Northern Hemisphere is projected to decline by 20% relative to today's area by 2040, and could be reduced by as much as two-thirds by 2080 under a scenario of high greenhouse gas emissions. Impacts will vary widely at regional and local scales, but local effects are difficult to project given the lack of fine-scale detail in models.

Land-based Ice and Sea Level

The loss of land ice is expected to accelerate after the middle of this century. New projections of glacier changes since 2011 provide more regional detail, showing for example that some glaciers in northeastern Russia, Siberia, and the Kamchatka Peninsula could completely disappear by mid-century.

Global sea-level rise is expected to accelerate, although uncertainties about the Greenland ice sheet's response to ongoing warming hamper scientists' ability to project the rate and magnitude of the increase. A recent analysis developed for SWIPA estimates that the Arctic will contribute 19–25 centimeters to global sea-level rise by the year 2100.

The SWIPA analysis estimates that when all sources of sea-level rise are considered (not just those from the Arctic), the rise in global sea level by 2100 would be at least 52 cm for a greenhouse gas reduction scenario and 74 cm for a business-as-usual scenario. These estimates are almost double the minimum estimates made by the IPCC in 2013.

After the Greenland ice sheet, the largest Arctic contributions to sea-level rise will come from glaciers in the Canadian Arctic, Alaska, and the Russian Arctic, along with glaciers surrounding the Greenland ice sheet.

Freshwater

The Arctic water cycle is expected to continue to intensify during this century. Mean precipitation and daily precipitation extremes will increase over mid- and high latitudes, with implications for the management of water resources, flow of freshwater into the Arctic Ocean, changes in sea ice temperature, and amplification of regional warming (through reduced surface reflectivity caused by a shift from snow to more rain in the warmer seasons).

Ecosystems

The rate and magnitude of changes projected for the Arctic will push some species out of their ranges, while other species may colonize new areas. For example, many species depend on sea ice for survival and reproduction and their populations may decline with changes in sea ice thickness and extent (as well as changes in the timing of ice formation and melt), while phytoplankton and populations of non-native species may increase due to the warmer waters and reductions in sea ice. More frequent wildfires and abrupt thawing of permafrost could accelerate ecological shifts, such as the spread of tall shrubs and trees into tundra.

Carbon Cycling

Reductions in sea ice and other changes may affect the amount of carbon dioxide absorbed by the Arctic Ocean, while thawing permafrost is expected to increase emissions of methane. However, projections of future impacts on Arctic sources and sinks of greenhouse gases are still hampered by data and knowledge gaps.

Photo: Knud Falk

Photo: © Nordroden / Shutterstock

What Are the Implications?

Changes underway in the Arctic have wide-ranging consequences for Arctic ecosystems and people living and working in the Arctic. The Arctic also plays an important role in global climate and weather, sea-level rise, and world commerce, which means that impacts in the Arctic resonate far south of the Arctic Circle. A recent economic analysis of the global costs of Arctic change estimated the cumulative cost at USD $7–90 trillion over the period 2010–2100.

The implications of most findings in SWIPA 2017 are not fundamentally different from those reported in 2011, but are supported by more evidence and in some cases warrant greater concern due to more significant impacts or new knowledge. A major new finding is that Arctic changes may influence weather far to the south (see text box on page 17 under Global Implications).

Challenges and Opportunities in the Arctic

The rapid changes underway in the Arctic affect lives, livelihoods, and ecosystems throughout the region, with both positive and negative consequences.

Access and Transportation

- The Arctic Ocean's open water season has already increased by 1–3 months over much of the ocean since the late 1970s, creating more opportunities for marine shipping, commercial fisheries, tourism, and access to resources.
- In contrast, losses and decreases in the thickness of lake and river ice and changes in permafrost conditions affect or threaten ice roads, restricting access to remote communities.
- Some northern communities have found it harder to obtain wild sources of food due to the shorter snow cover season (which affects travel to hunting grounds as well as animal habitat). The thinning of sea ice and the lengthening melt season also affect access to resources.

ADAPTING TO MULTIPLE DRIVERS OF CHANGE

Climate change is only one of many factors contributing to change in the Arctic. Oil and gas activities, mining, tourism, shipping, fisheries, economic development, and pollutants are just some of the other stressors faced by the Arctic today. Many of these factors interact with each other.

To better understand the interrelationships among multiple drivers of change in the Arctic, and to help decision-makers plan integrated adaptation strategies, AMAP is preparing an assessment on Adaptation Actions for a Changing Arctic, published in 2017.

Risks and Hazards to Arctic Communities

- Reductions in coastal (landfast) sea ice, combined with loss of land-based ice and permafrost, are leading to coastal erosion and flooding, affecting safety and in some cases the very existence of coastal communities.

- The increased mobility of sea ice, as well as the increased export of land ice into the ocean, lead to an increase in marine ice hazards.

- Future climate change may bring higher risks of avalanches and floods from rapid melting in some regions of the Arctic. In 2015, above-average precipitation and record spring warmth in north-central Alaska led to extensive flooding that closed the Dalton Highway—the only road to Alaska's North Slope oil fields—for 3 weeks, leading to an estimated USD $15 million in damages.

