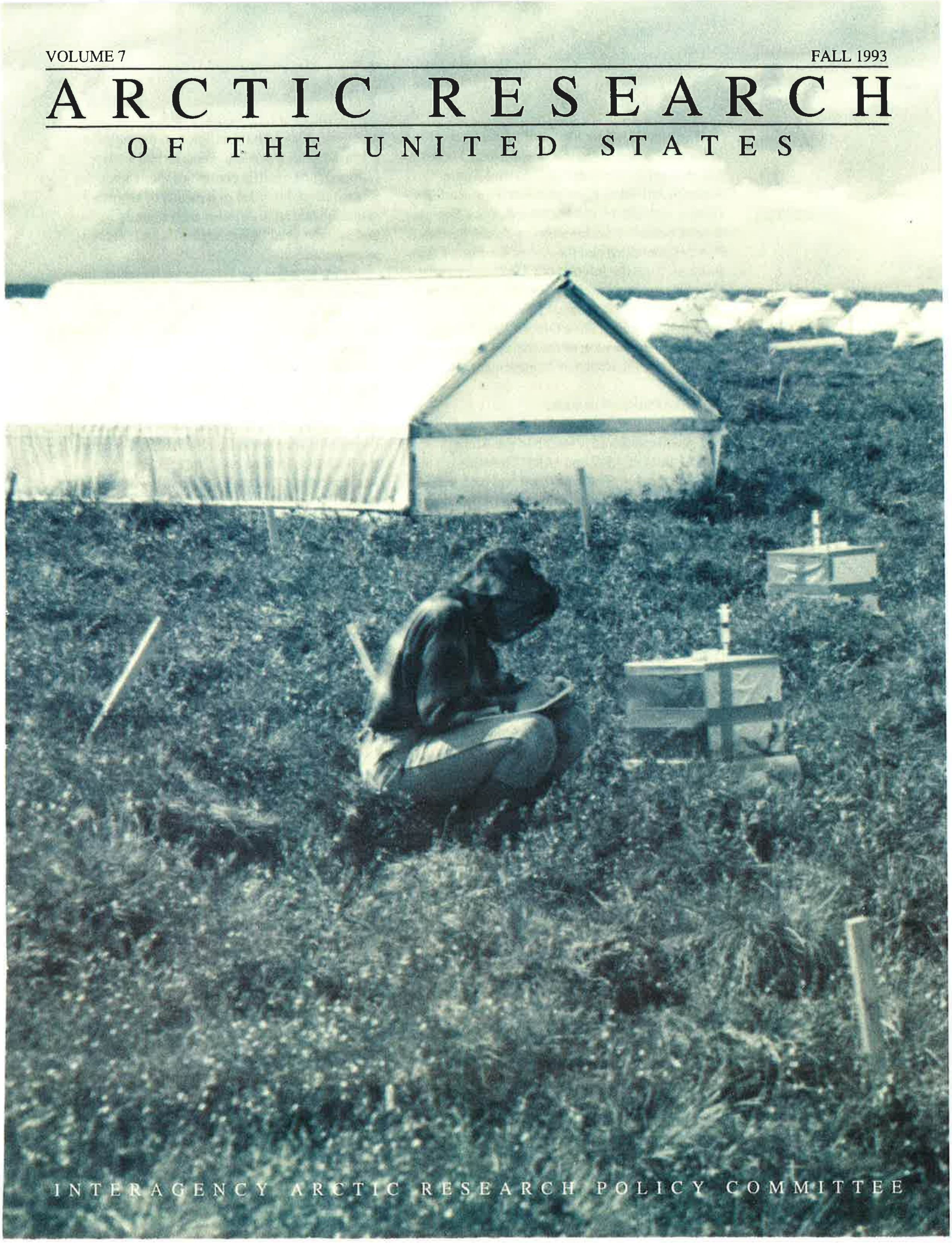
VOLUME 7 FALL 1993

ARCTIC RESEARCH
OF THE UNITED STATES



INTERAGENCY ARCTIC RESEARCH POLICY COMMITTEE

About the Journal

The journal *Arctic Research of the United States* is for people and organizations interested in learning about U.S. Government-financed Arctic research activities. It is published semi-annually (spring and fall) by the National Science Foundation on behalf of the Interagency Arctic Research Policy Committee and the Arctic Research Commission. Both the Interagency Committee and the Commission were authorized under the Arctic Research and Policy Act of 1984 (PL 98-373) and established by Executive Order 12501 (January 28, 1985). Publication of the journal has been approved by the Office of Management and Budget.

Arctic Research contains

- Reports on current and planned U.S. Government-sponsored research in the Arctic;
- Reports of ARC and IARPC meetings;
- Summaries of other current and planned Arctic research, including that of the State of Alaska, local governments, the private sector and other nations; and
- A calendar of forthcoming local, national and international meetings.

Arctic Research is aimed at national and international audiences of government officials, scientists, engineers, educators, private and public groups, and residents of the Arctic. The emphasis is on summary and survey articles covering U.S. Government-sponsored or -funded research rather than on technical reports, and the articles are intended to be comprehensible to a nontechnical audience. Although the articles go through the normal editorial process, manuscripts are not refereed for scientific content or merit since the journal is not intended as a means of reporting scientific research. Articles are generally invited and are reviewed by agency staffs and others as appropriate.

As indicated in the U.S. Arctic Research Plan, research is defined differently by different agencies. It may include basic and applied research, monitoring efforts, and other information-gathering activities. The definition of Arctic according to the ARPA is "all United States and foreign territory north of the Arctic Circle and all United States territory north and west of the boundary formed by the Porcupine, Yukon, and Kuskokwim Rivers; all contiguous seas, including the Arctic Ocean and the Beaufort, Bering, and Chukchi Seas; and the Aleutian chain." Areas outside of the boundary are discussed in the journal when considered relevant to the broader scope of Arctic research.

Issues of the journal will report on Arctic topics and activities. Included will be reports of conferences and workshops, university-based research and activities of state and local governments and public, private and resident organizations. Unsolicited nontechnical reports on research and related activities are welcome.

Address correspondence to Editor, *Arctic Research*, Office of Polar Programs, National Science Foundation, 4201 Wilson Boulevard, Arlington, Virginia 22230.

Cover

Measuring trace gas fluxes from tundra soils and vegetation near the Toolik Field Station in northern Alaska. The greenhouses in the background are used to manipulate air temperature and light over the tundra. These projects will help ecologists discover how an ecosystem will react to environmental change.

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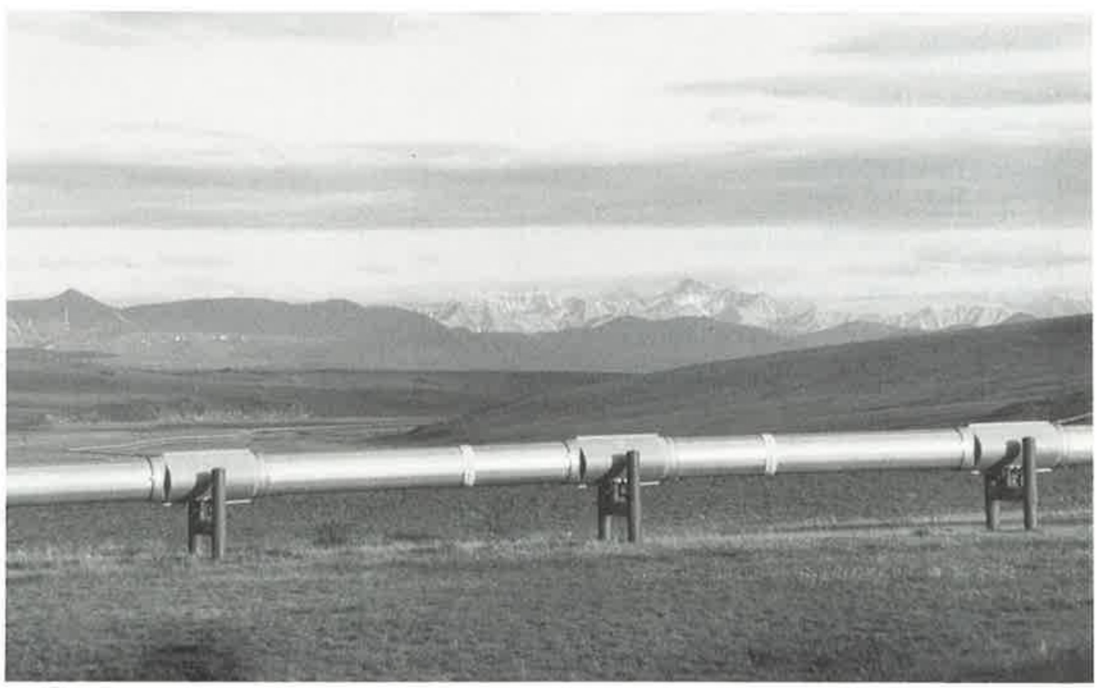
David W. Cate and Donna R. Valliere, Editors

Toolik Lake and surrounding landscape, which is typical of the foothills of the Brooks Range.



The Trans-Alaska Pipeline in the vicinity of Toolik Lake.

Arctic Ecosystem Response to Change

Research at the Toolik Lake Field Station in northern Alaska, a Long-Term Ecological Research (LTER) program site, is providing examples of how an ecosystem may be affected by environmental changes.

JOHN E. HOBBIE

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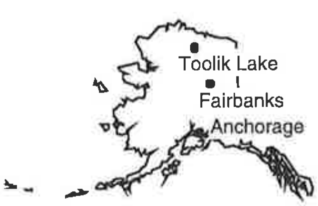
The Toolik Field Station of the University of Alaska is located in the northern foothills of the Brooks Range along the access corridor provided by the Alyeska Pipeline road. Since 1975 the Toolik Lake region has been the site of a continuing series of research projects on terrestrial and freshwater ecosystems. A number of these projects, sponsored by NSF's Office of Polar Programs and Division of Environmental Biology and by the Department of Energy, share the goal of discovering how Arctic ecosystems respond to change.

All ecosystems, not just those of the Arctic, continually encounter change in their environment. Human actions are now increasing the rate of many types of environmental change, ranging from climate change to nutrient additions. The challenge for ecologists who study ecosystems is now to predict how these systems will react to change. Will they be able to adapt? What amount of change is necessary before species will be lost? Under what conditions are functions of ecosystems lost? Will there be long-term changes in the types of ecosystems?



Various changes are now underway in terrestrial and freshwater environments worldwide. Climate change will change the temperature and precipitation of many areas of the world. This change will also affect the amount of water running off the land into streams and the transport of nutrients and organic matter into streams, lakes and oceans. Human activities add many materials, including sulfates, heavy metals, pesticides and nutrients, to the atmosphere, where they are transported for deposition far from the source. Human actions also change the land cover into farms or roads, directly add nutrients to waters, and change the populations of the larger animals by hunting and fishing.

Many of the changes work through effects on biologic and chemical processes. These processes, such as photosynthesis, predation and nutrient cycling in the soil, occur in all ecosystems. In other words, most processes are not unique to the Arctic. Instead they exist in a continuum of environmental conditions, with those in the Arctic often lying at one end of the continuum. While processes are controlled and interact differently in different ecosystems, there is a great deal of information about how processes respond to change that is transferable from a study in one ecosystem to the understanding of another.

Arctic ecosystems contain all the components, processes and interactions of any other ecosystem around the world. Yet they have certain characteristics that make them somewhat easier to study than many other ecosystems. For example, there are fewer species, there may be almost no grazing in some parts of the Arctic, and the dominant plants are low in stature and easy to measure. It is also relatively easy to carry out experiments on whole Arctic ecosystems. For these reasons the Arctic is an ideal location for ecosystem studies designed to investigate the rules and patterns underlying the responses to change of ecosystems.

Environmental Change in the Arctic

Various changes are now underway in the Arctic or may occur in the next several decades. Sustained global climate change is still difficult to separate from natural climate variability but is predicted to be greater in the Arctic than in other regions. Current predictions for the high latitudes (60–90°N) when the CO_2 has doubled are for a winter temperature change 2.0–2.4 times greater than the global average and a summer temperature change 0.5–0.7 times the global average. In other words, the winter increases will exceed the average global change and the summer increases will be somewhat less than the global average. Recent predictions by the Canadian Climate Center (CCC) general circulation model for expected temperatures in northern Alaska for a doubled CO_2 scenario are for a winter increase of 3–9°C and a summer increase of 2–5°C. Precipitation will likely be slightly greater in this region (95–110% of present).

Another type of change is the addition to Arctic ecosystems of chemicals such as sulfates, heavy metals and nutrients via airborne transport from

Changes in winter and summer temperatures and in precipitation simulated by the Canadian Climate Center global circulation model for a scenario of doubled CO_2. (After Maxwell 1992.)

	Winter		*Summer*	
	Temperature (°C)	*Precipitation (% of present)*	*Temperature (°C)*	*Precipitation (% of present)*
Arctic Islands	6–11	95–130	1–5	95–140
Northern Alaska	3–9	95–110	2–5	120–135
Lower Mackenzie	3–6	100–110	4–5	100–130
Keewatin	5.5–8	90–130	4–5.5	100–140
Eastern Arctic	6–11	90–125	2–5	100–140
Greenland	5–10	100–120*	3–7	100–120*
Finland and European Russia	4–8	110–120*	3–5	95–110*
Northcentral Russia	6–8	95–120*	2–6	90–130*
Northeastern Siberia	8–10	95–110*	2–8	100–140*
Arctic Basin	10–13	95–120*	0–2	95–150*

* Estimated.

lower latitudes. If ozone continues to be reduced, there will be a resultant increase in the amount of UV-B solar radiation. Land-use changes will also occur, and ecosystems will be affected by roads, by loss of actual area and by changes in drainage or water runoff caused by road or town construction. Mining and petroleum extraction also have the potential for pollution. Humans continue to change the populations of animals in Arctic ecosystems.

The climate change may affect many parts of the Arctic ecosystem. One important effect may be an increase in the length of the unfrozen period. There may be increases in microbial activity in the soil as the temperature increases or as the permafrost retreats farther beneath the surface. This activity, plus the increase in the amount of soil available to the plant roots, is likely to make more nutrients available to plants and result in changes in plant species and productivity. If there are changes in the permafrost and in the amount of precipitation, then the area of wet tundra soils will change, with eventual changes in the release of the greenhouse gases (carbon dioxide and methane) to the atmosphere.

The increasing road and pipeline network in the Arctic is only a part of the direct human influence. Roads block drainage in the foothills and coastal plain and create new wetlands. Road dust changes the chemistry of nearby soils and causes early snowmelt in the surrounding tundra. Roads also provide access for fishermen and for hunters of caribou and wolves. Changes in grazers, such as caribou, will influence the plants, while removal of the large lake trout has the capacity for changing the structure of the entire food web of lakes. Finally, the increase in population and improved sanitation of villages has the potential for adding nutrients to soil and stream waters.

Whole-System Approach to Research on Ecosystem Change

One approach to studying the effects of change is to measure in the laboratory the response of each species to various changes. When these studies are completed, however, the question remains of the response of these species when they are embedded in an ecosystem, where the ecosystem processes interact, adapt and often cause quite unexpected results. The approach taken at Toolik Lake is to study the response of a whole system to environmental change; an experiment is conducted with a whole ecosystem and with introduced changes to simulate a large-scale stress. The Toolik Lake area provides a variety of habitats for experimentation, including small lakes for fertilization and lake trout manipulations, streams for grayling manipulations and fertilization additions, and a variety of types of tundra for heat, shade and fertilization experiments.

Terrestrial Ecosystem Responses

Toolik Lake lies in the northern foothills of the Brooks Range at an elevation of 760 m, where the climate is typical of low Arctic regions. The mean annual air temperature is about –7°C, and 50% of the 20–40 cm of precipitation falls as snow. The sun is continuously above the horizon from mid-May to late July. The snow-free season lasts from late May to mid-September, with below-freezing temperatures possible at any time. The entire region is underlain by continuous permafrost, which exerts a major influence on the distribution, structure and function of terrestrial and aquatic ecosystems. Tussock tundra is the dominant vegetation form, but there are extensive areas of drier heath tundra on ridgetops and other well-drained sites, as well as areas of river-bottom willow communities.

Whole-system experiments in terrestrial ecosystems have focused on the question: How will tundra ecosystems change when the air temperature, amount of light or amount of available nutrients changes as a result of climate change or disturbance? To answer this we manipulated air temperatures on our experimental plots by placing small greenhouses made of wood and plastic sheeting over the tundra during the summer months. Light intensity was manipulated with shading, and nutrient increases were simulated by adding nitrogen and phosphorus fertilizer. Experiments have been run continuously for nine years. The greenhouses increased the average air temperature from a mean of 11.2°C to 14.7°. The soil temperature at 20 cm increased to 5.8°C in the greenhouses from 3.6° in the control plot, while the thaw depth of the soil changed from 38 cm in the control plot to 43 cm in the greenhouses.

After three years the fertilizer treatment was the only one that significantly affected primary productivity: there was an increase of 20–25%. The effect of fertilizer on productivity was the same whether or not the plants were in a greenhouse. However, in the fertilizer-only treatment most of the response was due to increased productivity of grasses and sedges ("graminoids"), while in the fertilizer-plus-greenhouse treatment deciduous shrubs (mostly dwarf birch) were most productive. After nine years the productivity in both fertilized plots was dominated by dwarf birch. One conclusion from this experiment is that productivity is controlled primarily by nutrient supply, while the species composition is controlled by other factors, including nutrients, temperature and light. Although productivity increased slightly in the greenhouse-only treatment, this probably resulted from increased soil temperatures and nutrient decomposition to inorganic nitrogen and phosphorus.

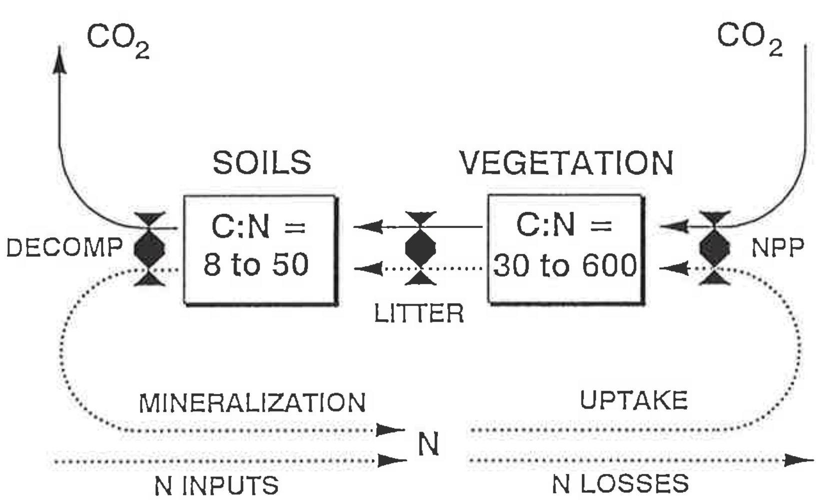
Another type of whole-system experiment directly addressed the question of the effect of a doubled CO_2 concentration in the atmosphere on the carbon storage of tundra. Walter Oechel used small transparent chambers to double the CO_2 and control the temperature on a plot near Toolik Lake. He found a strong initial increase in net carbon accumulation, reflecting the initial photosynthetic response to increased CO_2 concentration. However, after three summers the whole system had acclimated to the high CO_2, and the accumulation rates in the high-CO_2 experiments had declined to the same rates as the control.

The effect of the interactions between factors on net carbon storage in the whole ecosystem has been studied in only one experiment. Dwight Billings collected frozen soil and vegetation cores from wet sedge tundra and carried out experiments on the thawed cores for a simulated growing season in the Duke University phytotron. Initially the same photosynthetic response occurred in the high-CO_2 treatment as in Oechel's field experiments, and acclimation took nine weeks. Nitrogen addition caused a shift from a small net carbon loss to a large storage of carbon during one simulated growing season.

An interpretation of the results of all the whole-system experiments on the carbon and nutrient cycling have been summarized in a conceptual model. This model shows two main pools of organic matter in this tundra system: the vegetation and the soil organic matter. Carbon enters vegetation from the CO_2 in the atmosphere and is transferred to the soil as litter. Decomposition of soil carbon eventually returns the CO_2 to the atmosphere. Nitrogen enters the ecosystem by atmospheric deposition, nitrogen fixation or lateral transport in soil water or drifting snow. Soil nitrogen is taken up by the vegetation and is returned to the soil in litter. The soil organic nitrogen is mineralized to inorganic nitrogen, which is then taken up again by plants. This cycling of nitrogen between soil nitrogen and plants accounts for most of the nitrogen taken up by the plants in the Arctic, as well as in ecosystems throughout the earth.

In this model, links between the carbon and the nitrogen cycles are indicated by "bow ties." The first occurs when the net primary productivity of plants uses both carbon and nitrogen to make organic matter. This organic matter, composed of both carbon and nitrogen, then is passed on to the soil as litter (litter bow tie). During the process of decomposition, carbon is lost as CO_2 and the nitrogen is mineralized (decomp bow tie). The basic idea is that all pools and fluxes of organic matter must contain both carbon and nitrogen.

Because of these relationships and because nitrogen is in short supply in the tundra (as shown by the tundra response to fertilizer), the supply of nitrogen is a major bottleneck to the accumulation of plant biomass. When the CO_2 concentration of the atmosphere is increased, there can only be increased storage of carbon if there are increased amounts of nitrogen in forms that are available for plant uptake.



A conceptual model of the links between the cycles of carbon (solid arrows) and nitrogen (dotted arrows) in terrestrial ecosystems. Transfer of carbon dioxide (CO_2) into vegetation is mediated by the process of net primary production (NPP). This uptake of carbon is closely tied to the uptake of inorganic nitrogen from the soil. Both carbon and nitrogen enter the soil as litter. Carbon is given off from soils as CO_2 through the process of decomposition (DECOMP); the nitrogen associated with it is transformed (mineralized) from organic to inorganic form, thus becoming available to plants. The C:N ratios (weight of carbon per unit weight of nitrogen) shown represent the range of values characteristic of soils and vegetation in terrestrial ecosystems.

Lake Ecosystem Responses

Toolik Lake has a surface area of 150 ha and a maximum depth of 25 m. The ice thickness reaches 1.5 m, and the ice cover lasts from early October until mid- to late June. The lake stratifies in the summer, and the surface temperatures may reach 18°C during warm summers. Because of the low input of nutrients in the streams, the lake is oligotrophic. Lake trout, sculpin and grayling are the dominant fish.

Toolik Lake and the numerous small nearby lakes share the same general chemistry and biology. For this reason a whole lake can be used as an experimental subject, and the results of changing a control or stress will apply to many lakes. One key control of aquatic ecosystems is the amount of phosphorus and nitrogen entering a lake each year; this quantity controls the algal primary productivity, which in turn controls much of the structure and function of the entire ecosystem. This amount might well change if the air temperature changes in the Arctic. Temperature regulates weathering rates, decomposition and thaw depth in terrestrial ecosystem, all of which alter the flux of nutrients through terrestrial ecosystems and into lakes.

