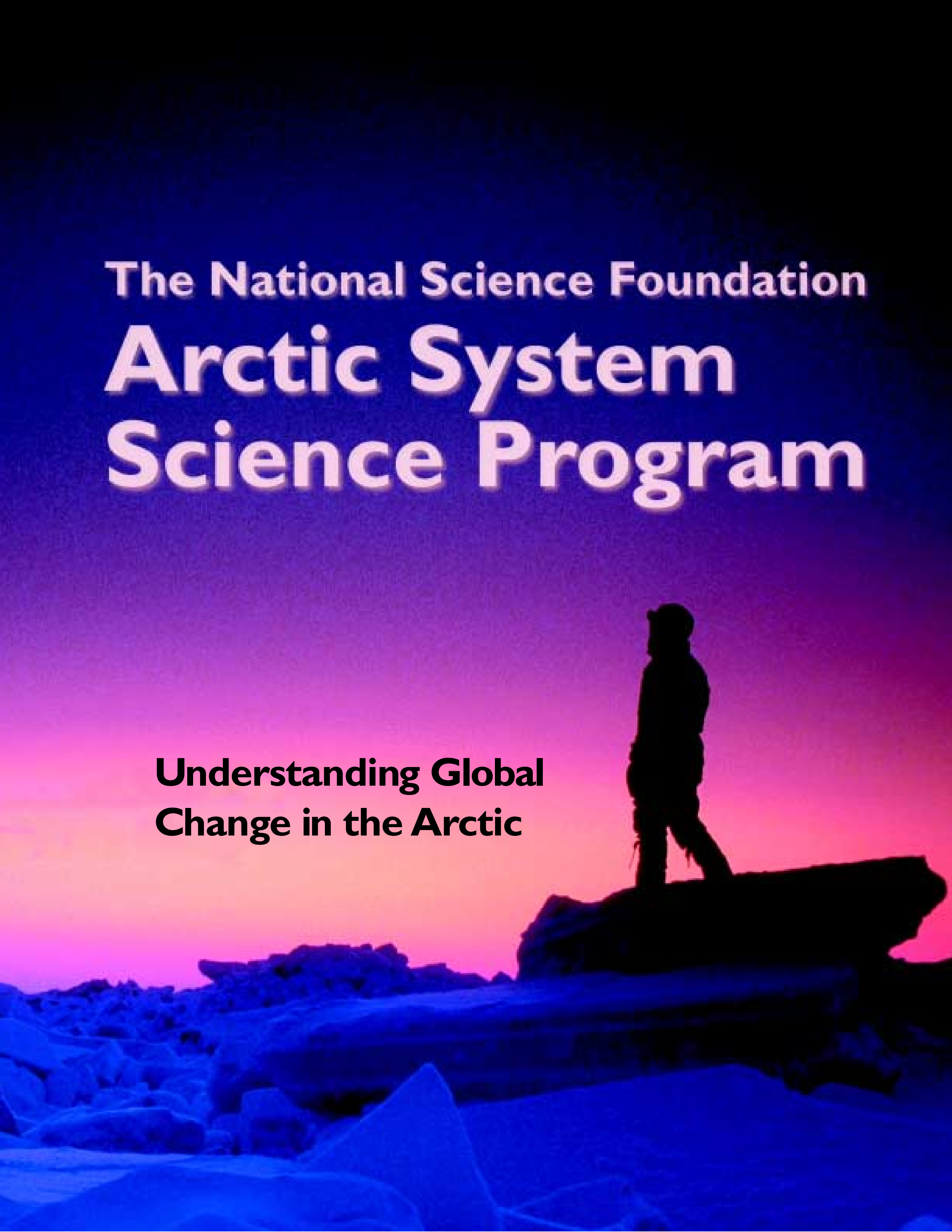
The National Science Foundation

Arctic System Science Program

Understanding Global Change in the Arctic



National and international research efforts have been organized to understand and predict the effects of global change. The largest American program is the ***U.S. Global Change Research Program,*** *which began in 1989 and involves 13 federal departments and agencies cooperating with one another and with international collaborators to investigate global change, including alterations in*

