Human Dimensions of the Arctic System

Interdisciplinary Approaches to the Dynamics of Social–Environment Relationships

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In 1997 the National Science Foundation Arctic System Science (ARCSS) program launched the Human Dimensions of the Arctic System (HARC) initiative. Its goal is to "understand the dynamics of linkages between human populations and the biological and physical environment of the Arctic, at scales ranging from local to global." Since its inception in 1989, ARCSS had focused on the physical and biological aspects of the Arctic system. The HARC initiative was intended to help expand the scope of ARCSS to include more work on the place of humans within that system. Taken together, HARC projects offer the most direct link between ARCSS research and society, providing relevant information on topics of importance to Arctic communities and the world at large.

HARC developed through projects proposed in response to the new initiative and through the incorporation of existing projects that had a clear focus on human dimensions. These projects had in common the involvement of several disciplines, innovative approaches to posing and studying research questions, and a foundation of prior collaboration or at least interaction among the researchers from various fields. In all of ARCSS, collaborative multi-investigator projects are the standard approach to addressing complex, systemic questions. The same is true of HARC, with the additional complication that the investigators come from several branches of science, not just the closely related disciplines in one area of study.

The projects carried out under HARC to date, some of which are described below, have helped the ARCSS program make considerable progress in its collective understanding of human dimensions topics and the methods and approaches best suited to their study. Nonetheless, the initiative has not attracted the quantity of proposals that was expected. There are several possible reasons, including the difficulty of assembling a large, multidisciplinary team while also establishing the necessary connections with those Arctic people who may be both subjects of and collaborators in the project. To try to generate more activity under HARC, and to provide a means by which current HARC investigators could interact and share ideas, NSF has funded a Science Management Office (SMO) for HARC since 2001, based on similar offices already set up for other ARCSS initiatives.

The SMO has held several online workshops, designed to spur creative interactions among researchers on HARC topics without the burden, cost, and size limitations of in-person workshops. The results of these workshops are available at the HARC web site (http://www.arcus.org/harc). To help turn some of the online ideas into actual proposals, the SMO received an incubation grant from NSF's Biocomplexity Program, which was used to bring prospective researchers together to discuss specific projects and the general challenges of HARC research. The SMO is also coordinating a special issue of the journal *Arctic* dedicated to human dimensions research. This issue is expected to be published in 2004.

In February 2002 the ARCSS program had an all-hands workshop to review progress and determine how the program should be restructured to build on what has been learned and to fill major gaps. One question was the place of HARC in the larger scheme of ARCSS. HARC had been seen either as an initiative pervading all aspects of ARCSS or as a largely separate venture with few tangible connections to the main thrust of ARCSS. Following the workshop, it has become clear that HARC is a critically important component of Arctic science and that a greater effort is needed to make explicit links between HARC and the other initiatives within ARCSS. As has been demonstrated many times throughout the ARCSS program, collaboration and integration among projects, crossing disciplines and themes, results in valuable achievements with greater relevance for society.

Examples of HARC Research

While the role of the SMO is important, the essence of HARC is in the projects. To date, these have been conceived separately by their research teams, without any larger effort to coordinate or direct the overall program. As noted above, links with other ARCSS initiatives are expected to become stronger in the near future, providing a degree of coordination that, ideally, will not interfere with the creativity and curiosity of potential HARC investigators. This section describes several HARC projects to give an idea of the scope of the initiative and the breadth of inquiry that has so far been undertaken.

Environment and Social Change in the North Atlantic Arc

Fishing communities are clearly linked to their environment, but the implications of those links, particularly when environmental conditions change, are sometimes far from obvious. Examining these links is the topic of a research project looking at four fisheries-dependent regions of the northern Atlantic: Newfoundland/Labrador, Greenland, Iceland, and Norway. The project integrates natural science (oceanography and biology) with both quantitative and qualitative social science. It has been supported in two stages, first by ARCSS, from 1996 to 2000, and then by the Arctic Social Science Program, from 2000 to 2003. (Although the ARCSS grant actually preceded the HARC initiative, this project addresses human dimensions issues and is therefore grouped with others funded specifically through HARC.)

The research team includes two social scientists and a biological oceanographer. By assembling and analyzing oceanographic, biological, fisheries, and socioeconomic databases at the finest practical scales, they have been able to document changes in social and environmental parameters, identify associations among those changes, and examine regional similarities and differences in adaptations. These findings have further allowed the development of an integrated environment–fisheries–employment model for policy research.

The study's results include:

- New analyses linking ocean–climate changes, marine ecology, fisheries, and the differential development of human communities in West Greenland;
- Analyses of how a fishery transformed its ecosystem, which transformed the fishery in turn, in northern Newfoundland;
- Comparative studies of the effects of fisheries crises on human populations in Norway, Iceland, Newfoundland, Greenland, and the Faroe Islands;
- Models of policy options and possible paths to recovery for a collapsed fishery off Newfoundland;
- Work examining how Arctic-origin salinity anomalies impacted two fishing communities of North Iceland; and
- A historical report on the development of fisheries in Greenland.

