Updated 20 December 2005

Surface Dynamics and Human Environments in the Arctic System Community of Practice (Co-oP)
Description of Science Priorities

Overview

Recent decades have brought about the transformation of the very surface of the Arctic. In the summer, areas of the ocean that were covered by bright white sea ice are now dark, open water. Low tundra vegetation has grown into—or been invaded by—tall shrubs and trees. Reindeer grazing, in some areas of the Arctic, transform vegetation across large areas. Pipelines, roads, and gravel pads occupy an increasing proportion of the land surface. The transformation of the arctic surface is both a visible manifestation of ongoing global change—including both climate change and industrial development—and, potentially, a driver of global change. Surface change is ubiquitous across the circumpolar Arctic, but the relative importance of different drivers of change varies around the Arctic. We are beginning to understand how some of these individual changes in the arctic surface might contribute to the overall trajectory of the arctic system in coming decades, but the collective effects of surface transformation on the trajectory of change in the arctic system remains poorly understood. *Understanding the cumulative and interactive effects of land and ocean surface transformation on the future state of the Arctic System is the central goal of the Surface Dynamics Co-OP.*

Research themes and priorities

Our Community of Practice organized around three fundamental questions related to earth surface change in the Arctic. (1) What are the rates and trajectories of earth surface change? (2) What are the relative roles of, and interactions among, climate and human activities in driving collective earth surface change on land and in the ocean? (3) 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 integrated field research projects aimed at understanding the causes, consequences, and linkages among land and ocean surface change in the circumpolar Arctic be a priority for future ARCSS research.

Our ultimate goal as a Community of Practice is thus to understand trajectories of change on the land and ocean surface: patterns of surface change, drivers of surface change, and implications of surface change. Research efforts should emphasize understanding three categories of processes.

- ➔ <u>Inherent terrestrial processes</u> include the processes crucial to understanding the trajectories and drivers of land surface change. The central questions within this domain include:
  - o What is the rate at which woody vegetation is expanding in the Arctic, and what factors control the rate of expansion? Where are the "hot spots" where rates of change are greatest?
  - o What is the relative importance of external climate forcing and cumulative development impacts as drivers of land surface change in the Arctic?

How is the relative importance of those drivers expected to change in the future?
    - What are the most important feedbacks on the Arctic climate system associated with land surface change? What is the likely trajectory of those feedbacks over the next century? Which feedbacks are most important now? Which feedbacks are likely to be most important under scenarios of future Arctic climate?
    - How does land surface change affect human activity (including both subsistence use and industrial-scale development)?
- ➔ Inherent ocean surface processes include the analogous processes that are crucial to understanding the trajectories and drivers of ocean surface change. The central questions within this domain include:
    - What are the winter and summer patterns of sea ice melt? What is the most likely trajectory of future melting in summer and winter? What are the spatial dynamics of sea ice formation and destruction, and how might those change in a warming climate?
    - What are the most important feedbacks on the Arctic climate system associated with changes in sea ice dynamics? What is the likely trajectory of those feedbacks over the next century? Which feedbacks are most important now? Which feedbacks are likely to be most important under scenarios of future Arctic climate?
    - What are the implications of sea surface change for human activity (including subsistence resource use, commercial fisheries, and transportation)?
- ➔ Land-Sea Interaction Processes are the most important processes linking sea-surface and land-surface change. We define importance by the effect of the linkage on the trajectory of the Arctic system (e.g., strong feedback loops involving both land and ocean) and societal relevance. These include both direct exchanges of energy/materials between the domains and indirect linkages that occur through shared human use of land and ocean resources. We emphasize that the processes linking sea-surface and land-surface change are not restricted geographically to the coastal region; rather, this category encompasses any process that connects, directly or indirectly, surface change in either domain. The focus here is on the most important interactions between surface change in the land and ocean domain, not an exhaustive exploration of all possible interactions. Central questions within this domain include:
    - Are there important direct feedbacks (e.g., runoff) between land-surface change and sea-surface change? What is the likely trajectory of those feedbacks over the next century?
    - What are the non-additive interactions between sea and land surface change with respect to industrial development? For example, to what extent is accelerated industrial development in the Arctic likely to be contingent upon simultaneous transformation of land and ocean surface?

- What are the non-additive interactions between sea and land surface change with respect to subsistence resource use? What are the implications of simultaneous disruption of land and ocean food webs?