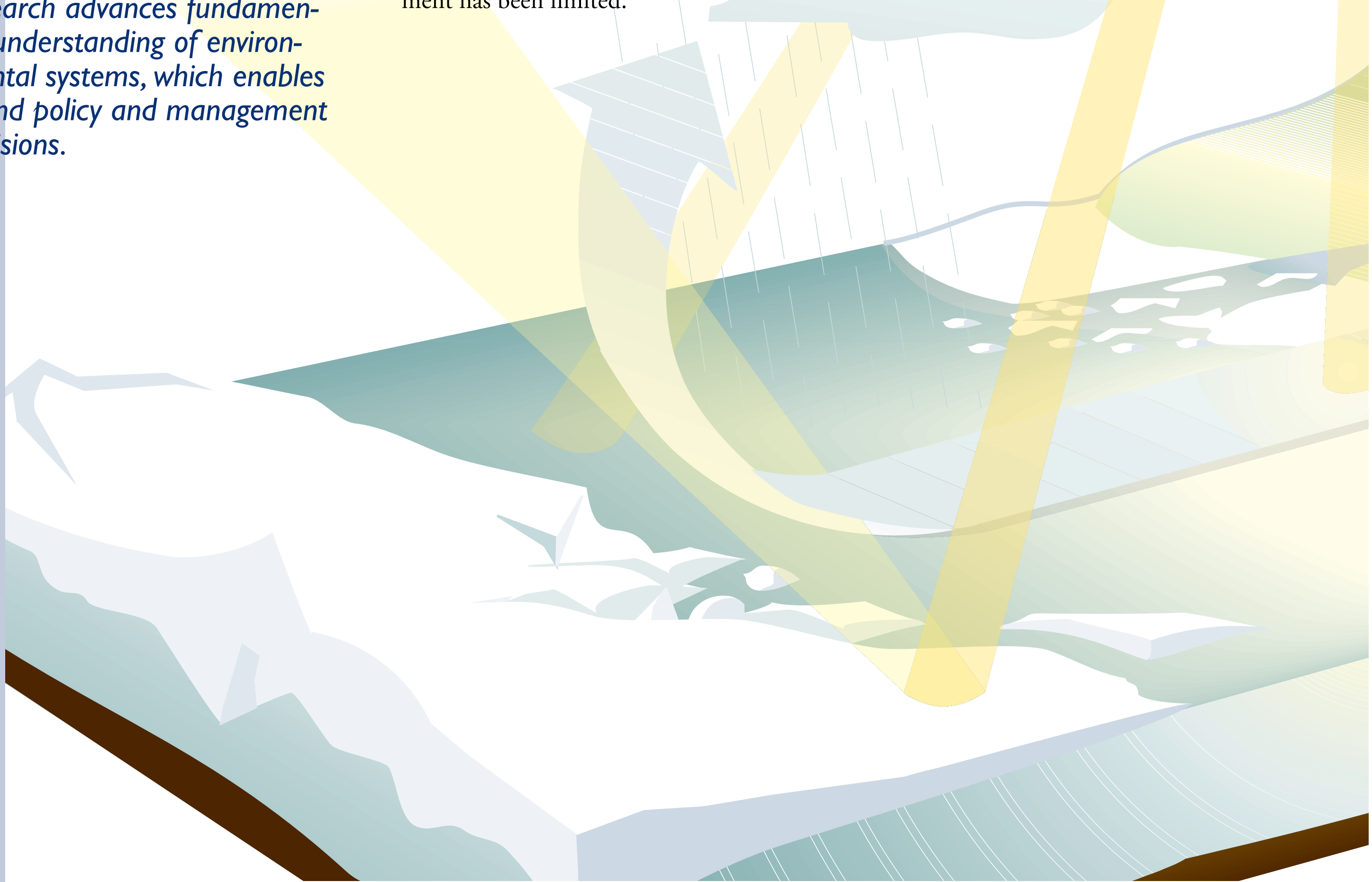
- *climate,*
- *land productivity,*
- *atmospheric chemistry,*
- *oceans and other water resources, and*
- *ecological systems.*

Among the 22 Global Change Research programs at the National Science Foundation (NSF) is the ***Arctic System Science (ARCSS) Program.*** *NSF is a major supporter of environmental research in the Arctic. This research advances fundamental understanding of environmental systems, which enables sound policy and management decisions.*