In one series of experiments we have tested the response of Arctic lakes to phosphorus and nitrogen addition. In this experiment a plastic and fiberglass curtain was stretched across a small lake, and fertilizer was added continuously during the summer to the downstream side. While the curtain was not watertight, most of the fertilizer stayed on one side. The experimental addition continued for six summers from 1985 to 1990.

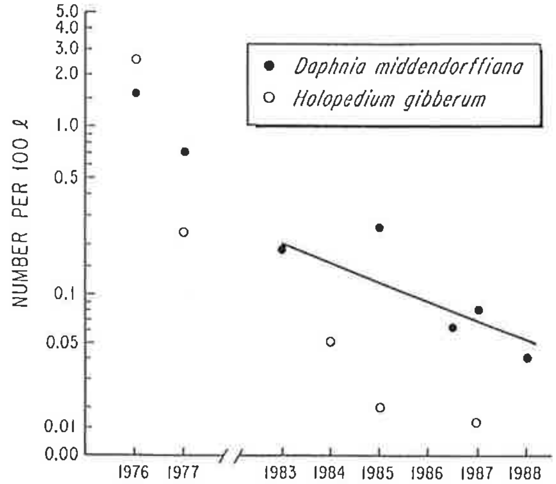
The added phosphorus caused a dramatic increase in the amount of algal primary production (photosynthesis) in the plankton. This increase in photosynthesis, typical of all lakes throughout the world, was about five times greater in the experimental section of the lake than in the control, reflecting the five-fold increase in the nutrients. What was unexpected was the fate of the phosphorus; over each winter it all became inextricably bound to the iron-rich sediments. Even after five summers of fertilization, all of the phosphorus was tied up in the sediments each spring, even though the water beneath the ice sheet was partially anaerobic. Eventually there has to be a threshold limit for phosphorus binding; this will occur when the sediment iron that is accessible becomes used up. In our experimental lake this may have occurred in 1990, as evidenced by the spring bloom of algae before the summer fertilization began.

The response of the experimental lake to phosphorus addition was slow, and it was buffered to some degree by the binding of phosphorus to the sediments. The same process should allow for a rapid recovery after the fertilization is ended. The recovery experiment is now underway in the experimental lake.

Another question addressed in this project is: What is the effect of changes in abundance of lake trout, the top predator of these ecosystems? It is well known from temperate lakes that these top predators control the abundance and species of organisms below them in the food web. This is the so-called "top-down" control of communities. Rapid changes in the top predator fishes in Arctic streams and lakes are caused by sport and sustenance fishing of these large fish when roads are built and human populations increase on the North Slope.

Our longest record of change due to fish removal comes from Toolik Lake, where increased fishing pressure during the last 15 years has had dramatic effects on the size structure and composition of fish populations. The average lake trout size declined from 578 g in 1977 to 318 g in 1986, and grayling moved from close to shore into the open water because of reduced lake trout predation. As a consequence of more zooplankton-eating grayling in the open water, large-bodied zooplankton species have decreased dramatically from 1975 to 1992. One, a predaceous copepod, decreased by a factor of two, while two cladocerans decreased by factors of 50 and 200. There is evidence that, in turn, the predatory *Heterocope* controls the abundance of small-bodied zooplankton. The smaller zooplankton in Toolik Lake still seem to be facing severe predation pressure because two smaller species decrease in abundance throughout the summer, whereas in other lakes in the area, which lack *Heterocope*, populations of these two species increase throughout the summer.

Experimental lake near Toolik Lake. A plastic and fiberglass curtain is being stretched across the lake so that nutrients can be added to one half of the lake while the other half serves as a control.



The abundance of large-bodied zooplankton in Toolik Lake from 1976 to 1988.

To investigate the higher trophic levels and their controls on populations below them, we have been monitoring and experimentally manipulating a series of other lakes. The experimental manipulations of top predator populations include a slow removal of lake trout from one lake, a fast removal of lake trout from Lake NE-12, and the introduction of lake trout to a third lake. The most striking result so far is a change in the distribution of the bottom-dwelling sculpin and predaceous burbot in response to complete removal of lake trout from Lake NE-12. We had expected that in the absence of predation pressure, sculpin would move away from the rocky shallows and out onto the soft sediment, where food is more available. Instead, sculpin moved even more toward the rocky shallows after the lake trout were removed. We also measured a large number of burbot moving from deep in the lake, where they can most easily avoid predation by lake trout, into the nearshore zones. This large increase in burbot in the shallows drove the sculpin away from the soft, exposed sediment. Apparently the control of sculpin by burbot predation is even stronger than was the control of sculpin by lake trout.

This fish manipulation study illustrates the high potential for an ecosystem response to changes in lakes. It also illustrates the amount of time necessary to carry out whole-system experiments in the Arctic. Even after five years the populations are still changing because of the slow rate of growth of the lake trout and burbot.

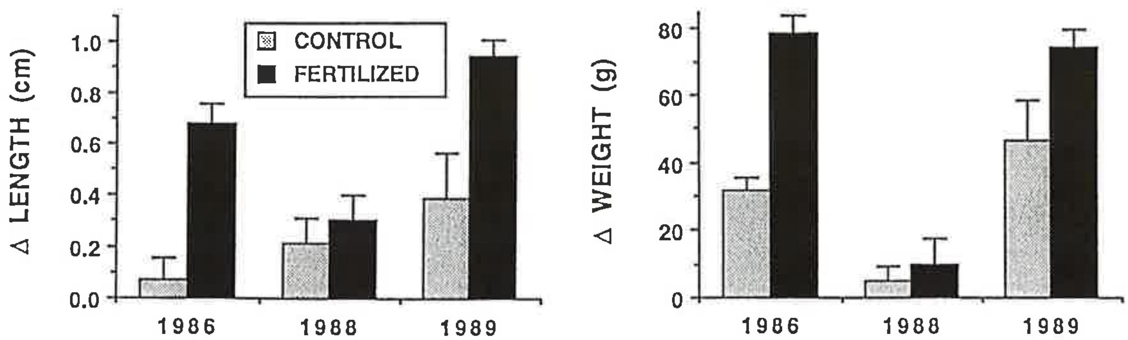
Stream Ecosystem Responses

The primary focus of the streams research is the Kuparuk River, a fourth-order stream where it crosses the Dalton Highway about 10 km northeast of Toolik Lake. The watershed above the road crossing is 143 km^2. The river is oligotrophic and contains but one species of fish, the Arctic grayling. Flow commences with spring runoff in mid- to late May and ends in late September to early October, when the river riffles dry up and the pools freeze completely.

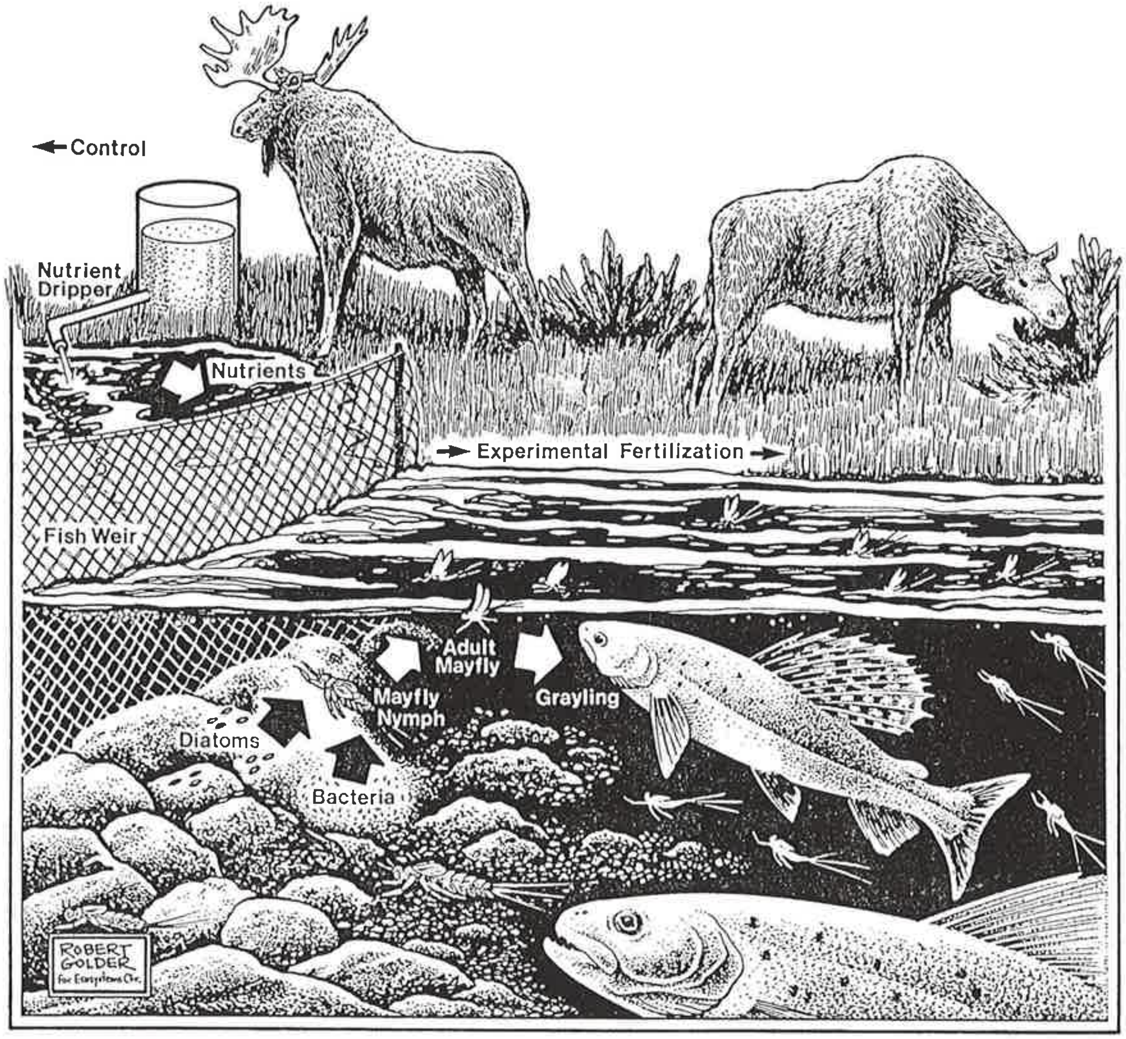
In the Kuparuk River we have carried out experiments to answer the question: What is the response of an Arctic river ecosystem to fertilization? Phosphorus was known from bioassay studies to be the key nutrient in the Kuparuk River. Beginning in 1983, phosphoric acid has been added to the river for six weeks each summer by continuous dripping. The amount added increased the phosphorus concentration tenfold over the mean of 1 part per billion of reactive dissolved phosphorus. An experiment in the river consists of an upstream control section, the nutrient dripper and several fish weirs of plastic mesh that hold grayling in a control or in fertilized sections of the river.

The sequence of responses that we have measured over the past ten years is as follows. Dissolved phosphate added to river water stimulated the growth of the diatoms and other algae growing on the stream rocks. The increased growth resulted in high amounts of algal chlorophyll in the 1983 and 1984 experiments. By 1985 and 1986, however, the insect larvae had increased in the river and consumed the production as unicellular algae (diatoms) as soon as photosynthesis occurred; the algal biomass did not increase in these years. Increases in algal production led to sloughing and export of algal biomass and increased excretion and mortality. Increased algal excretion and mortality stimulated bacterial activity, which was also stimulated directly by phosphorus addition. Increased bacterial activity and biomass made possible an increase in the rate of decomposition of refractory compounds such as lignocellulose and many components of the dissolved organic matter pool.

The increases in algal and bacterial biomass provided increased high-quality food for filtering and



Increased growth of adult Arctic grayling caused by the fertilization of the Kuparuk River. The data indicate the change in length and weight over the summer for fish held in control and fertilized sections of the river.



A whole system experiment on the Kuparuk River, including the continuous addition of phosphorus to the river and the use of fish weirs to isolate grayling in control and fertilized reaches of the river.

grazing insects such as mayflies. The insects responded with increased growth rate and, in the case of mayflies and caddis flies, with increases in density. However, the blackfly density in the fertilized reach declined due to competitive interaction with caddis flies. The increases in insects other than blackflies increased the available food for grayling; both young-of-the-year and adult grayling grew faster and achieved better condition in the fertilized reach. There was also a relationship between the river flow and the growth of adult grayling; growth was least in the drought year of 1990. In the long-term, if the experimental nutrient addition were expanded to include the whole river and barring other overriding but unknown population controls, we hypothesize that the fish population would increase. If so, it is possible that predation by fish would exert increased top-down control over insects such as mayflies or caddis flies, which are vulnerable to fish predation when drifting and emerging. Experimental evidence from bioassays using insecticides indicated that grazing insects control algal biomass. Finally, increases in epilithic algae and bacteria were responsible in part for uptake of added phosphorus and ammonium and for increased uptake of naturally abundant nitrate. Thus, the bottom-up effects of added nutrients were paralleled by several top-down effects of fish on insects, insects on insects, insects on algae, and algae on dissolved nutrient levels.

In summary, the entire biological system in the river is responsive to added phosphorus. The bottom-up effects propagate to all levels in the food web. Also, both top-down effects and competitive interactions are clearly important in the response of the ecosystem to fertilization.

Conclusions

The research at Toolik Lake reported here has made use of whole-ecosystem manipulations of temperature, nutrients and animals to investigate the possible effects of various environmental changes in the Arctic. Most of these changes, such as climate and nutrient deposition changes, have not yet occurred in the general environment of Toolik Lake as far as can be determined. Predictions of various effects are needed, however, to inform managers of the Arctic and global environments of consequences of various alternative actions or non-actions.

The ecosystems near the Toolik Lake research site are ideal for ecosystem experimentation. They are pristine for the most part, so unimpacted control systems are available (for example, the upstream sections of experimental rivers, lakes with the natural populations of large fish, tundra areas receiving very little atmospheric deposition of acid or nutrients). Human influences are now so prevalent throughout the world that it is often difficult to find suitable control ecosystems.

The same experiments serve applied and basic goals. Thus, they provide valuable information about the basic processes that control Arctic ecosystems, including photosynthesis, nutrient cycling and predator–prey interactions. This information forms the base of our understanding of Arctic ecosystems. The same processes are found in ecosystems worldwide, and research is now underway to develop generic, universal mathematical models that will apply to many types of ecosystems, including those of the Arctic. The type of research carried out at Toolik Lake has produced information about these various processes and how they operate and are limited at one extreme of the ranges of temperature, nutrient availability and the like.

Our results also show that the response of the terrestrial ecosystem to changes is more linked to the availability of nutrients than to small changes in temperature. Nitrogen could become more available through atmospheric deposition or through a change in the depth to permafrost, which would increase the depth of soil available to plant roots. An increase in plant productivity is an expected response, as is a change in the relative abundance of species already present in the plant community. For example, the experiments indicate a shift from dominance by sedges and grasses to dominance by birch as a result of increased nutrients and increased soil heating. If CO_2 increases, then the response of the plants will be also regulated by the availability of nitrogen. Increased sequestration of carbon in vegetation and soils will happen only if additional nitrogen becomes available from atmospheric deposition or from increased decomposition associated with soil warming and permafrost thawing.

The response of Arctic lakes and ponds to change was tested in two ways: response to increased nutrients and response to changes in the top predators, the lake trout. We found that small lakes were quite well buffered when nutrient inputs were increased. There was a rapid, one-season response of increased algal production, but the added phosphorous then became trapped by iron in the lake sediments. It took five years of fertilization in an experimental lake, at a rate five times the natural rate of phosphorus addition, for the phosphorus to remain in solution in the early spring and thus contribute to a lasting enrichment. In contrast, the animal communities responded dramatically to small changes in the abundance of lake trout. For example, as a likely result of increased fishing, several species of zooplankton in Toolik Lake have become virtually extinct over 15 years.

Stream experiments mainly tested responses to changes in nutrients. The response was difficult to quantify because of interactions within the ecosystem, but in the first several years there was an increase in production with little change in the species involved. For example, the response of algal growth to added phosphorus was masked after two years by an increase in grazing by larval insects. The nutrient additions did, however, translate into a striking increase in growth of the only fish in the stream, the Arctic grayling.

Publications

Readers may obtain information on some of the research described in this article from the following publications:

Arctic Climate: Potential for Change under Global Warming, by B. Maxwell: In *Arctic Ecosystems in a Changing Climate* (F.S. Chapin III, J.F. Reynolds, R.L. Jefferies, G.R. Shaver, J. Svoboda and E.W. Chu, Ed.), Academic Press, New York, p. 11–34, 1992.

Effects of Global Change on the Carbon Balance of Arctic Plants and Ecosystems, by W.C. Oechel and W.D. Billings: In *Arctic Ecosystems in a Changing Climate* (F.S. Chapin III, J.F. Reynolds, R.L. Jefferies, G.R. Shaver, J. Svoboda and E.W. Chu, Ed.), Academic Press, New York, p. 139–168, 1992.

Global Change and the Carbon Balance of Arctic Ecosystems, by G.R. Shaver, W.D. Billings, F.S. Chapin III, A.E. Giblin, K.J. Nadelhoffer, W.C. Oechel and E. B. Rastetter: BioScience, vol. 42, p. 433–441, 1992.

Long-Term Ecological Research at the Bonanza Creek Experimental Forest

Tbe Bonanza Creek Experimental Forest is one of two locations in Alaska that are part of the national network of 19 Long-Term Ecological Research (LTER) program sites.

KEITH VAN CLEVE AND LESLIE A. VIERECK

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Interior Alaskan forests are part of a circumpolar band of boreal forest. In interior Alaska these forests are unique for their association with an environment characterized by drastic seasonal fluctuations in day length (more than 21 hours on June 21 and less than 3 hours on December 21) and temperature (extremes of –50°C in January and over 33°C in July), a short growing season (100 days or less), consistently low soil temperatures, low precipitation (287 mm, a third of which occurs as snow) and the occurrence of permafrost. Approximately 31%, or 42,800,000 ha, of the total 136,000,000 ha comprising interior Alaska is forested. Forest land considered to be of commercial value totals about 9,600,000 ha.

The Bonanza Creek Experimental Forest (BNZ) is located approximately 20 km southwest of Fairbanks along the Parks Highway. BNZ is within the Tanana Valley State Forest, a unit managed by the Division of Forestry, State of Alaska. The vegetation of BNZ is a mosaic of forest and non-forest types resulting from interactions of topography, soils, slope and aspect, elevation and fire history in the uplands, and on the floodplain, recent history of flooding and deposition. The vegetation in general corresponds to four broad topographical zones: upland hills and ridges, lowland toeslopes and valley bottoms, old Tanana River terraces, and the active Tanana River floodplain.

Representatives of each of the major forest types occurring in central Alaska are found in the Experimental Forest. The six principal tree species that occur on BNZ have ranges that extend across North America to more southerly latitudes in eastern Canada. The presence of black spruce, larch and bogs generally indicates the presence of permafrost. Quaking aspen and white spruce generally indicate permafrost-free conditions. Paper birch is common on both permafrost and permafrost-free sites. Balsam poplar develops in extensive stands on permafrost-free floodplains.

Because of the cold-dominated environment at this latitude, soil development has been minimal. Morphological descriptions and physical and chemical analyses show little chemical alteration of the parent material. In the uplands, soils are classified as inceptisols, while inceptisols and entisols are encountered on the floodplain. Floodplain soils are salt affected. They display high surface concentrations of calcium sulfate and calcium carbonate early in succession. Both salts arise through pedogenic processes, and the carbonate also arises from parent material weathering in the Alaska Range.

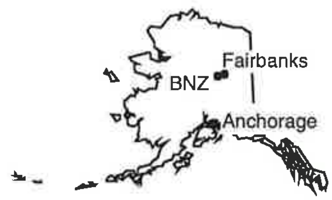
Site Characteristics

Interior Alaska is bounded on the south by the Alaska Range and on the north by the Brooks Range. The principal river system draining interior Alaska is the Yukon, and the river closely associated with our study area is the Tanana, which flows into the Yukon about 200 km below BNZ.

The Alaska Range is glacially sculptured and trends west and southwest 1000 km from the Canadian border to the Aleutian Range. It contains numerous peaks over 3000 m in elevation and culminates in Mt. McKinley at 6195 m. This mountain wall is an effective barrier to coastal air masses and is responsible for the continental climate experienced at BNZ.

The southern portion of the Yukon–Tanana Upland and adjacent Tanana River valley to the south is the location for our research activities at BNZ. The physiography and geology of this area include loess-mantled bedrock hills (the strongly weathered, Precambrian quartz–mica and quartzite schist of the Birch Creek formation), lower hill slopes and creek valley bottoms, organic-rich lowlands at the base of hills, and the Tanana River floodplain. The Tanana River valley is a large structural basin, and much of its bedrock floor is below sea level. Fluvial and glaciofluvial sediments, largely from the rising Alaska Range, have accumulated in deposits 91–230 m thick. These deposits have pushed the Tanana River northward, near the Yukon–Tanana Upland, as it flows through BNZ.

Central Alaska has not been glaciated, but small cirque glaciers occurred in local mountainous highlands. Glaciers from the Alaska Range approached to within 80 km of Fairbanks during extensive glacial expansions. In the general vicinity of BNZ, silt blown from the floodplain of the Tanana River was deposited as loess, blanketing ridges of the southern Yukon–Tanana Upland in deposits from a few centimeters thick on summits to more than 45 m on middle and lower slopes. The topography of the east-trending upland consists of rounded ridges 600–900 m in elevation with higher peaks projecting to between 1500 and 1800 m. The current tree line is at about 900 m.



Permafrost is discontinuous in the interior of Alaska and is continuous north of the continental divide in the Brooks Range. The permafrost is greater than 600 m thick in northern areas but is only one to several meters thick near its southern limits. In the vicinity of BNZ permafrost thickness ranges up to about 80 m on floodplains and 110 m in poorly drained lowlands.

In interior Alaska the permafrost distribution and active layer thickness (the portion of the soil profile that thaws and refreezes annually) are closely related to the topographic conditions of slope, aspect, drainage; the thermal properties of the parent material; and the vegetation. In BNZ the uplands, north aspects, valley bottoms and poorly drained lower slopes are generally underlain by permafrost. Well-drained south aspects and sediments adjacent to and beneath active river channels are permafrost-free.

Research Program Status

The principal objective of our research program is to conduct a long-term study of ecosystem structure and function by examining controls over successional processes in taiga forests of interior Alaska. The research assumes added significance at the far north location of our study site (64°N) in light of the potential for substantial temperature change in northern latitudes as a consequence of global warming.