- Warmer and drier conditions have contributed to an increase in severe wildfires in the Arctic areas of North America and Eurasia. For example, the severity and frequency of fires in the taiga forests of interior Alaska are higher now than at any point in the last 10,000 years, based on paleoecological reconstructions of fire history in the region.

- Communities and infrastructure built on frozen soils are significantly affected by thawing permafrost, one of the most economically costly impacts of climate change in the Arctic. The bearing capacity of building foundations has declined by 40–50% in some Siberian settlements since the 1960s, and the vast Bovanenkovo gas field in western Siberia has seen a recent increase in landslides related to thawing permafrost. Thawing permafrost may also contaminate freshwater resources when previously frozen industrial and municipal waste is released.

- Climate change presents risks to food and water security through changes in access to hunting areas and the distribution range of traditional food sources, contamination of drinking water supplies (including by harmful algal species), changes in traditional food preservation techniques, and potential increases in food contaminants.

Photo: Søren Rysgaard

Impacts on Wildlife and Ecosystems

- Reductions in snow cover change the availability of habitat for microorganisms, plants, animals, and birds.
- Winter thaws and rain-on-snow events can damage vegetation, while refreezing creates a layer of ice over the vegetation that may be difficult for animals to penetrate with their hooves, adversely affecting conditions for grazing animals such as caribou, reindeer, and musk ox.
- The thinning and loss of sea ice has many impacts on Arctic life, from promoting the growth of marine phytoplankton and creating more habitat for open-water species to loss of ice-associated algal species and disrupting the feeding platforms and life cycles of seals, polar bears and, in some areas, walrus.
- Food webs are affected by changes in the structure of ecological communities and shifts in the geographic ranges of species.

THE ARCTIC'S ROLE IN THE GLOBAL CLIMATE SYSTEM

Compared with mid-latitudes and the tropics, the Arctic receives relatively little energy from the Sun. Because most of the Arctic's surface is covered in snow and ice, much of the energy that it does receive is reflected back to space. These factors account for the Arctic's cold climate.

The Arctic acts as a global refrigerator by drawing warm ocean water from the south, cooling it, and ultimately sinking it toward the ocean bottom. Surface water moves in to replace the sinking water, creating ocean currents. This movement of warmer ocean waters to the north has a major influence on climate; it accounts for northern Europe's relatively mild climate compared with that of Canadian provinces at the same latitude, for example, and it keeps the tropics cooler than they would be otherwise.

Meltwater from Arctic glaciers, ice caps, and the Greenland ice sheet also influences climate by flooding the ocean with freshwater, affecting ocean circulation and weather patterns.

The Arctic is both a source and sink for greenhouse gases. Changes in the quantities of greenhouse gases such as carbon dioxide and methane stored or released in the Arctic can have a long-term impact on global climate.

Implications for Key Industries

- Increases in precipitation could make the Arctic a potential future source of freshwater and hydropower for southern areas.

- Climate change may facilitate access to oil, minerals, and other resources, although market forces may play a larger role than climate change in those industries' activities in the Arctic. Extraction of oil and gas will lead to more greenhouse gas emissions, exacerbating the impacts described here.

- Commercial fisheries may also be affected by climate change, in both positive and negative ways, due to changes in phytoplankton growth, changes in ocean temperature, northward shifts in the ranges of some fish species (e.g., the recent migration of mackerel into waters around Svalbard and Greenland), and acidification of the ocean by carbon dioxide.

Global Implications

Changes in the Arctic affect the rest of the world, not only in obvious ways (such as the Arctic's contribution to sea-level rise), but through the Arctic's role in the global climate system, its influence on ocean circulation, and its impacts on mid-latitude weather.

- Coastal communities, low-lying islands, and ecosystems throughout the world will be affected by the melting of land ice (glaciers and ice sheets) in the Arctic, which is projected to increase the rate of global sea-level rise. Impacts include coastal flooding, erosion, damage to buildings and infrastructure, changes in ecosystems, and contamination of drinking water sources.

- The implications mentioned above for shipping; access to oil, gas, and minerals; and impacts to fisheries have economic consequences outside the Arctic.

- Changes in Arctic sea ice cover, marine ecosystems, and the water cycle affect the amount of carbon dioxide that the Arctic Ocean absorbs from the atmosphere. The ocean becomes more acidic as it absorbs more carbon dioxide, with potential implications for marine life. Changes in snow cover and permafrost also affect carbon and nitrogen cycling, as well as methane emissions.

Photo: © B&C Alexander / ArcticPhoto

ARCTIC CHANGES AFFECT MID-LATITUDE WEATHER

One of the major new areas of research since 2011 is on connections between Arctic changes and mid-latitude weather. Some studies have linked the loss of land and sea ice, along with changes in snow cover, to changes in Northern Hemisphere storm tracks, floods, and winter weather patterns, and have even found evidence that Arctic changes influence the onset and rainfall of Southeast Asian monsoons.

While it is clear that Arctic changes can influence weather outside of the region, scientists are still working to characterize the nature, magnitude, and extent of the effects.

