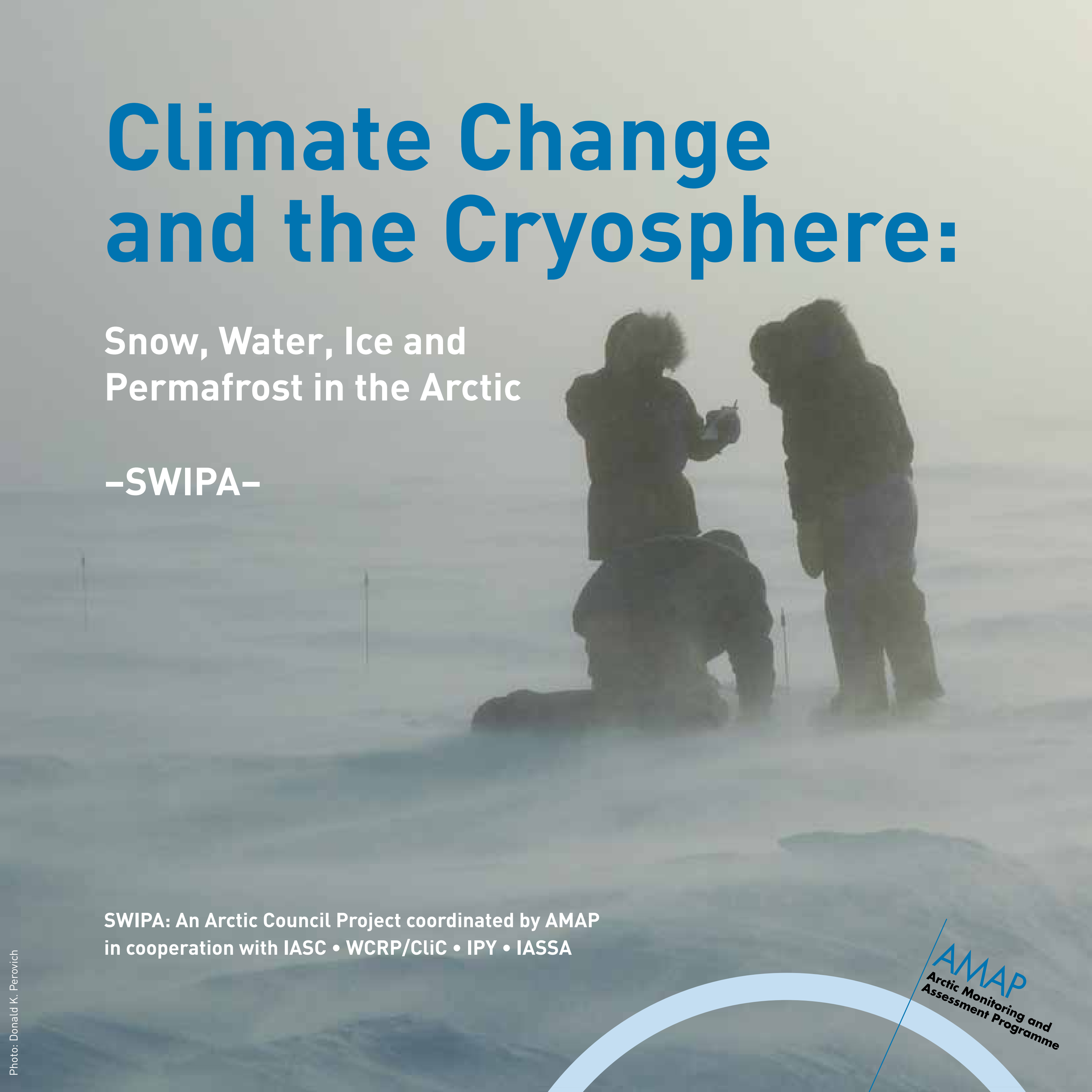


Climate Change and the Cryosphere:

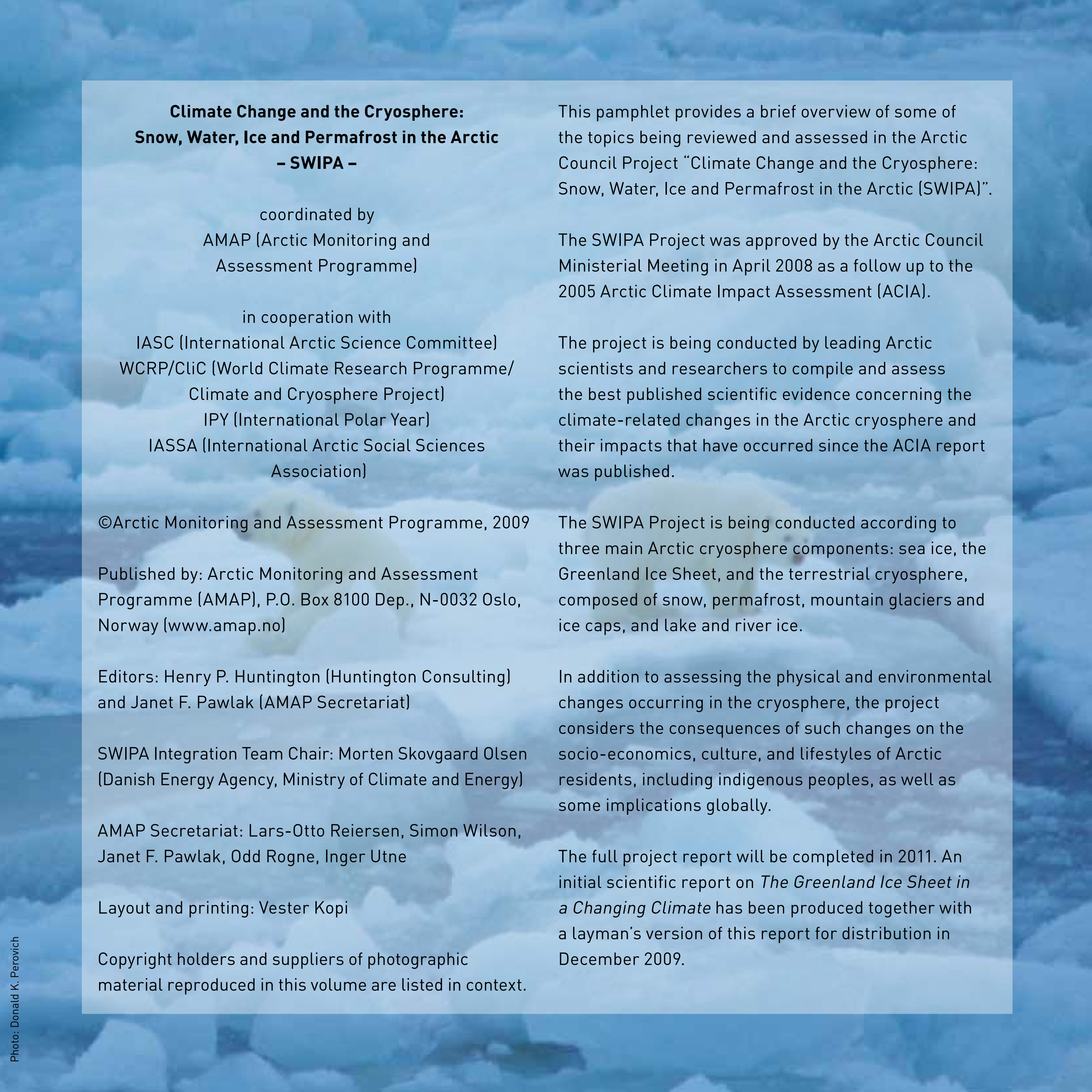
Snow, Water, Ice and Permafrost in the Arctic

–SWIPA–

SWIPA: An Arctic Council Project coordinated by AMAP in cooperation with IASC • WCRP/CliC • IPY • IASSA

Photo: Donald K. Perovich

AMAP
Arctic Monitoring and Assessment Programme



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This pamphlet provides a brief overview of some of the topics being reviewed and assessed in the Arctic Council Project "Climate Change and the Cryosphere: Snow, Water, Ice and Permafrost in the Arctic (SWIPA)".

The SWIPA Project was approved by the Arctic Council Ministerial Meeting in April 2008 as a follow up to the 2005 Arctic Climate Impact Assessment (ACIA).