Central Hypothesis

The pattern of succession is determined primarily by the initial soil physical and chemical environment of the site and by the life history traits of component species. The rate of successional change is determined by vegetation-caused changes in environment and ecosystem function. Our central hypothesis addresses the pattern and rate of succession and environmental controls of these phenomena. A combination of experiments and observations is used to document the changing nature of ecosystem controls during primary succession on river floodplains and during post-fire secondary succession in the uplands. The following aspects are emphasized:

- Vegetation change and demographic controls;
- Vegetation-caused changes in resources (moisture, temperature, light, nutrients) and standing crops of biomass and nutrients;
- Controls over the nutrient supply; and
- The role of herbivores as consumers and modifiers of succession.

Previous research enables us to identify a number of points along the successional trajectory that are of particular significance in the development of subarctic forests. We term these "turning points" to emphasize the fact that in relatively short time intervals critical changes in ecosystem structure are accompanied by functional changes that have far-reaching effects on ecosystem development. For example, the development of a complete ground cover of feather mosses is associated with soil cooling, consequent reduced organic matter decomposition, and slow rates of nutrient cycling. These turning points undoubtedly represent important changes in controls over ecosystem function and have been our primary criteria for choosing successional stages for intensive study.

- Hypothesis I: Change in species composition through succession is a function of life history traits modified by facilitative and competitive interactions.
- Hypothesis II: Vegetation-caused changes in resource (light, soil temperature, nutrients, and moisture) availability during succession control vegetation biomass, productivity, and organic matter and nutrient distribution.
- Hypothesis III: The availability of carbon accumulating on the forest floor as an energy supply for decomposer activity declines through succession, resulting in reduced rates of organic matter mineralization and a reduced supply of elements for plant growth.
- Hypothesis IV: Selective feeding by herbivores promotes replacement of palatable early successional species by unpalatable later successional species.

Research Design

Hypothesis I

Research to test this hypothesis has two principal thrusts:

- Life history and population studies; and
- Studies of facilitative and competitive interactions and physiological processes among the major plant species across successional stages.

In the former case, seed rain, buried seed stores and controls over seedling establishment, growth rate, mortality and longevity are being examined. An additional objective is to characterize the production and turnover of coarse and fine root biomass and assess the percentage of gross carbon fixation that is allocated to the growth and maintenance of coarse and fine roots. In the latter case, artificial communities were established to evaluate the long-term balance between facilitative and competitive interactions between alder and white spruce. During the initial five years of this research we can only examine seedling interactions. However, within 10–15 years we expect dense alder thickets to develop in which we can examine patterns of nitrogen accumulation and the impact of nitrogen accumulation on spruce saplings.

Hypothesis II

Research to test successional control of resource availability has the following principal thrusts:

- Contrasting the type of initiating disturbance for the successional sequence; and
- Examining vegetation response to change in resource availability.

To contrast the type of initiating disturbance, long-term successional change on sites recently disturbed by fire and logging is being examined. Fertilization treatments applied to selected plots on floodplain clearcuts will be used to assess nitrogen and phosphorus availability to recently planted floodplain species (white spruce, balsam poplar, aspen and thinleaf alder).

Vegetation response to changing resource availability is being examined using a series of nutrient availability treatments and a moisture deficit treatment in one turning point in both the floodplain and upland successional sequences. The nutrient availability treatments include sucrose, sawdust and nitrogen fertilizer applied separately on all replicates of the selected turning points. The moisture deficit treatment is applied to the turning point that represents the change from a hardwood-dominated canopy to a softwood-dominated canopy. Measurements to assess the impact of changing resource availability on plant growth include yearly diameter growth, foliage quantity and quality, litterfall quantity and quality, and fine root biomass and production.

Hypothesis III

Research to examine the successional control of forest floor carbon availability for microbial activity and, in turn, the element supply for plant use includes the following directions:

- Assessing the present organic structural and secondary chemical composition, as well as the inorganic element composition, of the forest floor in each of the upland and floodplain successional stages;
- Manipulating the substrate chemistry across the successional stages;
- Studying the influence of plant secondary chemicals on soil nitrogen dynamics; and
- Examining changes in microbial populations and their activity with succession.

The assessment of the present chemical composition of the forest floor will provide an indication of the change in decomposition and element loss for litter in the respective successional stages and will establish the time course for change in litter chemistry as the detrital materials approach the chemical composition of established forest floors. The control over decay and element recycling processes exerted by the organic chemical composition of the materials will be more clearly resolved by this experiment.

Manipulating substrate chemistry across the successional stages tests the hypothesis that with advancing succession, detrital materials become increasingly recalcitrant to decomposition, restricting element supplies for plant use. Readily metabolized and recalcitrant sources of carbon were separately applied to forest floors in all of the replicate successional stands. The consequence of these manipulations for decomposition and element supply is being assessed by estimating plant growth, litterfall production and chemistry, and soil respiration.

Laboratory incubations are being used to examine the influence of methanol and ether extracts of balsam poplar forest floors on ammonification and nitrification in alder forest floor organic matter. Chemicals included in the ether extracts appear to be most effective in reducing nitrification. The dominance of balsam poplar over alder with advancing floodplain succession is associated with marked reductions in nitrification in the field. Physiological controls over nitrifier population dynamics are also being examined.

Several approaches are being employed to examine the changes in microbial populations and their activity with succession, including measurement of microbial biomass and activity, fungal–bacterial ratios, and the ability of microbial populations to use byproducts of decomposition such as cellobiose and simple phenolics (vanillic acid).

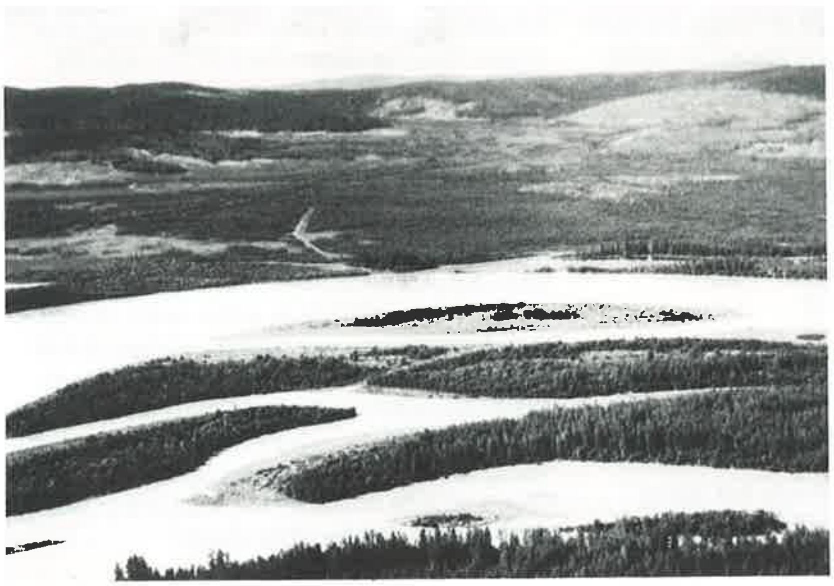
Hypothesis IV

Research to examine the influence of browsing by mammals on community and ecosystem processes has three major components:

- Measuring the effects of browsing by snowshoe hare and moose on the early stages of plant succession in floodplain forests and upland forests;

- Measuring the effects of browsing on litter quality; and
- Measuring the effects of browsing on the biomass of roots and the turnover of fine roots.

Exclosure studies are being used to determine the effects of browsing on plant succession. On the floodplain of the Tanana River, seven exclosures span the willow–alder interface: six include the vegetated silt stage of succession, and five include stands of sapling balsam poplars between the alder stage of succession and the spruce stage. On the uplands we have established two exclosures in the 1983 Bonanza Creek burn. Next year we will establish at least one more exclosure in the burn. These exclosures, with the exception of the exclosures in young poplar stands, enclose a minimum of 400 m^2. Within each of these exclosures and its paired control plot outside of the exclosure, we established at least five replicate 2-m^2 permanent quadrats. The poplar exclosures and their control plots are each 32 m^2 in area and contain one 2-m^2 quadrat. In these quadrats we are monitoring the effects of browsing on the establishment, growth, survival and productivity of woody species. We are also monitoring the growth and survival of 25 dominant individuals of important woody species inside and outside of each exclosure and in each successional stage included in the exclosures. The first data from these measurements indicate that browsing by snowshoe hare and moose on the Tanana River floodplain suppresses willow and balsam poplar growing in the tall willow stage of succession, thereby facilitating the transition from willow to alder.



Tanana River floodplain and adjacent uplands in the vicinity of the Bonanza Creek Experimental Forest. Floodplain and islands are in fhe foreground, lowland is in the middle distance and uplands are in the background.

Our studies of the effects of browsing on litter quality have demonstrated that browsing alters the carbon–nutrient balance of woody plants, resulting in an increase in nitrogen and a decrease in condensed tannin in the leaf litter. Associated with these changes in leaf litter chemistry is an increase in the rate at which stream invertebrates process leaf litter. Preliminary results further indicate that browsing also increases the rate at which leaf litter decomposes in terrestrial ecosystems. In the future we will study the mechanism of this browsing-induced change in the carbon–nutrient balance of individual woody plants and the effect it has on rates of litter decomposition in stream and terrestrial ecosystems. We are also initiating long-term monitoring of changes in the species composition of leaf litter brought about by browsing and how these changes affect nutrient cycling inside and outside of exclosures.

In the 1990 field season we began placing minirhizotron tubes for monitoring the effects of browsing on root biomass and turnover of fine roots. We expect that browsing of the intensity we have found on the Tanana River floodplain will affect root dynamics, because severe pruning results in increased root mortality.

Long-Term Monitoring

In addition to the basic research outlined in these four hypotheses, there is also a long-term monitoring program at BNZ of both climate and vegetation variables.

Climate at BNZ is monitored throughout the year at two primary weather stations: one in the upland and one on the floodplain. At these sites air and soil temperature, relative humidity, soil moisture, precipitation (rain and snow), wind speed and direction, total radiation and photosynthetically active radiation and evaporation are logged on an hourly basis and summarized as monthly and annual reports.

Selected environmental variables are monitored at one of each of the eight successional sites: three in the upland and five on the floodplain. At these sites air and soil temperatures are logged on an hourly basis during the entire year. Precipitation and depth of thaw of the soil are measured weekly in the summer.

Vegetation variables are measured at three sites in each of the five successional stages on the floodplain and three in the upland, for a total of 24 sites. At each site 20 vegetation plots are measured within a 50- × 60-m reference stand. Each vegetation plot consists of a 1-m^2 plot for ground vegetation and a 4-m^2 plot for shrubs. In addition, all trees and shrubs having a breast height diameter of 2.5 cm or larger are tagged and mapped. Ten trees of each species within the reference stand are also equipped with band dendrometers for measuring the annual diameter growth at breast height. In young successional stands the vegetation plots are monitored every two years; in mature types they are monitored every five years. In addition, litter trays have been placed in each reference stand and seed traps in one of each of the eight successional stages.

At four points around the perimeter of each reference stand the forest floor and mineral soil profile was described and sampled using standard procedures. Bulk samples of both materials were obtained for physical and chemical analysis. These assessments will be repeated at 10-year intervals.

Research Accomplishments

Although much of the effort of the first five years of the BNZ LTER program was devoted to setting up the climate stations and the network of sites and to establishing individual long-term studies, some preliminary results are available, partly because several of the 24 LTER sites were used during pre-LTER years for studies and monitoring.

Long-Term Monitoring

Although one does not expect short-term results from long-term monitoring, the value of these permanent monitoring efforts has been apparent during the first five years of the program. At the weather stations, we are able to demonstrate that during extremely cold periods the BNZ floodplain weather station does not show the influence of the human-development-caused "heat island" that now affects the Fairbanks Weather Bureau station. Temperatures at our LTER–2 weather station can be as much as 10°C lower than those at the Fairbanks airport, even though both sites are in the same topographic position and only a few meters different in altitude. Thus the LTER climate stations should be useful in determining long-term climate trends in interior Alaska.

Servicing a weather station in a floodplain black spruce forest at the BNZ site.

Another long-term measurement that may serve as a climate change indicator is the annual production of white spruce seeds. The number of seeds produced in a given year is highly correlated with the early summer temperatures the previous year. During the period of our record at one of the LTER white spruce stands (1969–1992), seed production has averaged 5.75 million seeds/ha, with some years producing no measurable seed. However, during the five-year period of the LTER studies, we measured a record seed year in white spruce (1987), with over 57 million seeds/ha.

Most important was the ability of the LTER monitoring system to record the major disturbance phenomenon that occurred in BNZ and adjacent areas in the winter of 1990-91. A record snowpack (146 cm deep with a 36-cm water equivalent, 144% more than the previous record) resulted in stem breakage of 10–30% in both upland and floodplain white spruce stands. By conducting a damage appraisal of all of the tagged and mapped trees in the LTER permanent plots, we were able to examine the patterns of breakage within stands, as well as patterns through the successional sequence in both upland and floodplain sites. We were also able to follow the needle and large woody debris additions to the forest floor by monitoring litter trays, and we will be able to document any changes in the forest floor vegetation that occur as a result of the nutrient influx and the opening of the canopy.

Below-Ground Plant Production

The study of the patterns in root growth and turnover within upland and floodplain successional forests provided some of the first data on root dynamics of taiga systems. Preliminary data from 1990 showed that fine roots contribute between 9 and 18% of the tree biomass, while constituting between 40 and 70% of total production. Fine root turnover time ranged from one year in balsam poplar stands to five years in white spruce stands. The study found good correlations between root coring methods and indirect budgets based on carbon fluxes, which suggest that over 80% of the soil-respired carbon may be derived from roots. The apparent uncoupling of soil respiration and litterfall points to the importance of root turnover to soil carbon and nutrient pools.

Nutrient and Moisture Control of Plant Productivity

Results from the nutrient and moisture control treatment studies begun in 1990 are still preliminary. However, pretreatment sampling of all treatment and control plots indicated that successional patterns of foliar chemistry in upland forests differ significantly from those of floodplain forests. While uplands and floodplains showed similar reductions in foliar nitrogen concentration through successional sequences, the decline in phosphorus concentration was more dramatic in upland stands, owing to significantly higher available soil phosphorus and thus higher foliar phosphorus concentrations following fire in upland sites. Low availability of soil phosphorus in floodplain soils, resulting from a higher pH, was associated with lower foliar phosphorus concentrations and higher lignin concentrations. Upland vegetation showed clear increases in lignin–nitrogen, lignin–phosphorus and cellulose–lignin ratios through successional sequences, but trends within floodplain stands were less apparent, due principally to the species-specific responses of alder. Successional trends in litter chemistry within upland and floodplain sites paralleled foliage chemistry. The generally lower content of phosphorus in floodplain litters was associated with higher lignin contents, particularly in the case of alder-dominated floodplain successional stages.

During 1990, the first year after treatment application, sucrose substantially increased soil respiration rates throughout the whole growing season at successional floodplain and upland sites, though the effect was generally greatest early in the season. This sucrose-induced increase in respiration declined to control levels in 1991. The other consistent result from the treatment experiments was that the drought treatment significantly reduced soil respiration rates; this pattern was repeated in 1991. Sawdust increased respiration throughout 1990 in both uplands and floodplains but most notably at early and mid-successional sites, suggesting that microbial growth may be carbon limited. Nitrogen fertilization also increased respiration rates during 1990; these increases were smallest at mid-successional sites of comparatively higher fertility in uplands and floodplains. Respiratory increases to both sawdust and nitrogen were reduced during 1991.

Decomposition Processes

During the first year the mass loss from a ten-year litter bag study averaged between 10 and 20% of the initial weight, with monthly incremental losses the following summer being influenced by patterns of both rainfall and temperature. Among the floodplain sites, decomposition was generally lowest in mid-successional balsam poplar and white spruce stands, while among upland sites, there was a general pattern of decreasing decomposition rates through succession. A study of winter decomposition from litter bags showed that during this first winter under the snow, spruce litter lost an average of 4% of its mass and birch litter lost 18%.

Leaf Litter in Streams

Leaf litter supplies most of the trophic basis for small streams in forested regions. We have experimentally investigated the effects of environmental history of trees on the food quality of leaf litter and the subsequent rate of leaf litter decomposition in streams. We have also examined the consequences of browsing by moose. We hypothesized that fertilization and moderate browsing (or pruning) would result in larger, less tough leaves that are higher in nitrogen and lower in tannin and that would decompose more quickly in streams, while defoliation would result in the opposite properties. Leaf area responded to treatments as predicted. The mass loss of both alder and poplar in streams appears to be consistent with our hypotheses. Birch likewise shows greater mass loss with fertilization and decreased mass loss with defoliation but appears to respond to browsing on a branch-to-branch basis, rather than on a whole-tree basis. Leaf litter derived from branches regrowing after moose browsing showed faster decomposition and differences in nitrogen and tannin compared to leaf litter from unbrowsed branches.

We suggest that ecological events affecting riparian zones may have profound effects on the quality of leaf litter entering streams and hence on stream food webs. Qualitative changes in riparian vegetation may, through effects on detrital food webs, affect higher trophic levels, such as fish, connecting the apparently unrelated disciplines of plant physiology, landscape management and fisheries biology.

Forest Floor Studies

We have been evaluating changes in soil organic matter quality through succession and how it is affected by manipulations of forest floor chemistry and moisture status. We have been developing several methods for determining the active pools of soil organic matter, including extraction, mineralization and isotope pool dilution methods. In most sites there is a strong correlation between extractable and mineralizable carbon, but in poplar forest floors the respirable carbon concentration is low, suggesting that poplar's complex secondary chemistry either inhibits microbial activity or makes the forest floor organic matter more recalcitrant.

Using ^{14}C glucose and ring-labeled 2-hydroxy and hydroxy benzoic acid, we have evaluated the ability of soil communities from different successional stages to metabolize simple phenolics and sugars. All compounds were metabolized rapidly, but there were large differences between the assimilation of different phenolics into biomass, suggesting that the phenolic chemistry of litter may substantially affect the stabilization of litter into soil organic matter.

Ether extracts of poplar litter significantly inhibit nitrification, suggesting an allelopathic effect. However, these extracts also cause net nitrogen immobilization, suggesting that the mechanism may occur via NH_4 limitation to the nitrifiers. We have undertaken a series of experiments to verify this hypothesis.

Measurements of potential microbial respiration (under optimal conditions) on samples from litter bags at each harvest indicate differences in substrate quality; white spruce litter is notably more recalcitrant than other litters. Microbial populations respond quickly to changes in moisture, indicating the importance of episodic rain events in controlling decomposition dynamics. These studies complement measures of substrate chemistry and faunal dynamics, providing a full picture of the interactions between abiotic and biotic factors in controlling decomposition.

Trace Gases

We have been measuring the fluxes of trace gas (particularly methane) from a range of successional stages and from within nitrogen-fertilized and sawdust-treated plots. Except for low-lying terraces, methane is consumed in the soil. Nitrogen fertilization and sawdust both reduce consumption in some stands.

Foliar Chemistry

To determine the effects of secondary metabolites on litter and organic matter decomposition, samples of green foliage and litter were collected in 1989, 1990 and 1991 from all sites. The data indicate that balsam poplar has between two and six times the tannin content of other floodplain and upland species. Fresh balsam poplar litter and the forest floor beneath balsam poplar stands also contain tannin. In addition, the monomeric phenolic content of balsam poplar is higher than that of other species. The data also indicate that tannin concentrations were generally higher in upland foliage than in floodplain foliage, ostensibly associated with the higher phosphorus content of upland vegetation. Although data have been collected for only one year, the site manipulations are beginning to show some effects on secondary chemicals of several species. For example, the foliage of white spruce from the drought treatment has a higher tannin content than in the control plots.

Exclosures

Four years of operation of moose and hare exclosures in the willow and alder stages of succession along the Tanana River floodplain has had significant effects on vegetation structure and composition and nutrient cycling processes along the floodplain. In the willow stage, browsing by snowshoe hare and moose significantly reduced the growth and increased the stem mortality of preferred species, resulting in a significant decline in litter production. In the alder stage, browsing has almost eliminated willow and poplar, favoring alder, a chemically defended species. When herbivores were excluded, willow and poplar rapidly recovered and are beginning to dominate the canopy. In addition to playing a key role in accelerating the successional shift from willow to alder, herbivores also had significant effects on litter production and element recycling. Browsing in the willow stage significantly reduced willow litter production, but leaves of browsed plants decomposed at a significantly faster rate than leaves collected from within the exclosure. In the alder stage the higher rate of alder litter decomposition, coupled with the nitrogen-fixing potential of the species, leads to increased nutrient enrichment.

Modeling

Our modeling efforts, using a biophysical–physiological approach and BNZ LTER data sets for calibration and validation, have resulted in the realization that there is a need to consider the following in the models:

- Below-ground dynamics in carbon budget questions for the boreal forest;
- The effect of the vegetation canopy (specifically trees and moss) on soil temperature dynamics;
- The extension of intensive site process work to an extensive area of the North American boreal forest; and
- The importance of precipitation patterns as a major control of forest productivity in global change analysis.

Future Directions

Our immediate objectives deal with documenting the results of experiments established to test controls of successional processes. Emphasis will be placed in the following areas:

- Controls of resource supply;
- Competition and facilitation;
- The impact of large and small mammal browsing on plant community development;

- Plant root growth dynamics;
- The role of invertebrate animals in forest floor decomposition;
- Trace gas production and consumption;
- Refinement of stand-level process models to assess change in successional processes in the context of global change; and
- Linking these models with geographic information systems to broaden the scale of understanding of ecosystem processes.

Establishing a workable data management program is a high priority, along with expanding our capability in geographic information systems. In both areas the State of Alaska and University of Alaska Fairbanks have provided substantial financial assistance.

We have cooperated in promoting a number of proposed activities with other LTER sites. Although funding for most of these activities has not materialized, we are eager to help launch newly funded, cross-site research. We are cooperating with the cross-site litter decomposition comparison, climatological data summaries and evaluation of variation in biological data.

New research initiatives undoubtedly will deal with climate change issues and the use of geographic information systems for integrating plot-based structural and functional knowledge at a landscape level. For example, experimental work may deal with plant community manipulations in the field to test plant species-specific secondary chemical control of soil processes in a context of increased soil temperature.

Publications

Readers may obtain information on some of the research described in this article from the following publications:

Interactions Between Woody Plants and Browsing Mammals Mediated by Secondary Metabolites, by J.P. Bryant, F.D. Provenza, J. Pastor, P.B. Reichardt, T P. Clausen and J.T. Du Toit: Annual Review of Ecology and Systematics, vol., 22, p. 431–446, 1991.