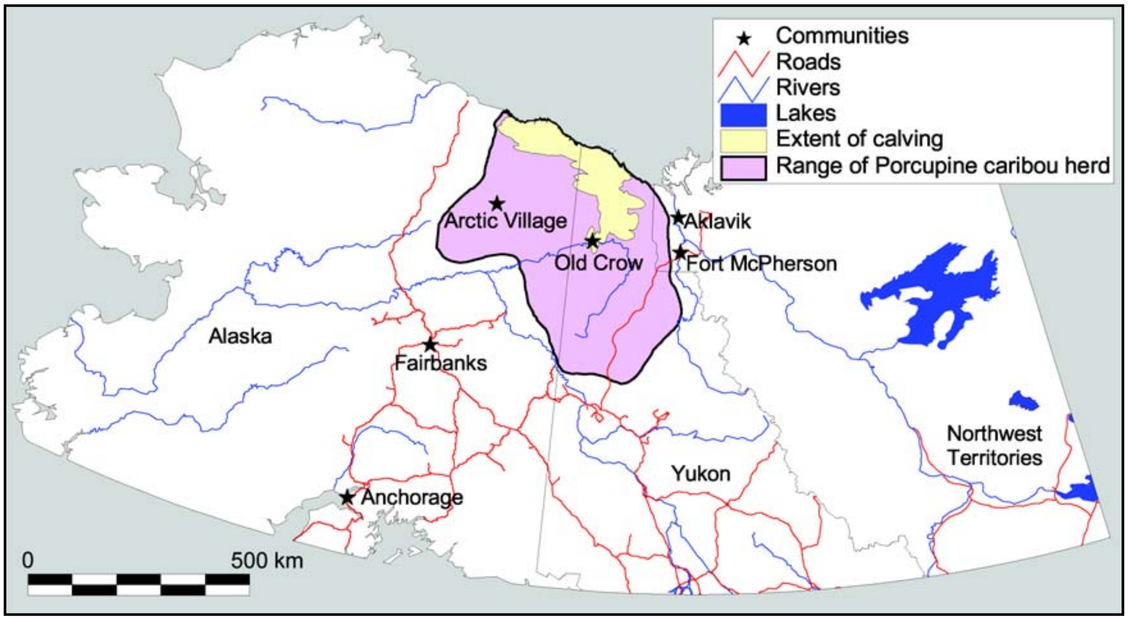
Further information and a complete list of references are available at the project web site (http://pubpages.unh.edu/~lch/naarchom.htm).

Sustainability of Arctic Communities

Beginning in 1996 the National Science Foundation supported an experiment in human dimensions research in the Arctic entitled Sustainability of Arctic Communities: Interactions Between Global Changes, Public Policies and Ecological Processes. (Like the previous project, the topic of this research clearly fits within HARC, although the project actually began before HARC was formally introduced and was jointly funded by ARCSS and the Methods and Models of Integrated Assessment Program.) Twenty-three researchers representing nine disciplines proposed to develop an integrated set of models responsive to policymakers' questions about the ability of Arctic communities in the range of the Porcupine caribou herd to sustain themselves in the face of global climate change. They hypothesized that the effects of climate change cannot usefully be studied out of the context of resource development, tourism, and government spending in the Arctic.

What started as an interdisciplinary team of researchers became an interdisciplinary collaboration of researchers and local knowledge holders from five Arctic communities: Aklavik, Ft. McPherson, Old Crow, Kaktovik, and Arctic Village. The project's partner communities defined sustainability in terms of five community goals:

- Continued use of, and respect for, the land and animals;
- A cash economy that is compatible with their relationship with the land and animals;
- Local control and responsibility for their homelands and resources;
- Education of young people in the twin areas of traditional knowledge and western science,



Range of the Porcupine caribou herd and its calving area.

and education of the outside world about community goals and ways of living; and

- A thriving culture that has a strong, clear identity, that is based on language and time on the land, and that honors and respects elders.

Drawing on local knowledge and 20 years of empirical research, the project developed a hierarchy of computer models intended to serve as a basis for discussion about alternative futures. Subsystem models (developed or refined in this project) simulated changes in vegetation; caribou population and energetics; employment, hunting, and migration; and resource-development-related effects on caribou. Based on sensitivity testing of these models over the range of scenarios being considered, the research team integrated simplified subsystem representations in a spreadsheet-based synthesis model. They incorporated the results of repeated simulations using the synthesis model in a web-based interactive Possible Futures Model. This model incorporates plain English explanations for modeling results and a feedback feature so that model users can help identify what may be missing or wrong.

