Near-Surface Processes in the Arctic System
Prospectus of Science Priorities

Recent decades have brought about the transformation of the combined surfaces of the Arctic. Marine areas that were formerly covered by sea ice are now open water in summer, significantly altering albedo, surface temperature, and atmospheric moisture. In the terrestrial realm, the dynamics of thaw lakes have altered throughout Alaska and Siberia as near-surface permafrost thaws. Tall shrubs and trees are replacing low tundra vegetation throughout the low Arctic. An increasing proportion of the land surface is also being transformed by industrial development such as pipelines, roads and mines.

These changes are both a visible manifestation and potential driver of ongoing global change across a range of spatial and temporal scales. Many of the impacts of ongoing climate change on humans – both in and out of the Arctic – will be mediated by these changes in the near-surface environment. Despite their importance, the collective impacts and relative importance of different drivers of change remain poorly understood. *The central goal of the Near-Surface Processes Co-OP is to understand the cumulative and interactive effects of near-surface terrestrial and marine environmental transformations on the future state of the Arctic System.*

Overview of the Near-Surface Processes Co-OP

Our Community of Practice is an integrated group of natural, social, and physical scientists (see Appendix for current participants) organized around three fundamental questions related to earth surface change in the Arctic.

(1) What are the rates and trajectories of spatiotemporal changes in the near-surface environment on land and in the ocean?
(2) What are the relative roles of, and interactions among, climate and human activities in driving changes in the near-surface environment on land and in the ocean?
(3) How will cumulative changes and their resultant feedbacks affect human societies and their use of Arctic resources? How might changes in the land and ocean surface, individually and collectively, interact with other forces of global change to affect human populations and resource use in the Arctic?

We propose that there exist several avenues to achieve these goals, including integration and re-analysis of existing data, coupled regional and global modeling efforts, and integrated field research projects aimed at filling data gaps and furthering our understanding of the causes, consequences, and linkages among land and ocean surface change in the circumpolar Arctic. Projects advancing the goals of this Co-OP should seek to understand near-surface change at broad spatial and temporal scales, with clear plans to integrate across multiple scales. We emphasize that achieving a broad-scale understanding of surface change will require research at a range of spatial scales, from plot-level science to efforts that span the circum-arctic. As such there is a critical need for both in-situ and remote sensing observational efforts and regional and global modeling.

The science priorities described in this document build on past ARCSS-related research. However, our Co-OP has defined an approach that will push future Arctic System science in novel and productive directions, as follows:

1. **Transition zones paradigm**. Whereas prior ARCSS research efforts, such as LAII and OAII, emphasized the interactions between the various 'domains' of the Arctic system (e.g., land and atmosphere, land and cryosphere), we suggest that the Arctic System can also be understood as a set of interfaces, or transition zones, between domains. We are proposing a coordinated research effort aimed at understanding the near-surface environment, as the interface between sub-surface permafrost and land/ocean and atmosphere. We define the near-surface transition zone loosely as follows: on land it extends from deep within the permafrost up to the tropopause, and on ocean from depths of 200-500 m to the tropopause. Each of our four research priorities, listed below, represents a crucial aspect of the near-surface transition zone. This emphasis on transition zones (or interfaces) rather than traditional approaches focused on domains themselves allows us to investigate the part of the Arctic System that is undergoing the most visible and rapid change, while avoiding the simplifying assumptions that are an inherent part of 'domain-centered' research efforts.
2. **Physical–human dimensions**. Physical and social scientists, along with researchers from the humanities, are working together toward the goal of understanding the critical components of Arctic System change that have the potential to acutely and chronically affect human societies. These efforts are supplemented and enhanced by including indigenous knowledge holders as collaborators because this group has both a unique understanding of local processes, and is most directly impacted by change. The cross-cutting focus of our Co-OP on both human and non-human dimensions of near-surface change is an important advance from the disciplinary based structure of the 'old ARCSS'.
3. **Humans as drivers and responders**. The conceptual framework views humans as both drivers of and responders to change in the Arctic. Within this framework, human activities and infrastructure (and the policies that guide use and development) are incorporated as both drivers of and responses to change in continuous feedback loops operating at various spatiotemporal scales.

Near-surface change on the land and ocean has been our focus in developing this document. The science priorities that are described here are not intended to provide an all-inclusive and comprehensive list of variables, processes or questions that need to be understood within the Arctic system as a whole. We have confined our efforts to near-surface transition zones, as described in greater detail below. At the close of this document we have outlined a suggestion for connections that should be developed with other research groups in order to embed this effort in broader and ongoing research addressing other aspects of Arctic System change.

