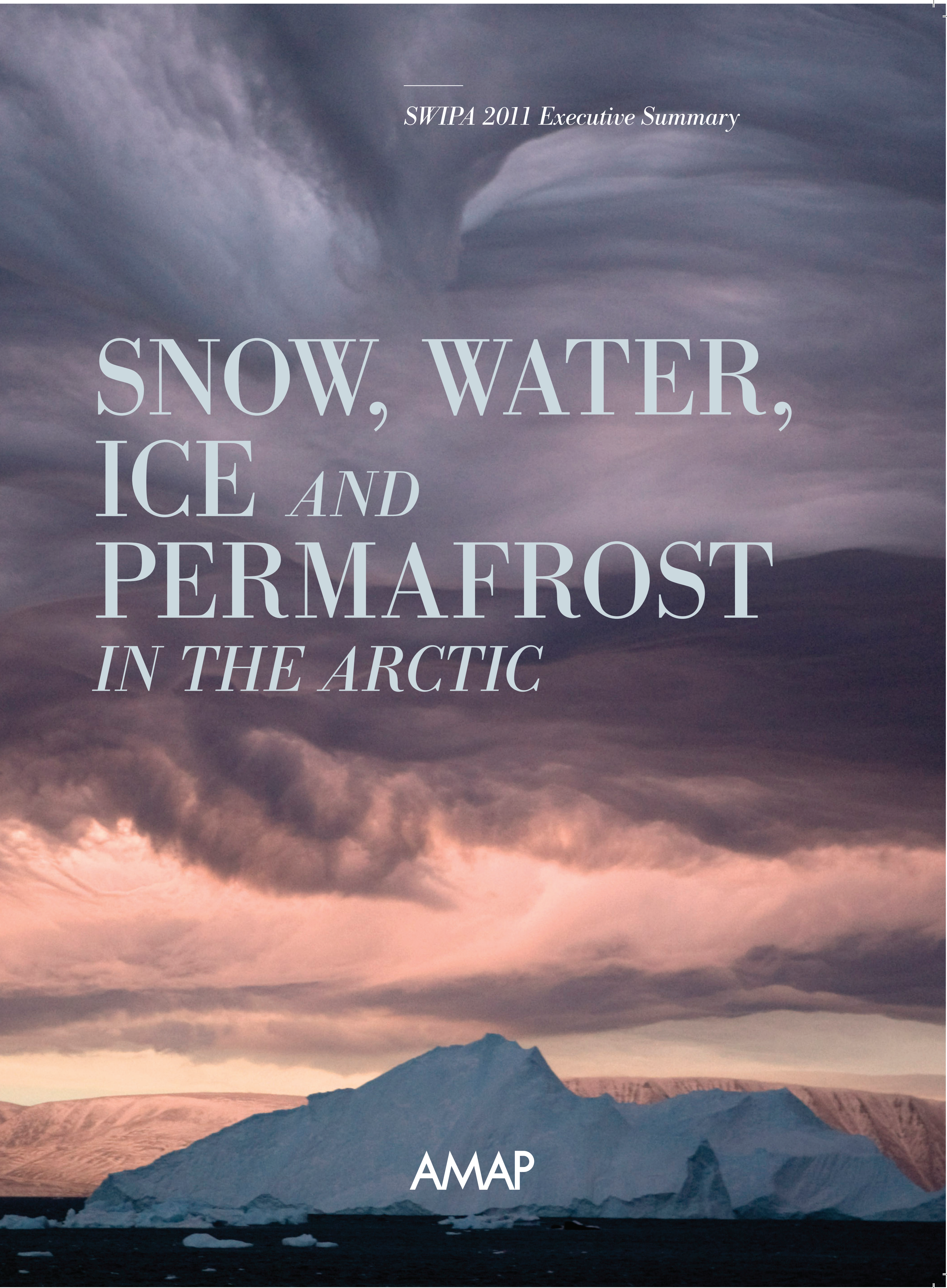
SWIPA 2011 Executive Summary

SNOW, WATER, ICE *AND* PERMAFROST *IN THE ARCTIC*



AMAP

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EXECUTIVE SUMMARY AND KEY MESSAGES

SWIPA Summary for policymakers

AMAP's new assessment of the impacts of climate change on Snow, Water, Ice and Permafrost in the Arctic (SWIPA) brings together the latest scientific knowledge about the changing state of each component of the Arctic 'cryosphere'. It examines how these changes will impact both the Arctic as a whole and people living within the Arctic and elsewhere in the world.