What has been learned so far? When the probability of warm summers, deep snows, high insect harassment, and high harvests were kept constant, chance occurrences of a sequence of “bad” years set in motion a large caribou population decline. In other runs an absence of such strings of bad years produces a large population increase. Even without global warming, then, over any given 40-year period, the chances of a decline in the caribou population are significant. The research team had hypothesized that, integrating the effects of summer forage, winter snow depth, and insect harassment, global warming would increase the probability of a herd increase. Repeated simulations suggest the opposite: the effects of periods of high insect harassment and more frequent winters with deep snows appear to outweigh the effects of better summer forage. Though the project’s community partners thought that these results do not take into account important variations within the region, all agreed that the simulations help to advance our understanding and identify knowledge gaps.

The research team compared the likelihood that the Porcupine caribou herd would show a decline over 40 years based on four oil development scenarios in which concentrations of cows and calves avoid progressively larger parts of the coastal plain during a three-week period in June. The team developed scenarios based on a new assessment of oil potential prepared by the U.S. Geological Survey coupled with an assessment of changing worldwide petroleum markets. They evaluated the relationship between development-related displacement and a change in calf survival. There was a significant inverse relationship between displacement distance and calf survival.

Based on modeled relationships, the most likely decline in the Porcupine caribou herd because of global warming does not appear to be accompanied by an increase in the number of years of poor hunting. A principal reason for this finding is that communities organize collective hunts when hunters are not able to meet their needs through individual and small group hunts, thus delaying years of poor hunting. This is a good example of how local knowledge can improve on the "linear thinking" so often imposed by using one model equation throughout the entire range of possible conditions. Modeling also confirmed the importance of sharing in mitigating effects of uncertainty brought about by variations in caribou migration patterns and job availability.

More important than any particular simulation result is what was learned about the feasibility of focusing such a broad range of disciplines and knowledge systems on a common research problem. It is possible to explicitly define dimensions of sustainability, to develop explicit scenarios for consideration, and to represent relationships that cross disciplines in a common modeling framework. It is also possible to focus on the "whys" rather than on what are inevitably highly uncertain projections of the future.

The Sustainability of Arctic Communities project is continuing under a second NSF grant. This phase of the project focuses on areas of key uncertainty, including:

- Climate and development effects on whaling for bowhead and beluga;
- Harvest and non-summer forage-related effects on the Porcupine caribou herd;
- Local management of resource development effects;
- Extension of modeling to other North American caribou herds, focusing on the relative importance of calving grounds; and
- Extension of modeling of a single community (Old Crow) to all communities in the Porcupine caribou region.

Further information, including the Possible Futures Model, is available at the project web site (http://www.taiga.net/sustain).

Reindeer Herding in Transition

Significant change has occurred in reindeer herding in the Seward Peninsula, Alaska, because of the migration of large numbers of the western Arctic caribou herd onto the peninsula in winter. Examining these changes, their relation to social and economic changes, and their environmental and socio-economic implications is the topic of an interdisciplinary project that began in 1999. The project is identifying climate factors that influence herding practices, the role of reindeer herding in local economies, the ecological impacts of caribou grazing, and the socio-economic consequences of losses of reindeer. To do so, it has five components:

- Socio-cultural studies, including interviews with reindeer herders;
- Data collection and survey sampling for the economic analyses;
- Installation of satellite-linked remote weather stations for climate monitoring;
- Set-up of experimental sites for vegetation studies; and
- Deployment of radio and satellite collars to monitor animal movements.

The interviews examine not only the social and economic aspects of herding, but also oral histories concerning traditional ecological knowledge of reindeer–environment interactions over the century that reindeer have been herded in the region. As part of the project's outreach efforts, excerpts from these interviews will be used in thematic radio shows addressing historical and present-day issues concerning reindeer herding in Alaska. Reindeer herding is an important part of the region's culture as well as its economy, and impacts to herding have substantial implications for identity as well as employment.

An economic model of reindeer herding is being developed to examine the role of reindeer herding in the economy of the Seward Peninsula. There are two products from reindeer herding: meat and velvet antler. The price of velvet antler has fluctuated greatly in the past decade, and the losses of reindeer from the influx of caribou has reduced harvests to the point that meat sales now generate more revenue than antler sales.

Seward Peninsula reindeer herders' cost of operation.

Goods and Services	Cost/Year ($)
Air charters and shipping	14,650
Snowmachines/ATVs	10,500
Vehicle repair services	1,725
Fuel and oil	3,500
Food for handlings	2,000
Handling/butchering supplies	2,000
Corral maintenance	1,575
Veterinarian instruments, drugs, ear tags	1,750
Recordkeeping, leases, credit	1,500
Miscellaneous supplies and services	460
Labor	2,500
Total annual cost estimate per herd	42,160
All herds*	590,240

* The total annual cost estimate for all Seward Peninsula reindeer operations is obtained by multiplying the total per herd cost estimate by 14 herds.