The project is being conducted by leading Arctic scientists and researchers to compile and assess the best published scientific evidence concerning the climate-related changes in the Arctic cryosphere and their impacts that have occurred since the ACIA report was published.

The SWIPA Project is being conducted according to three main Arctic cryosphere components: sea ice, the Greenland Ice Sheet, and the terrestrial cryosphere, composed of snow, permafrost, mountain glaciers and ice caps, and lake and river ice.

In addition to assessing the physical and environmental changes occurring in the cryosphere, the project considers the consequences of such changes on the socio-economics, culture, and lifestyles of Arctic residents, including indigenous peoples, as well as some implications globally.

The full project report will be completed in 2011. An initial scientific report on *The Greenland Ice Sheet in a Changing Climate* has been produced together with a layman's version of this report for distribution in December 2009.

CLIMATE CHANGE AND THE CRYOSPHERE: SNOW, WATER, ICE AND PERMAFROST IN THE ARCTIC

Photo: Henning Thing

The main dome at the NEEM research site on Greenland.

Photo: Henrik Egede Lassen

Ice flowing in a glacier on the Greenland Ice Sheet.

What is the cryosphere?

Snow, sea ice, river and lake ice, ice sheets and glaciers, permafrost—these are all components of the cryosphere, the world of frozen water which covers most areas of the Arctic.

What is happening in the cryosphere?

The Arctic cryosphere has changed dramatically during the past decade, with the retreat and thinning of sea ice, melting of the Greenland Ice Sheet and glaciers, thawing of permafrost, and less snow and ice. Although the natural variability of this complex system is large, the direction of change is clear and the rate of change has taken scientists by surprise.

Why is the cryosphere important?

The cryosphere has a major influence on the environment and living conditions in the Arctic and it has significant global implications. Arctic sea ice contributes to cooling the earth and helps drive global ocean circulation. It is an important habitat for polar bears, seals, and walruses. Coastal landfast ice protects coastlines from erosion and is a platform for indigenous hunters. The Greenland Ice Sheet contains about a tenth of the world's freshwater. Snow, freshwater ice, and permafrost shape landscapes, river flows, biology, and infrastructure development throughout the Arctic.

What is SWIPA all about?

The SWIPA project is bringing together Arctic scientists to compile and evaluate information from Arctic monitoring networks and recent international research activities, such as those carried out during the 2007-2008 International Polar Year (IPY), to better quantify and understand the recent changes to the cryosphere. The implications of these changes for people, in the Arctic and globally, are a key part of the study and are also being assessed.

The final SWIPA report will be delivered to the Arctic Council in the spring of 2011. A preliminary report on the Greenland Ice Sheet in a Changing Climate, one component of SWIPA, is being delivered to the Fifteenth Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) in December 2009.

RETREATING ARCTIC SEA ICE IS HAVING MAJOR ENVIRONMENTAL CONSEQUENCES

The extent of Arctic sea ice has decreased during the past thirty years. The past five years have seen the five lowest ice extents recorded during September, when sea ice is at its annual minimum. The loss of sea ice creates a positive feedback to warming, because the open water absorbs far more sunlight and heat than ice and snow.

The ice cover has also become thinner and younger, with a decreasing area of multi-year ice. These changes leave it more vulnerable during coming summers, setting the stage for further rapid retreat.

Sea ice is an essential habitat for animals such as polar bears and walruses. Reduced sea ice threatens both the food web that supports these species and the ice habitat in which they live for most of the year. Altered sea-ice characteristics will affect other parts of Arctic ecosystems including, e.g., the productivity of organisms living on, in, and associated with the ice.

The retreat of Arctic sea ice has increased coastal erosion, but also improved access to Arctic resources, and increased traffic on major shipping routes through and within the Arctic. The first transit of the Northeast Passage by commercial ships without icebreaker support occurred in the summer of 2009.