Effects of Mammal Browsing on the Chemistry of Deciduous Woody Plants, by J.P. Bryant, K. Danell, F.P. Provenza, P.B. Reichardt and T.P. Clausen: In *Phytochemical Induction by Herbivores* (D.W. Tallamy and M.J. Raup, Ed.), John Wiley and Sons, New York, p. 135–154, 1991.

Fine Root Production and Turnover in Taiga Forest Ecosystems of the Alaskan Interior, by R.W. Ruess and K. Van Cleve: Bulletin of the Ecological Society of America, vol. 72, no. 2, p. 235, 1991.

The United States Interagency Arctic Buoy Program

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Due to the remote nature and harsh climate of the polar regions, the Arctic Basin has been a data-sparse area of the earth, lacking an observation network similar to those in tropical, subtropical and subarctic oceans. The recent increase in public awareness of global climate change has renewed scientific interest in the collection of meteorological data in the Arctic. Global climate models predict that increased greenhouse gas concentrations may cause significantly greater warming in higher latitudes than in lower latitudes. However, the ability of these models to effectively predict the amount of warming in the Arctic is hampered by the absence of understanding of air–sea–ice processes and by inadequate data. Because of this, there are large disagreements between models on the amount that Arctic air temperatures may increase during the winter months.

Before we can observe climate change, we must precisely document the present climate in the Arctic Basin. The World Climate Research Programme/Joint Scientific Committee has recognized the need for an Arctic observational network to obtain in-situ measurements to document trends for global climate change modeling efforts. The most efficient means of obtaining Arctic meteorological and sea ice movement data are air- or surface-deployed drifting buoys. The United States Interagency Arctic Buoy Program will help fulfill this key aspect of the Arctic Climate System Study (ACSYS) strategy by contributing to the establishment of a comprehensive array of satellite-tracked drifting meteorological buoys.

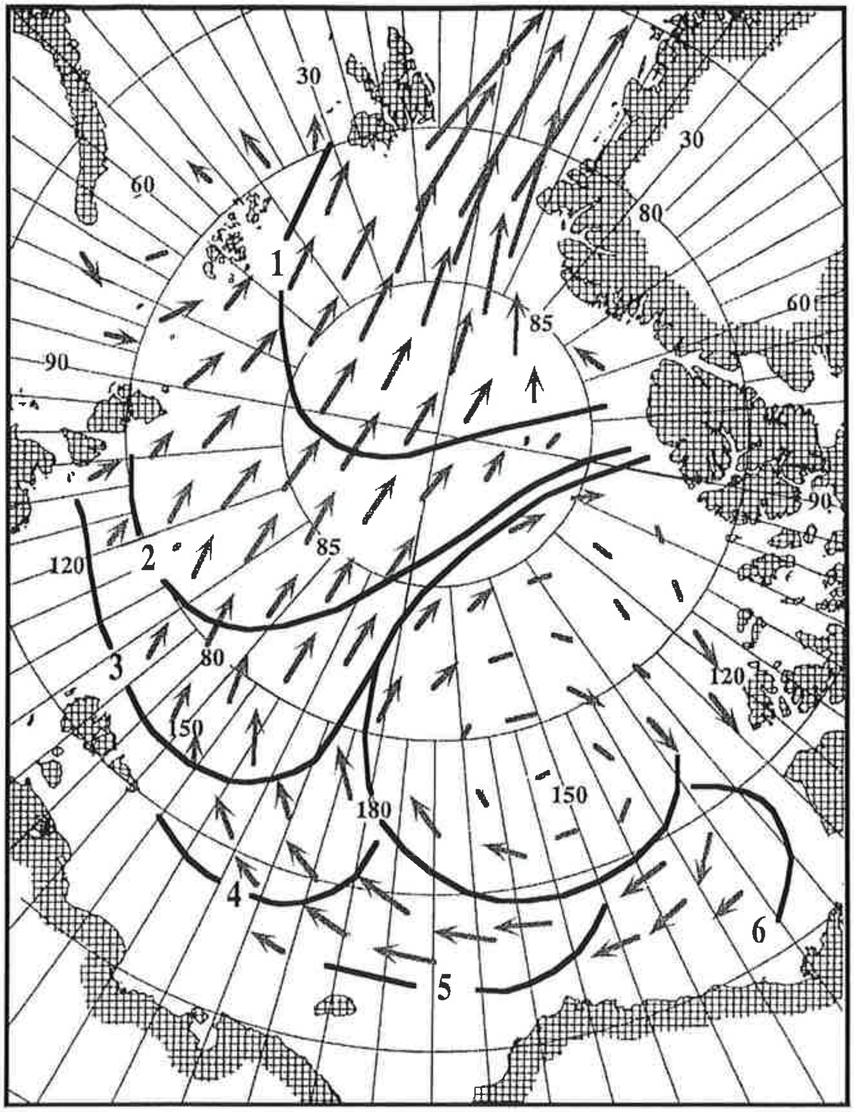
History

The first organized meteorological data collection effort in the Arctic was the Russian Drifting Automatic Radiometeorological Station (DARMS) program established in 1956. Interest and participation by the United States in drifting data buoys for use in the central Arctic Ocean began with the development, testing and deployment of buoys during the Arctic Ice Dynamics Joint Experiment (AIDJEX) from 1970 to 1976 in the Beaufort Sea. The deployment of a buoy array to gather environmental data throughout the entire Arctic Basin was first recommended by the U.S. National Academy of Sciences in 1974. In 1978 the National Science Foundation granted funds to the Polar Science Center of the University of Washington to acquire and deploy 20 buoys capable of collecting data over a large-scale square grid covering the Arctic Basin. This program was viewed as a contribution to the Global Weather Experiment in 1978-79 and led to the beginnings of a more formal United States Arctic buoy program.

The coordinated Arctic Ocean Drifting Buoy Program began in 1979 as part of the U.S. contribution to the Global Atmospheric Research Program (GARP). Several U.S. government agencies (National Oceanic and Atmospheric Administration, Office of Naval Research and National Science Foundation) funded this program, which incorporated air deployment and remote monitoring of buoys for both ice motion and atmospheric variables important to global weather forecasting models. The first few years of this baseline program proved extremely important, as incoming data established the reliability and overall cost-effectiveness of the Arctic buoys. As a direct result, program sponsorship expanded to other U.S. government agencies (Minerals Management Service) and countries (Canada and Norway). Financial support for the buoy program was typically provided by ad hoc funding from separate agency research budgets. The support from NOAA, for example, included the cost of acquiring data transmitted from the buoys as part of an agreement made between NOAA and the Centre Nationale des Etudes Spatiales (CNES), which operates the Argos satellite positioning system.

Beginning in 1988 the management and coordination of the program became difficult, as separate agencies focused research efforts on specific process studies rather than on the overall maintenance of the buoy array. This problem was further exacerbated when tightening agency budgets significantly reduced the funding to the Polar Science Center for collecting, processing and archiving environmental data. By early 1989 declining interest and program funding shortfalls seriously jeopardized the future of a reliable Arctic drifting buoy program.

At the beginning of 1991 the remaining U.S. contributors to the Arctic Buoy Program were the NOAA Office of Global Programs and the U.S. Naval Oceanographic Office. The Naval Oceanographic Office's annual White Trident exercise deployed Arctic buoys in support of Department of Defense operational mission requirements. Each spring they deployed 10 meteorological buoys in locations selected by the Navy/NOAA Joint Ice Center. Arctic buoys deployed by various academic



Number of years a buoy, deployed on sea ice, would take to drift and exit the Arctic Basin via the Fram Strait.

research institutions were typically used to gather data without regard to the already sparse network of buoys. It became apparent that any potential benefits that may result through coordination with other interested agencies were no longer possible unless program management was centralized within one agency.

Formation of the USIABP

By mid-1991 several government agencies with Arctic interests formally recognized the need to organize and collectively fund a coordinated effort to monitor and study the Arctic environment. In January 1992 the Navy/NOAA Joint Ice Center, as manager of the newly formed U.S. Interagency Arctic Buoy Program (USIABP), identified program shortfalls and assembled a plan to establish and maintain a reliable and comprehensive drifting buoy network.

The key component in this renewed interest in the Arctic drifting buoy program was a unique cooperative effort that combined the financial and manpower resources of nine government agencies or programs. Member agencies of the USIABP include three offices of the National Oceanic and Atmospheric Administration (the National Ocean Service, the Office of Global Programs and the Office of Oceanic and Atmospheric Research), the NOAA Surface and Upper Ocean Observation Project, the National Aeronautics and Space Administration, the National Science Foundation, the U.S. Naval Oceanographic Office, the Office of Naval Research, the U.S. Coast Guard and the Navy/NOAA Joint Ice Center.

The primary objective of the USIABP is to provide the management structure, funding and coordination necessary to establish and maintain a comprehensive climate monitoring system in the Arctic. To accomplish this goal the Navy/NOAA Joint Ice Center has integrated Arctic buoy data collection requirements for both the operational and scientific research communities.

Specific program goals are to:

- Maintain a baseline network of drifting buoys of sufficient spatial resolution and longevity to define surface synoptic-scale atmospheric pressure, air temperature and sea ice drift fields in the Arctic;
- Investigate new buoy technology to standardize the measurement of environmental variables;
- Establish a quality control program for the real-time distribution of data via the Global Telecommunications System (GTS); and
- Establish a research-quality database and archive at World Data Center A: Glaciology and B: Sea Ice.

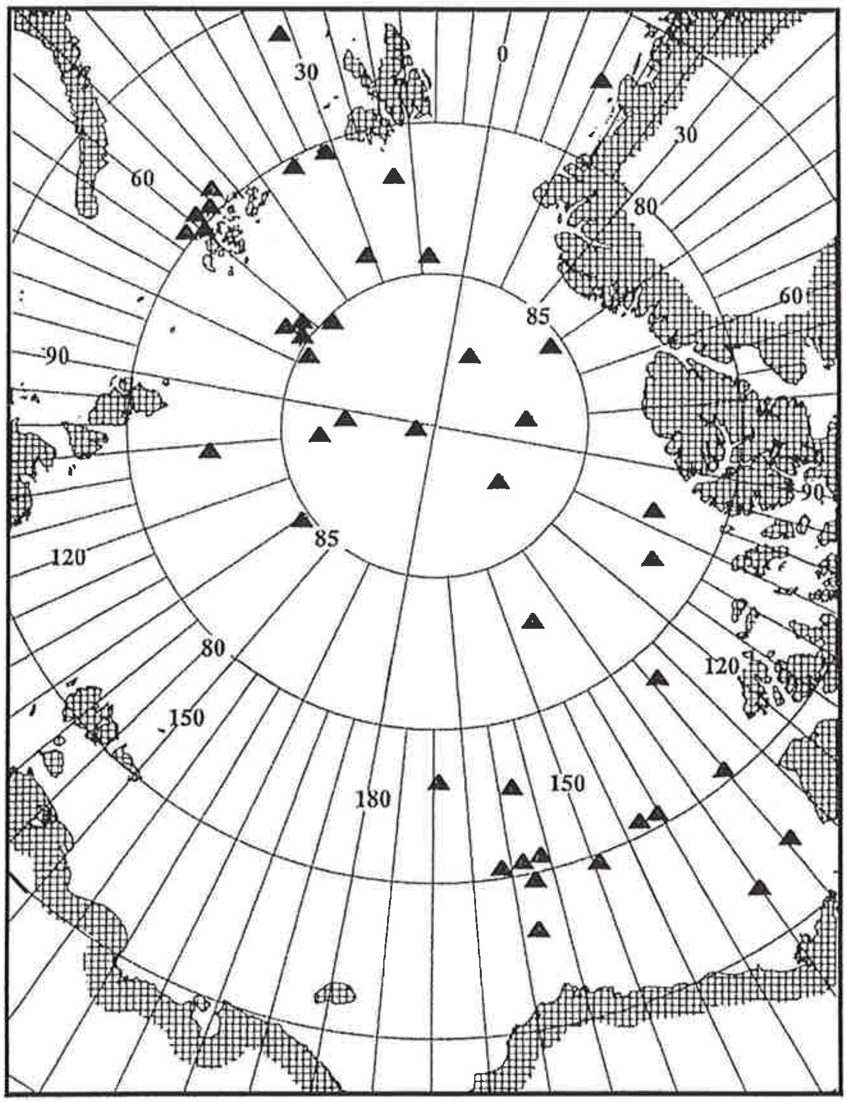
International Arctic Buoy Program

Any national Arctic buoy program would be best served if the concept of agency cooperation were extended to the international level. Numerous countries that border the Arctic Ocean are active in collecting meteorological observations by drifting buoys. The existence of these coincident programs and interest in international coordination led to the first preparatory meeting of the International Arctic Buoy Program (IABP), which was held during March 1991 in Edmonton, Canada. A set of operating principles detailing the management structure of the proposed IABP was drafted during this meeting and distributed to all potential participants for review.

The IABP operating principles were built on the premise of mutual cooperation between participants; program support would be derived solely from individual agency contributions. The principal

Participants in the International Arctic Buoy Program
June 1992

The Atmospheric Environment Service	Canada
The Navy/NOAA Joint Ice Center	U.S.A.
The Norwegian Meteorological Institute	Norway
The Norske Polarinstitutt	Norway
The Russian Committee for Hydrometeorology and Monitoring of Environment	Russia
The U.K. Meteorological Office	U.K.
The Marine Environmental Data Service	Canada
Alfred Wegener Institute for Polar and Marine Research	Germany
Institute of Ocean Sciences	Canada
Pacific Marine Environmental Laboratory	U.S.A.
Polar Science Center, University of Washington	U.S.A.
Scott Polar Research Institute	U.K.
Naval Oceanography Command	U.S.A.
U.S. Naval Oceanographic Office	U.S.A.
Service Argos	France, U.S.A.
Chr. Michelsen Institute	Norway
Arctic and Antarctic Research Institute	Russia
Canadian Coast Guard	Canada
WMO/ICSU World Climate Research Program	Switzerland
Nansen Environmental and Remote Sensing Centre	Norway



Positions of buoys within the International Arctic Buoy Program network on 2 March 1993.

goal of the IABP (like the USIABP) is to establish and maintain a comprehensive Arctic meteorological buoy network. To address this goal, an appointed program coordinator would foster cooperation by the following methods:

- Sharing of logistical assets;
- Coordination of buoy deployment sites;
- Real-time acquisition and distribution of data;
- A centralized quality controlled data archive; and
- Exchange of technical information.

The growing interest in international cooperation in the Arctic led to the successful formation of the IABP following a second meeting held in September 1991 in Seattle, Washington. The focus of this meeting was to review and finalize the IABP operating principles and draft the terms of reference for an overall program coordinator. An Executive Committee, consisting of representatives from Canada, Norway, Russia and the United States, was selected to provide program guidance to the appointed program coordinator.

Prior to the second annual meeting of the IABP held in June 1992 in Oslo, Norway, the IABP requested and received formal recognition as a Regional Action Group under the auspices of the WMO/IOC Drifting Buoy Cooperation Panel. As stated in the operating principles, the IABP program was formed to serve the participants in the program but would directly contribute to the World Climate Research and World Weather Watch Programs. IABP participants at this meeting included 20 scientific agencies representing 7 countries.

The USIABP played a significant role in the success of the IABP during 1992. USIABP contributions included the funding of the program coordination/data management function, the deployment of 15 meteorological buoys, and the addition of data to GTS from 6 oceanographic buoys.

Arctic Drifting Buoy Network

The spatial and temporal coverage of conventional ocean monitoring networks is sparse when compared to the large numbers of equivalent measurements on land. The density of observations over land is 10 to 10,000 times greater than over many ocean areas. This sparsity of observations poses considerable problems when initializing forecast models for large inaccessible areas like the Arctic Ocean.

During the early years of the Arctic Ocean Drifting Buoy Program, the proposed spacing and number of buoys in an optimal Arctic sampling network was a 400-km-square grid designed to measure daily ice motion and synoptic surface air pressure/geostrophic winds. As a result of this criterion, it would be necessary to evenly space 35–40 buoys to effectively cover the 7×10^6 km^2 area of the Arctic Basin (not including the Barents and Kara seas). It has since been proposed that the length scale for measuring ice motion in many coastal areas is considerably smaller because of the effects of ice stress, coastal currents and marginal ice zone processes. To further confuse the issue, no attempt has been made to determine the spatial length scale to effectively define surface air temperature fields in the Arctic.

During the first 12 years (1979–1990) of the Arctic Basin Buoy Program, the average operational lifetime of all meteorological buoys ranged from 15 to 18 months. Buoy longevity was often abbreviated due to limited power capacity, deployment losses, destructive failure due to ice deformation and the simple exit of the buoys from the basin due to the southward drift of ice through the Fram Strait. An annual average of 20 buoys were deployed onto the Arctic ice pack during those 12 years. Included in these numbers were many buoys without meteorological sensors and buoys that did not distribute environmental data via the GTS. The number of Arctic meteorological buoys operating at any one time during 1990 ranged from only 8 to 14.

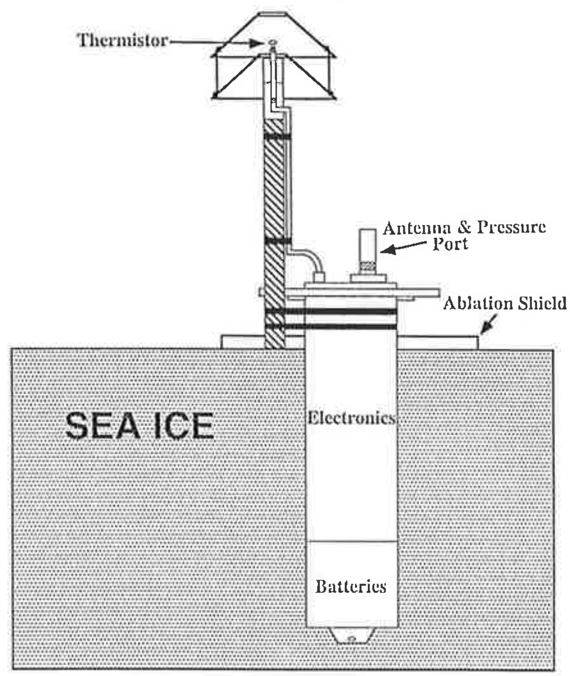
The USIABP, in cooperation with the IABP, increased both the total number and the areal coverage of Arctic buoys over the past year. The array now consists of 50 drifting buoys, with 64% equipped with meteorological sensors.

Arctic Drifting Buoy Design

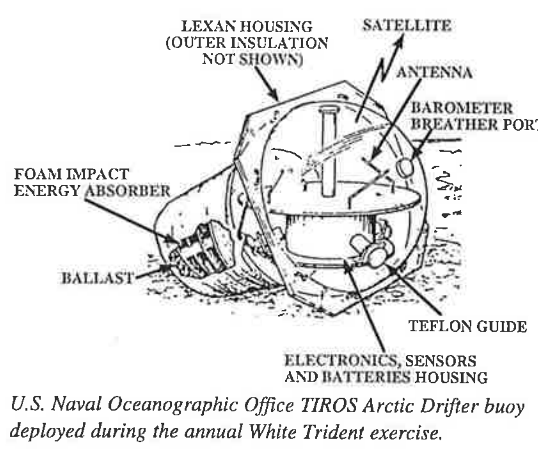
The majority of meteorological buoys used during the early years of the Arctic Basin Buoy Program were air-deployed spheres that contained a pressure sensor and a thermistor inside the buoy housing. This sensor arrangement satisfied the early goals of measuring accurate position and surface atmospheric pressure. During the first year of the program it was recognized that these buoy temperature readings did not reflect the true ambient air temperature. Measurement bias was found to be introduced by radiational heating and the insulating effects of the snow cover. A direct comparison of buoy temperatures to manned observations from the FRAM III ice camp revealed a bias of 4–8°C due to radiational heating, a diurnal cycle damped by 50% and an eight-hour delay in registering temperature changes because of the thermal inertia of the buoy.

Because of the measurement bias associated with past buoys, the USIABP has placed particular emphasis on the accurate performance of meteorological sensors and corresponding buoy design. The primary meteorological sensors incorporated into USIABP buoys are a quartz oscillator pressure sensor and a thermistor to measure air temperature. USIABP performance specifications require that atmospheric pressure must be measured with an accuracy of ±1.0 millibar (mb) and exhibit a long-term drift no greater than 0.5 mb per year. The thermistor must measure ambient air temperature to an accuracy of ±0.2°C. The temperature measurement problem of past buoys has been addressed by using an external thermistor design that provides a standardized exposure to the environment. This standardization includes ventilating the sensor, protecting it with a radiation shield, insulating it from other radiated hardware parts and locating it at a fixed sampling height. These design criteria were incorporated into the five USIABP buoys that have been deployed during the past year.

A comparative study conducted by the Polar Science Center of the University of Washington



Surface deployable buoy of the United States Interagency Arctic Buoy Program.



U.S. Naval Oceanographic Office TIROS Arctic Drifter buoy deployed during the annual White Trident exercise.

indicated that air temperatures from previously deployed buoys with an external thermistor design and collocated manned Soviet ice stations were highly correlated. A major USIABP initiative, to be conducted in the coming year, is a comparison and calibration of air temperature measurements from the various types of buoys collecting data in the Arctic. These buoy designs include the TIROS Arctic Drifters and Polar Ocean Profilers deployed during the annual White Trident exercise by the Naval Oceanographic Office. The proposed establishment of an air temperature measurement standard for Arctic buoys represents an important first step in addressing the requirements for research in climate change.

Real-Time Meteorological Data

In-situ Arctic meteorological data are collected, transmitted and processed in near real-time by the Data Collection and Location System (DCLS) of Service Argos. Data accessed by the NOAA polar-orbiting satellites are downlinked to telemetry receiving stations and then relayed to two global processing centers. These data can then be separated into two categories:

- Data that are distributed via the GTS for operational use in weather and sea ice forecasting; and
- "Historical data" that are processed, quality controlled and archived to meet the established needs of the scientific research community.

One of the program goals of the Navy/NOAA Joint Ice Center is to encourage all Arctic buoy operators to distribute buoy data via the Global Telecommunications System. Arctic meteorological data are presently disseminated via GTS under six different bulletin headers. Nearly 85% of the meteorological buoys in the International Arctic Buoy Program now distribute data via GTS. This past year, the JIC, in cooperation with the NOS Ocean Products Center (OPC), increased the number of buoys reporting on GTS by placing data from six U.S. Navy oceanographic buoys under a newly formed bulletin header. Plans are to distribute data from all future USIABP Arctic buoys under three bulletin headers.