The last three components examine climate and ecological impacts of caribou. Weather stations have been set up, satellite collars have been placed on both caribou and reindeer, and vegetation plots have been set up for experimentation. Studies of the foraging ecology of caribou and reindeer have shown the potential for competition during winter months. One offshoot of the telemetry exercise is the transfer of technology to reindeer herders. The project team held a workshop to introduce satellite telemetry, GIS, and Internet technologies to reindeer herders as a management tool. The extensive participation of the herders in the project is both critical to the research itself and an excellent means of ensuring that the methods and results of the project can be applied where possible to the benefit of the herders.

The Barrow Symposium on Sea Ice

Subsistence whalers on Alaska's North Slope depend on their knowledge of sea ice to travel, camp, and hunt safely and effectively. Sea ice scientists probe the same ice through microscopes, bore holes, and remote sensing. How can these complementary forms of knowledge be shared so that both groups can help inform the others' knowledge? This was the challenge of the Barrow Symposium on Sea Ice, held in Barrow in October and November 2000.

To prepare for the symposium, researchers and community members selected five case studies spread over more than four decades. Each case study was described in detail, a process involving meteorology, oral history, oceanography, traditional knowledge, sea ice physics, and other disciplines to draw on the various sources available and to capture the many aspects not only of the ice but also of the ways that hunters and others use and understand the ice. For this reason the research team was large and diverse, with a strong emphasis on community involvement from the beginning.

Additional researchers and community members took part in the symposium itself, which resulted in three days of highly interactive discussions about the five case studies. The dynamics of ice movement were of particular interest, especially the process of spring breakup. In 1957 a catastrophic shattering of sea ice left whalers scrambling for shore, having abandoned their whaling gear on the ice. An analysis of the weather events at the time showed that although the particular conditions were not common, they had occurred several other times in the past eight decades for which weather records are available. The role of wind, storm surges, and ice formation were examined, with one elder pointing out that the ice that spring was regarded as suspect because it contained a very high proportion of fragile multi-year ice, which unlike first-year ice is more likely to shatter than deform. This collaborative reconstruction gave a much more complete view of the event than would have been possible from a single source.

The role of technology in studying ice and forecasting ice conditions was another topic of great interest to whalers and scientists alike. Reliance on global-positioning satellite systems and the availability of advanced search-and-rescue capabilities such as helicopters may be leading whaling crews to take more risks on the spring ice. In recent years, hunters have occasionally been carried out to sea when the shorefast ice breaks free, requiring a rescue operation. To date, no lives have been lost, but there is naturally considerable concern about safety. Providing remote sensing imagery to the whalers, and getting their help in ground-truthing the images, is one option in helping avoid surprises during whaling. At the same time, decreasing the whalers' reliance on traditional knowledge may erode the social standing of elders whose experience and expertise was previously essential, and it may lead to increased risk by lowering the attentiveness of whalers to important clues in the ice around them. These social factors are an important consideration in our understanding of the relationship of hunters and sea ice.

The Kola Peninsula Project

The Kola Peninsula is one of the most populated and polluted regions in the Arctic. The American Association for the Advancement of Science's Program on Europe and Central Asia, the Institute for Ecological Economics at the University of Maryland, and the Kola Science Center in Apatity, Russia, are in the first phase of a multi-year U.S.–Russian research effort to increase understanding of the role of human dynamics on ecosystem functions and explore development strategies to enhance ecosystem health, ecological sustainability, and economic diversity. The project initially focuses on the Imandra Lake watershed and then will examine the Kola and Tuloma River watersheds. All of these watersheds cut through the heart of the industrially developed ecosystems of the Kola Peninsula and account for the release of major pollutants into the Barents and White

Seas and the Arctic Ocean.

Four research questions are being examined:

- What effect has the post-Soviet decrease in industrial and human activity had on the ecological health or resilience of the watershed?
- What future models of economic and social development in the region can increase economic productivity while not degrading the health of the watershed?
- How can integrated modeling be used as a consensus-building tool for making decisions about further economic and social development of the region?
- What are the possible scenarios for future development of the region under changing global conditions, such as global warming?

Using a watershed as the unit of analysis, the project will:

- Describe each watershed's terrestrial and aquatic biogeochemical cycles and their changes over the past 65 years;
- Develop a working model of each watershed; and
- Involve local stakeholders through the model development, testing, and implementation phases.