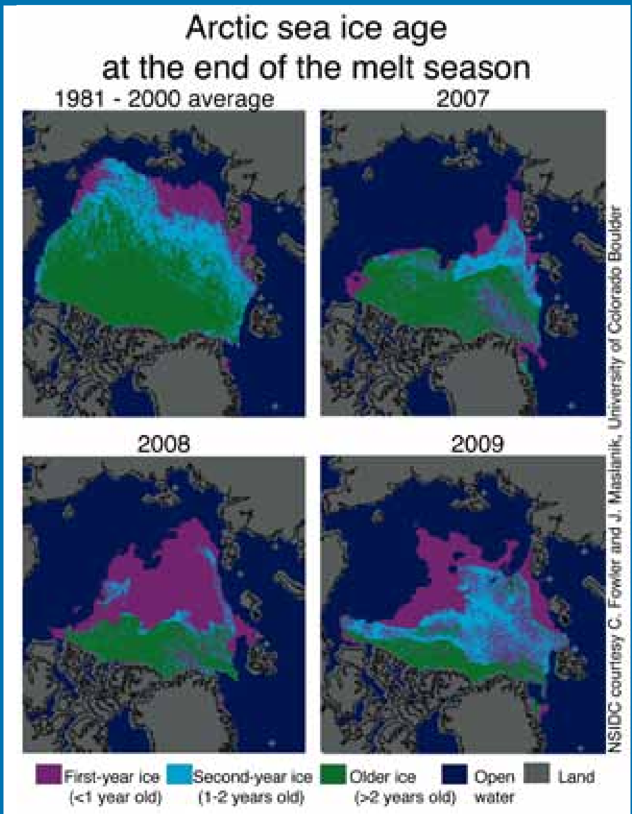
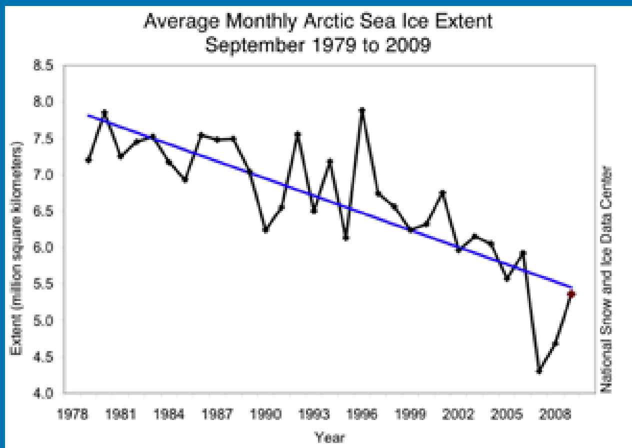


Photo: B&C Alexander / ArcticPhoto

Polar bear on thin ice distributing his weight, Cape Churchill, Canada.



THE GREENLAND ICE SHEET IS MELTING MORE RAPIDLY

The Greenland Ice Sheet is the second largest ice sheet in the world, after the East Antarctic Ice Sheet, and the largest body of ice in the Northern Hemisphere. It contains about 3 million km^3 of ice. If it were to melt completely, a process that climate models suggest would take more than 3000 years, global sea level would rise by almost 7 m.

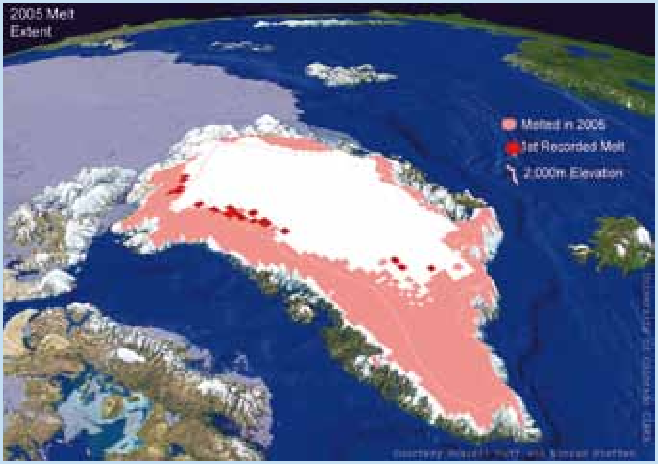
With warmer temperatures over the past few decades, there has been an increased melting of the ice sheet and discharging of icebergs along the coast. In recent years, the Ice Sheet has lost around 160 km^3 of ice each year to the sea; this dramatic loss of ice has surprised scientists who are studying the Ice Sheet.