'Cryosphere' is the scientific term for that part of the Earth's surface that is seasonally or perennially frozen. It includes snow, frozen ground, ice on rivers and lakes, glaciers, ice caps, ice sheets and sea ice. The cryosphere structures the physical environment of the Arctic. It provides services to humans such as freshwater supplies and transport routes. The cryosphere is an integral part of the climate system, and affects climate regionally and globally.

The SWIPA Assessment follows on from the Arctic Climate Impact Assessment (ACIA), published in 2005. It aims to update the findings from ACIA and to provide more in-depth coverage of issues related to the Arctic cryosphere.

The observed changes in sea ice on the Arctic Ocean and in the mass of the Greenland Ice Sheet and Arctic ice caps and glaciers over the past ten years are dramatic and represent an obvious departure from the long-term patterns.

Some elements of the cryosphere, such as the extent of snow, ice over water, and the dynamics of glaciers and ice streams vary greatly over short timescales (seasonally, or from year to year) and from place to place. Other aspects of the cryosphere, such as the extent of permafrost and large ice sheets, vary and change over decadal time scales and large areas. Distinguishing long-term change from natural variability requires data to be collected at many locations over many years and carefully analyzed. Detecting these cryospheric responses to changing climate presents different challenges and requires long term records as well as high frequency observations.

WHY THE ARCTIC CRYOSPHERE IS CHANGING

The past six years (2005–2010) have been the warmest period ever recorded in the Arctic. Higher surface air temperatures are driving changes in the cryosphere.

Key finding 1

There is evidence that two components of the Arctic cryosphere – snow and sea ice – are interacting with the climate system to accelerate warming.

Key finding 2

The Arctic is warming. Surface air temperatures in the Arctic since 2005 have been higher than for any five-year period since measurements began around 1880. The increase in annual average temperature since 1980 has been twice as high over the Arctic as it has been over the rest of the world. Evidence from lake sediments, tree rings and ice cores indicates that Arctic summer temperatures have been higher in the past few decades than at any time in the past 2000 years. Previously unseen weather patterns and ocean currents have been observed, including higher inflows of warm water entering the Arctic Ocean from the Pacific. These changes are the main drivers of change in the Arctic cryosphere.

In attributing the cause of warming in the Arctic, SWIPA refers to the findings of the Fourth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC). This states that *"Most of the observed increase in global average temperatures since the mid-20th century is very likely* [> 90% probability] *due to the observed increase in anthropogenic GHG* [greenhouse gas] *concentrations".*

Climate-cryosphere interactions may now be accelerating warming

The greatest increase in surface air temperature has happened in autumn, in regions where sea ice has disappeared by the end of summer. This suggests that the sea is absorbing more of the sun's energy during the summer because of the loss of ice cover. The extra energy is being released as heat in autumn, further warming the Arctic lower atmosphere. Over land, the number of days with snow cover has changed mostly in spring. Early snow melt is accelerated by earlier and stronger warming of land surfaces that are no longer snow-covered.

These processes are termed 'feedbacks'. Snow feedbacks are well known. The sea ice feedback has been anticipated by climate scientists, but clear evidence for it has only been observed in the Arctic in the past five years.

A number of other potential feedback mechanisms at play in the Arctic have been identified. These mechanisms can alter the rate or even direction of climate change and associated changes in the cryosphere. Of those feedbacks expected to have strong effects, eight lead to further and/or accelerated warming, and just one leads to cooling. The intensity of feedbacks between the cryosphere and climate are not yet well quantified, either within the Arctic or globally. This lends considerable uncertainty to predictions of how much and how fast the cryosphere and the Arctic environment will change.

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HOW THE ARCTIC CRYOSPHERE IS CHANGING

The extent and duration of snow cover and sea ice have decreased across the Arctic. Temperatures in the permafrost have risen by up to 2 °C. The southern limit of permafrost has moved northward in Russia and Canada.

Key finding 3

The largest and most permanent bodies of ice in the Arctic – multi-year sea ice, mountain glaciers, ice caps and the Greenland Ice Sheet – have all been declining faster since 2000 than they did in the previous decade.

Key finding 4

Model projections reported by the Intergovernmental Panel on Climate Change (IPCC) in 2007 underestimated the rates of change now observed in sea ice.