The Imandra Lake watershed and the Kola and Tuloma River watersheds were selected because they provide diverse mixes of human land use, as well as serious environmental degradation through numerous causes. This interdisciplinary project combines natural systems research and social science research. The result will be a better understanding of site-specific contributions to large-scale models of the Arctic systems functions and threats. To date, the project has developed a model for Lake Imandra, charting the concentrations of certain contaminants over time as development activities change, and has held stakeholder meetings in several communities. The willingness of community members to speak openly appears to vary widely, largely as a result of different economic and social relationships between residents and industry. More information is available at the project web site (http://www.aaas.org/international/eca/kola/).

Landscapes and Seascapes in the North Atlantic

Iceland is particularly vulnerable to environmental changes, including the impacts of both climate and volcanism. Iceland's vulnerability to climate impacts in the past, and potentially in the future, is due in large measure to the variability of the climate. The project called Landscapes and Seascapes: Linkages between Marine and Terrestrial Environments and Human Population in the North Atlantic may be seen in the context of current concerns regarding potential future global and Arctic changes, the crisis in the world's fisheries, and concerns regarding land use and continuing erosion of land surfaces in Iceland. The research focus is threefold:

- A number of specific climatological and environmental questions related to the documentation of twentieth-century changes and the assessment of potential future changes relative to the recent past;
- Assessment of the impacts of these environmental factors on a specific society (Iceland) in the context of other socio-economic pressures; and
- Actual and potential human adaptations to these impacts and the implications of such adaptive strategies for sustainable development.

To provide data with which to assess the impact of future environmental changes on Icelandic society, the project team is also reviewing and synthesizing results from recent coupled Ocean/Atmosphere General Circulation Models (O/AGCMs) to answer several questions:

- What are the predicted changes in precipitation and temperature in Iceland over the next 10–100 years?
- What are the corresponding predicted changes in sea surface temperatures around Iceland?
- What are the predicted variations in the East Greenland sea ice over the next 10–100 years?
- What are the predicted variations in ocean currents around Iceland in 10–100 years?

The project includes two specific case studies, one conducted in the Myvatn area of northern Iceland, which is focused mainly on a farming and land-use economy, and the other in southern Iceland (the Westman Islands), which is focused mainly on a fisheries-based economy. The case studies will address some of the local and regional implications of environmental variations and changes. Specifically, researchers have been asking farmers and fishers how they have adapted and/or responded to certain climatological and environmental events in the recent past, as well as how they might adapt and/or respond to climatological and environmental scenarios that are predicted in the near future. The team has been particularly impressed by the wealth of local knowledge found among both farmers and boat skippers who have been interviewed. The information gathered in this manner will yield much insight into sustainable development in Arctic and sub-Arctic regions in the future.

A strong research team, based in the U.S. and in Iceland, includes both social scientists and natural scientists with backgrounds in fisheries, anthropology of fishing communities, climatology, and human ecology. This diversity of backgrounds allows the team to analyze and interpret records of climate, agriculture, fisheries, the knowledge of farmers and fishermen, and other indications of climate variation and its impacts on the Icelandic economy, society, and culture. Some specific research questions addressing the documentation of twentieth century changes include:

- How have precipitation and temperature patterns in Iceland varied?
- How have sea surface temperatures in the vicinity of Iceland varied?
- How has the East Greenland sea ice varied?
- What changes in ocean currents around Iceland can be established?
- What are current annual yields of grass per hectare in Iceland?
- How many sheep, cattle, and horses are currently kept in different parts of Iceland?
- Given the problems with erosion in Iceland, how do farmers justify the numbers of livestock kept?
- What are the annual fisheries catches in Icelandic waters (specifically cod and herring) and what factors influence these catches?

Climate Variability and Change on the Alaskan North Slope

The purpose of this project—An Integrated Assessment of Climate Variability and Change in the Alaskan North Slope Coastal Region—is to help the community of Barrow, Alaska, adapt to climate variability and change by integrating scientific research in various disciplines into policy alternatives that address the community's primary concerns. It employs a wide range of methods, which were chosen based on specific community concerns highlighted in initial exploratory meetings between members of the research team and Barrow residents. Coastal erosion and flooding were identified as the most important topics to the community, and the eventual research team was assembled with that in mind.

The basic approach is to make a map of past events and responses and then to use this to construct a picture of future vulnerabilities and the potential for policy development. Hence, the project has or will:

- Characterize the impact of climate variability on the physical processes that cause extreme flooding and erosion events;
- Investigate these processes to understand the important mechanisms at work;
- Document past extreme flooding and erosion events and the community responses to them;
- Use physical and statistical models to try out "what if" scenarios concerning climate and environmental changes and community-suggested solutions;
- Assess the state of climate modeling specific for the Barrow area; and
- Examine the range of, and controls on, future climate scenarios for the region.