Research Priorities for Understanding Near-Surface Change

We focus on four critical components of near-surface change in the Arctic: changes in the ***dynamics of thaw lake*** formation, expansion, and drainage; changes in ***vegetation cover***; changes in the ***ice/ocean surface***; and the impact of ***industrial development*** and exploration. Each of these components has demonstrated significant recent change, has potential for continued rapid change, has strong feedbacks to the climate system, and has a large potential impact on human populations. A central component of our research is the coupling of the bio-physical and human elements of the Arctic system. In Figure 1, the bio-physical variables and sub-systems are highlighted by the light blue rectangle; human social and economic sub-systems are highlighted by the pale yellow oval. Human interactions with the bio-physical sub-systems primarily take the form of subsistence activities (which both affect and respond to ecosystem food web dynamics) and industrial development (including preliminary phases of development, such as exploration, which may have little direct effect on the surface but may have potentially large effects on species such as caribou and waterfowl). These components of the arctic system are coupled to the global system through two primary mechanisms. First, arctic surface change has strong feedbacks on the arctic climate system, as illustrated by the red arrows linking the four components of change with the arctic climate system. These feedbacks are primarily related to changes in surface energy exchange and greenhouse gas fluxes. Second, changes in the global climate system are hypothesized to affect local, national, and international policies governing industrial development in the Arctic.

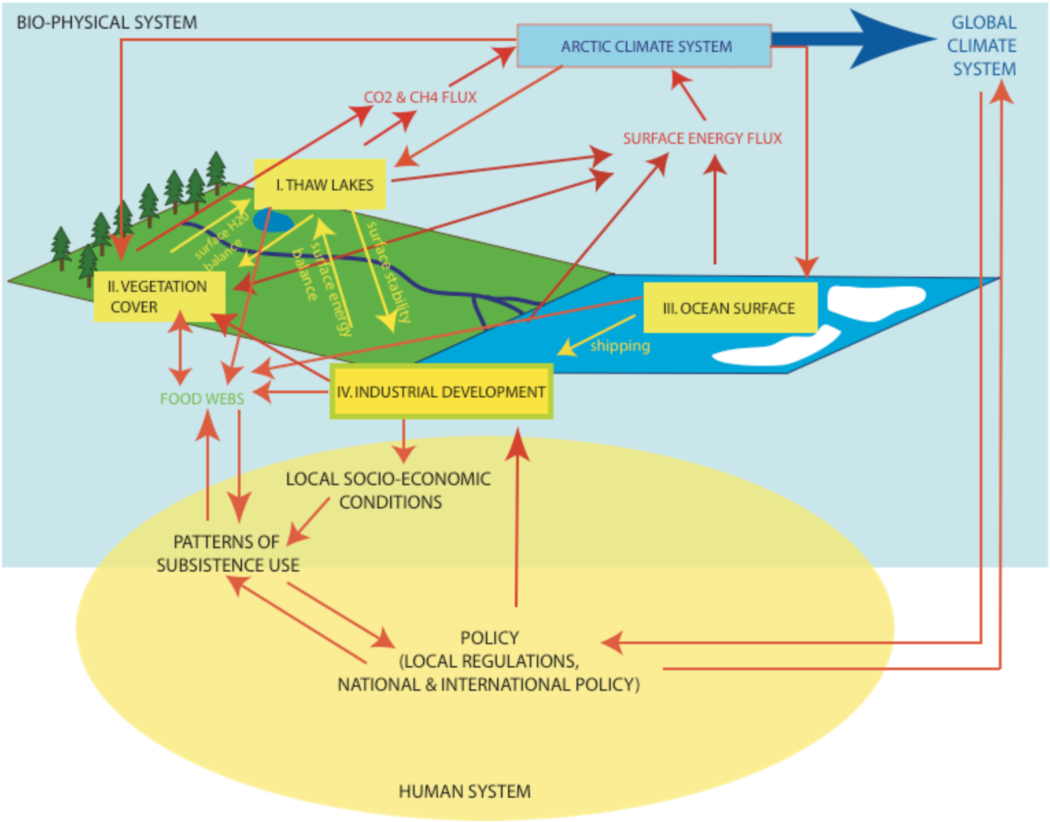

Figure 1. Components of the Arctic System addressed by the Surface Dynamics Co-OP