As designated by the Joint IOC/WMO Drifting Buoy Cooperation Panel, the JIC and NOS OPC are responsible for the quality control of data from all USIABP buoys. NOS OPC performs this real-time data quality control through an interactive computer system known as the Quality Improvement Performance System (QUIPS). Surface synoptic observations, obtained from GTS bulletins, are run through an initial comparison to first-guess fields from NMC's Global Data Assimilation Model and Aviation Model. Measurements that fall outside predetermined thresholds are "flagged" and referred to OPC analysts for review. During this review the QUIPS will show the difference between the questionable platform measurement and interpolated first-guess values, display a plot of the platform's cruise track, display a history (previous eight days) of observations from the platform and compare platform observations to neighboring buoys. This information allows the analysts to make real-time quality control decisions, which are made available to the NMC models. The results from this quality control are subsequently made available to platform managers via monthly status reports posted on the bulletin board BUOY.QC of the OMNET electronic mail service.

Three unwanted visitors investigating a buoy recently deployed by the Polar Star *in the Chukchi Sea during the summer of 1992.*

Archived Meteorological Data

The management function for data archival of all USIABP and IABP buoys is performed by the Polar Science Center of the University of Washington. The main data management task is to act as primary recipient of data collected by all IABP Arctic buoys and to establish and maintain a research-quality database. This function is directly funded through the USIABP as a formal contribution or service to the International Arctic Buoy Program.

Database generation is a three-step process that begins with the receipt of monthly tapes of basic decoded Argos data. In Step 1 these raw data are quality controlled to eliminate outlier reports due to sensor drift or instrument malfunction. In Step 2 these data are spatially and temporally interpolated to produce three-hourly data of surface atmospheric pressure and air temperature. These data are then merged into existing databases maintained by the Polar Science Center. In Step 3 this interpolated database is used to generate a variety of derived products, including twelve-hour analyses of surface pressure and air temperature, monthly mean surface pressure fields, and daily ice velocity estimates for a fixed grid of points on the Arctic Basin. A data summary and all derived products are published in an annual Arctic Ocean Buoy Program Data Report. All digital databases are forwarded to the World Data Centers A: Glaciology and B: Sea Ice for archival.

1993 USIABP Initiatives

USIABP 1993 initiatives include an increased focus on the following three issues:

- Continued buoy deployments and coordination of deployment sites;
- Data management and the creation of a research-quality database; and
- Design and implementation of a comparative calibration study of measurements collected from all buoy designs now in use in the Arctic.

During 1993 the USIABP deployed 17 meteorological buoys in the Arctic Basin. The deployment sites for these buoys were chosen based on the estimated longevity and position of existing buoys, the logistical restrictions and the deployment plans of other participating agencies and countries in the IABP. Through cooperation with the Hydrometeorology Service of Russia, the White Trident exercise air-deployed nine buoys in the eastern sector of the Arctic. The remaining eight USIABP buoys were deployed throughout the Arctic using a variety of assets and activities, including the USCG icebreaker *Polar Star* in the Chukchi Sea, a U.S. submarine scientific cruise in the high Arctic basin, and aerial assets supplying ice camp Aplis in the Beaufort Sea. The Polar Science Center will continue to provide coordination support among all IABP participants.

Monetary support for the management of meteorological data collected by all IABP buoys will be provided by the USIABP in 1993. The Polar Science Center delivered the 1992 Arctic buoy database to the World Data Centers A and B in October 1993.

During the summer of 1993 the USIABP continued to conduct a comparative calibration and performance evaluation of all buoy designs now in use by the IABP. Particular emphasis is being placed on the performance of air temperature instruments. Determining the quality of Arctic air temperature measurements, establishing a standard accepted accuracy and investigating the spatial requirements of a buoy network to effectively define surface air temperatures fields are of primary interest to the USIABP.

Publications

Readers may obtain further information about the research described in this article from the following publications:

IPCC, 1990: Climate Change: The IPCC Scientific Assessment, edited by J.T. Houghton, G.J. Jenkins and J.J. Ephraums: Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, 1990.

ACSYS, 1992. Report of the World Climate Research Programme Joint Scientific Committee. JSC-XIII/Doc. 5, Annex , vol. 9, no. 3, 1992.

American Meteorological Society Proceedings: 9th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanology and Hydrology, by M. Waters, C.M. Caruso, W.H. Gemmill, W.S. Richardson and W.G. Pichel: American Meteorological Society, p. 210–215, 1993.

Arctic Buoy Program, by N. Untersteiner and A.S. Thorndike: Polar Record, vol. 21, no. 131, p. 127–135, 1982.

Arctic Ocean Buoy Program Data Report: 1 January 1981–31 December 1981, by A.S. Thorndike, R. Colony and E.A. Munoz. Polar Science Center, University of Washington, 1982.

The 1992 Arctic Leads Experiment

An Overview of the Meteorology

DANIEL E. WOLFE, DOMINIQUE RUFFIEUX AND CHRIS W. FAIRALL

Daniel E. Wolfe and Chris W. Fairall work for NOAA and the Atmospheric Studies group of the Wave Propagation Laboratory in Boulder, Colorado. Dominique Ruffieux works for the Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder.

In March and April 1992, the Leads Experiment (LeadEx) was staged, sponsored by the Office of Naval Research. LeadEx's goal was to study the effect of open leads on the polar ocean and atmosphere, using a main base camp on the Arctic ice pack northeast of Prudhoe Bay, Alaska. This paper presents an overview of the meteorological measurements made at the base camp and at the leads during LeadEx.

Background

Current numerical weather prediction models operating on synoptic and larger scales (greater than 2000 km) are based on very limited data sets in the Arctic. They do not adequately incorporate the physics of the over-ice atmospheric boundary layer. On smaller scales appropriate to individual leads or groups of leads, the data deficit is even greater. Leads are crack-like openings caused by ice deformation and can range in width from a few meters to thousands of meters. During the winter, air–water temperature differences of 20–40°C can generate large upward fluxes of sensible and latent heat from the lead surface. These fluxes influence the atmosphere in three ways:

- They contribute to the sensible heat, which raises the mean air temperature;
- They add water vapor, which on condensing and freezing releases latent heat and, by forming fog or cloud, may perturb the net radiation balance and even result in precipitation; and
- They are a source of buoyancy, which generates turbulent kinetic energy for mixing.

The evolution of this plume of warmer, moister air as it is advected over the downwind ice surface and interacts with the overlying boundary layer has not been well observed or modeled. Arctic leads represent only about 1% of the surface area of the Arctic ice pack, but it is claimed that they contribute 50% of the heat and moisture exchange at the surface during the winter. To fully understand the impact of leads, it also necessary to study the non-perturbed environment.

Although, in the broadest sense, the characteristics of the wintertime marine boundary layer are well understood, the details of its internal structure and its temporal evolution are not well known or modeled. Experience at lower latitudes, and also at the South Pole, indicate that the stable nocturnal boundary layer is often composed of many temperature layers at different heights with varying thermal stratification. The stable wintertime Arctic inversion—warm air on top of cold air—is one such layer that persists and often oscillates in a wave-like manner when disturbed from below or above. An important longer-term effect of leads may be the production of a mechanism by which tropospheric and stratospheric air can be mixed through what traditionally has been thought of as the impenetrable Arctic inversion.

LeadEx was designed to clarify some of these processes. Initial research began in 1989 with laboratory studies and numerical modeling. In early March 1992, a main base camp was established on the Arctic ice pack approximately 240 km northeast of Prudhoe Bay, Alaska. Deployments were made from the base camp by helicopter to four leads, with the majority of data gathered at the last two leads.

A LeadEx post-experiment workshop was held on 5–7 October 1992 in Seattle. Short- and long-term goals for both the meteorological and oceanographic portions of the experiment were discussed. Interaction, cooperative analysis and publication plans were defined. Five specific meteorological topics of concern included:

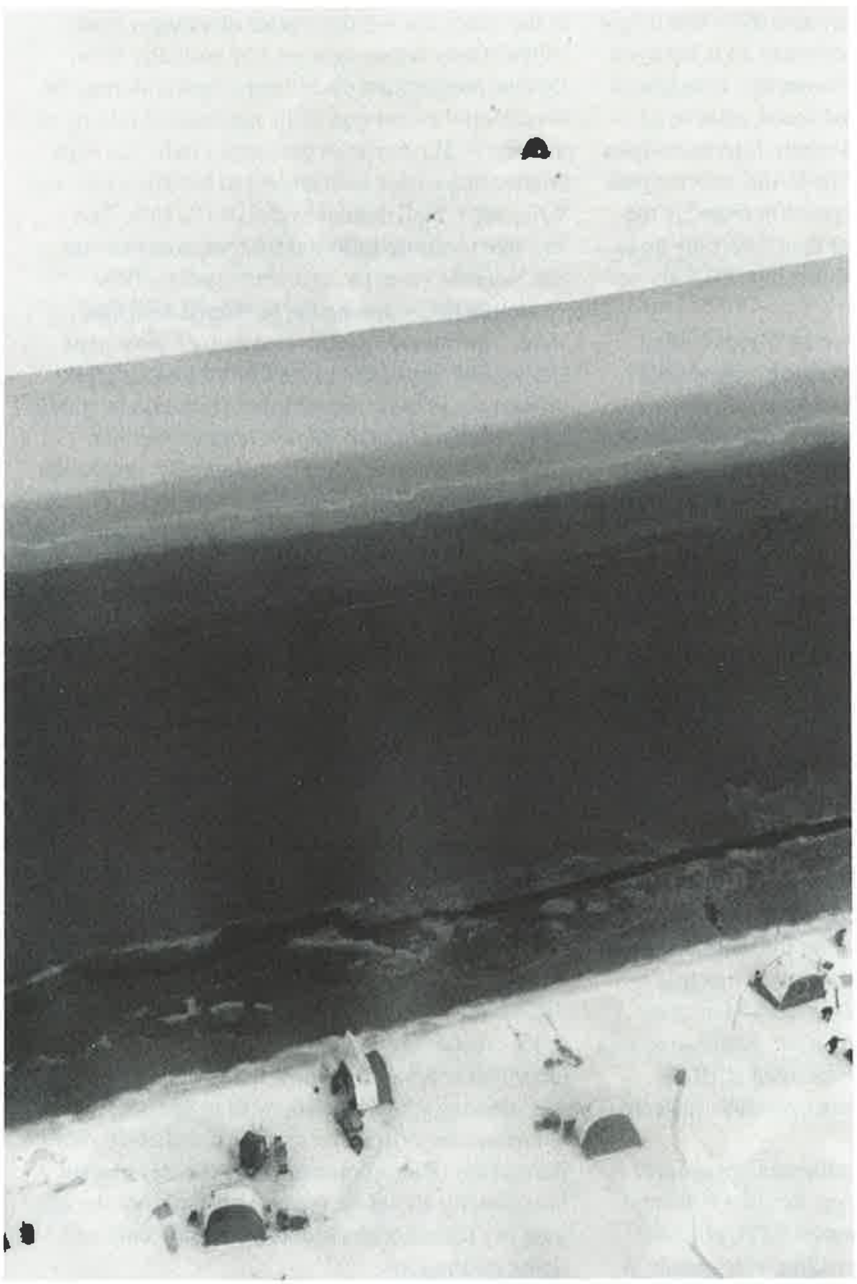
- Surface energy observations and one-dimensional modeling (case studies);
- Geostrophic drag calculations (profiler and surface flux measurements);
- Atmospheric structures, features and effects from leads;
- LeadEx climatology (lower troposphere and surface energy budget); and
- Low-level jet case study for 15–18 April (observations and three-dimensional modeling).

A data workbook for the various aspects of LeadEx is being prepared. The ice camp meteorology portion will incorporate a summary of the base camp and lead meteorology. Time-series plots of basic meteorological variables will be presented, along with outlines of the data available and information on how to access these data. This workbook is intended to provide LeadEx data users with a first reference when attempting to correlate their data with the basic meteorology.

Not covered in this paper, but very important to the overall meteorology, are the extensive aircraft, satellite and meteorological buoy data. Work is already under way to compare satellite-derived surface energy budget variables to those measured at the base camp.

Meteorological Operations Summary

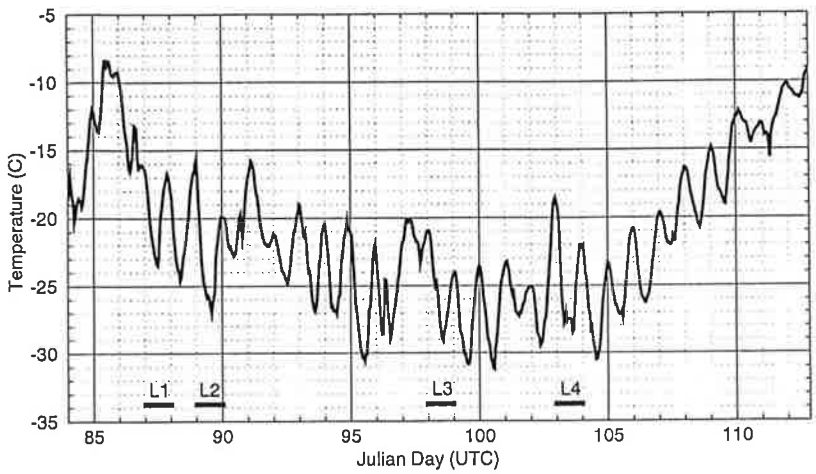
Lead measurement operations. The oceanographic huts are on the upwind side of the lead, with a lone meteorological hut on the downwind side.



During LeadEx, NOAA's Wave Propagation Laboratory deployed an array of surface-based sensors, remote and in situ, to the base camp. This suite of sensors provided continuous Arctic boundary-layer profiles and surface energy data for studies of the stable planetary boundary layer (PBL). Similar instrumentation was deployed by helicopter at several leads to investigate the effect of leads on the PBL and larger-scale weather patterns. Scientific operations were conducted from 25 March to 20 April 1992. At the base camp, hourly wind and temperature profiles were measured using NOAA's 915-MHz profiler and Radio Acoustic Sounding System (RASS). Additional deep wind and temperature profiles were obtained from rawinsonde ascents. A laser ceilometer measured the cloud-base height and aerosol backscatter. Low-level profiles of temperature structure and acoustic backscatter were measured by means of a single-axis Doppler minisodar. Several independent measurements of vertical velocity and inversion height were also available from these remote sensors, profiler and minisodar. Pressure fluctuations were measured using a small-scale, three-sensor, μ-pressure array to observe gravity wave signatures. A surface micrometeorological site positioned slightly east of the base camp included a three-axis sonic anemometer for measuring the three wind components and virtual temperature, short- and long-wave radiation sensors, and instruments taking standard wind, pressure, temperature and relative humidity measurements.

The maximum vertical range varied from 1 to 4 km for the profiler and 0.15 to 1 km for RASS temperature profiles, depending on the meteorological conditions. Ceilometer data contain information on cloud-base height and actual aerosol backscatter intensities, which exhibit excellent correlation with variations in the maximum range of the profiler. Doppler minisodar and μ-pressure array data show periods with significant wave activity as well as quiet periods.

The initial results are very encouraging since this was the first time a wind profiler with RASS had been operated continuously in the cold, dry Arctic environment. The NOAA wind profiler operated without the standard ground clutter fences in high (0.1 km) and low (0.4 km) vertical resolution modes. Along with the hourly consensus data, spectra data were recorded every 1.5 minutes. Concurrent RASS consensus temperature profiles, taken at 0.1-km vertical resolution, coincide with 5-minute sampling at 1-hour intervals. Calculations of the real-time performance of the profiler in the dry Arctic environment indicate that the radar efficiency was greater than 85% up to 1.0 km, dropping sharply to 60% by 1.2 km for the higher-power 0.4-km mode. This compares to greater than 95% efficiency up to 1.4 km, dropping off to 60% near 2.3 km, for a profiler operated at Page, Arizona, a continental dry environment. Visual observa-



Temperatures (hourly averages) 2 m above the ground at the base camp. L1, L2, L3 and L4 are the four major lead measurement periods.

tions, along with ceilometer data, indicate that the height coverage increased in the presence of clouds or ice crystals as expected; they also show that height coverage often changed by more than 2 km between two consecutive hours. RASS coverage, both spatial and temporal, depends on wind speed, relative humidity and temperature. High winds, high humidities and low temperatures reduce the RASS return signal. The efficiency of the RASS system operated in the Arctic was estimated at greater than 85% only up to 300 m, dropping off rapidly to less than 20% above 500 m.

A recently developed minisodar also provided information on wave structure, along with vertical velocities and boundary layer structure. Continuous facsimile records for the base camp show the growth and variability of the Arctic boundary layer throughout LeadEx. The evolution of the mixed layer on the clear days is often marked by a sharp decrease in height late in the day. Minisodars at the lead were used to capture a similar picture of the boundary layer upwind and downwind of a lead.

Surface energy measurements were made using matched pairs of short- and long-wave radiation sensors pointed upward and downward. Calculations of 5-minute-average net short- and long-wave radiation, surface albedo, surface skin temperature and total sky irradiance temperature are possible from the base camp instruments. On clear days the diurnal variations of the 2-m-high and surface skin temperatures were about 6° and 15°C, respectively. Daylight changed from 11 to 17 hours over the duration of the experiment, which can translate into as much as a 50% increase in incoming solar radiation on clear days. Surface flux measurements are available from a three-axis sonic anemometer sampling at 10 Hz. Again, similar instruments were operated at selected leads.

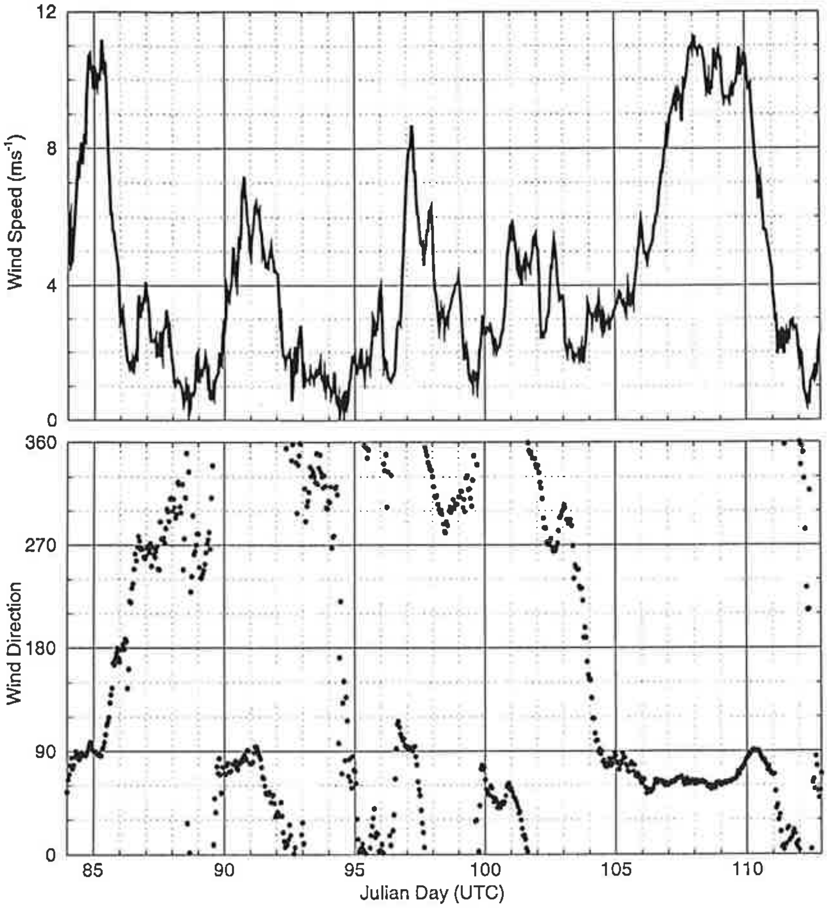
Rawinsonde ascents supplemented upper-level winds beyond the profiler range. Routine 0000 and 1200 Universal Time Coordinated (UTC) flights were launched daily, corresponding with ascents at Barrow and Deadhorse, Alaska. Special ascents were also made during aircraft operations, for a total of 75 launches.

Weather Synopsis

The time series for the temperature 2 m above the ground shows a distinct U-shaped pattern, a result of a persistent cold northerly flow throughout the middle portion of the experiment. Temperatures ranged from a high of –8°C to a low of –32°C. The beginning and end of LeadEx were characterized by strong (greater than 10 m/s) east-southeasterly flow produced by a strong pressure gradient with a low to the south and a high to the north. Two of the leads studied were during the cold windy periods. Also evident in the winds are 4–5 day cycles of stronger east-southeasterly winds separated by northerly flow. Diurnal temperature cycles were weaker during the strong wind events due to the mechanical mixing of the winds. The moisture time series indicates high relative humidities with respect to ice (the mean was 90%) with small diurnal cycles of 10–15%. The absolute moisture followed the temperature trend and increased with the east-southeasterly flow.

Comparisons among the profiler/RASS time series, rawinsonde ascents and surface tower data show good agreement in the overall trend, despite differences in basic measurement techniques. Rawinsonde profiles initially show a strong inversion (17°C) to a depth of 1 km that gradually weakened until it disappeared completely by 12 April. The surface-based nocturnal inversion was still present, even though the upper-level inversion had dissipated. As discussed above, the trend in temperature is caused by the steady, cold, northerly flow. Coupling this with the evolution of the inversion requires that greater cooling take place at upper levels to weaken the inversion. Similarly the return of the inversion, corresponding in time with surface warming, requires greater upper-level warming. It should be noted that the inversion height corresponds to the highest efficiency range of the profiler.

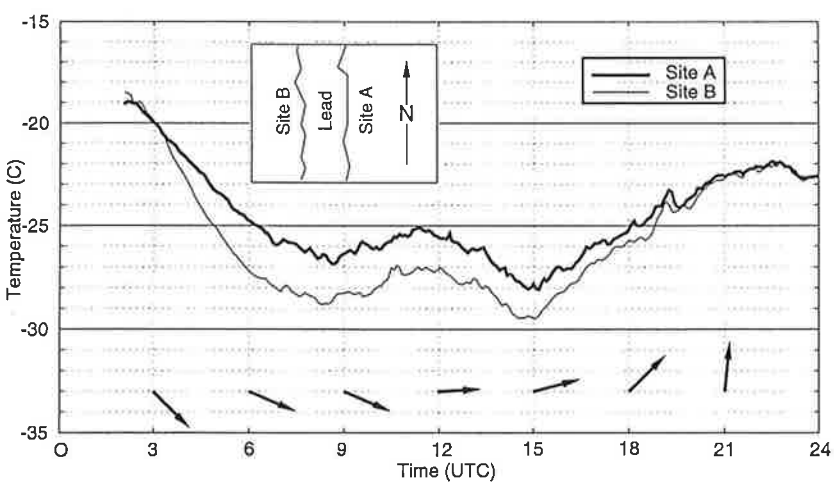
The cloud amount and type will need to be studied in detail because it is particularly important in understanding the Arctic energy budget. Ceilometer cloud-base information indicates that clouds were present 38% of the time, with 8% obscured skies. Light snow or ice crystal showers are included with the 38%. Obscured conditions include heavy snow showers, fog, blowing snow or other weather phenomena that attenuates the ceilometer signal immediately above the surface. The ceilometer observes only a small area directly above the sensor and therefore can infer total sky conditions or cloud cover only with additional information.