For this study to succeed, it is essential to understand residents' perspectives on climate variability and change in order to focus the scientific research on their principal concerns and eventually to advise them on possible policy responses to priority problems. An active partnership is possible because residents continue to be concerned about issues of climate change and variability on the North Slope. The research team has begun to construct this partnership through a series of public seminars, meetings with a variety of local citizens and groups, and discussions with local schoolteachers and students.

This project requires a breadth and depth of expertise, reflected in the participation of eight principal investigators from the fields of atmospheric sciences, anthropology, geology, political science, sea ice physics, and climate impacts. Nine other scientists are involved in the project, plus seven students. To make sure the group functions as a team, everybody on the project has a responsibility to interact with stakeholders as much as possible, and anyone can come along on the trips to Barrow.

Although it is too early to anticipate key results, research so far has turned up several interesting findings:

- Cyclone frequency and intensity over the Arctic as a whole have increased in the past 50 years, but, surprisingly, in the region affecting Barrow (the Beaufort–Chukchi sector), the only increase has been in summer cyclone intensity. On the other hand, average winds at Barrow do show a significant

increase, especially in winter. Dramatically apparent in the wind-event record is a relatively quiet period from the late 1960s to the early 1980s, a period during which Barrow grew greatly.
- The variations in atmospheric circulation in this sector are not significantly correlated with the Arctic Oscillation, although the Pacific North American (PNA) teleconnection pattern index does show a link to some variables. This is important if there is going to be any chance of linking future large-scale climate scenarios to changes of local importance.
- North Slope residents clearly perceive that the climate of the region has changed in living memory. Factors influencing this perception include the fact that auguring for foundations in Barrow has had to go deeper to reach permafrost, snowmelt onset at hunting camps is becoming unpredictable, the sun is feeling hotter, and the summer mosquito population is increasing. Careful examination of the climate records at Barrow generally supports these perceptions.
- The Beaufort–Chukchi cyclones of October 1963 and August 2000 produced the highest winds ever recorded in Barrow. The October 1963 storm caused significant flooding, contaminated drinking water, and interrupted power supplies. The August 2000 storm caused the wreck of a six-million-dollar dredge and removed roofs from 40 buildings. From the characteristics of the two storms, researchers concluded that the observed retreat in the western Arctic ice cover is unlikely to be an important contributor to increasing cyclonic activity in the future, although it may contribute to increases in storm surge and wave damage when storms do occur.

Further work is now being done to evaluate erosion mitigation strategies suggested by Barrow residents, as part of the continuing interaction of researchers and community members that characterizes this project. More information is available at the project web site (http://nome.Colorado.edu/HARC).

Future Directions

HARC's future will build on this record of research while linking more closely with other initiatives within ARCSS and with related activities elsewhere. This section describes some of those other activities and how they relate to HARC.

Arctic-CHAMP

One of the new ARCSS initiatives is the Pan-Arctic Community-Wide Hydrological Analysis and Monitoring Program (Arctic-CHAMP), which seeks to understand the hydrological cycle in the Arctic. Part of that effort consists of examining the human role in relation to hydrology, including both human influences on the cycle and the impacts that changes in hydrology may have for people. There are several examples of such influences and impacts. People can affect the hydrological cycle in several ways, including controlling or changing runoff and river flow patterns through dams and changes in land use. Conversely the flow of water through the Arctic environment is critical to society in many ways, including drinking water, erosion, travel and transport, construction on permafrost, and impacts to the fish and wildlife that people depend on.

Studying the links between people and the hydrological cycle poses a typically HARC-like challenge. There are considerable gaps and uncertainties in our understanding of many aspects of Arctic hydrology, especially in terms of feedbacks and links among the various processes by which water circulates through the environment. An online workshop on Humans and Hydrology, organized by the HARC SMO, identified several important topics and ripe questions for research. These include ways to incorporate environmental change into community planning, the vulnerability of Arctic communities with specific reference to waste disposal practices, the degree to which infrastructure engineering standards are likely to accommodate permafrost warming, and the characterization of human–hydrology interactions on a variety of scales to identify geographic and other patterns of significance. Research on the human dimensions of the hydrological cycle should help make such topics an integral part of Arctic-CHAMP.

Land–Shelf Interactions

The Land–Shelf Interactions (LSI) initiative is an outgrowth of efforts within the Russian–American Initiative for Shelf–Land Environments in the Arctic (RAISE) project umbrella, which supports U.S.–Russian bilateral research on environmental change in the Russian Arctic. Because of the substantial influence of the Eurasian landmass on Arctic runoff, climate, sea ice formation, water mass formation, and other processes that impact environmental responses to change, the

Arctic cannot be properly understood in a systemic manner without coordinated, interdisciplinary efforts in the Russian Arctic. However, many aspects of environmental change at the Arctic land–sea boundary can also be appropriately studied outside of Russia, so this science planning effort is generic, rather than geographically delimited, and will include research efforts in Alaska and other portions of the Arctic.