I. The Thaw Lake cycle

Thaw lakes cover about 20% of the continuous permafrost zone of northern Alaska (as well as a substantial part of the Canadian and Eurasian Arctic), and are an excellent model system in which to explore the interfaces between permafrost, the water cycle, vegetation, and atmospheric processes. The basins that develop when lakes eventually drain constitute an additional 26% of the terrestrial surface. Lakes are therefore the primary geomorphic component of the landscape, and lake processes are the dominant geomorphic agent of change. Thaw lakes represent the effects of permafrost thermokarst at the surface, and respond to regional or global climate forcing. Lakes, in turn, alter the thermal regime of the underlying permafrost. Drained thaw lake basins are sites for preferential accumulation of soil organic carbon which could become mobilized given regional warming. Larger lakes and lake basins provide habitat for fish and wildlife, and are important natural resources for indigenous people, municipalities and industry. In addition to being the location of some of the most active C, water, and nutrient stocks and cycles, thaw lakes represent an excellent model system for investigating changes in surface properties at relevant temporal and spatial scales for ARCSS. Central themes to be addressed by the Near-Surface Dynamics CO-OP include:

1. What are the formative and dynamic thaw lake processes, and how do they vary over time and space?
2. What are the important feedback cycles and fluxes between lakes and permafrost, vegetation, the atmosphere, and the global biogeochemical cycle?
3. How are thaw lake used by humans, and how can this resource be sustained given the growing pressure from local communities and industry in the face of climate-driven change?

Table 1. Key processes and questions relevant to understanding changing thaw lake dynamics.

Process	**Description and rationale**
Thaw lake initiation	Does the thaw-lake cycle exist in northern Alaska, and what is the duration? Generally, how long have thaw–lake processes been operating? Specifically, at what rate do lakes expand, what are the primary drainage mechanisms, and what are the spatiotemporal patterns? How has past climate and geomorphic change (last ~20,000 years??) affected the development, extent, and eventual drainage of thaw lakes across diverse arctic landscape types? How is carbon sequestration and peat accumulation within the drained thaw lake basins related to past climatic changes? We are seeing changes in thaw lakes throughout Alaska and in Siberia, but they appear to have different driving mechanisms in different regions. What are the factors controlling recent thaw lake changes?
Lake physical processes (erosion, thermokarst, orientation)	Have erosion and sedimentation patterns in thaw lakes changed appreciably since the benchmark studies of the mid-1960s? If so, do they support current models for thaw lake genesis, the thaw lake cycle and climate change? How do thaw-lake orientation and morphometry vary over space and time, and do sharp gradients exist? Are the orientation and morphometric characteristics of thaw lakes invariant over a broad range of scale or do they involve geomorphic thresholds? What factors influence the 3-d lake morphometry (shape, size, orientation, depth)? How can climatic influences be separated from the effects of local factors? What are the proximate causes of regional differences in thaw lakes including size distribution, shape, and dynamics?
Lake response to environmental change	How will the abundance and distribution of present-day lakes and wetlands change in response to continued Arctic warming? Does the rate of thaw lake expansion and/or contraction, drainage, and size frequency distribution change as a consequence of climate change, and can thaw lake statistics be used as an integrative measure of climatic trends? Can remotely sensed data provide proxy information for current and recent thaw lake erosion and sedimentation patterns given adequate ground truth? How do changes in lakes translate or relate to