Understanding Global

The Earth system has always been dynamic and changing, but because of human activities, it now is changing at an ever-increasing pace. Climate models suggest, and recent data indicate, that changes will be amplified in the Arctic and, thus, will be detected there first. The Arctic is an ideal place to study global change because of the relative simplicity and vulnerability of its ecosystems:

- The arctic environment interacts in complex and significant ways with global climate systems. For example, floating sea ice affects the global weather by acting as a variable lid on the polar oceans, reflecting the sun's energy rather than allowing it to be absorbed by the dark ocean. The ice cover also prevents the release of the ocean's heat energy upward to the atmosphere.
- The permafrost, ice sheets, and lake and ocean sediments contain records of past climates that can describe complex climate systems.
- The Arctic is one of two heat "sinks" in the global heat engine; the Antarctic is the other.
- The region has large reserves of natural resources, some of which have been extensively developed and used. The cumulative effects of development and exploitation on natural systems are major concerns of global change research and can be readily studied in the Arctic.
- Global change is likely to have profound consequences for the region's human communities, particularly the indigenous people who depend on local resources.
- Much of the region is remote, so basic scientific understanding of the arctic environment has been limited.



Change in the Arctic: Arctic System Science

Since 1989, the Arctic System Science (ARCSS) Program has been a leader within the research community in implementing a systems science approach to the study of a region. U.S. and international investigators have worked throughout the Arctic, collaborating on integrated long-term research. ARCSS researchers are striving to understand the responses of physical, biological, and social systems within the Arctic to global changes, and how changes in the Arctic may affect the rest of the globe. The goals of the ARCSS Program are:

- to understand the processes of the arctic system that interact with the total Earth system and contribute to, or are influenced by, global change, in order
- to advance the scientific basis for predicting environmental change, and for formulating policy options in response to the anticipated impacts of global changes on human beings and societal support systems.

The ARCSS Program contributes a regional perspective to the development of a thorough scientific understanding of the Earth system, providing the foundation for understanding climate fluctuations and long-term climate change, as well as vulnerabilities to changes in other important environmental factors. This research is a critical investment toward informed decision making on environmental issues and the future of this nation.