Wind speeds and directions (hourly averages) 3 m above the ground at the base camp.

Lead Results

Temperatures 2 m above the ground upwind and downwind of Lead 4 on Julian day 103 (12 April). The arrows show the wind direction. Site A was located downwind at the start of the sampling period and Site B was upwind. The lead was oriented north–south and was refreezing during this time.



Preliminary lead results are very exciting. The temperatures 2 m above the ground show an increase in the temperature of 2°C downwind from Lead 4, possibly reflecting the influence of the warm water on the colder air flowing over it. The lead was oriented north–south and winds were initially from the northwest. Two points to consider when analyzing these data further are the refreezing of the lead and the continuous wind shift of over 180° throughout this period. The consequences of the wind shift are believed to be small since the lead was totally frozen over, meaning that there was no longer an upwind or a downwind side with respect to open water by the time the wind reversed direction. Winds were backing, becoming parallel to the lead from the south around 1800 UTC. The upwind and downwind temperatures reflect the refreezing and wind shift as the 2°C difference decreased to almost 0°C by the end of the period. Absolute moisture data over the same time period show an identical pattern, increasing on the downwind side. Additional data from the minisodars on the structure and depth of the surface layer and flux measurements from the sonics should help confirm these preliminary results.

Summary

LeadEx provided the opportunity to collect a unique meteorological data set in the Arctic. Nearly continuous profiles of winds, temperature and many other variables, coupled with surface energy and flux measurements, reveal a highly variable boundary-layer structure at the base camp. How much of this variability results from leads in the region has yet to be fully studied. Early results show evidence of the leads' influence on the surface layer. Wind profiler operations proved extremely reliable up to 1 km, while extended coverage was highly dependent on atmospheric scatterers such as snow and ice crystals. RASS temperature profiles were severely limited by strong winds and low temperatures. Well-defined synoptic and diurnal weather patterns covering a wide range of conditions are observed in the data.

Publications

Readers may obtain further information on the instrumentation, data and research described in this article from the following publications:

Sodar Observations of the Stable Lower Atmospheric Boundary Layer at Barrow, Alaska, by T.K. Cheung: Boundary-Layer Meteorology, vol. 57, p. 251–274, 1991.

Field Tests of a Lower Tropospheric Wind Profiler, by W.L. Ecklund, D.A. Carter, B.B. Balsley, P.A. Currier, J.L. Green, B.L. Weber and K.S. Gage: Radio Science, vol. 25, p. 899–906, 1990.

A Climatology of Gravity Waves and Other Coherent Disturbances at the Boulder Atmospheric Observatory during March–April 1984, by F. Einaudi, A.J. Bedard Jr. and J.J. Finnigan: Journal of Atmospheric Science, vol. 46, p. 303–329, 1989.

LeadEx Data Report, Part 1; Weather Analysis and Satellite Images, by R.W. Fett, T.F. Lee and Lt. W.W. Rodie: National Oceanic and Atmospheric Research Laboratory, Technical Note 295, 1992.

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Turbulence Structure of the Atmospheric Surface Layer over the Arctic Ice and near a Lead, by J.E. Gaynor, D.E. Wolfe and Y. Jing-Ping: Preprint, Third Conference on Polar Meteorology and Oceanography, Portland, Oregon, Sept. 29–Oct. 2, 1992.

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Remote Sensing of the Arctic Boundary Layer, by D.E. Wolfe, C.W. Fairall, J.J. Jordan and D.W. Gregg: Preprint, Third Conference on Polar Meteorology and Oceanography, Portland, Oregon, Sept. 29–Oct. 2, 1992, p. J33–J36.

Surface Energy Measurements on the Arctic Ice Pack, by D.E. Wolfe, C.W. Fairall and D. Ruffieux: Preprint, Third Conference on Polar Meteorology and Oceanography, Portland, Oregon, Sept. 29–Oct. 2, 1992, p. 72–75.

New Perspectives on the Arctic:

"The Changing Role of the United States in the Circumpolar North"

Prepared by Elizabeth Leighton, formerly a U.S. Foreign Service Officer on Special Assignment to the University of Alaska Fairbanks.

The first major conference on U.S. Arctic policy, "The Changing Role of the United States in the Circumpolar North," held at the University of Alaska Fairbanks on August 12–14, 1992, initiated a vigorous reassessment of U.S. Arctic policy goals and objectives. Participants concluded that the areas of environmental protection and the role of indigenous peoples in policy formulation and decision making require greater attention and action. National security concerns in the Arctic must be reevaluated in the post-Cold War era. The need for greater public involvement in the policy process was highlighted by many participants. The conference itself represented a first step in that direction.

The State Department, in its role as lead agency on international Arctic policy, agreed to reexamine U.S. efforts in the Arctic and to review the conference proposals and recommendations. The State Department also announced its intention to establish a Public Advisory Committee on Arctic Policy as a means of enhancing public participation in the policymaking process.

The conference included participation from a broad cross section of governmental and non-governmental organizations, including the State of Alaska, academic experts, Federal agencies, Arctic residents, and industry and environmental representatives. A Canadian government official presented Canada's proposal for an International Arctic Council. The counselor for Russian–American relations at the Russian Embassy in Washington, D.C., gave the keynote address.

The conference, hosted by the University of Alaska Fairbanks, was organized to address recent changes in the Arctic political climate and to call for a fresh look at U.S. policy objectives in the Arctic. The framework for U.S. Arctic policy, established at the Presidential level in 1971, was last reviewed at that level in 1983. Since then the Arctic has entered an era of accelerated political, social and economic change that has both necessitated and fostered unprecedented international circumpolar cooperation.

The strategic gridlock of Cold War Arctic confrontation has ended. Now the Arctic is seen as a region for greater multilateral cooperation. Environmental concerns have spurred circumpolar governments to work together towards addressing environmental degradation. Indigenous peoples in the Arctic have organized the Inuit Circumpolar Conference and other entities to raise political, social, health, economic and environmental issues with Arctic governments. New economic ventures and opportunities for circumpolar research continue to develop.

Conference participants asked, Do these unfolding events require a change in U.S. Arctic policy? Current U.S. Arctic policy notes the unique and critical interests in the Arctic relating directly to national security, rational development, scientific research and international cooperation. These general objectives are the four pillars of U.S. Arctic policy. The conference explored how this policy blueprint might benefit from reevaluation and revision and made general recommendations for consideration in policy reassessment.

The Rapid Pace of Increased Arctic Cooperation

1986:	International scientific community begins discussions for establishment of an International Arctic Science Committee
1987:	U.S.S.R. President Mikhail Gorbachev outlines proposals for regional cooperation among Arctic states, reversing the Soviet Union's Cold War Arctic policy doctrines and marking a new openness in Arctic matters
1990:	Founding meeting of the International Arctic Science Committee is held
June 1991:	Ministers of Arctic governments adopt an Arctic Environmental Protection Strategy
July 1991:	Canadian government formally proposes the formation of an Arctic Council, which would serve as an umbrella organization for all Arctic cooperation
November 1991:	The Governor of Alaska hosts the founding meeting of the Northern Forum
1992:	Arctic Environmental Protection Strategy Working Group meets

Conference Agenda

Alaska's Governor Walter Hickel welcomed the participants by emphasizing that "...the Age of the Arctic is upon us, and it will be an age of great opportunity." He noted that the State of Alaska hosts the secretariat of the Northern Forum, an association of regional governments that is now exploring economic development opportunities such as the Northern Sea Route.

Assistant Secretary of State Curtis Bohlen addressed the opening session with a review of U.S. Arctic policy. He stated that political developments, such as the emergence of Russia as a potential partner rather than an adversary, "increased autonomy for indigenous peoples across the Arctic and intensified international concern for the environment, are already changing the way we view the Arctic." He concluded, "We must now devise an Arctic policy which will safeguard our national security, not just in military terms, but by protecting the global human environment." To help in the process of policy development, Mr. Bohlen announced the establishment of a Public Advisory Committee on Arctic Policy. This committee will include participants from academia, industry, environmental groups, Native organizations, local governments and other Arctic-related areas.

Conference panels were designed to facilitate a common understanding of the varied interests and concerns in the Arctic and to identify different perspectives on Arctic policy issues—human, economic development, environment, research and national security. Discussions focused on key issues facing Arctic policymakers: wildlife management, sustainable development, biodiversity, research and national security. Two themes were consistently highlighted in the panels: the role of Arctic residents in policymaking and the importance of environmental protection.

Panel I: Native Concerns in the North

Case Study: Methods of Cooperative Wildlife Management

Jeslie Kaleak, mayor of the North Slope Borough, emphasized the absolute necessity of involving Native peoples in the research and management of wildlife resources. "For centuries, the Inupiat have regulated their hunt based on traditional beliefs that are rich in legends and oral history about our relationship with the creator, his environment, and wildlife." The panel responded to his remarks with comments on the successes and failures of cooperative management in Alaska. The Alaska Eskimo Whaling Commission was cited as an effective means of cooperative management, because the commission has the authority to allocate the quota for the bowhead hunt. Kathryn Frost, a marine mammals biologist with the Alaska Department of Fish and Game, noted, "all of the partners in a cooperative undertaking have to have some stake in the actions that occur at the end."

A theme emerged that U.S. Arctic policy might acknowledge the need for change in how wildlife in the Arctic is managed, recognizing the transboundary nature of wildlife by suggesting a shift from the central government-dominated systems to new co-management and cooperative management systems. The U.S. Fish and Wildlife Service noted that it will host the next meeting on Conservation of Arctic Flora and Fauna, a component of the Arctic Environmental Protection Strategy. Arctic countries are working together to identify issues and concerns of mutual interest in flora and fauna research and management.

Panel II: Sustainable Northern Economies

Case Study: Red Dog Mine

Participants discussed requirements for sustainable development in the North. The lead–zinc Red Dog Mine in northwest Alaska was used as a case study for the panel. The choice of a nonrenewable resource development activity for a case study led to a spirited discussion of what constitutes sustainable development.

NANA Development Corporation, a Native regional corporation, is in partnership with the Canadian company Cominco in operating the mine. According to John Shively, president of the NANA Development Corporation, the project was designed from the point of view of local people. "The local people, in terms of the NANA shareholders, own the land and set the guidelines for this project." NANA believes the mine is sustainable in the sense that skills are developed and income is generated that can be used towards other local economic development such as tourism. The bottom line for NANA is cultural sustainability, not just profit.

The significance of the discussion was the recognition that the larger web of human needs in society is inextricably tied to concerns for the environment. In the North, local control and investment in human resources are integral to sustainable development. Panelists emphasized the need for long-term planning, or thinking "seven generations forward." While no single project can offer permanent security for local residents, long-term vision and wise use of capital resources contribute to the development of local services and businesses. Northerners need to think beyond the life of individual projects to how the economy can be supported.

Panel III: Conserving Arctic Biodiversity

Case Study: Protected Areas

David Cline, National Audubon Society, suggested that the U.S. goal should be to conserve and restore biological diversity in the Arctic for its intrinsic value and for human well-being. In implementing this goal, there must be "maximum opportunities for meaningful involvement of indigenous Arctic peoples in all aspects of biodiversity conservation," while meeting essential human resource needs. Panelists emphasized the human element of biodiversity protection—culture, jobs and spiritual needs: sustain biodiversity and cultural diversity but do not preserve them in a zoo or museum setting.

Denis Galvin, National Park Service, discussed the Beringian Heritage International Park as an example of an international protected area that recognizes the cultural as well as the scientific heritage of Beringia. He pointed to the need for protected areas because of a lack of ecosystem understanding. "Protected areas are an acknowledgment of that ignorance. They are set aside for a more passive treatment by man to preserve the processes that support the systems and to increase our understanding of them."

Panel IV: Arctic Research

Case Study: Pollution in the Arctic

Juan Roederer, former chair of the Arctic Research Commission, raised the political issues facing researchers today seeking answers for critical environmental questions in the Arctic. "Do we need scientific proof beyond a reasonable doubt before important environmental decisions are made? How can we explain that the earth system is so complicated that predictions are often inherently impossible? How can we explain that scientific questions require years of study that cannot be accelerated by governmental fiat or even money?"

Stephanie Pfirman, Environmental Defense Fund, argued that enough is already known of the sources and effects of pollutants to start clean-up programs. Panelists agreed that more research is needed. Scientists need to change their language so they can explain their concerns to policymakers. Policymakers need to listen. They must work in tandem to understand environmental questions and develop stable, long-term research programs required to answer these questions. Finally, researchers have an obligation to help people understand environmental problems where they live. In particular, knowledge, training and education must be made available to indigenous peoples. Assistance and collaboration with Russian research programs weighed heavily in the discussion. Conversion of military hardware for science, declassification of data and access to Russian data should be urgently pursued.

Panel V: Evolving Issues on National Security in the Arctic

Case Study: U.S. Arctic and Oceans Policy

When the Arctic was a strategically significant arena for superpower military competition, all other aspects of Arctic international relations were constrained by that reality. National security concerns limited the interaction among military, environment, science and economic development interests. The panel urged reassessment of the national security definition in the Arctic, pointing to possible changes embracing environmental and economic concerns.

Captain Joseph Baggett, Department of Defense, maintained that the U.S. national interest remains in preserving a stable Arctic region. U.S. policymakers should not be too quick to disengage entirely from all military activity in the area. Panelists and conference participants debated this approach, with many believing that the Arctic is now a strategic backwater and that military activities, particularly those involving nuclear operations, should be reduced. A strongly supported concept was that the protection, development and sustainability of national Arctic interests require less of a military capability and more of a science input.

Although formally unstated at the national decision-making level, participants suggested that the concept of national security has already broadened to include the health and well-being of Arctic residents and maintaining the ecological integrity of the Arctic. As national objectives these concepts would call for more support and investment for scientific study. Russia is a natural ally in scientific collaboration and sustaining Arctic resources. As in the other panels, the issue of "who decides in the Arctic" is important. Charlie Johnson, of the Inuit Circumpolar Conference, said, "the Arctic is more than a strategic zone or storehouse of resources. It is the homeland of indigenous peoples."

Plenary Session

Gilles Breton, Canadian Office of Circumpolar Affairs, Department of Indian and Northern Affairs and Development, presented Canada's case for an Arctic Council. The council's primary objective would be to provide greater stability and prosperity to the Arctic region. It would create a permanent forum for discussing issues of common interest and for promoting circumpolar cooperation. Oran Young, Institute for Arctic Studies at Dartmouth College, urged participants to "meet the challenge of a multiple-use region in a way that reconciles the concerns of the major players and protects the integrity of the region as a whole. We have entered a period in which opportunity is knocking. We have not had this kind of prospect for pursuing international cooperation in this region during the last century."

Conference participants took up Dr. Young's charge as they broke into working groups. The first session focused on setting priorities, the second on how those priorities might be achieved based on the panel discussions. Working groups reported policy recommendations back to the conference.

Conference Conclusions

Generally most participants agreed that U.S. Arctic policy goals and objectives should be reconsidered in light of the new global political climate and its impact on the Arctic. Environmental protection

Copies of the conference proceedings may be requested from Conferences and Special Events, 117 Eielson Building, University of Alaska Fairbanks, Fairbanks, Alaska 99775; Phone: 907-474-7800; Fax: 907-474-5592.

and participation of Arctic residents in the policy process should be considered as overarching objectives, taken in conjunction with national security, development and research. Specifically, participants suggested a review of the 1983 U.S. Arctic policy statement (National Security Decision Directive 90) in light of current concerns:

- Enhancing the role of Arctic residents, especially indigenous peoples, in policy development and implementation;
- Defining national security interests in the post-Cold War situation, highlighting economic and environmental security as well as national defense interests;
- Supporting development in the Arctic that protects the quality of the environment;
- Promoting scientific research and open data exchange in the Arctic, recognizing their unique role in global change studies;
- Sustaining the biological and cultural diversity in the Arctic; and
- Supporting regional and international cooperation to achieve these goals.

The working groups outlined some specific initiatives for U.S. Arctic policymakers. This listing does not represent consensus conclusions but provides a flavor of the working group results:

- Take a leadership role in the Arctic Environmental Protection Strategy;
- Evaluate the tasks and operations of institutions created under the Arctic Research and Policy Act of 1984: the Arctic Research Commission and the Interagency Arctic Research Policy Committee;
- Design and fund a long-term interdisciplinary action plan for Arctic contaminants research in conjunction with U.S. participation in the Arctic Monitoring and Assessment Program;
- Fund U.S. membership dues and participation in the International Arctic Science Committee;
- Incorporate the protection and restoration of the Arctic environment as an underlying principle of U.S. aid to the Russian Federation;
- Evaluate Agenda 21 (U.N. Conference on Environment and Development) in terms of U.S. Arctic policy goals;
- Establish the Department of State Arctic Public Advisory Committee as soon as possible and consult with this body on the review of U.S. Arctic policy in Alaska and Washington, D.C.

In the final conference session, representatives from each of the stakeholder groups summarized the conference on behalf of the participants. They concluded that the conference in and of itself made great strides in furthering communication and understanding among people and organizations in the Arctic. It was hoped that this dialog will continue through the Public Advisory Committee and on an expanded informal basis.

Conference participants discussed the role for indigenous peoples in policymaking at length, and many concluded that the development and implementation of Arctic policy must include meaningful participation of indigenous peoples, although there was no consensus on the definition for "meaningful." Environmental groups also sought an enhanced role in policymaking. The conference left no doubt that there is and should continue to be a prominent role for science in national Arctic policy.

Most participants agreed that the time had come for an updating of U.S. Arctic policy and that National Security Decision Directive 90 is the appropriate place to begin. Clearly the priorities have shifted since it was issued a decade ago, such as the importance of environment, human health and Native concerns. The conference proceedings provide a basis for this review.

The conference proceedings have been presented to the Department of State for consideration by the Interagency Arctic Policy Working Group.

Conservation of Arctic Flora and Fauna International Working Group

Prepared by Elizabeth Leighton, formerly a U.S. Foreign Service Officer on Special Assignment to the University of Alaska Fairbanks.

The Conservation of Arctic Flora and Fauna (CAFF) International Working Group held its second meeting in Fairbanks, Alaska, in May 1993. CAFF is a component of the Arctic Environmental Protection Strategy (AEPS), adopted by ministerial declaration in 1991 in Rovaniemi, Finland. Since 1991 the CAFF working group has made significant progress towards creating a distinct forum for scientists, indigenous peoples and conservation managers to exchange information and data, to cooperate on research and management of Arctic flora and fauna and their habitats, and to examine and improve upon regulatory and conservation practices.

The 1993 CAFF meeting was hosted and chaired by the United States under the leadership of the U.S. Fish and Wildlife Service and the Alaska Department of Fish and Game. Representatives of the eight Arctic countries (Canada, Finland, Greenland for Denmark, Iceland, Norway, Russia, Sweden and United States) attended the meeting. Several groups participated as observers (Netherlands, Germany, Inuit Circumpolar Conference, World Wide Fund for Nature International, U.S. Arctic Network, International Arctic Science Committee and Northern Forum).

The CAFF Working Group continued its work along the guidelines established in the Agreement on the Conservation of Arctic Flora and Fauna, namely exchange of information and data, cooperation on research and management of Arctic flora and fauna and their habitats, and examination and improvement of regulatory and conservation practices.

Through work plan status reports and technical sessions, delegates reexamined the objectives of the work plan and outlined future actions. A new work plan was drafted based on the working session conclusions. Highlights of the working session reports and the work plan action items follow.

Habitat Conservation

The draft report on the State of Habitat Protection in the Arctic is viewed as the first step towards defining cooperation among the Arctic countries in protecting important habitats. Delegates recognized that habitat protection does not rely exclusively on protected areas and in the long term a strategy for species and habitat conservation and sustainable use must be developed. The report includes the following subjects:

- Mapping of protected areas in the Arctic;
- Review of management practices and regulations pertaining to these protected areas;
- Assessment of gaps in the protected area system; and
- Examples of habitat conservation measures outside the protected areas in the Arctic.

The report is supplemented with plans and proposals for new protected areas in the Arctic. The report collates information provided by the eight Arctic countries. The information requested included:

- Definition of the Arctic;
- Classifications of Arctic habitat types into physical geographical regions, natural regions or ecozones;
- Identification of major threats to habitat;
- IUCN conservation management categories for protected areas;
- Overview of legislation and management of protected areas; and
- Identification of gaps in protected areas.

Delegates agreed to complete the habitat protection report and to prepare a plan for a network of protected Arctic areas that ensures necessary protection of Arctic ecosystems, recognizes the role of indigenous cultures and provides a common process by which member countries may advance the formation of circumpolar protected areas.

Integration of Indigenous Peoples' Knowledge

CAFF reaffirmed its commitment to the principle of the sustainable use and conservation of Arctic resources, particularly for the benefit of indigenous peoples. CAFF identified specific initiatives to develop a process for collecting and integrating traditional ecological knowledge and better defining participation of indigenous peoples in CAFF. Such initiatives include:

- A pilot project on environmental and ecological mapping of traditional knowledge;
- A directory of indigenous knowledge databases; and
- Consideration of ethical principles for Arctic research.

Flora and Fauna Conservation

CAFF initiated the task of developing national lists of rare, vulnerable and endangered flora and fauna species for the Arctic. It noted the difficulty in producing uniform lists due to considerable discrepancies in the criteria for listing species and the lack of a common geographic definition of the Arctic.

The ecosystem analyses help the Arctic countries to identify gaps in knowledge about the Arctic, to identify indicators of environmental change and to focus attention on resource protection issues of common interest and concern. Specifically CAFF will:

- Evaluate and update national lists of rare, vulnerable and endangered flora and fauna species based on a common set of criteria;
- Produce a vegetation map in collaboration with ongoing international activities;
- Identify the full spectrum of threats to Arctic flora, fauna and their habitats;
- Develop a circumpolar conservation strategy for murres, a seabird of common concern; and
- Establish a circumpolar seabird group and bulletin to facilitate and coordinate research and management activities of mutual interest.

Circumpolar Database

The U.S. proposed a circumpolar database responsive to such diverse groups as fish and wildlife biologists, plant scientists, global change specialists, environmental planners, resource managers and ecologists. Specifically the project will:

- Develop a prototype database for Alaska;
- Fund international activity for a circumpolar mapping program; and
- Establish an information system working group.

Framework and Structure for the CAFF Program

To assist the fulfillment of CAFF objectives, delegates agreed to develop a framework to identify priorities and establish programs and guidelines. Delegates approved an administrative structure, establishing the chair as the host country and the vice chair as the next host. Iceland will host the 1994 CAFF meeting, and Russia offered to host the meeting in 1995.