	changes in the surrounding areas and conditions? Do shrinking lakes accompany drying of adjacent soils, succession of dominant vegetation species, and wider scale degradation of permafrost? And if so, to what extent (both spatially and in terms of percent change of the variable in question) do these changes relate to the lakes' rate of change.
Lake biological processes	What is known about communities in thaw lakes (microbes, algae, macrophytes, fauna) and is there difference (species diversity, abundance, functional groups) between lakes and tundra soils and between lakes and underlying permafrost? Are the current dynamics of thaw lakes formation influenced (catalyzed, accelerated) by microbial processes in permafrost? How significant is methanogenesis and biological heat generation in the lake thaw bulb? Is there stimulation of microbial activity at the 'permafrost-water' interface? What particular biogeochemical processes contribute to the currently observed changes in thaw lake geometry? What are the relationships between changes in climate and the surrounding tundra and extant aquatic communities, and what data are required to predict the response of thaw lakes and their biotic communities to climate changes? How do factors such as thaw lake morphometry, orientation, surrounding soil & vegetation characteristics and the spatiotemporal dynamics of lake drainage, expansion & contraction influence the biota and the trophic structure of lakes?
Lake-permafrost interactions	What is the response of ground thermal regime (talik formation/freeze-up, active layer and permafrost temperatures) under thaw lakes & basins to climate changes in the Arctic; what is the nature of the lake/basin and atmosphere interaction? What is the ground thermal status under lakes & basins at various stages of the thaw lake cycle, especially over the centennial to millennial scale?
Energy, water, and nutrient fluxes	What is the role of thaw-lakes in the energy and water cycling of lake-rich regions of the Arctic? What are the impacts of large-scale teleconnections on the water balance of thaw lakes? What are the fluxes of heat, water and nutrients as well as the C-fluxes through the following boundaries: (a) underlying permafrost & lake water (vertical mass- energy transfer); (b) adjacent permafrost & lake water (horizontal transfer); (c) lake & atmosphere?
Temporal changes in fluxes	What plant and soil processes control vegetation succession after the drying of thaw lakes, and what are the biogeochemical feedback consequences at short and long time scales? What are the biogeochemical consequences of the thaw lake cycle, and especially on carbon currently sequestered?
Spatiotemporal variation	How do successional processes in thaw lakes of Alaska differ from those throughout the Arctic? Do the more rapid dynamics of the thaw lake cycle influence the degree of synchrony in lake characteristics (biotic, physical & chemical); is there a greater degree of synchrony among lakes in thaw lake regions than in more temperate regions where the dynamics of lake changes/evolution differ?
Lake-human interactions	What are the uses that humans make of thaw lakes? How have these uses persisted or altered over time? To what extent are any such changes due to changes in the lakes themselves, as opposed to societal changes in the community using the lakes?
Lakes as resources	What characteristics make specific thaw lakes especially suitable for various human uses such as fishing, drinking water, and bird hunting? Are these characteristics related in any way to the stage or age of the lake (e.g., how long does it take to establish a viable fish population)?
Indigenous Knowledge	How can IK be included in this research to promote mutually beneficial relationships that improve our understanding of landscape changes in general and thaw-lake processes in particular? How can we incorporate IK of biotic communities in thaw lakes and streams, and compare these observations to data collected in the region? Do indigenous people manage resource extraction rates (fish, waterfowl, etc.) and, if so, how?

II. Vegetation cover

The Arctic tundra biome, which dominates the Arctic terrestrial surface, can be thought of as continuous, narrow ecotone between forested vegetation to the south (in the southern Arctic and subarctic) and the Arctic Ocean to the north. The vegetation that makes up this biome can be understood, in our paradigm of exploring interfaces or transition zones, as the interface between land surface and atmosphere. Changes in physical variables such as temperature and precipitation have already led to significant alterations of this biome, with forest vegetation expanding from the south, tall woody tundra vegetation expanding throughout the low Arctic, and productivity and abundance of key functional groups such as lichen, mosses, and sedges changing at the northern edge of this gradient. Taller vegetation more effectively traps snow, with consequent thermal impact on the underlying permafrost. These changes in the cover of the land surface are one of the most visible manifestations of climate change in the Arctic, and have significant consequences for energy budgets, biodiversity, human use of arctic resources, and global feedbacks. A complete documentation of the spatial and temporal patterns of change in the Arctic land surface is an important goal, and, indeed, patterns of change are already being investigated in a number of existing projects (see Linkages section below). The Near-Surface Dynamics Community of Practice is focused on investigating several questions with respect to land cover change.

1. What are the driving mechanisms of vegetation change, and how do they vary over time and space?
2. What are the temporal trajectories and spatial patterns of future change?
3. What are the consequences of change for human societies and upper trophic levels within food webs?
4. How does vegetation change impact the stability of permafrost and thermokarst?

The key processes and variables necessary to address these questions are summarized in Table 2.

Table 2. Key processes and variables relevant to understanding change in vegetation cover.

