# SEARCH 5-Year Goals

# *Version: 28 Sept (includes revisions from community input)*

# Improve Understanding, Advance Prediction, and Explore Consequences of

# Changing Arctic Sea Ice

# *Draft webpage:* [*http://www.arcus.org/search/sea-ice*](http://www.arcus.org/search/sea-ice)

## Introduction

Arctic sea ice extent has been well below normal since 2007. Climate models suggest that this trend signifies a transition towards an Arctic Ocean with greatly diminished or absent summer ice cover by mid-century or earlier. Significant reduction in summer sea ice will have substantial repercussions, including extended open-water seasons fostering offshore resource development and increased maritime activity, changes in the behavior and health of marine mammals, and impacts on arctic and sub-arctic weather patterns. Predictions of sea ice changes will have large uncertainties without sustained observations; improved understanding of ice, ocean, land, and atmospheric processes; and advances in coupled and system models.

This goal addresses urgent and timely needs for improved sea ice information and will help resolve the following questions:

* Why the sea-ice is diminishing and what processes determine the rate of change?
* What are the linkages between a changing polar region and lower latitudes?
* When can a seasonally ice-free or greatly ice-diminished Arctic Ocean be expected?
* What are the most important impacts of sea ice loss on social-ecological systems?

The scientific and societal relevance of improved understanding and response to a changing arctic ice cover has been underscored by a variety of planning documents. In focusing a set of SEARCH activities on sea ice, we build on past interagency activities such as the SEARCH Sea Ice Outlook, as well as:

* NOAA's Arctic Vision and Strategy, which has improved sea-ice prediction at the top of its goals: [http://www.noaanews.noaa.gov/stories2010/20100519\_arctic.html](http://www.noaanews.noaa.gov/stories2010/20100519_arctic.html" \o "http://www.noaanews.noaa.gov/stories2010/20100519_arctic.html" \t "_blank)
* The National Ocean Policy strategy document that references the need to improve sea ice prediction and to assess its impacts on arctic ecosystems and human activities: [http://www.whitehouse.gov/administration/eop/oceans/implementationplan](http://www.whitehouse.gov/administration/eop/oceans/implementationplan" \o "http://www.whitehouse.gov/administration/eop/oceans/implementationplan" \t "_blank)
* The priorities set forth in the U.S. Arctic Research Commission's report on Goals and Objectives for Arctic Research: [http://www.arctic.gov/publications/2011-12\_usarc\_goals.html](http://www.arctic.gov/publications/2011-12_usarc_goals.html" \o "http://www.arctic.gov/publications/2011-12_usarc_goals.html" \t "_blank)
* The International Study of Arctic Change's (2010) recent science plan, which underscores the central role of sea ice in modulating arctic environmental and socio-economic change: [http://www.arcticchange.org/publications;](http://www.arcticchange.org/publications;" \o "http://www.arcticchange.org/publications;" \t "_blank)
* The 2009 National Presidential Directive on Arctic Region Policy: [http://www.fas.org/irp/offdocs/nspd/nspd-66.htm;](http://www.fas.org/irp/offdocs/nspd/nspd-66.htm;" \o "http://www.fas.org/irp/offdocs/nspd/nspd-66.htm;" \t "_blank) and
* The IARPC 5-year plan that defines interagency efforts related to sea ice research and forecasting: [http://www.nsf.gov/od/opp/arctic/iarpc/arc\_res\_plan\_index.jsp](http://www.nsf.gov/od/opp/arctic/iarpc/arc_res_plan_index.jsp" \o "http://www.nsf.gov/od/opp/arctic/iarpc/arc_res_plan_index.jsp" \t "_blank)

In keeping with the SEARCH vision and mission, the objectives listed below focus on areas where interagency approaches will improve understanding and prediction of arctic sea-ice change and its consequences.