The overall objective of the current science planning effort is to lay the groundwork for a coordinated, interdisciplinary research opportunity in the Arctic that would focus on the coastal zone and would support land-, river-, and sea-based researchers who would take advantage of coordinated logistical capabilities that would otherwise be unavailable. LSI will be specifically centered on these research problems at the land–sea margin in the Arctic by focusing on the scientific challenges of environmental change in human and biological communities and related physical and chemical systems. Another important focus should be on the role of food chains and the efficiency of transfers of carbon, nitrogen, contaminants, and other constituents from the environment, through marine and terrestrial organisms, to local communities. Because of the relatively high density of human communities in Arctic coastal zones, these foci provide an opportunity to address the linkages between marine and terrestrial ecosystems in ways that have direct relevance to society. This initiative could also examine the role of people in the Arctic system as an important mediator of interactions between marine and terrestrial food webs, which in turn affect the productivity of these systems. It is also worth noting that many uncertainties concerning environmental change in the Arctic can be approached through the study of past changes in biological communities in response to environmental change, including the responses of human communities.

As a result, study of the human dimensions of environmental change will be an important component of the overall LSI research program because of the heavy dependence of local Arctic communities on marine and terrestrial resources. The nearshore area is vital for many Arctic residents. Coastal communities depend on access to the sea and sea ice but are vulnerable to flooding and erosion. Significant subsistence activities take place in the nearshore area. The interactions among terrestrial, freshwater, and marine systems govern the boundary conditions associated with the nearshore as well as feedbacks on each of those systems. These interactions have a human element, too, as people affect the nearshore and are in turn affected by it. To involve natural scientists, social scientists, and Arctic residents in a discussion of this topic, one of the HARC online workshops was dedicated to this topic. (Transcripts and the workshop report can be found at the HARC web site). Among the topics that were touched on by workshop participants were the relationship of environmental change to community planning, human impacts on ecosystem health, environmental vulnerabilities, and past responses to environmental change.

In particular, it was recognized that changes in oceanographic features such as the presence of sea ice and the extent of nearshore brackish water may have significant impacts on the productivity and biodiversity of nearshore areas. From a physical standpoint, biological recovery to disturbance and biogeochemical cycles in general are slow at high latitudes. Human activities, too, may have an impact in this zone, such as through the outflow of municipal waste. It is also important to recognize that humans have modified the nearshore environment for thousands of years, and the changing role of people within the ecosystem needs to be taken into account. The effects of environmental changes on humans depend greatly on the impacts to species that are hunted or fished or to access routes across sea ice or through nearshore waters and river mouths.

The contributions made by participants in the HARC workshop have been incorporated into a more general science plan that is guiding LSI project development. Additional workshops and an implementation plan are likely prior to the initiation of any field research.

More information, including the current draft of the science plan, is available at the LSI website (http://arctic.bio.utk.edu/#raise).

SEARCH

A larger effort to examine environmental change in the Arctic is the Study of Environmental Arctic Change, or SEARCH, a multi-agency, coordinated effort to study variability and change in atmospheric, marine, and terrestrial systems that may be related to the polar vortex. The model for SEARCH is the program of research on the El Niño–Southern Oscillation (ENSO). ENSO-related research has tried to improve understanding of how changes in the environment important to people (such as fisheries, agriculture, and storms) may be related to ENSO variability. ENSO observations and research have even supported alerts of probable El Niño events, thereby helping regions to anticipate the need for economic adjustments, disaster relief, and the like.

SEARCH science planning envisions three panels to focus research efforts: Detecting Change, Understanding Change, and Responding to Change. The Detecting Change panel focuses on compiling a systematic database of long-term observations to detect and monitor Arctic environmental change. A key research question concerns the ability to detect conditions producing regime shifts. Small changes in one part of the environment may, under some conditions, produce a dramatic, non-linear change in another part (for example, ocean circulation affecting marine species composition).

Historical and archeological studies can play an important role in developing a long-term database of pan-Arctic environmental change. Relevant historical studies might include identifying and analyzing long-term records of human activities such as fishing and transportation, as well as compiling oral histories of environmental change. Coastal archeological sites contain shell middens and faunal remains whose chemical signatures can provide evidence of past climate variation. Comparing the presence or absence of human use at diverse terrestrial sites across the Arctic may also suggest Arctic-wide changes contained in patterns of regional or local changes.

The Understanding Change component of SEARCH consists of modeling studies to test ideas about links among different components of atmospheric, marine, and terrestrial systems, as well as process studies to understand potentially important feedbacks. Modeling studies may start by analyzing covariation in diverse but hypothetically linked data series (for example, the AO index, precipitation, poleward heat flux, indicators of ecosystem change, and social and economic factors), and the development of explanations for this covariability. For example, one approach might be to construct models of human activity and environmental connections based on re-analysis of paleo- and historical data.