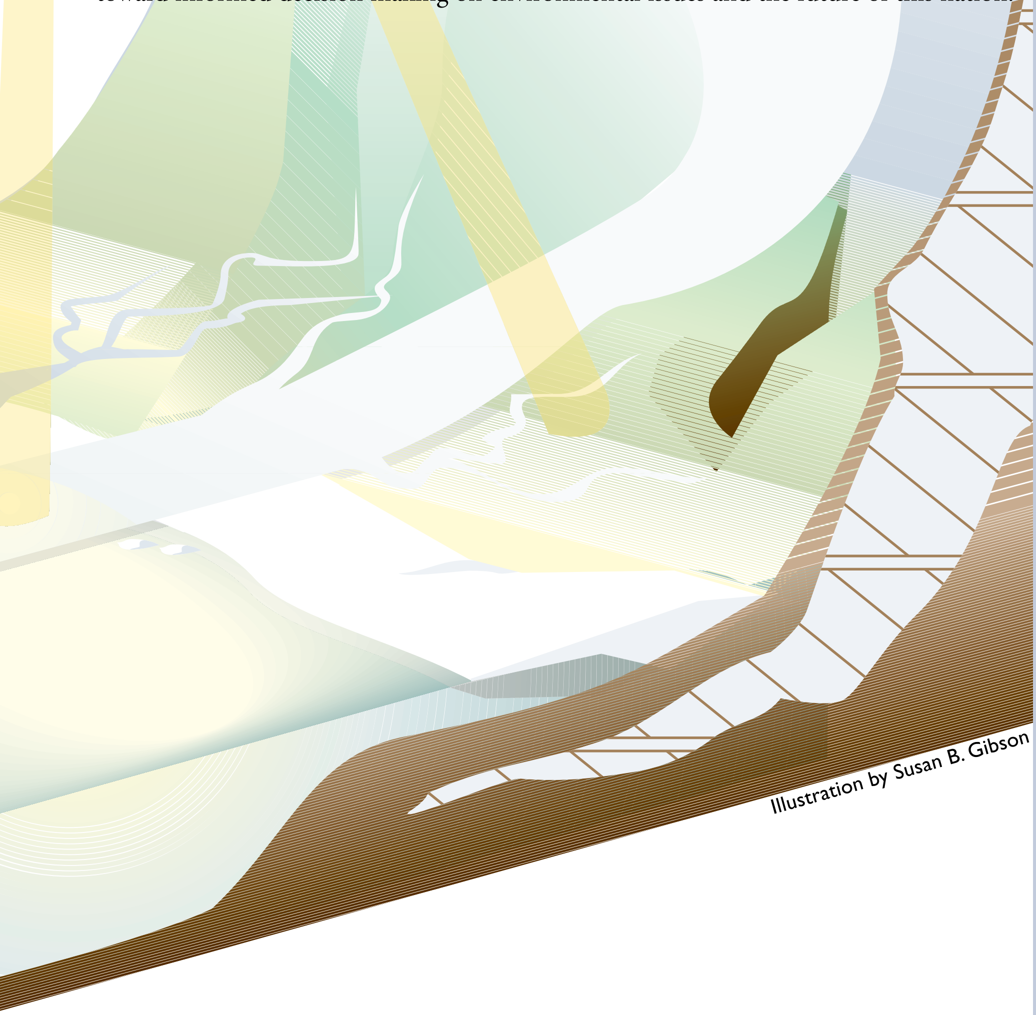


Illustration by Susan B. Gibson

What is "System Science"?

Because the Earth is an integrated system of interacting components, environmental research requires a systems perspective—relating discoveries across fields of science to explain the processes and interactions among the air, water, earth, ice, plants, animals, and people of a region.

Understanding these complex interactions at the scale of the Arctic system requires organized multidisciplinary research. ARCSS scientists from diverse disciplines are using the systems approach to environmental science to study perplexing problems such as global change. This requires focused scientific strategies to bring collaborating individuals together, comparing their information to develop an integrated understanding of intricate and dynamic systems. The eventual goal of this approach is to be able to assess the sensitivity of and predict the future behavior of environmental systems to change.

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ARCSS has several linked ongoing components. ***Ocean-Atmosphere-Ice Interactions*** *and* ***Land-Atmosphere-Ice Interactions*** *investigate modern interactions and processes.* ***Paleoenvironmental Arctic Sciences*** *studies records of past climate change in the Arctic.* ***Human Dimensions of the Arctic System*** *considers human activity as an integral part of the whole arctic system, both as a vital driver of climate change and as a link among the terrestrial, marine, and climate subsystems. ARCSS also supports integrating research results across components and projects through* ***Synthesis, Integration and Modeling Studies.***

Because of the improved understanding of the arctic system developed through the initial ARCSS research projects, investigators now are able to work on ***more complex questions*** *about the interrelationships among components of the arctic system and the relationship of the arctic system to the Earth system. ARCSS plans to investigate the following* ***major questions*** *(1–4) over the next few years:*

1 How and why does the arctic climate system change, and how much does it vary naturally?

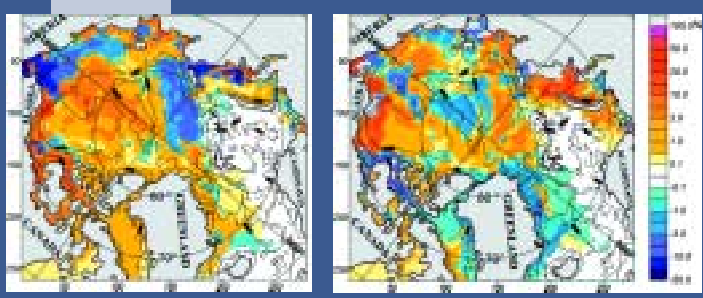
As one step toward explaining the current arctic climate and predicting future changes, we need to understand variations in the past climate. Describing the range of natural environmental variability, including major climate events such as ice ages, will help evaluate the sensitivity of the Arctic to both natural and human-caused forces. In 1993, ARCSS researchers completed drilling of a 3,000-meter-long ice core from the Greenland ice sheet, a high-resolution record of the Earth's climate and atmosphere over the last 110,000 years. Contrary to previous ideas of the stability of the Earth's climate, the core established that major climate changes can occur rapidly, shifting from one climate mode to another over decades, rather than centuries. With perspectives gained from the Greenland ice core and extended by other studies, ARCSS researchers now seek to answer questions such as:

How do interactions among the Arctic Ocean, sea ice, and the atmosphere affect the global climate system?