Canada proposed a small secretariat on an interim basis to facilitate coordination of CAFF activities and provide support to the chair in preparing for the annual CAFF meetings. The secretariat will be based in Ottawa.

Final Report

In addition to the work plan, CAFF drafted the following general recommendations to guide the CAFF program, as an integral component of the AEPS, in the future:

- Establish linkages to the U.N. Convention on Biological Diversity and other appropriate international fora with Arctic components;
- Assess management strategies in circumpolar protected areas with the aim of identifying successful management practices and procedures;
- Develop strategies for conserving Arctic flora, fauna and habitats that do not rely strictly on establishing and maintaining protected areas;
- Include the Arctic marine environment in the identification of habitats important to maintaining diversity and conservation of Arctic flora and fauna;
- Explore and develop innovative management agreements and mechanisms for the conservation and sustainable use of Arctic flora and fauna involving indigenous peoples and appropriate governments;
- Develop appropriate means or mechanisms to ensure the effective participation of indigenous peoples in AEPS activities;
- Encourage participation of indigenous peoples' groups to gather and contribute information on traditional uses and values of Arctic flora and fauna and to nominate species for special concern, where appropriate; and
- Examine current international agreements relating to Arctic flora and fauna to see where they can be strengthened and, if necessary, to make recommendations for their improvement.

A full CAFF report, including reports and work plans from the 1992 meeting in Ottawa and the 1993 meeting in Fairbanks, was submitted to the second AEPS ministerial in Nuuk, Greenland, in September 1993.

Interagency Arctic Research Policy Committee

Committee Members, Agency Representatives and Guests Present: *Frederick Bernthal, National Science Foundation; Raymond Arnaudo, Department of State; Grant Aufderhaar, Department of Defense; Barbara Bailey, Central Intelligence Agency; William Fitzhugh, Smithsonian Institution; David Garrison, Staff,* [illegible] [illegible] *Administration; Art Patrinos, Department of Energy; Elizabeth Ann Rieke, Department of Interior; Courtney Riordan, Environmental Protection Agency; Mark Schaefer, Office of Science and Technology Policy; W. Craig Vanderwagen, Department of Health and Human Services; Michael Vanwoert, National Aeronautics and Space Administration; Alan Walker, U.S. Coast Guard, Department of Transportation.*

Eleventh Meeting
July 1, 1993

Frederick Bernthal (NSF) convened the meeting at the National Science Foundation, Washington, D.C. Following introductions, Dr. Donald O'Dowd, Chair of the Arctic Research Commission, discussed issues of current concern to the Commission. First, Dr. O'Dowd addressed the support structure for Arctic science. The Commission suggests a system be established where logistic support for research is budgeted separately from science support, as is the practice for the Antarctic. Second, Dr. O'Dowd indicated that the Commission was pleased that the IARPC had responded to its August 1992 resolution calling for a multiagency scientific plan to evaluate the problem of Arctic contaminants, namely the dumping of radioactive materials and the dispersal of industrial pollutants. Dr. O'Dowd identified the third issue from the Commission: the need for a single, integrated, coherent multiagency budget request for Arctic research. He also emphasized the need for all Federal agencies to consult with the Commission before undertaking major Federal actions related to Arctic research.

Dr. Bernthal responded to the remarks made by Dr. O'Dowd, indicating that some action was under way directed at improving logistics for marine research and that the Commission's other thoughts on improving logistics for Arctic research were worthy of further discussion and possible implementation. At the suggestion of Dr. Bernthal, Mark Schaefer (OSTP) agreed to work with OMB on issues of agency budgets for Arctic research.

Raymond Arnaudo (DOS) presented an overview of the first comprehensive review of U.S. Arctic policy since 1983. The new policy places more emphasis on environmental issues, greater cooperation and involvement of the states and indigenous peoples, improving wildlife management strategies, and the need and growing importance of bilateral cooperation with the Russians. The fundamental points of U.S. interest in the Arctic, identified by the new policy, are environmental protection, international cooperation and institution building, national security and defense, indigenous peoples, environmentally sustainable development and scientific research.

Dr. Bernthal then addressed the issue of Arctic contamination and discussed events that had transpired since the IARPC's August 1992 meeting, when the Committee approved a Policy Statement on Arctic Contamination. In November the IARPC adopted an Agenda for Action to implement the Policy Statement and in May 1993 convened a workshop in Anchorage, Alaska.

Lou Codispoti (ONR) reported that as a result of Congressional and IARPC concern about one aspect of Arctic contamination, the dumping of nuclear waste materials in the Arctic by the former Soviet Union, a one-time appropriation of $10 million was allocated to the Department of Defense. Some additional funds have been contributed by other cooperating agencies, and a program to investigate the problem has been initiated under the direction of the ONR. The program has funded 25 research proposals and several workshops. The workshops have indicated that although there is no immediate threat to Alaska from nuclear dumping, long-term effects on fisheries and other Arctic biota remain a concern. Data and information collected during several cruises and from the funded research projects will provide a better perspective on nuclear contamination in two to three years.

Paul Ringold (EPA) led a discussion of the IARPC's Policy Statement on Arctic Contamination and the Agenda for Action for implementing the Policy Statement. Dr. Ringold introduced his remarks with a brief review of policy background, noting that during the late 1980s through about 1992, a number of concerns arose internationally and domestically about persistent organics, heavy metals and radionuclides. Internationally this resulted in the development of the Arctic Environmental Protection Strategy and the establishment of the Arctic Monitoring and Assessment Program (AMAP). Domestically the IARPC responded by establishing the AMAP Work Group, co-chaired by the EPA and the NOAA. In December 1992, AMAP adopted a monitoring plan directed at measuring levels of anthropogenic pollutants in the Arctic and assessing their effects on the Arctic environment. The main objective of the AMAP plan is to focus the actions of individual nations in their efforts to assess the problem of Arctic contamination.

During 1992, recognition of the large-scale dumping of radionuclides and other wastes in the Arctic by the former Soviet Union increased the level of concern, and the IARPC responded with its Policy Statement and Agenda for Action. The Workshop on Arctic Contamination held in Anchorage was one of the first steps taken in response to the Action Agenda.

Conclusions from the workshop were:

- Pollutants—radioactivity, heavy metals and persistent organics—from outside the Arctic can biomagnify in the food chains, and the associated risks are unknown.
- There has been extensive pollution in Russia, and the potential for transport of these pollutants is unclear.
- There is no evidence of regional-scale radionuclide waste risk at present; long-term risk, however, is uncertain.

Dr. Ringold (EPA) presented the IARPC staff's recommendations for future action. The first action, a short-term response, would be to continue the development of data synthesis and communication efforts as well as the evaluation of available data. Interaction with the Russian government and scientists and the planned collection of samples would continue. The second action, a longer-term response, would be to develop an interagency research, monitoring and assessment plan for a FY 95 or FY 96 initiative. The discussion of the recommendations that followed Dr. Ringold's presentation was generally favorable. Dr. Bernthal emphasized the importance of working with OMB and suggested that OSTP could help in this effort. A recommendation was made to proceed to implement both the short-term response and IARPC's longer-term response, to include consideration of risk issues and to use all available Government data and information in developing the structure of the longer-term research proposal. The recommendations were voted on and passed unanimously.

Dr. Bernthal commented that all agencies of the IARPC had approved the 1993 Biennial Revision to the U.S. Arctic Research Plan, subject to a few minor editorial revisions. He noted that a final copy must be submitted to the White House by July 31, 1993. A recommendation to transmit the Plan to the White House was voted on and approved.

United States Arctic Research Commission

Commission Members Present: *Donald D. O'Dowd, Chairperson; James O. Campbell; Ben C. Gerwick; Clifford D. Groh; Charles H. Johnson; Luis M. Proenza, Vice Chair; and Charles Myers representing the Ex-Officio Member Fred Bernthal.*

Staff: *Philip L. Johnson, Executive Director; and Lyle D. Perrigo, Head, Alaska Office.*

Commission Advisors: *Walter Bugno, Mim Dixon, Peter McCroy and John Middaugh.*

Visitors: *Marvin Bailey, Centers for Disease Control, Alaska; David Barret, Alaska Native Medical Center; James E. Berner, Alaska IHS; Martin Bozeman, ARCOAlaska; Linda Comerci, EPA-Anchorage; Cleve Cowles, Jerry Imm and Thomas Newbury, Minerals Management Service; Jim Deagen, Office of Sen. Murkowski; Ted E. DeLaca, University of Alaska Fairbanks; Sven Ebbesson, Institute for Circumpolar Health Studies, University of Alaska; Steve Findlay and Mike Joyce, ARCO; Tom Healy and David Hoffman, Arctic Region Supercomputing Center, University of Alaska; Carla Hefferich, Geophysical Institute, Press University of Alaska; Carl Hild, RURALCAP and American Society of Circumpolar Health; J.R. Kirkland, FBA, Inc.; Anne P. Lanier, IHS–MNHS; Laura Lee McCauley, ARCUS; D.R. Ritchie, Bureau of Land Management; Bill Seitz, Fish and Wildlife Service–Research; Loren Setlow, Polar Research Board; John Sibert, Alaska Science and Technology Foundation; Barbara Sokolov, University of Alaska Anchorage; Mead Treadwell, Alaska Dept. of Environ. Conservation; Bob Wainwright, CDC/NCID; Menghua Wei, Arctic Science Organization of China*

Thirty-First Meeting May 26–27, 1993

Report of the Chair

Chairperson Donald O'Dowd noted that Commissioners James Campbell, Clifford Groh and Charles Johnson with Lyle Perrigo had visited the ARCUS offices, the Geophysical Institute SAR Facility, and the Poker Flat Research Range near Fairbanks, Alaska. The University of Alaska Fairbanks announced in May the establishment of an Office of Arctic Research and selected Dr. Ted DeLaca to head this office.

The third Biennial Revision of the U.S. Research Plan, 1994-95, has been reviewed by the Commission and its Advisors, and comments were provided to IARPC.

The Commission participated in the Workshop on Arctic Contaminants held in Anchorage, Alaska, on May 3–7, 1993. The proceedings will be published in the journal *Arctic Research of the U.S.* It was evident from this conference that more scientific information is needed before a comprehensive risk assessment can be completed. To obtain the requisite information, a research plan and U.S. leadership must emerge to guide this effort. Among the elements of such a plan should be:

- Analysis of historical and archival data;
- Specific studies of causal relationships linking contamination with people and their food chain;
- Integration and multidisciplinary synthesis of existing and new data;
- Risk evaluation; and
- A public information campaign.

Arctic residents need to be consulted at every appropriate stage.

Alaska Governor's Office

Mead Treadwell, Deputy Commissioner, Alaska Department of Environmental Conservation, reported that Governor Hickel has three priorities in the Arctic:

- International recognition for the Northern Forum;
- Restoration of sustainable development to the Arctic Environmental Protection Strategy; and
- Development of the Northern Sea Route.

Because of the release of radiation at Tomsk, Russia, in April, there is additional concern for air monitoring in Alaska. An Alaskan delegation plans to visit the Bilibino nuclear power station in the Far East in 1993. He also discussed joint analysis with EPA of mussels for contaminants, an analytical chemistry laboratory in Juneau, and continuing concerns for rural sanitation and for wetlands regulation.

Interagency Arctic Research Policy Committee

Charles Myers, Office of Polar Programs, NSF, reported that Dr. Neil Sullivan began May 17, 1993, as Director of OPP. IARPC organized and conducted the Workshop on Arctic Contamination in Anchorage in May in response to the policy adopted in August and the Action Plan adopted in November. IARPC will next meet on July 1 to approve the Biennial Revision of the U.S. Arctic Research Plan before forwarding it to the President and to review progress in assessing Arctic contaminants. Meanwhile the IARPC staff are assisting the Office of Naval Research in evaluating proposals for an appropriation of $10 million to assess radioactive material released in the Arctic.

Loren Setlow, Director of the Polar Research Board, defined PRB as a unit of the National Research Council established in 1958 at the request of NSF. The Board advises the Federal government on matters of science and technical issues in both polar regions. It takes into consideration national interests and international opportunities in the Arctic and Antarctic. The Board serves as the U.S. National Committee for the International Arctic Science Committee (IASC) and for the Scientific Committee on Antarctic Research (SCAR). In June PRB will release a report, "Arctic Contributions to Social Science and Public Policy."

A new Committee on the Bering Sea Ecosystem of 13 experts will have its initial meeting in June. Philip Johnson was invited to participate as a liaison with the Commission. An 18-month study is intended to examine what is known, identify gaps in research and suggest improvements in management practices. A workshop will be convened in Anchorage this fall and another in Seattle. This study is funded by the Department of State.

Chinese Arctic Science Organization

Menghua Wei, Director, Chinese Arctic Science Organization, briefly reported on the establishment of his new group, which is planning an expedition to the North Pole. Dr. Wei is also a Professor at the Institute of Geology of the State Seismological

Bureau in Beijing. He has been a visiting scientist at Barrow, Alaska, on several occasions.

Review of U.S. Arctic Policy

Philip Johnson reported that the review of Arctic policy, chaired by the Department of State and requested by the National Security Council, was not yet completed. It is likely that ARC would be able to review the final report.

Arctic Region Supercomputing Center

Tom Healy, Director of the Arctic Region Supercomputing Center in Fairbanks, discussed the features of the Cray Y-MP supercomputer now being used in Fairbanks and the funded plan to add a massive parallel capability (YMPP) in 1994. It has the largest known memory in the world today, much larger than the NCAR facility visited by the Commission in March.

Alaska Science and Technology Foundation

John Sibert, Director, ASTF, described his four-year-old organization as focused on applied research leading to economic developments. Eighty-three proposals have been funded through 1992. ASTF has a small grants program (less than $20,000) in addition to project support. Dr. Sibert suggested he would welcome a comparison of ARC vs. ASTF priorities.

Arctic Health Research

Barbara Sokolov, Director, UAA Library, reported on a nearly completed project to compile a bibliography, "The Health of the Inuit of North American." There are 2742 citations in 487 different journals. The bibliography is to be published by the Nordic Council and will also be added to PolarPac, the Arctic bibliography on CD-ROM. This bibliography was enhanced by the dedicated contributions of Dr. Robert Fortuine.

Chairperson O'Dowd invited the panel of Alaska health experts to introduce themselves. They were:

- Dr. Marvin Bailey, Center for Health Defects, CDC, and Coordinator, Alaska fetal alcohol syndrome prevention project;
- Dr. David Barret, Medical Director, Alaska Native Medical Center;
- Dr. James Berner, Director, Community Health Services, Alaska Native Medical Center;
- Dr. George Conway, Chief, Alaska Activity, NIOSH;
- Dr. Mim Dixon, Director, Chief Andrew Isaac Health Center;
- Dr. Sven Ebbesson, Acting Director, Institute for Circumpolar Health, and President-Elect, American Society of Circumpolar Health, UAA;
- Dr. John Middaugh, Alaska State Epidemiologist, Dept. of Health and Social Services;
- Dr. Robert Wainwright, Director, Arctic Investigations Program, CDC.

Chairperson O'Dowd then asked each panelist to comment on whether Arctic health research was adequately coordinated among Federal agencies and with the State of Alaska. In general the panelists, who represent a broad area of clinical medicine, health care delivery and health investigations in Alaska, agreed that there was a high level of coordination, consultation and exchange of information among health professionals within Alaska. However, the relevant population of health leaders is modest in size, and the amount of research to be coordinated is very small.

Chairperson O'Dowd next asked each panelist to suggest their top priorities for needed health research. A number of panelists pointed to the success over the past 30 years in reducing infectious disease occurrence, and therefore natives are now dying from different causes. Morbidity is now highest from a set of causes related to behavioral and cultural clashes; alcohol is a major factor (suicide, accidents, FAS). The State has established relatively good disease surveillance and reporting. Research is needed on the relationship between economic status and environmental diseases. Other health problems include seasonal depression associated with weather and dark winters, selected diseases associated with poor sanitation, occupational injuries, drugs and certain cancers. Health problems and priorities in other Arctic countries are similar.

Chairperson O'Dowd then asked what can best be done in Alaska. The panelists observed that Alaska has no medical school and has a very small number of investigators who can compete for national health research funding—there is no critical mass of health researchers in Alaska. Dr. Ebbesson suggested that a remedy could be a Health Center grant to the university of perhaps $600,000 per year to recruit a critical mass for selected health research. Luis Proenza suggested a $10–20 million infusion was desirable.

Philip Johnson asked if it was appropriate for the Alaska health leadership to prepare a case statement of needed research and opportunity that had wide support as an actual basis for approaching Federal officials. John Middaugh replied that this had been done several times and existed in the form of the National Arctic Health Science Policy published in 1984 by the American Public Health Association. Carl Hild pointed out that in November 1992 the American Public Health Association published a state-by-state "America's Public Health Report Card." Alaska ranks statistically low among the 50 states in unhealthy behaviors and environmental pollution, but high in categories of health care responses.

The near absence of Federal health agency participation in any Arctic forum or organization was observed. John Middaugh recommended the Department of Health and Human Services be requested to establish an "arctic desk," or at least designate contacts in each unit of the department to help facilitate Arctic research. Some panelists thought that the lack of Federal agency interest was because 1) research costs are higher in Alaska, 2) the research benefits only a small population, and 3) few Alaskans serve on health proposal review panels.

Upon discussion the Commission decided to contact high-level representatives of the Department of Health and Human Services to discuss the principal health issues in the Arctic and the extremely small response by DHHS.

Coordination of Federal Arctic Research in Alaska

Chairperson O'Dowd asked panelists on Coordination of Federal Arctic Research to introduce themselves. The panelists were:

- Linda Comerci, Environmental Protection Specialist, Alaska Operations Office, Environmental Protection Agency. She works primarily on wetland issues.
- Paul Haertel, Associate Regional Director for Resources, Alaska Regional Office, National Park Service. His organization is concerned with cultural resources, environmental quality considerations, planning, mining and minerals, coastal programs, subsistence, and natural resource sciences.
- Jerry L. Imm, Chief, Environmental Studies Section, Alaska OCS Region, Minerals Management Service. For the past 16 years he has managed MMS environmental issues studies in Alaska. He has interfaced with the Arctic Research Commission since its formation in 1985.
- Ronald J. Morris, Supervisor, Western Alaska Field Office, National Marine Fisheries Service. His field office is involved in marine mammal resource and habitat work.
- D.R. Ritchie, Arctic District Manager, Bureau of Land Management. His group manages public lands in the Arctic. A considerable amount of the effort of his group is devoted to the land along the Trans-Alaska Pipeline corridor.
- William K. Seitz, Assistant Director of Research, Alaska Regional Office, Fish and Wildlife Service. This FWS research group conducts work on marine mammals, migratory birds, anadromous fish, and Eastern Arctic Coastal Plain terrestrial wildlife. Current Interior Department plans call for the research group to become part of new organization, the National Biology Survey.
- Orson Smith, Alaska District, U.S. Army Corps of Engineers. This office of the Corps works primarily on channel and harbor projects. Three projects in their initial states of development are enhancement of coastal navigation between Arctic communities, extension of the shipping season in the Kuskokwim and Yukon delta regions, and navigational issues relating to the use of the Northern Sea Route.

In response to a question, each panelist indicated that they had read ARPA. They also recognized that coordination with the Commission in accord with Section 105c was generally not done. Copies of the proceedings of the Federal Arctic Research Information Workshop, convened in Anchorage in March 1991, were distributed. Research in Alaska sponsored by eleven agencies was summarized at this conference.

Each panelist characterized the role of his or her agency in Arctic research. The Minerals Management Service had $27 million in research on offshore oil concerns in 1980; now the level is $3 million. The Fish and Wildlife Service conducts about $6 million in research involving 90–100 people. Most topics are issue-driven, and the best coordination across agencies occurs in the field among individual researchers. The Department of Interior representatives indicated concern and uncertainty regarding the consequences in Alaska of a newly planned Bureau of National Survey to be organized primarily from existing personnel and projects.

In general, panelists reported good coordination and exchange of information at the research level in Alaska, fair coordination between research and management components of Federal and state agencies, and mixed reactions regarding coordination with headquarters personnel.

In response to a question about what could be done to improve the effective coordination of investment in research, panelists felt that providing a better focus for research goals and objectives would better integrate the Federal research efforts. Currently there is only limited relation among projects. Duplication is not the issue, but gaps and mutual attainments of national needs and cost effectiveness is. Some agencies are accustomed to being directed to specific issues, each with different customers (FWS), whereas others (USFS) are adopting an ecosystem focus. Some agencies (EPA, NMFS) are driven by regulations such as the Endangered Species Act. Insufficient funds and poor understanding of Alaska in Washington are considered continuing problems.

Agencies with responsibilities for Federal lands practice multiple-use management. These agencies find that research is the key to their success. Their greatest need is for synthesis and integration of research results. Charles Johnson reminded participants of the potential value of using traditional Native knowledge.

Halon Suppressant

Steve Findlay, ARCO, presented the oil industry's concern for replacement or conservation of halon 1211 and 1301. As a result of the Clean Air Act and the Montreal international protocol, these fire suppressants are banned from further manufacture after December 1993. The Prudhoe oil facilities, which use large quantities, need either halon or a substitute to operate safely. Users are establishing a recycle bank to share halon gas.

Discussion of Arctic Logistics

Philip Johnson referred to background material before the Members that set forth three options for updating the Commission's recommendations on Arctic research logistics [per ARPA, Section 104(5)]. The options are to 1) defer consideration, 2) update recommendations in a letter format or 3) issue a new report to replace the one published in 1988. Discussion acknowledged that some previous recommendations had been addressed, but new ones had emerged attending the changes in Russia and the availability of selected military assets such as submarines. Concern was expressed, however, for continued availability for Arctic support of the LC-130, ski-equipped airplanes operated by New York Air National Guard (109th squadron). Charles Myers reported that NSF had issued an RFP for rebidding of the PICO contract consisting of two elements: engineering services and logistic information coordination.

The Commission concurred that a letter be prepared of updated Arctic logistic recommendations addressed to IARPC and circulated to Members for review and comment.

Commission Tasks and Status

Philip Johnson provided a brief status report on tasks before the Commission not previously discussed. Regarding progress to assure a dedicated science cruise using a U.S. Navy submarine in 1993, he asked, on behalf of Commissioner Newton, endorsement of the following statement:

> "The first dedicated arctic science cruise by a submarine in over 30 years will occur during the summer of 1993. The cruise will be supported by a U.S. Navy nuclear submarine.
>
> "This first cruise, however, represents only the initial effort needed in order for the scientific community to gain an in-depth understanding of the deep water of the Arctic Basin. Significant knowledge gaps exist in every science area: oceanography, bathymetry, geology, ice cover, and atmospheric science. Only a nuclear submarine can collect the range and depth of data in all seasons and in a timely manner to fill these voids. Thus the continued availability of a nuclear submarine is critical. It uniquely supports the long-term planning to fulfill existing high priority arctic research requirements.
>
> "Having participated in the development and planning of this first cruise and recognizing the value of such a continuing effort, the Arctic Research Commission formally endorses the creation of a dedicated program by the U.S. Navy supporting the use of a nuclear submarine for Arctic Ocean civilian science."