The table below identifies the key scientific priorities that we consider to be central to understanding the questions listed above. Our goal is to identify only the most critical variables; this list is not intended, therefore, to provide a comprehensive list of all components of the Arctic land and ocean systems. Achieving our goal of understanding the consequences of simultaneous land and ocean surface change for the Arctic System will require an integrated emphasis on the most central processes and variables. Some variables (e.g., transportation, harvest of animal populations) appear in multiple categories; we hypothesize that they may function as processes linking ocean and land surface change under particular climate regimes. Of particularly interest to us is the temporal variability and spatial heterogeneity in linkages: how will feedbacks from/to these variables change over time and under different climate scenarios? How does the relative importance of various feedbacks vary across the circumpolar Arctic? The temporal variability in linkages can either be thought of in terms of continuous variation (e.g., how does surface heat exchange vary with climate change?) or in terms of discrete climate regimes (e.g., in what ways are the linkages among ocean and land surface different in cold/wet versus warm/dry climates?).

Science Priority	**Rationale**
Inherent terrestrial variables and processes	
Permafrost thaw	Permafrost thaw is in some ways a 'keystone' process that has been identified as a control over vegetation change, C exchange, runoff, and nutrient cycling. Permafrost also controls industrial development and transportation. It is thus implicated in feedbacks to both atmosphere, ocean, and human components of the Arctic. As a process it has exhibited rapid change, but there are details about how permafrost thaw links to other variables that still need to be worked out. We anticipate linking with the Thaw Lakes and Basins Community of Practice to develop these ideas.
Change in vegetation structure	Expansion of woody vegetation (forest and shrub-tundra) has been well documented in recent years, and represents one of the most important aspects of land surface change in the Arctic. Expansion of woody vegetation has the potential to lead to strong positive feedbacks on warming. Although we know that expansion of woody vegetation is widespread, the rate of expansion over the next several decades and the areal extent of expansion remain unknown.
Soil C and nutrient cycling	Expansion of woody vegetation is likely to lead to increases in aboveground C storage. Net ecosystem C flux, however, is strongly influenced by the fate of belowground pools of C. Studies of how warming will affect belowground 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.
Food web dynamics	Land surface change will affect the quality of habitat for herbivores, both through expansion of woody vegetation (and thus reduction in low herbaceous tundra types) and (potentially) industrial development. Changes in the abundance and distribution of herbivores will, in turn, influence subsistence harvest of land animals (particularly caribou).

Industrial development	Subsurface resources have gained tremendous value in the past year and development is becoming a major arguing point in many parts of the rural Arctic where development was previously not considered because of high costs. It is impossible, with our current knowledge, to fully evaluate the net effect of development, but we know with certainty that there will be measurable and immeasurable ecological, societal, and environmental impacts on some level.
Transportation	Transportation is likely to exhibit a highly non-linear response to warming. Initially, the melting of permafrost and loss of surface ice and snow seem likely to make transportation more costly. For example, frozen rivers have historically served as reliable transportation corridors, but may become unsafe. River crossings that could formerly be handled with an ice bridge that lasted for six months a year may now need an expensive permanent bridge. In the long term, however, if thawing eventually leads to surface drying, transportation may become less costly and large areas of the Arctic that were previously prohibitively expensive to reach and develop may become accessible.
Inherent ocean surface variables and processes	
Sea ice cover/thickness	Like permafrost on land, sea ice is the 'keystone' physical variable that shapes the ocean surface. 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.
Food web processes	Marine food webs are key to understanding the future trajectory of the Arctic system for two reasons. First, primary productivity in the Arctic Ocean is one pathway by which CO_2 may be removed from the atmosphere. Second, marine food webs are used by humans for both subsistence and commercial food gathering.
Harvest of ocean animal populations	Changes in the ocean surface in the arctic- loss of sea ice, for example- may alter food webs and increase or decrease the abundance of harvestable fish. Shifts in the availability of marine food resources, for both subsistence and commercial harvest, represent one of the major impacts of ocean surface change on humans. This variable may also function as an edge variable if simultaneous shifts in land and ocean food webs lead to non-additive impacts.
Transportation	Reduction in sea ice thickness and extent may open the Arctic Ocean to shipping, while reducing the suitability of the ocean surface for winter/spring travel by Arctic residents. This may, in turn, alter hunting patterns by subsistence hunters. Increased shipping along the ocean surface may have minimal impacts on the ocean itself, but if shipping increases at the same time that conditions for industrial development change on the land surface, the combined impacts could be large. Transportation may thus function as an "edge" variable under some climate scenarios.
Variables and processes linking land and ocean surface change	
Harvest of animal populations	Simultaneous changes in land and ocean animal populations may have interactive effects on human populations. 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.