The ice and snow of the Arctic reflects five to 10 times as much of the sun's energy as does the open ocean. Evidence already indicates that sea-ice extent has decreased dramatically in the last 30 years, and these changes in reflectivity (and associated changes in cloud formation and extent) will affect how much of the sun's radiation is retained as heat and how much is reflected back to space. As their understanding of the importance of cloud processes has grown, scientists have realized that new measurements of sea-ice thickness and distribution, ocean circulation, cloudiness, radiation, and snow cover are needed. Integrating these measurements into models of the interactions between global and arctic climate will help us to understand contemporary processes and predict future climate change.

How will feedback processes within the arctic system influence global climate change?

Strong evidence suggests that feedback processes will amplify warming in the Arctic and impact the global climate. For example, thawing of permafrost allows decomposition of frozen organic material and releases greenhouse gases. This increase in greenhouse gases further increases temperatures and thaws more permafrost. Similar feedback loops involving clouds, ocean, snow and ice, terrestrial vegetation, and greenhouse gases produced and stored by arctic tundra, marine sediments, and permafrost may either mitigate or strengthen the impacts of regional and global climate change.



Wieslaw Maslowski

Observations and models of the surface layers of the Arctic Ocean indicate a significant increase in concentrations of fresh or lower salinity water (red and yellow) in the Makarov and Canada Basins between the 1980s and early 1990s (left). Models predict a shift of fresh water back into the Eurasian Basin (right) between 1993 and 1998, which may affect global ocean circulation and, thus, arctic and global climate (Maslowski et al., *2000, submitted to* Annals of Glaciology).

Richard Alley

The drill dome for the Greenland Ice Sheet Program 2 (GISP2) at Summit, Greenland

How are water and nutrients transported in the Arctic and around the globe?

Leaf litter and other detritus decompose very slowly in cold arctic soils and waters. In many areas of the Arctic, the detritus builds up to form thick, organic-rich soils that hold tremendous amounts of carbon. ARCSS research has shown that as the Arctic has warmed in recent years, decomposition has accelerated. The enhanced breakdown of trapped organic matter releases the greenhouse gases carbon dioxide and methane, changing the Arctic from a carbon "sink" (more carbon enters the terrestrial ecosystem than leaves it) to a carbon "source" (a region that produces a net emission of greenhouse gases). Different areas produce different amounts of greenhouse gases, depending on factors such as the moisture content, temperature, dominant vegetation, snow cover, and soil nutrients, all of which are affected by climate change. A detailed understanding of the interactions among nutrients, carbon dioxide, methane, water, and energy will be needed to address other challenging questions:

What changes will occur in arctic hydrologic and biogeochemical systems, and what will be their effects?

We know that the biological processes that control the release or uptake of carbon dioxide and methane and the cycling of nutrients and other elements depend on the amount of water available. We don't fully understand the mechanisms and the interaction of these processes or how they will be affected by changing climate. Warming in the Arctic may bring more precipitation, increasing runoff and changing salinity, stratification, and circulation of the Arctic Ocean. Warming is already increasing river bank and coastal erosion into the Arctic Ocean, transferring nutrients from the land to the continental shelves. Ongoing data collection and analyses and continuously refined models will improve predictions of change in arctic ice, water, and biogeochemical cycles.

How are freshwater, ice, and other tracers transported and transformed in the Arctic Ocean?