Improving Our Understanding

The authors of SWIPA 2017 identified a number of areas where addressing data gaps and improving understanding of key processes would aid efforts to characterize the changes underway and to project changes in the future. Two overarching needs identified in the SWIPA 2017 report include 1) improving predictions for the timing of future Arctic changes (which requires a better understanding of feedbacks in the Arctic cryosphere); and 2) improving confidence in predictions of interactions between the Arctic and global systems.

The report also identifies many more specific data gaps and research needs. For example, detailed data on permafrost are lacking from important areas, such as the High Arctic regions of Canada and Russia. Gaps in our understanding of other factors, such as the storage and drainage of glacial meltwater, storage and export of continental freshwater and resulting effects on marine processes, the role of snow in the evolution of sea ice, interactions between snow and vegetation, and connections between Arctic changes and weather at lower latitudes, hamper efforts to model future impacts of warming in the Arctic. Data gaps also impede predictions of how Arctic ecosystems will respond to climate change, making it difficult to identify specific regions of the Arctic that may be most vulnerable to ecosystem shifts in the future.

Increasing the coverage of observations, in space and time, will help fill some of these gaps. Remotely sensed data from satellites, balloons, ships, aircraft, and underwater instruments have greatly improved our capability to monitor change in the Arctic, although the data have limitations in terms of resolution and applicability, and still need to be verified with on-site observations.

Some important needs relate to the difficulty of providing useful climate model projections at the local scale. The lack of local-level projections can impede efforts to develop adaptation strategies—especially in the case of permafrost, where impacts are influenced strongly by local topography and hydrology.

The reliability of future projections will be improved by reducing uncertainties related to factors such as the sensitivity of the Greenland ice sheet to climate change and the impacts of freshwater inflows on ocean processes. Other modeling-related challenges include capturing the effects of natural climate variability, which can obscure trends, and resolving differences across models' projected changes past mid-century. Despite these concerns, it is important to note that projections for the next several decades differ little across models or scenarios, and models do a generally good job of recreating past and current trends.

Recommended Action Steps

The key findings of SWIPA 2017 have implications for policy and planning in four broad areas:

Limit Future Change

Stabilizing Arctic warming and its associated impacts will require substantial near-term cuts in net global greenhouse gas emissions. Full implementation of the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC) will cause Arctic temperatures to stabilize—at a higher level than today—in the latter half of this century. This will require much larger cuts in global greenhouse gas emissions than those planned under current nationally determined contributions to the fulfillment of the UNFCCC.

The Arctic states, permanent participants, and observers to the Arctic Council should individually and collectively lead global efforts for an early, ambitious, and full implementation of the Paris COP21 Agreement, including efforts to reduce emissions of short-lived climate forcers.

Adapt to Near-Term Impacts

The transformative changes underway in the Arctic will continue and in some cases accelerate until at least mid-century regardless of efforts to reduce emissions. Impacts from climate change are thus expected to intensify for at least the next three to four decades, creating a clear and urgent need for knowledge and strategies to help Arctic communities and global society adapt to new conditions and reduce vulnerabilities to expected impacts. Addressing major knowledge gaps will help ensure adaptation strategies are grounded in a solid understanding of potential impacts and interactions.

The Arctic Council and other international organizations should prioritize research and knowledge-building efforts leading to enhanced certainty in predictions of changes and their consequences at local to global scales, facilitating the development of effective adaptation responses to changes in the Arctic cryosphere.

Support the Advancement of Understanding

SWIPA 2017 demonstrates great advances in our understanding of changes in the Arctic cryosphere, but also reveals major knowledge gaps. It also identifies several unmet scientific goals and specific areas where more observations and research are needed. As awareness of Arctic climate change and its consequences has grown, a number of international organizations, such as the Intergovernmental Panel on Climate Change (IPCC), the World Meteorological Organization (WMO), and the International Council for Science (ICSU) through the International Arctic Science Committee (IASC), have become increasingly engaged in understanding the implications of Arctic change. Making advances in these areas will require international coordination; long-term commitments to funding; the application of traditional and local knowledge; engagement with stakeholders; and coordinated and enhanced observation networks.

The Arctic Council should continue its efforts to monitor, assess, and understand Arctic climate change and its implications. It should also support and interact with efforts of international organizations and conventions such as IPCC, WMO, the UNFCCC, and the Convention on Long-Range Transboundary Air Pollution (CLRTAP) to promote the inclusion of Arctic perspectives in their work.

Raise Public Awareness of the Implications of Changes in the Arctic Cryosphere

Outreach and public sharing of information about Arctic climate change, its consequences, uncertainties, risks, adaptation options, and effects of emission reductions are key to informed governance and policy development.

The Arctic Council, permanent participants, and observers to the Council should prioritize informing and educating the public about observations, projections, and implications of Arctic climate change.

Photo: Søren Rysgaard

Snow, Water, Ice and Permafrost in the Arctic

Summary for Policy-makers

This document presents the AMAP 2017 Snow, Water, Ice and Permafrost in the Arctic (SWIPA) Assessment Summary for Policy-makers. More detailed information on the results of the assessment can be found in the SWIPA Scientific Assessment Report. For more information, contact the AMAP Secretariat.

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