Transportation and industrial development	Loss of sea ice opens up the possibility of industrial shipping in the Arctic—the elusive 'northwest passage' sought by explorers. With the potential for industrial shipping comes the possibility of greater amounts of development on the arctic coast. If permafrost dynamics change to the point that conditions for road-building and industrial development improve on land *and* conditions for shipping improve on sea, the cumulative effects could be much greater than the individual effects of any one change.
CO_2 exchange	One of the major avenues by which changes at the surface of the land and ocean domain can be 'exported' to other domains is if surface change affects ecosystem C flux. On land, surface changes like an expansion of woody vegetation may have large consequences for aboveground C uptake and storage. Changes in permafrost may have similarly large (if not larger) impacts on belowground C flux. On the ocean, loss of sea ice is likely to alter both biological C uptake and ocean/atmosphere C exchange.
Surface heat exchange	The surface changes that are occurring on land and in the ocean are associated with large changes in surface energy exchange. Replacement of low tundra by woody tundra or forest, for example, increases atmospheric heating. Although this feedback has had only minor influences on climate thus far, if vegetation change continues at a rapid rate this feedback could become increasingly important in coming decades. Similarly, progressive loss of sea ice increases heat transport from the ocean to the atmosphere; this feedback is also likely to strengthen if past trajectories of thinning sea ice continue.
Runoff	We hypothesize that increased runoff into the Arctic Ocean is the largest "edge" effect from land to ocean. The influx of freshwater into the Arctic Ocean has the potential to alter the ocean surface by affecting ocean currents, sea ice formation, and food webs.
Coastal erosion	Coastal erosion is one of the most important direct 'edge' effects from ocean to land; it is the mechanism by which changes in the ocean surface directly alter the land surface and the lives of the residents inhabiting the arctic shoreline.
Coastal weather patterns	Changes in summer sea ice affect coastal climate in summer and fall, including wind speeds, temperature, precipitation, and timing of green-up, with many potentially cascading effects.

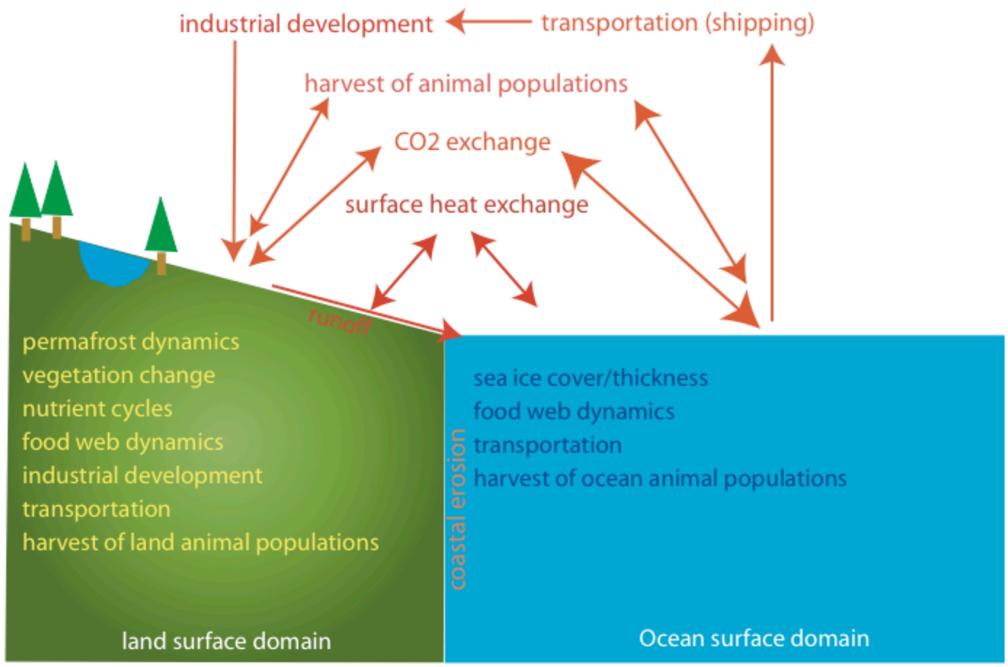

Figure 1. Schematic representation of land and ocean surface processes, and the edge processes (red text/arrows) that link them. Variables are defined in the previous table; note that some variables may function, depending on climate state, as both edge and inherent variables.