The Arctic Ocean differs from other oceans because it supports a sea ice cover and is primarily stratified by salt rather than by temperature. Its vast continental shelves, where most of the air-sea exchanges occur, also receive a disproportionate amount of freshwater from large rivers in Siberia and elsewhere. The Arctic Ocean flows into and mixes with the waters of the North Atlantic. Here, cold, salty water sinks down, driving a global ocean circulation "conveyor belt" that redistributes heat around the planet. Increased freshwater from the Arctic flowing into the North Atlantic could shut off the conveyor belt, with far-reaching consequences for global climate, including drastic cooling of northern Europe and further warming of mid-latitudes. Predicting such changes will require more information about the interdependent processes of precipitation, river runoff, sea ice, and ocean circulation in the Arctic Basin, and the synthesis of research results using coupled ocean-atmosphere-ice models.

D.A. Walker

A change in the dominant vegetation in tundra ecosystems may affect caribou, a species important to subsistence economies across the Arctic.

SHEBA Project Office, University of Washington

The Canadian icebreaker Des Groseilliers *was deliberately frozen into the ice of the Arctic Ocean for an entire year as a research platform for the SHEBA project.*

How will the structure, function, and stability of arctic ecosystems be affected by global change?

Another set of ARCSS projects studies the response of individual plant species to simulated warming in a series of replicated experiments around the circumpolar Arctic. In general, the increased growth of tundra plants in response to warming decreases with time, suggesting that factors such as nutrient availability also constrain growth in these ecosystems. As plants and animals interact with increasing carbon dioxide and ultraviolet radiation, and altered nutrients in soils and waters, the ecosystems they live in will be altered:

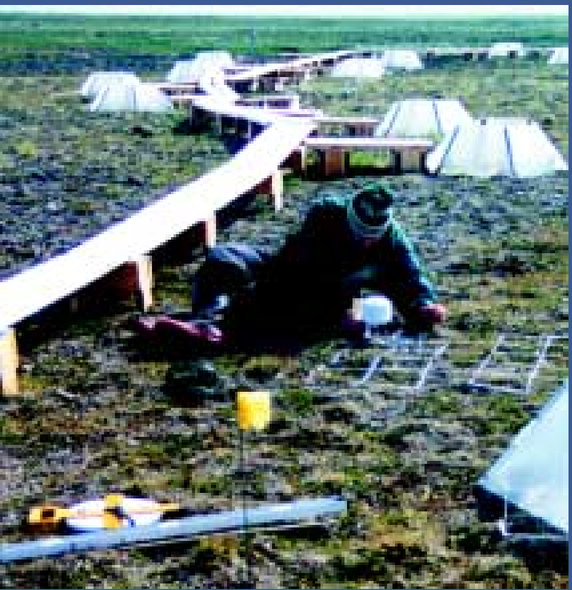
What changes will occur in arctic plant and animal communities and ecosystems, and what effect will these changes have?

The transitional zone between tundra and boreal forest is narrow; with past climate warming, tundra ecosystems have given way to forest, causing changes in distribution of animal species. Major increases in northern forests may also affect climate by increasing the land's capture of solar radiation. Increased tree growth may absorb carbon dioxide. Understanding these interactions well enough to predict them will require longer term observations, carefully controlled experiments, and ecosystem modeling.

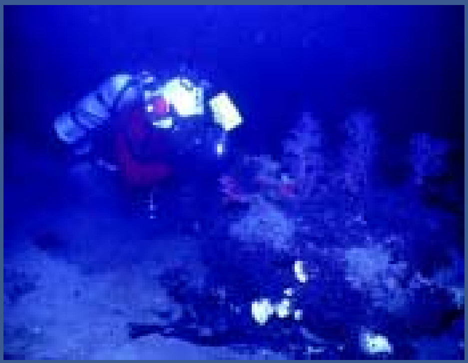
How will the ecosystems of the Arctic Ocean and its adjacent seas change during the next 100 years, and what will be the effects of these changes?

For most of the year, arctic sea-ice cover limits the light available to the tiny plants called phytoplankton that form the base of the food web. In summer, seasonal ice break up releases trapped nutrients, and increasing sunlight sparks a prodigious bloom of phytoplankton. This seasonal cycle of productivity is the basis for a complex but short food web—a web that includes economically important fisheries, marine mammals, and humans. Alterations in that web have implications far beyond the Arctic.