Process or variable	**Description and rationale**
Ecosystem/community structure	Vegetation change has been documented through the tundra biome, with widespread changes occurring in abundance of key functional groups (shrubs, moss, lichen, sedges). Further documentation of temporal changes in community structure, with special emphasis on spatial heterogeneity in the trajectories of change, is needed.
Food web structure	It is assumed that changes in vegetation—increased shrubbiness, for example—will have large effects on higher trophic levels, as amounts of preferred forage species increase and decrease. Changes in food web structure may feedback on vegetation (for example, decreased herbivory may lead to increases in the abundance of preferred species). Changes in food web structure are also a key mechanism by which vegetation change affects Arctic residents. Exploration of the consequences of ongoing vegetation change for higher trophic levels is thus a key goal of this community.
Industrial development	Expansion of industrial development—roads, buildings, mines—has direct effects on vegetation, caused by clearing of land and removal of biomass. Industrial development also has important indirect effects on vegetation via

	its influence on surface energy flux, permafrost, and water balance. Industrial development in the form of roads may also provide an avenue for the invasion of exotic species into the Arctic.
Surface energy flux	Surface energy flux is one of the key processes by which changes in vegetation can feedback on the climate system. Further understanding of the effects of changes in plant functional types on surface energy flux is needed, particularly in those zones and locations that have not been well studied thus far.
Evapotranspiration and surface water balance	Changes in dominant vegetation are likely to be highly sensitive to changes in surface water balance, and to have a large effect on evapotranspiration. Understanding the role of surface water balance as both a driver of ecosystem change (e.g., effects of changes in thaw lake cycle on terrestrial vegetation) and a responder to ecosystem change (e.g., effects of increased shrubbiness on surface hydrology) is an important goal of this community.
Snow cover and duration	Snow cover has a profound influence on vegetation, primarily by modifying the severity of the winter environment and moderating soil temperature. Vegetation, in turn, has a profound influence on snow cover: taller vegetation generally traps snow. Previous research has identified important linkages among snow cover, energy feedbacks, vegetation, and soil nutrients.
Soil C and nutrient pools and cycles	Changes in vegetation – particularly those that involve shifts in the abundance of woody plants and peat-forming mosses—are linked to changes in C/nutrient cycling. Feedbacks between vegetation change and nutrient cycling have already been identified for some aspects of vegetation change (e.g., increased shrubbiness), and undoubtedly exist for many more. Studies of how warming will affect belowground thermal and biochemical processes, and how those processes will interact with vegetation change, are needed to assess the trajectory of net ecosystem C flux in the next several decades.

III. Ice/ocean surface

Changes on and near the ocean surface have paralleled changes in land cover and, like the vegetation on land, the ocean surface (with or without ice cover) is the interface between the marine environment and the atmosphere. As with land-cover change, changes on and near the ice/ocean surface are both a visible manifestation of warming and a key avenue by which warming will affect human activity in the Arctic. (Indeed, marine transportation has already been affected by sea ice changes, as has access to marine food and other resources.) Broad declines in sea ice extent and thickness, warmer sea temperatures, and changes in ocean circulation have been well documented in recent years, and are the subject of a number of ongoing efforts (e.g., SEARCH, NOAA's State of the Arctic initiative), which we will leverage rather than reduplicate. The ice/ocean research developed from the Near-Surface Dynamics Co-OP will emphasize understanding transition zones, interactions and coupled physical–human dimensions. It is anticipated that regional-scale studies will be focused predominantly on circumarctic marginal seas, in relative proximity to land. We suggest that our overall goal of understanding collective near-surface change in the Arctic requires addressing the following questions.

1. What are the spatiotemporal patterns and future trajectories of change in sea ice cover and thickness, in near-surface ocean properties, and in processes that control air–sea exchange such as near-surface winds and wave height?
2. What are the implications of these changes biogeophysically (e.g., for upper trophic levels and on the stability of subsea permafrost and gas hydrates) and for humans?

Table 3. Key variables within the "ice/ocean surface" domain most relevant to understanding near-surface change in the Arctic.

Process or variable	**Description and rationale**
Sea ice cover	Like vegetation on land, sea ice is the 'keystone' physical variable that shapes the ocean surface and the near-surface transition zone. The dynamics (temporal and spatial) of changing sea ice cover are crucial for predicting the trajectory of change in the arctic climate system, the trajectory of change in marine food webs, as well as impacts on subsistence and industrial-scale human use of the marine environment. Key aspects are e.g., degree, duration and timing of ice-free conditions north of Alaska and in other marginal seas.
Sea ice thickness	Sea ice thickness is a crucial determinant of factors like ocean heat exchange and ease of transportation across and/or through sea ice. Changes in the multi-year ice area may be as important sea-ice thickness per se for near-surface change.
Sea surface temperature	We include these two variables as key components of the ocean surface domain for the simple reason that as sea ice cover and thickness declines, these variables will be increasingly relevant descriptors of the state of the Arctic Ocean. Sea surface temperature and near-surface winds are crucial factors in heat, moisture, and gas exchange between the Arctic Ocean and the atmosphere. Wave state has critical human dimensions implications- there is already evidence (at least anecdotally) that increased wave height along the Arctic coast is inhibiting transportation in small watercraft.
Wind and wave state	