Constructing a comprehensive Arctic system model will likely require different approaches to accommodate diverse space and time scales relevant to the atmosphere, marine and terrestrial systems, and social systems. While useful models already exist for aspects of the physical systems, ecological and social models only exist for a few regions of the Arctic. System-wide modeling may need to start with simplistic ecological and social models extrapolated from small regions. Nevertheless, SEARCH's comprehensive approach provides a significant new opportunity to characterize links and vulnerabilities of interconnected Arctic human and natural systems.

Certain critical feedbacks within the Arctic systems may attract more detailed attention from modelers. The freshwater balance provides one such feedback (see CHAMP above). Human activities may cause large-scale changes in land cover (such as fire control, grazing, and expansion of agriculture) or trace gas and particulate emissions that may, for example, affect albedo and moisture fluxes at the land surface. Changes in marine food webs from fish harvesting and aquaculture may interact with thermohaline changes and biogeochemical cycling. Social scientists may be interested in modeling interactions between global and Arctic social and environmental change: for example, how Arctic environmental changes affect environments and societies at lower latitudes, and how lower-latitude environmental, economic, and social changes affect Arctic ecosystems and societies. Archeological data can again play a role in testing the models' simulated responses against the paleoenvironmental record.

The Responding to Change component addresses the impact of the physical changes on ecosystems and societies, distinguishing between climate-related changes and those caused by other factors, such as resource utilization, pollution, economic development, and population growth. Of particular interest is the question of whether threshold phenomena exist in human–environment interaction, for example, how Arctic communities are adapted to normal ecological variation, and under what circumstances extreme environmental changes might cross a threshold to trigger social changes. Archeological and historical records may be useful in documenting and analyzing past large shifts in human activity and potential connections to environmental change.

SEARCH envisions developing a systematic method of connecting scientists with northern communities. It calls for establishing science–community communication networks in which researchers share data and findings with local governments and citizens and receive regular feedback on issues of concern. Structured community-driven monitoring programs can contribute to the Understanding Change component of SEARCH by providing early signals of change undetected by remote sensing methods, as well as by detecting environmental changes that are important to the communities and industries. Arctic residents could also participate through these networks in the Understanding Change component by reviewing model predictions for ecosystem change and suggesting new hypotheses and explanations of observed and predicted change.

The SEARCH study plan distinguishes between near-term activities and more distant goals for each of the three study areas. More distant goals include developing a modeling capability that moves toward prediction of future changes. Ideally, linked physical system, ecosystem, and social models (terrestrial and marine) of Arctic environmental change will address relationships between local changes and system-wide changes at sufficient temporal and spatial detail to make credible predictions of key variables at the regional and community level.

More information about the program as a whole is available at the SEARCH web site (http://psc.apl.washington.edu/search/index.html).

Conclusions

Research on the human dimensions of the Arctic system, similar to research on human dimensions of global change generally, is a challenging topic, laced with uncertainty, requiring creative and innovative approaches to come to terms with the dynamic links between social and natural systems, each of which is dynamic in itself. Typically social sciences research regards the natural environment as essentially static or at least variable in relatively simple ways, so that the complexity of the social setting can be examined without addressing complexity in the natural environment. Most natural sciences research does the opposite, treating human inputs and extractions in simple fashion so that the focus on the study can remain on natural complexity. Human dimensions research is the connection between these modes of studying complexity, and one major challenge is avoiding the conclusion that it is too complex to make sense of at all. Instead, as the previous sections indicate, HARC provides an opportunity to try new ideas, to work collaboratively with those who might otherwise have been only the subjects of research, and to understand how Arctic system and global change research can help society.

This last point is easy to overlook or discount. The test of basic research should not be a direct link to societal benefits, and the scientific justification for programs like ARCSS is well established. The role of HARC is not to justify ARCSS, nor to explain it to the public, nor to try to reshape ARCSS. Instead, HARC can help ensure that the results and lessons of ARCSS research—including HARC projects—assist Arctic communities and the global society address the implications of Arctic and global change. How, exactly, are people in the Arctic affected by their environment and the ways in which it changes? How, exactly, do social processes influence that relationship? What, exactly, are the ways in which people use information from ARCSS and elsewhere to plan for or adapt to anticipated environmental and social changes? Researchers are often reluctant to draw firm conclusions, citing continued uncertainty and the need for further observation and study. Such prudence is creditable, but when decisions are being made today, society must accept uncertainty and try to accommodate it as well as possible. As we better understand the role of humans in the Arctic system, we will better understand how even an imperfect understanding can be a tremendous asset to those faced with the uncertainties of the future.

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