## Objectives (5-year time frame)

### 1. Improve the understanding of atmosphere, sea-ice, and ocean system interactions through a combination of enhanced observations and process-based modeling studies

1.1. Develop suitable observational and modeling frameworks to identify and quantify the causes of sea ice variability and long-term decline.

1.2. Develop interagency and international support for year-round, coordinated atmosphere, sea-ice, and ocean observations in the sea-ice environment of the central Arctic Basin.

1.3. Identify and assess the impact of model uncertainties in key disciplinary and interdisciplinary processes on simulated intra- and inter-annual sea-ice variability. These processes include arctic clouds and their radiative impacts, sea-ice albedo changes, surface energy fluxes, vertical momentum transfer, and ocean vertical heat transport.

1.4. Develop and facilitate community efforts to incorporate advances made via observational and process-based modeling studies into larger-scale models.

### 2. Improve sea ice prediction from daily to decadal timescales

2.1. Develop interagency and international support for the [SEARCH Sea Ice Outlook](http://www.arcus.org/search/seaiceoutlook/index.php) to expand contributor base, incorporate and advocate for needed multi-disciplinary observations, conduct assessments of predictive success, improve forecasts through synthesis of methodologies, and develop additional products.

2.2. Define a cross-agency Arctic Observing Network (AON) implementation plan that identifies critical gaps, ensures optimal observation deployment, enhances understanding of sea-ice change, and facilitates sea ice predictions across time and space scales. Identify research gaps and needs, including multidisciplinary studies and the integration of observations and modeling perspectives to improve forecast products; work with agencies to implement activities to fill research gaps.

2.3. Develop interagency and international support for enhanced observations of the arctic atmosphere via buoys, soundings, etc. in order to constrain, evaluate, and improve operational model performance in the central Arctic.

2.4. Integrate AON sea-ice measurements into global observational networks and data assimilation efforts through national and international mechanisms, e.g., [SAON](http://www.arcticobserving.org" \t "_blank), [CliC Arctic Sea Ice Working Group](http://www.climate-cryosphere.org/activities/working-groups-and-panels/clic-arctic-sea-ice-working-group.html" \t "_blank), an Arctic Observing Summit.

2.5. Contribute to national and international activities on sea ice forecasting and science needs (e.g., [NAS 2012](http://dels.nationalacademies.org/Study-In-Progress/Future-Arctic/DELS-PRB-10-03" \t "_blank)).

2.6. Assess the present and evolving state of the ice cover, examine overall predictability of the sea ice system, and improve and evaluate predictive methods and success across timescales. Develop cross-disciplinary scenarios to explore trajectories towards a seasonally ice-free Arctic Ocean.

2.7. Support a sea ice forecasting "Community of Practice" that addresses all forecast scales.

### 3. Explore the breadth of consequences of a seasonally ice-free Arctic Ocean across human and natural systems.

3.1. Develop the capability to link sea ice prediction products to measures of change in marine ecosystems and impacts on arctic communities across temporal and spatial scales—from local to regional to basin scales.

3.2. Build on the [Sea Ice for Walrus Outlook](http://www.arcus.org/search/siwo) to determine specific information needs of stakeholders and modify standard ice prediction products where possible to address these needs.

3.3. Prioritize observational sites for investigating linkages between sea ice, marine ecosystems, and impacts.

3.4. Develop suitable measures of marine ecosystem change; identify at-risk infrastructures and ecosystem services.

3.5. Advance research on the interactions between arctic sea ice and societal aspects, such as energy and large-scale resource development, transportation, territorial issues, and impacts on ecosystems and living conditions of arctic residents.

### 4. Assess how arctic sea-ice changes interact with mid-latitude weather and climate

4.1. Identify the impacts of a changing climate on sea ice loss; sea ice loss on patterns of atmospheric circulation and precipitation; oceanic circulation both within and beyond the Arctic, including the meridional overturning circulation in the Atlantic Ocean; and weather patterns in middle latitudes.

4.2. Communicate the importance of uncertainties and potential surprises and develop a probabilistic framework for use by decision-makers.