IV. Industrial development

Industrial-scale development in the Arctic is likely to be strongly affected by changes in land and sea ice covers; industrial-scale development is also likely to be an increasingly important driver of changes in land cover in the Arctic. Although much of the Arctic remains "pristine", the GLOBIO project[1] found that large areas of the Arctic are already within the "impact zone" of human settlements and infrastructure. Much of our focus in this section is on the *impacts* of land cover and sea ice change on human activity, but we also feel it is crucial to consider how the role of humans as direct *drivers* of change in the Arctic may alter over time through myriad feedbacks. As the Arctic becomes more accessible, this trend is likely to continue and direct human activity may become an increasingly important driver of land cover change at various spatial scales. Achieving our overall research goal requires addressing three key questions.

1. How are changes in land cover and sea ice cover likely to affect resource use at multiple scales in the Arctic?
2. How are changes in land cover and sea ice cover likely to affect possible trajectories of industrial development, natural hazards, and infrastructure stability in the Arctic?
3. What are the relative contributions of human activities in driving changes in land cover, both currently and under future change scenarios?

Answering these questions will require investigation of the variables and processes summarized in Table 4.

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[1] http://www.globio.info/region/polar/

Table 4. Key processes and variables relevant to understand changing patterns of industrial development.

Process or Variable	**Description and Rationale**
Sociopolitical and geopolitical responses	The Arctic has been a venue for change over millennia but increasingly rapid rates of change challenge social and geopolitical systems which exhibit qualities of both remoteness and modernity. Social responses to change, including policy and decision-making at regional levels, may significantly influence the ways in which cultures adapt and evolve. Functional degradation of land and ocean networks can result in both acute (catastrophic) and cumulative (gradual) changes in human societies and their policies. These, in turn, affect other biotic and abiotic systems on different spatial and temporal scales and can result in both opportunity and risk. Thresholds at which social systems become incapable of adapting to change comprise areas of inquiry that will fill a much-needed gap in estimating and managing future scenarios. Sociocultural responses are poorly understood yet critical to our understanding of how the Arctic system will behave as a system
Transportation, industrial development and infrastructure	Transportation on the land surface is likely to exhibit a highly non-linear response to warming. If permafrost thawing eventually leads to differential ground subsidence and thermokarst, transportation may become more costly as existing infrastructure area destabilized. As transportation changes, rates of industrial development are likely to increase, both on land and in offshore areas. (Oil and gas development in offshore areas of the Barents Sea, for example, has already begun and is expected to accelerate dramatically within the next decade.) Development is becoming a contentious issue in many parts of the rural arctic where development was previously not considered because of high costs. Reduction in sea ice thickness and extent may open the Arctic Ocean to shipping, while reducing the suitability of the ocean surface for travel and subsistence activities by Arctic residents. Increased shipping along the ocean surface may have minimal impacts on the ocean itself, but the effects of changes in shipping concurrently with industrial development are unknown. Transportation may function as a linking variable under some climate scenarios. The GLOBIO project identified that significant areas of the Arctic, particularly in Eurasia, are already well within the impact zone of human development (defined as the area in which biological processes are affected by human activity and infrastructure). The vision of the Arctic as a pristine landscape free of industrial development is unsupported by existing data, and industrial development has the potential to act as a significant driver of change in coming years.
Harvest/use of biological resources	Simultaneous changes in land cover and sea ice are likely to have significant impacts on upper trophic levels and thus disrupt the harvest and use (e.g., reindeer herding) of animal populations for both subsistence and commercial reasons. Furthermore, the simultaneous nature of food web disruption on land and at sea may lead to non-linear interactions. For example, disruption of land-based food resources might lead to more pressure on ocean-based food resources (or vice versa). Changes in either terrestrial or marine-based development activity may also affect hunting and fishing pressure in coastal areas. Expanding thaw lakes or increased thermokarst may increase waterfowl habitat while simultaneously reducing caribou grazing area.