The melting Greenland Ice Sheet sends massive quantities of freshwater into the sea around Greenland. This will affect marine ecology in the area and global ocean circulation patterns. It is already clear that this melting is contributing to the global rise in sea level. By the end of this century, recent projections indicate that water from the Greenland Ice Sheet and other sources, plus thermal expansion due to ocean warming, may result in a sea level rise of around 1 m.

The first results from this part of the SWIPA project are available in the report: *The Greenland Ice Sheet in a Changing Climate.*

Photo: Henrik Egede Lassen

Ice-dammed melt-water lake on Greenland after draining.



Extent of surface melt on the Greenland Ice Sheet in 2005, as shown in red.

PERMAFROST IS THAWING AND MAY LEAD TO MAJOR GREENHOUSE GAS RELEASES

Permafrost—ground that remains below freezing for at least two consecutive years—is found throughout the Arctic and in vast areas of Asia as far south as the Tibetan Plateau. Permafrost has warmed in many areas in the last two to three decades. This warming has resulted in the loss of permafrost along the margins of the permafrost zone.

Thawing of permafrost can lead to waterlogged soils and slumping of land. In mountain areas, thawing ground can cause landslides. Along coastlines, the loss of permafrost can result in more rapid erosion. Some lakes are held in place by permafrost and can drain if the ground thaws. These changes in terrain are followed by major changes in the vegetation of the affected areas.

Much Arctic infrastructure, including buildings, roads, and pipelines, is built on permafrost. Changes in permafrost and associated land subsidence can cause considerable and costly damage to infrastructure, and thus major problems for Arctic residents and businesses.

At the global scale, thawing permafrost may create an enormous positive feedback to climate warming. Huge quantities of carbon, released largely in the form of methane—a potent greenhouse gas—are locked in the ground within permafrost, and massive amounts of methane are trapped within permafrost below the seabed of the Arctic continental shelves. Studies suggest that if even 1% of this methane is released, it could trigger abrupt worldwide climate change.

Photo: Trofim Mamimov.

"Drunken forest" occurs when the ground becomes unstable due to permafrost thawing.

Photo: Steven Kazlowski/Science Faction/Corbis

Tundra polygons in Alaska held in place by permafrost.

Photo: Joe McDonald/CORBIS

Telephone poles set in tripods for support in the permafrost region of Churchill, Manitoba, Canada.

SNOW COVER IS DECREASING, AFFECTING OTHER PARTS OF THE CRYOSPHERE AND ENVIRONMENT

Snow cover is a defining characteristic of the Arctic environment, covering the landscape for 8 to 10 months of the year. Although there are regional differences, there has been an overall decrease in Arctic snow cover during the past 30 years and the spring melt is coming earlier and earlier.

Snow cover reflects the majority of the sunlight falling on it back into space, helping keep the planet cool. When snow is absent, much more sunlight is absorbed, leading to further warming. Small particles of soot absorb sunlight and cause snow to melt much more quickly, especially in spring. Burning of fuels and other materials produces soot, which can be carried in the air from locations far to the south before settling onto snow. Even low concentrations of soot can have a major effect.

Snow protects vegetation from harsh winter conditions, but snow quality has been changing. There has been an increase in rain-on-snow and mid-winter thaw events that can be devastating for plants, which may be coated in ice or exposed to harsh temperatures after a thaw. Animals may lose lairs in the snow or may not be able to break through a layer of ice to reach food.

The flow of northern rivers is intimately connected with the amount of snow and the timing of the melt. Changes in these patterns will affect fish, hydro-electric power, and the overall hydrology of the region.

Because snow insulates the ground from low air temperatures, reduced snow in mid-winter may actually help keep permafrost intact in some areas.

Snow affects Arctic residents directly in many ways and also indirectly through its impacts on wildlife, fish, and the landscape. Some changes may be beneficial. For example, a shorter snow season will reduce costs such as highway maintenance during winter. Other changes, such as loss of recreational opportunities and tourism potential, may harm northern communities.

Photo: Henrik Egede Lassen

Soot and other particles on snow on the Greenland Ice Sheet.