Key finding 5

The extent and duration of snow cover have decreased throughout the Arctic. The Arctic land area covered by snow in early summer has reduced by 18% since 1966. Coastal areas of Alaska and northern Fennoscandia have seen the strongest decreases in the number of days with snow cover. The change is largely caused by snow melting earlier in the spring. Snow depth has decreased in some areas such as the North American Arctic, but has increased in others such as northern Russia.

Permafrost – permanently frozen ground – underlies most of the Arctic land area and extends under parts of the Arctic Ocean. Temperatures in the permafrost have risen by up to 2 °C over the past two to three decades, particularly in colder sites (typical permafrost temperatures range from -16 °C to just below 0 °C, depending on the location). The depth of soil above the permafrost that seasonally thaws each year has increased in Scandinavia, Arctic Russia west of the Urals, and inland Alaska. The southern limit of the permafrost retreated northward by 30 to 80 km in Russia between 1970 and 2005, and by 130 km during the past 50 years in Quebec.

Ice cover on lakes and rivers in the Northern Hemisphere is breaking-up earlier than previously observed. Studies of sediments in High Arctic lakes indicate that the duration of ice cover on some lakes has declined significantly over the past 100 years. The rates of change in lake and river ice conditions vary across the Arctic, although there are few long-term systematic observations.

Large bodies of ice are melting faster

Net loss of mass from the Greenland Ice Sheet has increased from an estimated 50 Gt per year (50 000 000 000 metric tonnes per year) in the period 1995–2000 to ~200 Gt per year in the period 2004–2008. The current loss (~200 Gt per year) represents enough water to supply more than one billion city-dwellers.

Nearly all glaciers and ice caps in the Arctic have shrunk over the past 100 years. The rate of ice loss increased over the past decade in most regions, but especially in Arctic Canada and southern Alaska. Total loss of ice from glaciers and smaller ice caps in the Arctic probably exceeded 150 Gt per year in the past decade, similar to the estimated amount being lost from the Greenland Ice Sheet.

Arctic sea-ice decline has been faster during the past ten years than in the previous 20 years. This decline in sea-ice extent is faster than projected by the models used in the IPCC's Fourth Assessment Report in 2007. The area of sea ice persisting in summer (polar pack ice) has been at or near record low levels every year since 2001. It is now about one third smaller than the average summer sea-ice cover from 1979 to 2000. New observations reveal that average sea-ice thickness is decreasing and the sea-ice cover is now dominated by younger, thinner ice.

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MORE CHANGE IS EXPECTED

Average Arctic autumn-winter temperatures are projected to increase by between 3 and 6 °C by 2080, even using scenarios in which greenhouse gas emissions are projected to be lower than they have been for the past ten years.

The climate models used for SWIPA do not include possible feedback effects within the cryosphere system that may release additional stores of greenhouse gases from Arctic environments.

Arctic snowfall and rain are projected to increase in all seasons, but mostly in winter. Despite this, Arctic landscapes are generally expected to dry out more during summer. This is because higher air temperatures mean that more water evaporates, snow melt finishes earlier, and water flow regimes are altered.

With increasing snowfall, all projections show maximum snow depth during winter increasing over many areas. The greatest increases (15–30% by 2050) are expected in Siberia. Even so, snow will tend to lie on the ground for 10–20% less time each year over most of the Arctic, due to earlier melting in spring.

Models project continued thawing of permafrost.

Projections show that sea-ice thickness and summer sea-ice extent will continue to decline in the coming decades, although considerable variation from year to year will remain. A nearly ice-free summer is now considered likely for the Arctic Ocean by mid-century. This means there will no longer be any thick multi-year ice consistently present.

Climate model projections show a 10–30% reduction in the mass of mountain glaciers and ice caps by the end of the century.

The Greenland Ice Sheet is expected to melt faster than it is melting now, but no current models can predict exactly how this and other land-based ice masses in the Arctic will respond to projected changes in the climate. This is because ice dynamics and complex interactions between ocean, snow, ice and the atmosphere are not fully understood.

Maximum snow depth is expected to increase over many areas by 2050, with greatest increases over Siberia. Despite this, average snow cover duration is projected to decline by up to 20% by 2050.

Key finding 6

The Arctic Ocean is projected to become nearly ice-free in summer within this century, likely within the next thirty to forty years.