Coupling of bio-physical and human socio-economic systems

The four previously described aspects of changes in the near-surface environment interact with diverse patterns of human activity in the Arctic. Depending on the spatial and temporal scales of study, effects can range from changes in subsistence resource use to trans-national development of remote resources (e.g., mining and energy development). Local and regional patterns of use have already been affected by surface transformation. Coastal residents report changes in access to marine food resources, for example, in conjunction with changing sea ice patterns. Changes in coastal weather that accompany loss of landfast ice have affected the ability of indigenous people to use small boats to travel and hunt.

We propose that human interactions with near-surface changes can be understood in the context of two connected feedback loops. The first of these loops is anchored in effects of the near-surface environment on marine and terrestrial food webs and hence the abundance of key prey species (marine mammals, fish, caribou, waterfowl; Figure 1). Patterns of subsistence use of these resources can be affected by near-surface change through two mechanisms. First, direct effects of changes in the near-surface environment can influence patterns of resource use. Expanding thaw lakes and increased thermokarst may increase the available habitat for migrating waterfowl, leading to an increase in use of that food resource. Similarly, industrial development may alter the abundance and/or movement patterns of some key species. (Inupiat hunters report that seismic exploration *preceding* oilfield development in NPRA is influencing movement patterns and abundance of species such as caribou.) Second, changes in local socio-economic conditions that coincide with industrial development may alter patterns of subsistence use (decreasing, for example, reliance on traditional food sources). A comprehensive analysis of the effects of near-surface environmental change on subsistence resource use needs, therefore, to consider the synergistic effects of simultaneous changes in the various components of the near-surface environment. Furthermore, humans need to be considered as both a responder to change (e.g., altering patterns of resource use as prey species fluctuate in abundance) and as a driver of change. Subsistence resource use, for example, may affect prey species abundance. It is also plausible that concern over the effects of development on prey species and other resources could affect policy and thus feedback on industrial development. We feel that it is essential that research into human interactions with near-surface change recognize that humans are both drivers and responders.

The second feedback loop defining human interactions with the near-surface environment is anchored in the policy realm, and involves industrial development that is often initiated by, and frequently has large effects on, non-Arctic residents. Policy-making institutions at the local, regional, national, and international scales are the ultimate driver of industrial development in the Arctic and are *also* drivers (to some extent) of the global climate system. Understanding the interactions between policy-making institutions and local dynamics within the Arctic is an important goal of this research.

Coupling of near-surface change to the global climate system

A final element of our research priorities is to define the relevance of changes in the near-surface environment in the Arctic to the world beyond the Arctic. The effects of changes on thaw lake dynamics, for example, to Arctic residents is clear. But what is the relevance of these changes to people beyond the Arctic? We propose two primary linkages that connect near-surface changes to the global system. First, one of the goals of our research is to understand how changes in the near-surface environment are both driven by and feedback to the Arctic climate system by altering the surface energy flux and fluxes of greenhouse gases. It is through changes in these fluxes that local, regional, and global changes in the atmosphere will be effected. Examples of changes to be considered include changes in cloud cover regimes, storm tracks, frequencies, and intensity, and global teleconnections. For example, draining of thaw lakes will lead to large changes in surface heat, moisture, and carbon fluxes all of which can impact local to global scales of the climate system. Influences on the Arctic climate system are one critical avenue by which patchy, small-scale changes within the arctic influence the global climate system (red arrows; Figure 1). Second, as mentioned in the previous section, policy-making institutions are described in our conceptual model (Figure 1) as the primary driver of industrial development. Because the policies that determine patterns of development in the Arctic primarily originate beyond the Arctic (and are primarily determined by the needs—e.g., oil consumption—of people who live far from the Arctic), this is an important connection between the Arctic and the global system.

Linkages with other groups

The ideas and processes summarized in this document do not exist in isolation. As we have developed our ideas, it has become clear that there are a number of existing groups investigating similar or related topics. We provide a summary of those groups here. As the science planning process proceeds, formal coordination of activities among groups should be promoted in order to reduce redundancy and make the most effective use of areas where interests overlap.