4.3. Advance research on the interactions between arctic sea ice and global physical systems such snow cover extent, ocean and atmospheric circulation patterns, and mid-latitude effects.

**Document and Understand How Degradation of Near-Surface Permafrost Will Affect Arctic and Global Systems**

## *Draft webpage:* [*http://www.arcus.org/search/permafrost*](http://www.arcus.org/search/permafrost)

## Introduction

The arctic landscape is changing in response to climate warming. Essential characteristics of the arctic landscape are controlled by its unique climate and by the presence of permafrost. Relatively rapid degradation of near-surface, ice-rich permafrost caused by climate change is adversely affecting human infrastructure, altering arctic ecosystem structure and function, changing the surface energy balance, and has the potential to dramatically impact arctic hydrological process and increase greenhouse gas emissions. Therefore, it is imperative to address fundamental gaps in scientific knowledge of permafrost characteristics and dynamics to support planning, management, and climate policy efforts. Specifically there is an urgent need to assess the vulnerability of permafrost to thaw and to understand the local and global feedbacks when this happens. Substantial amounts of organic matter are frozen in near-surface permafrost. An unknown portion of this material will become available for microbial processing in the future, which may result in enhanced release of carbon dioxide, methane, and nitrous oxide. Greater release of these gases from sub-sea and terrestrial permafrost will likely create a positive feedback loop in which future climate warming causes further degradation of permafrost, which releases more greenhouse gases, leading to further warming and additional degradation of remaining permafrost. Such a feedback loop could result in accelerated warming throughout the globe, which will strongly impact ongoing climate mitigation efforts and climate adaptation planning. This feedback loop, and the potential damage and costs it could generate, highlights the strong global connections between lower latitudes and the Arctic. In particular, there is a growing realization that there are strong interactions between degradation of near-surface permafrost and dynamics of the Earth climate system and that these interactions may have substantial influences on global environmental, economic, and social systems. Critically important science and data gaps about the consequences of loss of near-surface permafrost are identified in the following objectives.

## Objectives (5-Year Timeframe)

### Science Objectives:

#### 1. Improve observation and prediction of the nature, timing, and location of permafrost thaw.

1.1. Identify indicators of change in the state of permafrost to serve as early warning signs for possible tipping points in the state of the arctic system.

1.2. Enhance existing efforts to create a comprehensive observing system to document changes in these critical indicators and to provide data for calibration and validation of models.

1.3. Determine which components of arctic landscapes are most sensitive to permafrost thaw and pose the greatest risks to human infrastructure and ecosystem services.

1.4. Develop models and probabilistic forecasting tools to quantify uncertainties in the timing and extent of permafrost thaw in the next few decades and centuries.

1.5. Characterize the extent and rates of degradation of sub-sea permafrost.

#### 2. Improve prediction of how degradation of near-surface permafrost will influence the dynamics of the arctic landscape.

2.1. Promote field and modeling efforts to predict how climate change and degradation of near-surface permafrost will alter the surface energy balance and hydrology in the Arctic at local to regional scales.

2.2. Refine estimates of the total mass, quality, and vulnerability of soil carbon by depth and region.

2.3. Identify the key variables that are likely to control the mobility and availability of carbon, nitrogen, and phosphorus from thawed permafrost and how these and other important biogeochemical materials will be processed by microbes and vegetation.

2.4. Encourage laboratory, field, and modeling efforts to estimate the amounts of critical greenhouse gases (CO2, CH4, and N2O) released to the atmosphere in the future as permafrost thaws.

#### 3. Improve prediction of how permafrost degradation will influence fish, wildlife, and human communities.

3.1. Determine how degradation of near-surface permafrost will affect soil stability, vegetation communities, and surface and subsurface hydrology.

3.2. Identify how these factors will influence habitat suitability and distribution and the sustainability of fish and wildlife populations.