Photo: B&C Alexander / ArcticPhoto

Reindeer digging to reach lichen at its winter pastures in Yamal, Siberia, Russia.

MOUNTAIN GLACIERS AND ICE CAPS ARE SHRINKING

Small ice caps and mountain glaciers in the Arctic cover an area of over 400,000 km^2, accounting for 55% of the world's total land ice area outside the Greenland and Antarctic ice sheets. The shrinking of mountain glaciers and ice caps worldwide is currently the largest single land ice contributor to global sea level rise. The largest regional contributor is the Arctic, including Alaska.

Reductions in glacier-covered areas are widespread across the Arctic and the rates of retreat have increased over the past 15 to 20 years. In Russia, for example, mountain glaciers have lost from 17% to 50% of their surface area during the past five or six decades.

Icebergs calved from Arctic glaciers can be a serious hazard to marine navigation and to offshore oil and gas activities in areas such as the Barents Sea. The collapse of floating ice shelves in northern Ellesmere Island has destroyed unique ecosystems in melt ponds on top of the shelves. It has also produced large ice islands that could drift into the Beaufort Sea, where oil and gas exploration is active.

The loss of glaciers can affect hydroelectric power production, as river flow changes. Glaciers are also a major attraction for many tourists to northern regions, and their loss may reduce the number of visitors to areas with popular glaciers.

Muir and Riggs Glaciers

Photos: 1941 William O. Field; 2004 Bruce F. Molnia (USGS). Both photos courtesy of NSIDC

Retreat of the Muir Glacier in Alaska from 1941 to 2004.

Photo: Maria Ananicheva

Glacier 32 (right) of the Northern Massif of Suntar-Khayata, Russia.

Columbia Glacier, Alaska, in retreat, August 2009.

Photo: W. Tad Pfeffer

LAKES AND RIVERS ARE MELTING EARLIER IN SPRING

Freshwater ice on lakes and rivers is a dominant feature of the Arctic, where lakes are covered by ice for 6 to 12 months each year. Climate change is resulting in earlier dates of ice break-up. Lakes in the northernmost High Arctic are becoming ice-free in summer for the first time, with wide-ranging influence on their ecological properties.

In many areas of the Arctic, lakes or large rivers cover a considerable part of the landscape. A significant shortening of the duration of ice coverage can have profound impacts on local, regional, and even larger-scale climate over the Arctic. For example, shorter durations of ice cover will affect the amount of evaporation from lakes and thus rainfall patterns.

Throughout the Arctic, communities and various types of infrastructure are linked in winter by a network of roads built over frozen lakes and rivers. A shorter ice season will greatly reduce the viability of ice roads and thus transportation options in many areas of the Arctic.

During spring break-up, river ice can form jams which block the river, leading to floods. These can affect hydroelectric dams as well as riverbank communities, which can be affected by both flooding and by rapid erosion of riverbanks.

Photo: B&C Alexander / ArcticPhoto

Aerial view of the Mackenzie River and Delta near Inuvik, NWT, Canada.

Photo: B&C Alexander / ArcticPhoto

On a winter road, a truck travels through water on the surface of the frozen Garmanda River, Evensk, Magadan Region, E. Siberia, Russia

Photo: Henning Thing

The spring melt can lead to rapid flows of water.

CRYOSPHERIC CHANGES INTERACT TO AFFECT HUMANS AND THE ENVIRONMENT

The changes in the cryosphere highlighted here interact in many ways. The interactions affect people in the Arctic and beyond, along with local, regional, and global environments. Understanding the results of these interactions is a major scientific challenge and a key SWIPA activity. Some of the many topics and questions under study in the SWIPA project are:

- How will the increased flow of freshwater from the melting of the Greenland Ice Sheet, and mountain glaciers and small ice caps in the Arctic influence ocean circulation, marine food webs, and the people who depend on them?
- What is the total effect of cryosphere changes on climate, through changes in reflection of solar energy, release of greenhouse gases, and other feedbacks?
- What additional monitoring and observations are needed around the Arctic to better track cryospheric change and its many implications?
- What will be the effects of cryospheric change on individuals, communities, and regions in the Arctic, and how will those effects vary by location and economic sector?
- What will be the effects for global society from rising sea level and increasing climate change resulting from a changing Arctic cryosphere?
- Given that many changes under way will not easily be halted or reversed, what adaptations are possible, in the Arctic and beyond?