Key finding 7

HOW THESE CHANGES AFFECT ARCTIC ECOSYSTEMS AND PEOPLE

Changes in the cryosphere cause fundamental changes in Arctic ecosystems

Changes in the amount of snow and the structure of the snowpack affect soils, plants and animals. Some species, such as pink-footed goose, benefit from less snow cover in spring. But animals grazing through snow, such as reindeer/caribou, suffer if winter rainfall creates an ice-crust over the snow. This is already happening more often in northern Canada and Scandinavia.

Less snow and faster melting are causing summer drought in forests, wetlands, and lakes supplied by snow melt. Thawing permafrost is also causing wetlands in some areas to drain and dry out, while creating new wetlands elsewhere.

The loss of ice cover over rivers, lakes and seas is changing animal and plant communities in the water.

The loss of large areas of sea ice represents devastating habitat loss for some ice-adapted species, including polar bear, seals, walrus, narwhal and some microbial communities. Many animals, including bowhead whales, depend on tiny crustaceans that thrive near the sea ice. This food source is changing as the ice edge recedes.

These changes to ecosystems directly affect supplies of water, fish, timber, traditional/local foods and grazing land used by Arctic people. For example, it has been suggested that stocks of some sub-Arctic and Arctic-adapted fish species, including commercially important species, could change as sea ice recedes. Uncertainty about changing supplies of living natural resources makes it difficult to plan for the future.

Forestry may benefit from thawing permafrost in areas where there is enough water for trees to grow, but insect pests are increasingly causing problems. Some hunted animals, such as seals and walruses, are declining in numbers as ice conditions change. Others are moving to new locations, so hunters have to travel further to reach them.

Cryospheric change affects Arctic livelihoods and living conditions

Access to northern areas via the sea is increasing during the summer as sea ice disappears; allowing increased shipping and industrial activity. Offshore oil and gas activities will benefit from a longer open water season, although threats from icebergs may increase due to increased iceberg production. The International Maritime Organization is devising new mandatory guidelines for ships operating in ice-covered waters. Sea-ice decline creates challenges for local residents who use the ice as a platform for travel and hunting; these challenges may include travelling farther over uncertain ice conditions and increased hazards.

On land, access to many areas is becoming more difficult as ice roads melt earlier and freeze later and as permafrost degrades. Industrial operations reliant on ice roads will need to concentrate heavy load transport into the coldest part of the year. Shorter seasons where ice and snow roads can be used severely impact communities

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that rely on land transport of goods to maintain reasonable retail costs and ensure economic viability, particularly in northern Canada and Russia. Some land areas become more accessible for mining as glaciers and ice caps recede.

Thawing permafrost is causing increased deformation of buildings, roads, runways and other man-made structures in some areas, although poor design in the past is a contributing factor. New design methods are being developed that consider the likelihood of environmental change. Buildings and other infrastructure are at risk from heavier snow loads and floods caused by the release of ice jams in rivers or sudden emptying of glacial lakes.

Two-thirds of the Arctic coastline is held together and protected by ice. When land-fast sea ice melts earlier and permafrost thaws, rapid erosion can occur. Along the coasts bordering the Laptev and Beaufort seas, coastal retreat rates of more than two metres per year have been recorded. A number of Inuit villages in Alaska are preparing to relocate in response to the encroaching sea.

In the short term, increased glacier melt creates new opportunities for hydroelectricity generation. This has potential benefits for industry. In the longer term, the volume of meltwater will decrease as glaciers shrink, potentially affecting electricity production.

Melting ice and snow release contaminants that have been stored for many years, allowing the contaminants to re-enter the environment. Exposure of people and top predators to contaminants that accumulate in food chains could further increase.

Increased access to the Arctic creates new economic opportunities. Cruise ship tourism is increasing. More people are coming to witness the effects of climate change on Arctic glaciers, for example at the Ilulissat Icefjord in Greenland. Increased tourism may challenge lifestyles and services in local communities as well as increase the demand for effective infrastructure (e.g., air services, marine navigation aids, and other safety measures). Loss of Arctic wildlife and change of scenery may adversely affect the tourist industry in the long term.

Cryospheric change combined with rapid development creates opportunities and challenges for Arctic residents. Traditional knowledge can help to detect change and adapt to it. While traditional knowledge continues to evolve, it is a challenge to ensure that this knowledge is being passed on to younger generations as lifestyles change. Some aspects of traditional knowledge become less applicable as the cryosphere and other components of the Arctic system change even more rapidly and become less predictable.