3.3. Determine how ecosystem services that are critical to human existence in the Arctic will change. This goal ties directly to the "Society and Policy" goal.

3.4. Estimate the costs of mitigation or replacement of infrastructure that will be at risk from thawing permafrost.

### Coordination Objectives:

#### 4. Identify gaps in Arctic Observing Network datasets and the resources needed to fill those gaps.

4.1. Position SEARCH to coordinate observing efforts focused on permafrost dynamics, identify gaps, and encourage individual science projects to produce data that will complement the data collected by various data collection and observing networks.

4.2. Help coordinate the exchange of data necessary for modeling studies; review how model predictions identify new needs for data from observing or data collection networks.

#### 5. Identify partners who can facilitate progress on the science objectives for the SEARCH permafrost goal.

5.1. Prioritize knowledge required to support our understanding of how changing permafrost affects the arctic landscape.

5.2. Work with federal agencies that have made substantial investments in research on permafrost that directly or indirectly supports SEARCH objectives. **For example:**

1. [NASA's Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE)](http://science.jpl.nasa.gov/projects/CARVE/" \t "_blank) and [Arctic-Boreal Vulnerability Experiment (ABoVE)](http://cce.nasa.gov/terrestrial_ecology/scoping.html" \l "above" \t "_blank) have objectives that parallel many of SEARCH's objectives. In addition, NASA maintains numerous sensors on different platforms that can add substantial value to projects supported by partnering programs.
2. DOE's [Next Generation Ecosystem Experiment (NGEE)](http://ngee.ornl.gov/" \t "_blank) has programmatic objectives that directly address several SEARCH science objectives.
3. The [Arctic Landscape Conservation Cooperative (LCC)](http://arcticlcc.org/" \t "_blank) initiative is currently supporting projects that will make existing information more readily available to the science and management community.
4. NSF's [Office of Polar Programs](http://www.nsf.gov/dir/index.jsp?org=OPP" \t "_blank) provides essential support for long-term observation of and basic research on permafrost.
5. [USGS](http://www.usgs.gov/" \t "_blank) supports permafrost borehole and soil climate change programs.
6. The NPS has invested substantial funding in [Inventory and Monitoring programs](http://science.nature.nps.gov/im/" \t "_blank)within the Arctic Parks system, which cover a substantial portion of the Alaskan Arctic region.

5.3. Explore whether industry partners would be willing to share proprietary data that could help fill gaps about the spatial (and perhaps temporal) distribution of permafrost characteristics.

### Stakeholder Objectives:

#### 6. Improve delivery of information and knowledge about change in the arctic landscape to stakeholders.

6.1. Ensure a steady flow of information about the status and findings of permafrost-related science efforts.

6.2. Develop effective means to communicate findings and progress in ways that appeal and are useful to the public and to non-­‐technical decision makers.

#### 7. Create opportunities to receive feedback about permafrost degradation from stakeholders.

7.1. Identify opportunities and mechanisms to ingest experience and knowledge that could help achieve the Science Objectives.

# Improve Predictions of Future Land-ice Loss and Impacts on Sea Level

# *Draft webpage: http://www.arcus.org/search/land-ice*

## Introduction

Land ice loss—especially from northern hemisphere glaciers and the Greenland ice sheet—now exceeds thermal expansion in its contribution to rising sea level. While the loss of glacier mass has continued for the past few decades with a slight increase in recent years, the rate of mass loss from the Greenland ice sheet has dramatically increased in the past decade and continues to increase. These rapid changes are the result of increased discharge from grounded ice into the ocean and from increased ice melting, which more than outweigh increases in surface accumulation. In light of these observational facts, it is unsettling that neither quantitative prediction of future land ice loss nor credible estimation of an upper bound of future sea level are possible (IPCC, 2007). Correcting this situation requires a predictive understanding of the processes responsible for land ice loss.