Changes observed in the Bering Sea in the last few years, for example, include abnormal plankton blooms, extreme die-offs of seabirds, and rapid decline in some fish and marine mammal populations. Arctic marine ecosystems appear to react to many different environmental variables in the atmosphere and the ocean, but overall, climate-driven variability is significant and difficult to predict.



Robert D. Hollister



Ken Dunton

Lee Cooper

Above: An undergraduate research project near Atqasuk, Alaska, is documenting the spatial variation in temperature within the small "greenhouses" used to simulate a warming of the tundra
Above right: A diver photographs soft corals, red algae, kelp, and sponges in a Beaufort Sea boulder patch kelp community
Above far right: Sampling for Melosira (diatoms) in the Arctic Ocean

Richard Caulfield

Hunters in Qeqertarsuaq, central West Greenland (Kalaallit Nunaat) go out in April on Disko Bay to catch seals, small whales, and waterfowl.

How will global change interact with human activity in the Arctic?

During the next five years, the ARCSS Program will work toward the following objectives:

- *develop a comprehensive understanding of current and past* ***environmental variability*** *in the Arctic by documenting changes and assessing possible mechanisms responsible for the observed variations;*
- *expand the scale of* ***quantitative environmental assessments*** *from the regional to the circumpolar;*
- *incorporate our knowledge into* ***predictive models*** *of climate and environmental change in the Arctic and assess the consequences of change on human activities;*
- *integrate our knowledge of the arctic system into models of* ***global and regional change;*** *and*
- *use models to characterize sensitivities and* ***identify vulnerabilities*** *in the climate system.*

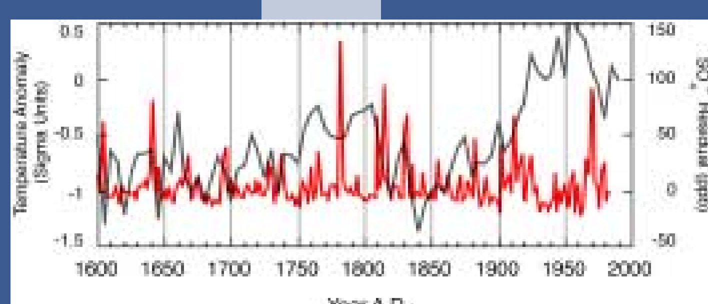
In one major effort to understand past climate and the role of human activities, ARCSS researchers integrated data from a variety of sources to create a combined picture of climate in the Arctic over the past 400 years. They found that the 19th century was anomalously cold, while the 20th century was warmer than any period since at least 1600. The researchers also estimated the effects of factors hypothesized to affect climate, including greenhouse gases, volcanic eruptions that contribute sulfate into the atmosphere, and solar activity. They found that warmer average arctic temperatures during much of the 1900s could not be explained by natural patterns of variability alone. After about 1920, greenhouse gases from human industry played an increasingly dominant role in the warming of the Arctic. The role of human activity in climate change in the Arctic and, conversely, the effects of global change on humans are important topics for future ARCSS Program investigations:

How will humans affect and be affected by changes in the arctic system?

Because human activities in the Arctic depend closely upon the environment, natural or human-caused changes are likely to have far-reaching social, cultural, and economic effects. In addition to change driven by seasonal extremes and variability, human activity within the region, such as large-scale oil development, alteration of fire regimes, or redirection of freshwater flow to the arctic basin are likely to have far-reaching and complex effects. These effects are not limited to the Arctic. For example, major Atlantic and Pacific fisheries depend on ocean conditions influenced by arctic processes, affected, in turn, by changes in climate. The human capacity to adapt and respond will be essential as people strive to accommodate exacerbated fluctuations and accelerating rates of change in their natural and social environments.

Henry Huntington

Industrial facilities at Norilsk, Russia, in 1995. Norilsk, in northern Siberia, is the world's largest point source of atmospheric pollution in the Arctic.



Synthesis of paleo records from across the Arctic. The black line shows temperature variation compared to a long-term average. The red line shows volcanic sulfate (SO_2), which should cause the climate to cool. The increase in temperature since 1920 cannot be explained by natural causes alone. (Overpeck, J., et al. *1997. Arctic Environmental Change of the Last Four Centuries.* Science *278: 1251–1256.)*

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