1. Complexity and Synthesis in Arctic Hydrology Community of Practice (Alessa et al.): The Hydrology Co-OP clearly overlaps with our science priorities by addressing issues of freshwater dynamics and availability as they interact with human use and activities.
2. NOAA's State of the Arctic Initiative: Oceanographers at NOAA are currently preparing a report on the State of the Arctic. Their ongoing efforts to monitor sea ice thickness and extent may cover many of the areas identified above as being necessary research efforts to document patterns and mechanisms of changes in sea ice cover.
3. Synthesis of Arctic System Science (SASS) projects including but not limited to the project: "Greening of the Arctic – synthesis and models to examine the effect of climate, sea-ice and terrain on circumpolar vegetation changes" (below).
4. Greening of the Arctic initiative (Walker et al.): NSF has funded at least three related research projects exploring aspects of land cover change (and in some cases links to sea ice dynamics) in the arctic. These projects will contribute to the goal of documenting and understanding patterns of land cover change.
5. Human Dimensions of the Arctic System: Understanding the role of humans within and beyond the Arctic, as both drivers of and responders to change, is one of the primary objectives of this prospectus, so our Co-OP has clear linkages to the HARC initiative.

Appendix 1. Members of the Near-Surface Processes Community of Practice

Andrea Lloyd, Middlebury College, VT (paleoecology of treeline environments)
Ken Hinkel, University of Cincinnati, OH (lakes as primary geomorphic agent)

Lilian Alessa, University of Alaska, Anchorage, AK (human dimensions, complex systems)
Richard Beck, University of Cincinnati, OH (thaw lake sedimentology, remote sensing, IT)
Jim Bockheim, University of Wisconsin, WI (thaw lake basin soils)
Syndonia Bret-Harte, University of Alaska, Fairbanks, AK (plant ecology)
Chris Burn, Carleton University (thaw lake geomorphology)
John Cassano, University of Colorado, CO (polar weather and climate)
Chris Cuomo, University of Georgia, GA (social-natural science interactions)
Dirk Derksen, USGS, Anchorage, AK (hydrology and water fowl)
Claude Duguay, University of Alaska, Fairbanks, AK (remote sensing of thaw lakes)
Wendy Eisner, University of Cincinnati, OH (paleolakes, indigenous knowledge)
Eugenie Euskirchen, University of Alaska, Fairbanks, AK
Craig Fleener, Council of Athabaskan Tribal Governments, AK
S. Craig Gerlach, University of Alaska, Fairbanks, AK
Larrry Hinzman, University of Alaska, Fairbanks, AK (thaw lake changes and consequences)
Henry Huntington, Huntington Consulting, AK (macro sociology related to thaw lakes)
Ben Jones, USGS, Anchorage (thaw lake change with remote sensing, GIS)
Steve Kokelj, Indian and Northern Affairs Canada (lake water chemistry)
Scott Lamoureux, Queens University (paleoclimatology, paleohydrology of thaw lakes)
Carl Markon, USGS, Anchorage, AK (thaw lakes and water fowl)
Eric Maurer, University of Cincinnati, OH (extant and paleolakes, synchronous changes)
Glen MacDonald, UCLA
Martin Miles, Environmental Systems Analysis Research Center, CO (sea ice and circumarctic marginal seas)
Jeff Munroe, Middlebury College, VT (lake erosion and sedimentation processes)
Maribeth Murray, University of Alaska, Fairbanks, AK (archeology, human dimensions)
Fritz Nelson, University of Delaware, DE (permafrost, spatial analysis and statistics, spatiotemporal patterns of change)
Nicolai Panikov, Stevens Institute of Technology (microorganisms in cryogenic settings, methanogenesis)
Kim Peterson, University of Alaska Anchorage, AK (thaw lakes as agents in landscape evolution and vegetation succession, biogeochemical changes)
Joshua Schimel, University of California Santa Barbara, CA
Gaius Shaver, Marine Biological Laboratory, MA
Larry Smith, UCLA (remote sensing of thaw lakes—western Siberia in continuous and discontinuous permafrost)
Michael Steele, University of Washington, WA
Heidi Steltzer, Colorado State University, CO
Craig Tweedie, University of Texas at El Paso, TX (ecology, local variation in plant communities over time, remote sensing, IT)

Donald (Skip) Walker, University of Alaska, Fairbanks (vegetation ecology)
Jeffrey Welker, University of Alaska, Anchorage, AK (terrestrial ecology, biocomplexity, thaw lake succession)
Daniel White, University of Alaska, Fairbanks, AK (hydrology)
Tingjun Zhang, National Snow and Ice Data Center, CO (atmosphere, lake development interaction, lake freezing depth and effects, lake drainage consequences)

AC Liaisons:
Craig Nicolson, University of Massachusetts, MA
Matthew Sturm, Cold Regions Research and Engineering Laboratory, AK