Photo: Donald K. Perovich

Equipment being transported on sleds during a sea ice expedition.


Photo: Henning Thing

Research on the Greenland Ice Sheet demands heavy logistics.

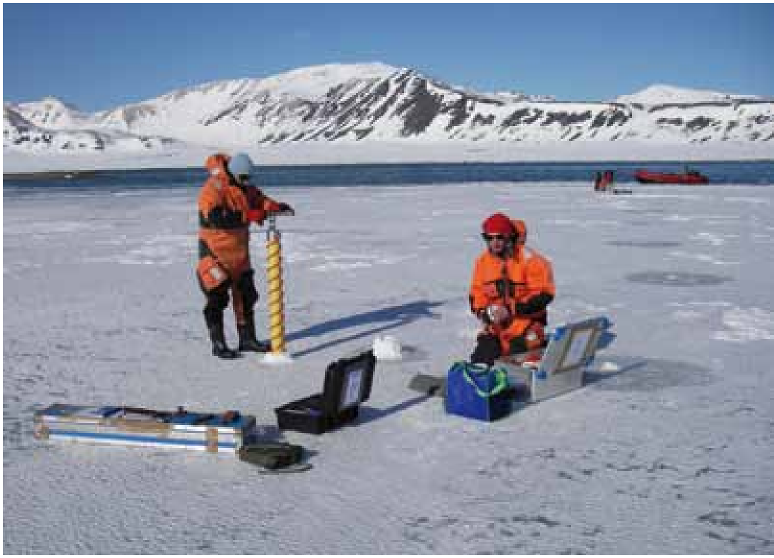


Photo: Sebastian Gerland

Sampling of fast ice in Krossfjorden, Svalbard, 2006.

ORGANIZATION OF THE SWIPA COMPONENTS (convening lead authors and countries)

Preface
Executive Summary/Key findings
Introduction

Modelling
Leads: John Walsh, James Overland (USA)
Vladimir Kattsov (Russia)

Component 1: Arctic sea ice in a changing climate
Leads: Sebastian Gerland (Norway)
Mats Granskog (Norway)
Kim Holmén (Norway)
Jeffrey R. Key, Walt Meier (USA)

Component 2: The Greenland Ice Sheet in a Changing Climate
Lead: Dorthe Dahl-Jensen (Denmark)

Component 3: The Terrestrial Cryosphere in a Changing Climate
Leads: Terry Prowse (Canada)
Terry Callaghan (Sweden)

Module 1: Changing snow cover and its impacts
Lead: Terry Callaghan (Sweden)
Margareta Johansson (Sweden)

Module 2: Changing permafrost characteristics, distribution and extent, and their impacts
Lead: Terry Callaghan (Sweden)
Margareta Johansson (Sweden)

Module 3: Mountain glaciers and ice caps
Leads: Maria Ananicheva (Russia)
Martin Sharp (Canada)
Edward Josberger (USA)
Jon-Ove Hagen (Norway)

Module 4: Changing river and lake ice, and their effects
Leads: Igor Shiklomanov (Russia)
Terry Prowse (Canada)

Integrated synthesis

Arctic water budget
Leads: Terry Prowse (Canada)
Igor Shiklomanov (Russia)

Cryo-interactions: antagonistic/synergistic effects of the various cryosphere components
Leads: Martin Sharp, Ross Brown (Canada)
Maria Ananicheva (Russia)

Feedbacks synthesis (Greenhouse gases; radiative forcing; thermohaline circulation)
Leads Terry Callaghan (Sweden)
Margareta Johansson (Sweden)
Jeff Key (USA)

Human dimensions of changes in the cryosphere
(Societal impacts; current and future adaptation)
Leads: Grete Hovelsrud (Norway)
Birger Poppel (Greenland)

Observations and long-term monitoring
Leads: Barry Goodison (WMO)
Jeff Key (USA)

Conclusions and recommendations

Sampling of seawater beneath thin fast ice in Kongsfjorden, Svalbard, in 2006. Photo: Sebastian Gerland

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