Changes in the cryosphere cause fundamental changes to the characteristics of Arctic ecosystems and in some cases loss of entire habitats. This has consequences for people who receive benefits from Arctic ecosystems.

Key finding 8

The observed and expected future changes to the Arctic cryosphere impact Arctic society on many levels. There are challenges, particularly for local communities and traditional ways of life. There are also new opportunities.

Key finding 9

Transport options and access to resources are radically changed by differences in the distribution and seasonal occurrence of snow, water, ice and permafrost in the Arctic. This affects both daily living and commercial activities.

Key finding 10

Arctic infrastructure faces increased risks of damage due to changes in the cryosphere, particularly the loss of permafrost and land-fast sea ice.

Key finding 11

WHY CHANGES IN THE ARCTIC MATTER GLOBALLY

Changes in the Arctic cryosphere have impacts on global climate and sea level

When highly reflective snow and ice surfaces melt away, they reveal darker land or ocean surfaces that absorb more of the sun's energy. The result is enhanced warming of the Earth's surface and the air above it. There is evidence that this is happening over the Arctic Ocean as the sea ice retreats, as well as on land as snow melts earlier.

Overall emissions of methane and carbon dioxide from the Arctic could increase due to warming of soils and freshwater systems, and thawing of ancient frozen soil beneath the seabed.

The combined outcome of these effects on global climate is not yet known.

All the main sources of freshwater entering the Arctic Ocean are increasing – river discharge, rain/snow, and melting glaciers, ice caps, and the Greenland Ice Sheet. Recent calculations estimate that an extra 7700 km^3 of freshwater – equivalent to one metre of water over the entire land surface of Australia – has been added to the Arctic Ocean in recent years. There is a risk that this could alter large-scale ocean currents that affect climate on a continental scale.

Melting glaciers and ice sheets worldwide have become the biggest contributor to global sea level rise. Arctic glaciers, ice caps, and the Greenland Ice Sheet contributed 1.3 mm – over 40% – of the total 3.1 mm global sea level rise observed every year between 2003 and 2008. These contributions from the Arctic to global sea level rise are much greater than previously measured.

High uncertainty surrounds estimates of future global sea level. Latest models predict a rise of 0.9 to 1.6 m above the 1990 level by 2100, with Arctic ice making a significant contribution.

Changes in the Arctic cryosphere affect global society

Sea level rise is one of the most serious societal impacts of cryospheric change. Higher average sea level and more damaging storm surges will directly affect millions of people in low-lying coastal flood plains. Sea level rise increases the risk of inundation in coastal cities such as Shanghai and New York.

On the other hand, global economic activity may benefit from cryospheric changes in the Arctic. For example, opening transpolar sea routes across the Arctic Ocean will reduce the distance for ships travelling between Europe and the Pacific by 40% compared to current routes. This could reduce emissions and energy use.

Some unique Arctic species, such as the narwhal, face particular threats as the cryosphere changes. The decline of cryospheric habitats such as sea ice and wetlands over permafrost will impact on migratory species of mammals and birds from elsewhere in the world. These adverse effects on biodiversity are of global concern.

Loss of ice and snow in the Arctic enhances climate warming by increasing absorption of the sun's energy at the surface of the planet. It could also dramatically increase emissions of carbon dioxide and methane and change large-scale ocean currents. The combined outcome of these effects is not yet known.

Key finding 12

Arctic glaciers, ice caps and the Greenland Ice Sheet contributed over 40% of the global sea level rise of around 3 mm per year observed between 2003 and 2008. In the future, global sea level is projected to rise by 0.9–1.6 m by 2100 and Arctic ice loss will make a substantial contribution to this.

Key finding 13

WHAT SHOULD BE DONE

Everyone who lives, works or does business in the Arctic will need to adapt to changes in the cryosphere. Adaptation also requires leadership from governments and international bodies, and increased investment in infrastructure.

Key finding 14

There remains a great deal of uncertainty about how fast the Arctic cryosphere will change in the future and what the ultimate impacts of the changes will be. Interactions ('feedbacks') between elements of the cryosphere and climate system are particularly uncertain. Concerted monitoring and research is needed to reduce this uncertainty.

Key finding 15

Adaptation is urgent and needed at all levels

Cryospheric change affects people at the local level first, and local communities will need to devise strategies to cope with emerging risks.