Greenland contains enough ice to raise sea level an average of 6.5 meters. Glaciers and ice caps, occurring mostly in the Arctic, could contribute an additional 0.35 meters. Roughly one third of people live at or near the coast and will be directly affected by rising sea level. The direct impacts of a one-meter sea level rise include the displacement of over 100 million people, loss of nearly one trillion dollars in global gross domestic product (GDP), and the flooding of 2.2 million km2 (Anthoff et al., 2006). Effective mitigation or adaptation strategies to respond to higher future sea level require credible and accurate projections of future land ice loss.

## Objectives (5-year time frame)

### 1. Determine the impact of ocean waters on tidewater and outlet glaciers

Observations of the spatial patterns and magnitudes of land-ice loss indicate the dominant role that ocean heat has in forcing increased ice discharge. Process studies that include circulation of the water near the ice, rapid melting of floating glacier tongues, calving at the glacier terminus, and the glacier's response (terminus position and changing elevation and velocity field) as these changes propagate inland are at an early stage.

1.1. Collect bathymetric data proximal and sub-glacially on a number (5-10) of large and/or recently responsive tidewater glaciers, including ice sheet outlet glaciers.

1.2. Develop, adapt, and deploy oceanographic instrumentation to monitor water properties in the vicinity of active tidewater glaciers. Link oceanographic measurements with simultaneous measurements of ice flow and calving.

1.3. Monitor glacier elevation and velocity to quantify the strength and extent of glacier response to oceanic changes.

1.4. Expand modeling efforts to simulate the intense interactive processes at play between ocean and ice in narrow fjords.

1.5. Through a combination of existing observations and new models, link oceanographic circulation on continental shelves (extending into the fjord environments) with oceanographic conditions in the deeper ocean and atmospheric patterns.

### 2. Determine the processes controlling the intra-annual and inter-annual variability of land ice discharge

It has recently been discovered that meltwater formed at the surface of an ice sheet can cause a large and sudden increase in ice flow speed. More generally, the dynamic interaction of subglacial water flow with the overlying ice leads to multiple processes that either increase ice flow through lowered basal friction, or decrease ice flow through enlarged subglacial channels that lower effective pressures. A new functional relationship between the forcing effect of surface meltwater and ice flow must be determined based on extensive field observations to properly incorporate this effect in predictive models of future ice sheet behavior. Basal resistance can vary for non-hydrologic reasons such as deformation and sedimentation of subglacial material, yet the impact on glacier flow speed is very poorly understood. For the narrower outlet glaciers, or those with extremely low basal shear stresses, the lateral resistance of slower moving ice adjacent to the glacier can dominate the glacier's flow speed.

2.1. Collect and analyze new data on surface melt fluxes; the propagation and development of surface, englacial, and subglacial hydrologic networks; and the corresponding three-dimensional ice motions over multiple seasons and years. Projections of surface melt can then be extended to estimates of changing ice discharge.

2.2. Explore the subglacial environment, for example with advanced ice-penetrating radar systems, to assess resistive stresses that modulate ice flow rates.

2.3. Monitor deformation and thermal conditions within glacier marginal areas over seasonal and interannual time scales to quantify the sensitivity of outlet glacier discharge to changes in the glacier margins.

### 3. Improve predictions of pan-arctic surface precipitation and methods to accurately downscale precipitation patterns to the glacier basin scale

Precipitation and melting are major components of determining the overall growth or loss of land ice. Nearly half of the ice loss experienced by the Greenland ice sheet during the past 50 years is attributed to changes in its surface mass balance (sum of all accumulation effects minus all ablative effects). Meteorological modeling of precipitation patterns over the large ice sheet are robust in the relatively broad, featureless interior (for example, with Regional Atmospheric Climate Model (RACMO), but are more difficult at the mountainous coast and very poor in the alpine regions occupied by much of the remaining arctic land ice. Global circulation models provide the best predictions of future precipitation magnitude and distribution but lack spatial detail. Downscaling general circulation model/global climate model (GCM) output, or even output from regional climate models, such as RACMO, to account for the influences of local orography is poorly developed and must be improved. This is a relatively specialized area of climate modeling, but requires attention before it becomes the limiting uncertainty in projections of future land ice loss.