At national and regional levels, adaptation requires leadership from governments and international bodies to establish new laws and regulations. For example, new fishing regulations will be required as fish stocks change. New standards will need to be developed for construction, particularly in areas affected by thawing permafrost.

Governments will need to invest in transport networks to cope with the shorter ice road season. Search and rescue operations will need to be enhanced to respond to increasing traffic and risks at sea, and accurate forecasts of weather and sea conditions are required to ensure travel safety.

Arctic communities are resilient and will actively respond to cryospheric change. However, rapid rates of change may outpace adaptation capacity. Knowledge and research are needed to foresee how living conditions are likely to change, and to evaluate possible adaptation options. Concerns of indigenous peoples need particular attention in this regard.

Changes in the cryosphere are not the only driver of change in the Arctic. Cryospheric change and climate change occur in the context of societal change, which may be even more challenging. The combined effects of societal, climatic and cryospheric change must be taken into account in adaptation strategies.

Cutting greenhouse gas emissions globally is urgent

Climate change represents an urgent and potentially irreversible threat to human societies. Global climate modeling studies show that deep and immediate cuts in global greenhouse gas emissions are required to hold the increase in global average temperatures below 2 °C above pre-industrial levels. Combating human-induced climate change is an urgent common challenge for the international community, requiring immediate global action and international commitment.

Following the ACIA report, published in 2005, Ministers of the Arctic Council acknowledged that *"timely, measured and concerted action is needed to address global emissions."* They endorsed a number of policy recommendations for reducing greenhouse gas emissions, including to *"Adopt ... strategies ...* [to] *address net greenhouse gas emissions and limit them in the long term to levels consistent with the ultimate objective of the UNFCCC* [United Nations Framework Convention on Climate Change]."

The key findings of the SWIPA assessment, especially the rapid and accelerated rates of change in Arctic cryosphere conditions, emphasize the need for greater urgency in taking these actions.

Uncertainty can be reduced by further research

Current monitoring, research and model results provide high confidence that significant changes are occurring in the Arctic cryosphere and that these changes will continue in the future. Some of the observed changes align with expectations but one major component of the cryosphere (sea ice) has reacted faster than anticipated just five years ago. Even so, substantial uncertainty remains, particularly concerning the future timing of

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changes, and the effects of interactions (feedbacks) between components of the cryosphere and climate system.

To reduce the uncertainty in future assessments, more robust observational networks are needed. Satellites and airborne measurements have improved the ability to observe some elements of the Arctic cryosphere such as sea-ice extent and snow cover. Monitoring of other key elements of the cryosphere, notably sea-ice thickness, snow depth, permafrost and glaciers, requires surface-based observations.

Many surface-based snow, freshwater ice, and precipitation gauge networks have diminished or have been completely lost, and sites for measuring sea ice, land ice, and physical properties of snow are sparse. Observational networks need to be expanded to provide a robust set of cryospheric data for monitoring, model improvement and satellite product validation.

The biggest unanswered questions identified by this report are:

- What will happen to the Arctic Ocean and its ecosystems as freshwater is added by melting ice and increased river flow?
- How quickly could the Greenland Ice Sheet melt?
- How will changes in the Arctic cryosphere affect the global climate?
- How will the changes affect Arctic societies and economies?

Answering some of these questions requires improved monitoring networks. A better understanding of the complex interactions between the physical, chemical and biological environments in the Arctic is needed. There is a lack of systematically collected information on the effects of cryospheric change on human society.

Communicating about cryospheric change and its effects

The SWIPA assessment documents the importance of climate-induced changes in Arctic snow, water and ice conditions and the profound implications for the local, regional, and global society.

Active communication of this new knowledge, to enhance global, national, and local awareness, will help to ensure that the SWIPA assessment generates benefits for people in the Arctic.

A co-ordinated response to cryospheric change

The combined effects of the changing cryosphere, climate change, and rapid development in the Arctic will create political challenges for Arctic societies, as well as the global community. Traditional livelihoods are most vulnerable to changes in the cryosphere. There is a need for co-operation and co-ordinated effort at all levels, to respond to change and increase the resilience of Arctic ecosystems and societies.

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This document presents the Executive Summary of the 2011 SWIPA Assessment. More detailed information on the results of the SWIPA Assessment can be found in the SWIPA Scientific Assessment Report and related SWIPA Overview Report that are currently being prepared for publication. For more information contact the AMAP Secretariat.

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