3.1. Meteorological modeling of alpine environments should be expanded to include the various components of glacier accumulation and ablation.

3.2. Test areas where densely sampled data in both space and time exist should be incorporated into meteorological models at both the local scale (0.1–1 km) and meso-scale (10–100km) to investigate accurate downscaling strategies.

### 4. Quantify the regional pattern of relative sea-­‐level change driven by the predicted pattern of land ice loss

The magnitude of future sea level is usually stated as a globally averaged value. Regional changes in sea level can vary up to many tens of percent from the global mean, depending on how additional water from lost land ice and thermal expansion of the upper mixed layer of the ocean are distributed by ocean currents and the changes in the gravity field resulting from changes in mass redistribution (Mitrovica et al., 2001). Because much of the expected land ice loss is sourced in various locations distributed across the Arctic, the variability of sea level change is expected to be particularly large in the Arctic.

4.1. Global gravity models should be employed to explore the possible patterns of isostatic (i.e., local) sea level change. Recent observations of ice mass loss can be extrapolated to future decades. Along with predictions of possible future land ice loss, these future patterns provide a rich sample space within which ranges of possible and likely sea level change across all arctic coastlines.

4.2. The ever-increasing set of observations of local sea level can be compared with predictions based on the observed pattern of land ice loss to improve the veracity of gravity models.

# Analyze Societal and Policy Implications of Arctic Environmental Change

*Draft webpage:* [*http://www.arcus.org/search/society*](http://www.arcus.org/search/society)

## Introduction

Against the backdrop of rapidly changing arctic environments, it is critical to understand how people living in the Arctic perceive, understand, and respond to those changes. It is also imperative to understand how arctic change is perceived outside the Arctic, including how these perceptions—accurate or not—influence the development of policy. Because the Arctic varies dramatically across time and space, across ecosystems and cultures, collaboration with local communities in the investigation, analysis, and communication of studies is central for the most comprehensive understanding on local, regional, national, and global levels. Furthermore, since human perceptions and responses are shaped largely by cultural norms and other social and economic forces, they are most appropriately studied through social research. For example, as Arctic societies perceive, anticipate, and respond to arctic change, their active role complicates modeled and other natural science prediction. Therefore, to address human responses to arctic change both within Arctic societies, and in the more distant but also critically involved society outside the Arctic, this goal requires strong links with social science.

## Objectives (5‐Year Timeframe)

### 1. Understand Arctic inhabitants’ experiences and responses to environmental change, and develop methods to anticipate future adaptations.

1.1. Summarize findings to date on how Arctic communities, both urban and rural, are perceiving, understanding, responding, and adapting to arctic change.

1.2. Generate a comprehensive assessment of societal response based on that summary.

1.3. Develop community-relevant scenarios of sea ice loss, permafrost degradation, coastal erosion, and other environmental change that will affect communities into the future.

1.4. Develop methods to anticipate societal response, using empirically-¬‐based predictions and scenarios that address emerging challenges and planning needs, for example with respect to relocation of threatened communities, changes in transportation modes and routes, and access to and location of resources.

1.5. Test those methods by conducting cross-¬‐sectional and longitudinal studies of responses, policies, and unintended consequences of change (such as sea level and weather effects) to provide insights for near-¬‐future choices.

### 2. Assess and improve public and policy perceptions and knowledge about arctic environmental issues

2.1. Design and conduct rigorous studies of perceptions and knowledge about arctic environmental issues among the general public, Arctic residents, and other stakeholders.

2.2. Evaluate the progress to date, the gaps in and the successes and failures of, efforts to communicate and educate the broad public about arctic change.

2.3. Develop innovative ways to strengthen communication efforts especially through effective outreach and education approaches that build on the findings of this research.