The Commission unanimously endorsed the statement.

Other Business

Upon discussion the Commission agreed that the Federal trustees be urged to designate at least $5 million of the unallocated $25 million from the *Exxon Valdez* criminal settlement to support Arctic/Subarctic Oil Spill Research under the provisions of Title V (Prince William Sound Oil Spill Recovery Institute) and Title VII (Interagency Oil Pollution Research and Development) of the Oil Pollution Act of 1990, to match the commitment made by the State of Alaska, and that Congress is urged to fully fund an Arctic/Subarctic oil spill research program as authorized by Title V of the Oil Pollution Act of 1990.

The Commission recommended that IARPC be asked how they are implementing ARPA Section 108a(5), which specifies that IARPC shall "provide the necessary coordination, data, and assistance for the preparation of a single integrated, coherent, and multiagency budget request for Arctic research." The Commission recognizes this as a key provision of the law.

Thirty-Second Meeting September 8–9, 1993

Report of the Chair

Chairperson O'Dowd reported on activities since its meeting in May. Updated and revised recommendations on logistics for Arctic research were sent to the Chair of IARPC. A letter to the three Federal trustees of the *Exxon Valdez* Oil Spill Trust Fund recommended funds to match funds provided by the State of Alaska for the Prince William Sound Oil Spill Recovery Institute at Cordova. In a letter

Commission Members Present: *Donald D. O'Dowd, Chairperson; James O. Campbell; Charles H. Johnson; George B. Newton; Luis M. Proenza, Vice Chair; and John B. Talmadge representing the Ex-Officio Member Fred Bernthal.* Staff: *Philip L. Johnson, Executive Director; and Lyle D. Perrigo, Head, Alaska Office.*

Commission Advisor: *Imants Virsnieks.*

Visitors: *Helen Bolen, Maniilaq Association; David Garman, U.S. Senate; Merritt Helfferich, Geophysical Institute, University of Alaska Fairbanks; Willie Hensley, NANA Corp.; Judy Johnson, Arlington, Virginia; Peggy Newton, McLean, Virginia; Dalene Perrigo, Perrigo Technology, Inc.; Caleb Pungowiyi, Inuit Circumpolar Conf.; Luke Sampson, Mayor's Office, Kotzebue; Pete Schaeffer, Vice President, NANA; Jeff Smith, City Manager, Kotzebue; Mead Treadwell, State of Alaska, DEC; Ida Twing, Vancouver, Washington.*

addressed to Secretary Shalala, the Commission requested full participation by DHHS in Arctic health research and designation of key contacts in the various research funding agencies of the Department of Health and Human Services.

On July 1, 1993, the Chair addressed the annual meeting of the Interagency Arctic Research Policy Committee and conveyed three concerns of the Commission. First, the five major logistic recommendations conveyed by letter to IARPC were presented:

- The Commission urges that a central source for Arctic logistic information be established as soon as possible.
- It is time to develop a comprehensive system in which logistic support of Arctic research is budgeted separately from science support, as is the practice for Antarctic research.
- The Commission urges inclusion of a request by NSF for the construction or lease of an Arctic research vessel.
- The Commission urges that appropriate IARPC agencies conducting ocean research to prepare an integrated science plan for use of Navy submarines coordinated with other available platforms to utilize this opportunity most effectively.
- IARPC agencies should recognize, support and coordinate a growing array of research facilities intended for Arctic research. Additional instrumentation and monitoring requirements could be developed employing dual-use (military and civilian) technologies.

IARPC may wish to reactivate its Working Group on Logistics to consider these recommendations and to help assure that optimal use is made of scarce logistics resources. A letter from NSF in response to these recommendations indicated that such a working group will be activated.

The Commission's second concern is for a focused Federal initiative on Arctic contaminants. The Commission issued a resolution in August 1992 calling on IARPC to prepare and coordinate a multiagency scientific plan to evaluate this concern—not only dumping of radioactive materials but dispersal of industrial pollutants in the Arctic. IARPC adopted a policy and an action plan in 1992, and the Chair reported that they are planning a program and budget initiative on this important matter.

A third issue is a growing concern that the Arctic Research and Policy Act of 1984 is not being fully implemented. Section 108 of the law specifies that a central duty of IARPC is to "(5) provide the necessary coordination, data, and assistance for preparation of a *single integrated, coherent, and multiagency budget request* for Arctic research." In a letter to the Chair of IARPC, the Commission requested to know how IARPC is implementing this requirement.

The ARPA law also requires "all federal agencies to consult with the Commission before undertaking major actions relating to Arctic research." The Commission has, thus far, not been consulted on a systematic basis.

Meanwhile, the staff in Washington, D.C., has relocated the Commission office to Arlington, Virginia, near the new NSF building and at 20% less rent. The staff has issued two contracts in support of the Commission's business: one to the firm of Wilmer, Cutler and Pickering for legal advice and one to Professor Rex Brown, George Mason University, for a phase one assessment of various tradeoffs in oil and gas development. A report on the latter will be given at the December meeting in Washington, D.C.

Jack Talmadge reported that NSF, after consulting with OMB, had responded by letter to the Commission's inquiry concerning the specification in ARPA to "provide the necessary coordination, data and assistance for the preparation of a single, integrated, coherent and multiagency budget request for Arctic research." The NSF letter states that staff currently solicit budget information from IARPC agencies and provide an Arctic budget tabulation to OMB. OMB uses this information in preparation of the President's budget. It appears from the NSF response that:

- Arctic research will compete within each agency for its level of support in accordance with various agency priorities.
- OMB is not now inclined to provide guidance on the Arctic or to circumvent agencies' internal planning.
- The Arctic interagency process will not be treated differently from other cross-agency reviews.

The focus will be on clear program goals, priorities, measurable progress and performance.

Luke Sampson, on behalf of Mayor Chuck Greene, Kotzebue, Alaska, welcomed the Commission to Kotzebue and the Northwest Arctic Borough. He went on to say, "...the Inupiat who live in the Arctic continue to need your scientific support in order to maintain *the lifestyle* of their choice. Our people's lifestyle is based upon our close interrelationship with our Arctic environment. The bounty that the land and sea provide for us is constantly being challenged, regulated, tested, studied or monitored with the wonders of Western technology. We believe many of those things are for a good purpose and will be for the betterment of the human race; however, please remember that we who live here are also 'at risk'!"

Mead Treadwell, Deputy Commissioner, Alaska

Dept. of Environmental Conservation, reported that an Alaska delegation visited the Bilibino Nuclear Power Plant on Russia's Chukotka Peninsula and learned that this 20-year-old plant does not meet Russia's own safety standards for nuclear power facilities. Nuclear wastes are stored near the reactor room. He credited the openness of their visit, in part, to the Commission's visit there in July 1992. In response to concern for potential release of radiation, agreements were reached for technical support from the U.S. and for a notification process to alert Alaska officials if radioactive materials are released from this plant. A monitoring system is to be in place by 1996.

Mead Treadwell reported that EPA intends to close its Arctic contaminants research program in FY 95. The current funding is about $800,000, primarily via the ERL-Corvallis Laboratory. This decision also implies that EPA will resign as co-chair of the IARPC Task Force on the Arctic Monitoring and Assessment Program (AMAP).

Mead Treadwell discussed promising plans to advance the use of the Poker Flat Research Range by using Russian SS-25 rockets to launch medium-size satellites with sophisticated remote sensors into polar orbits. The launcher is mounted on a vehicle and arrangements for importing it are under way.

Science Education and Native Knowledge

Willie Hensley, NANA Corporation and former Alaska State Senator, welcomed the Commission to "my hometown," and thanked Senator Murkowski for establishing the Commission, indicating that it had provided a needed focus and must continue to help define needed Arctic research goals.

Mr. Hensley finds that the old style of science has not served the Natives very well. They are no longer willing to be research guinea pigs. Natives used to be cooperative with researchers who came to the villages, but they feel misled by values and practices of science that are different from their culture. The Native lessons of long-time survival should be incorporated into education. Modern house design as well as water and sewer systems fail because the designers do not understand the Arctic. Although some countries have been more sensitive than others, circumpolar Natives have suffered from inappropriate Western technology. Scientists should involve Arctic residents in seeking knowledge and help teach principles of research in village schools. Kotzebue is improving school skills in math and writing. In both research and education, villages need to respond to issues raised by economic development, but also to include non-economic issues such as subsistence culture in the curriculum.

The biggest research requirement for Natives is their health and the health of the fish and animals important to their culture. A second research priority is the identification of sources of energy. It was observed that Native knowledge might be usefully integrated with Western science via the medium of geographic information systems.

Charles Johnson emphasized that many Natives feel that there is no institutional access to decision making on matters that affect them. Native groups intend to seek support for a Native Science Institute that would:

- Help incorporate Native knowledge into research planning;
- Help Natives participate in research;
- Create a mechanism for feedback of research findings to Arctic residents; and
- Promote science education.

Jeff Smith, Kotzebue City Manager, recommended cultural research centers at places such as Kotzebue as a means to support research, encourage the exchange of information and provide feedback to schools.

Imants Versnieks pointed out the need for a logistics clearinghouse to facilitate the transfer of information to researchers. He reported that the capability now exists to routinely put camps on the sea ice virtually anywhere. He also recommended that polar science would be more efficiently served if the LC-130 ski-equipped aircraft in the Antarctic and those based in New York (109th Squadron, Air National Guard) were placed under one management.

Comments from Agencies and Organizations

Dave Garman, U.S. Senator Murkowski's Office, confirmed that the NSF budget request to begin acquisition of an Arctic research vessel had been struck by the Senate Appropriations Committee at the request of Senator Bennett Johnston. Apparently Senator Johnston wants a political agreement to build and operate the ship by a Louisiana firm rather than by competitive bidding.

Mr. Garman reported that an amendment to the DOD appropriations bill had been accepted that would provide for the Polar Research Board to conduct a study of the iodine-131 tests of thyroid activity in Arctic residents. These experiments were conducted in the late 1950s. The purpose of this review would be to establish the facts and allay unwarranted suspicions in Alaska.

Interagency Arctic Research Policy Committee (IARPC)

Jack Talmadge, NSF, reported that IARPC had completed and published the Biennial Revision of the U.S. Arctic Research Plan in the current issue of the journal *Arctic Research of the U.S.* The Plan shows actual U.S. expenditures for Arctic research in

FY 92 of $148 million, with $155 million budgeted for FY 93 and $145 million proposed for FY 94. The increase in FY 93 is attributed primarily to a one-time appropriation of $10 million to assess Russian nuclear contamination.

Mr. Talmadge reported that the NSF Office of Polar Programs is reviewing its advisory structure and asked if the Commission would work with the NSF to achieve a new advisory structure for Arctic research. The Chair assured the NSF representative that the Commission would respond and will expect to discuss such a plan at its next meeting.

Inuit Circumpolar Conference

Caleb Pungowiyi, Acting President of the Inuit Circumpolar Conference (ICC), reported that ICC is an international organization that represents approximately 115,000 Inuit living in the Arctic regions of Alaska, Canada, Greenland and the Chukotka Region in the Commonwealth of Independent States (formerly the U.S.S.R.). The principal goals of the ICC are:

- To strengthen unity among the Inuit of the region;
- To promote Inuit rights and interests on an international level;
- To seek full and active partnership in the political, economic and social development of circumpolar regions in order to promote greater self-sufficiency among Inuit and to ensure the growth of their culture; and
- To develop and encourage long-term policies that safeguard the Arctic environment.

The ICC holds a General Assembly every three years, inviting delegates from each member region to work together to develop policies and other initiatives. An Inuit Elders' Conference is held at the same time to direct and enrich discussions. The ICC is granted status as a non-governmental organization within the United National Economic and Social Council.

Caleb Pungowiyi stated that it was important to Natives to work toward protection of the Arctic. Integration and use of Native knowledge for management of natural resources is a goal, though there is some confusion as to how best to do so. It is vital for Natives to participate in policy arenas that affect them.

Collocation of Agencies

Merritt Helfferich, Geophysical Institute, UAF, described a need to overcome Federal procurement barriers, which delay or prohibit collocating of units of Federal research agencies on university campuses.

The University of Alaska seeks to collocate several Federal and state agencies in a new addition to the Geophysical Institute's C.T. Elvey Building to:

- Improve collaboration for Arctic research and education;
- Increase the efficiency of information transfer among universities, government and the private sector;
- Improve personal linkages among researchers, engineers, students, technicians and industry; and
- Increase the effectiveness of research by cooperative use of facilities and equipment.

The agencies to be collocated include:

- The National Weather Service Weather Forecast Office;
- Three units of the U.S. Geological Survey;
- The Alaska Division of Geological and Geophysical Surveys;
- A proposed glaciological research unit of the National Park Service;
- The Alaska Aerospace Development Corporation; and
- Units of the Department of Energy.

Other agencies may seek collocation later.

Barriers to collocation created by current Federal and state regulations include procurement requirements to secure space at "market" real estate rental rates; procurements to secure space competitively; and requirements for universities to build facilities using "prevailing" labor rates.

Merritt Helfferich believes that, in the absence of Federal policy supporting collocation, the State of Alaska might find itself in the position of subsidizing Federal agency space to achieve national goals, should construction funding be available.

Upon discussion the Commission agreed to recommend appropriate actions to the Alaska delegation to facilitate collocation of Federal research units to campus in Alaska.

Other Business

George Newton reported on the accomplishments of the 1993 Arctic science submarine cruise. The USS *Pargo* operated under the Arctic ice pack for 23 days and systematically surveyed over 4900 nautical miles on a track from the North Pole to the Alaskan continental shelf. This effort concluded the week of 13 September.

While quantitative results are not available at this early time, reports from the senior scientist on board, Dr. Ted DeLaca of the University of Alaska Fairbanks (via the ship's commanding officer), indicated that all science objectives were being met and the collection of data in both volume and quality has far exceeded expectations.

Fifteen surfacings through the ice were conducted to execute atmospheric science measurements, to collect deep ocean water samples and to implant six meteorological and oceanographic sensing buoys (the most ever implanted on a cruise). These surfacings also highlighted the fact that the flexibility of the submarine enables it to conduct data collection both above and below the sea ice.

Never before has so much scientific data been collected on one operation in the Arctic Ocean. The cruise has supported the data requests of 45 individual U.S. scientists, five of whom were on board. This result is considered extraordinary for an operation that was planned and executed on seven months' notice.

Selected Meetings of Interest

Listed here is a compilation of recent and forthcoming meetings, workshops and conferences on Arctic or northern topics and activities. Readers are invited to submit information on upcoming meetings, as well as reports on national or international meetings attended, to Editor, Arctic Research, *Office of Polar Programs, National Science Foundation, 4201 Wilson Boulevard, Arlington, Virginia 22230.*

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Arctic Opportunities
13–16 September 1993, Rovaniemi, Finland
Contact: Raija Kivilahti, Arctic Centre, University of Lapland, P.O. Box 122, SF-96101 Rovaniemi, Finland
Phone: +358-60-324 778
Fax: +358-60-324 760

Fourth International CO_2 Conference
13–17 September 1993, Carqueiranne, France
Contact: Institute National des Sciences, de l'univers/ CNRS (Maritine Revillon, INSU), 77 Avenue Denfert Rochereau, 75014 Paris, France
Phone: 33-1-40-51-20-08
Fax: 33-1-40-51-21-49

44th Arctic Science Conference: Circumpolar Information Exchange
15–18 September 1993, Whitehorse, Yukon, Canada
Contact: Arctic Science Conference, P.O. Box 31137, Whitehorse, Yukon Y1A 5P7, Canada
Phone: (403) 667-4288
Fax: (403) 633-6965

5th World Wilderness Conference: Wild Nature and Sustainable Living in Circumpolar Regions
24 September–1 October 1993, Tromsø, Norway
Contact: The Northern Forum, Offices of the Secretariat, 4101 University Drive, Alaska Pacific University, Carr-Gottstein Academic Center, Suite 211, Anchorage, Alaska 99508
Phone: (907) 561-6645
Fax: (907) 561-6645

5th World Wilderness Congress: Wild Nature and Sustainable Living in Circumpolar Regions
25 September–1 October 1993, Tromsø, Norway
Contact: Charlotte Winsnes, Congress Director, Joint Secretariat, Post Box 190, 9001 Tromsø, Norway
Phone: +47 83 80 811
Fax: +47 83 80 618

MARSIN '93—International Conference on Marine Simulation and Ship Manoeuvrability
26 September–2 October 1993, St. John's, Newfoundland, Canada
Contact: Mrs. J. Harris, MARSIN '93 Conference Coordinator, Marine Institute, P.O. Box 4920, St. John's, Newfoundland A1C 5R3 Canada
Phone: (709) 778-0660
Fax: (709) 778-0346

4th Northern Regions Conference—People in the Arctic: Regional Rights and Regional Management
27 September–3 October 1993, Tromsø, Norway
Contact: 4th Northern Regions Conference, Joint Secretariat, Post Box 190, 9001 Tromsø, Norway
Phone: +47 83 80 811
Fax: +47 83 80 618

Fourth International Symposium on Thermal Engineering and Science for Cold Regions
28 September–1 October 1993, Hanover, N.H.
Contact: Virgil Lunardini, USA Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, New Hampshire 03755-1290
Phone: (603)646-4326
Fax: (603) 646-4640
Telex: 710 366 1826

International Symposium on the Ecological Effects of Arctic Airborne Contaminants
4–8 October 1993, Reykjavik, Iceland
Contact: Debra Steward, Technical Resources, Inc., 3202 Tower Oaks Boulevard, Rockville, Maryland 20852
Phone: (301) 770-3513
Fax: (301) 468-2245

Beijing 93'S International Symposium on Sea Ice
19–22 October 1993, Beijing, China
Contact: Ms. Shi Ping, Office of Beijing 93'S International Symposium on Sea Ice, Da Hui Si No. 8, Haidian District, National Research Center for Marine Environmental Forecasts, Beijing 100081, China
Phone: (861)-8313593

Redressing the Imbalance: Health Human Resources in Rural and Northern Communities
21–24 October 1993, Thunder Bay, Ontario, Canada
Contact: Connie Hartviksen, Redressing the Imbalance, c/o Northern Health Human Resources Research Unit, Health Sciences North, Lakehead University, 955 Oliver Road, Thunder Bay, Ontario P7B 5E4, Canada
Phone: (807) 343-2135
Fax: (807) 343-2104

Growth and Environment: Challenging Extreme Frontiers—2nd International Design for Extreme Environments Assembly
23–28 October 1993, Montreal, Canada
Contact: IDEEA Two, Centre for Northern Studies and Research, Burnside Hall, Suite 720, McGill University, 805 Sherbrooke Street West, Montreal, Quebec H3A 2K6, Canada
Phone: (514) 398-6052
Fax: (514) 398-8364

Sea Level Changes: Measurements and Analysis
9–10 December 1993, London, United Kingdom
Contact: PSMSL, Proudman Oceanographic Laboratory, Bidston Observatory, Birkenhead, Merseyside L43 7RA, United Kingdom
Fax: 44-51-653-6269

1994

Circumpolar Ecosystems in Winter 3
16–21 February 1994, Churchill, Manitoba, Canada
Contact: CEW-3, Churchill Northern Studies Centre, P.O. Box 610, Churchill, Manitoba R0B 0E0, Canada
Phone: (204) 675-2307
Fax: (204) 675-2139

Seventh International Cold Regions Engineering Specialty Conference
7–9 March 1994, Edmonton, Alberta, Canada
Contact: Dr. Daniel W. Smith, Department of Civil Engineering, University of Alberta, Edmonton, Alberta T6G 2G7, Canada

Polar Tech '94
22–25 March 1994, Luleå, Sweden
Contact: CENTEX, Lena Allheim Karbin, Luleå University of Technology, S-95187, Luleå, Sweden

ISOPE-94; The Fourth International Offshore and Polar Engineering Conference
10–15 April 1994, Osaka, Japan
Contact: ISOPE, P.O. Box 1107, Golden, Colorado 80402-1107
Fax: 1-303-420-3760

Third Circumpolar Symposium on Remote Sensing of Arctic Environments
16–20 May 1994, Fairbanks, Alaska
Contact: Ken Dean, Conference Chair, University of Alaska Fairbanks
Phone: (907) 474-7364
Fax: (907) 474-7290
E-mail: kdean@geewiz.gi.alaska.edu

ISCORD 1994—International Symposium on Cold Regions Development
13–16 June 1994, Espoo, Finland
Contact: ISCORD '94 Symposium Secretariat, c/o Association of Finnish Civil Engineers RIL, Meritullinkatu 16 A 5, SF-00170 Helsinki, Finland
Phone: +358 0 1356300
Fax: +358 0 1357669

Bipolar Information Initiatives: The Needs of Polar Research—15th Polar Libraries Colloquy
3–8 July 1994, Cambridge, United Kingdom
Contact: William Mills, Scott Polar Research Institute, Cambridge CB2 1ER, U.K.
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Fax: 0223-336549
E-mail: wjm13@uk.ac.cam.phx

International Conference on the Arctic and North Pacific: Bridges of Science Between North America and the Russian Far East
25 August–2 September 1994, Anchorage Alaska, and Vladivostok, Russia
Contact: Dr. Gunter Weller, Geophysical Institute, University of Alaska, Fairbanks, Alaska 99775-0800
Fax: (907) 474-7290
E-mail: gunter@dino.gi.alaska.edu

Second International Conference on Arctic Margins (ICAM)
September 1994, Magadan, Russia
Contact: Dennis Thurston, Anchorage, Alaska
Phone: (907) 271-6545, 6010

1994 International Conference on Arctic Margins
5–9 September 1994, Magadan, Russia
Contact: Kirill V. Simakov, North East Scientific Centre, 16 Portovaya Street, Magadan, 685000 Russia, or Dennis K. Thurston, U.S. Minerals Management Service, 949 E. 36th Avenue, Rm 605, Anchorage, Alaska 99508-4320
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(7-41) 3 223-0953 (Kirill Simakov, Russia)
(907) 271-6545 (Dennis Thurston)
Fax: (907) 271-6565

1995

ISOPE-95: 5th International Offshore and Polar Engineering Conference
11–16 June 1995, The Hague, The Netherlands
Contact: Technical Program Committee, Attn: Prof. Jin S. Chung, ISOPE, P.O. Box 1107, Golden, Colorado 80402-1107
Phone: (303) 273-3673
Fax: (303) 420-3760

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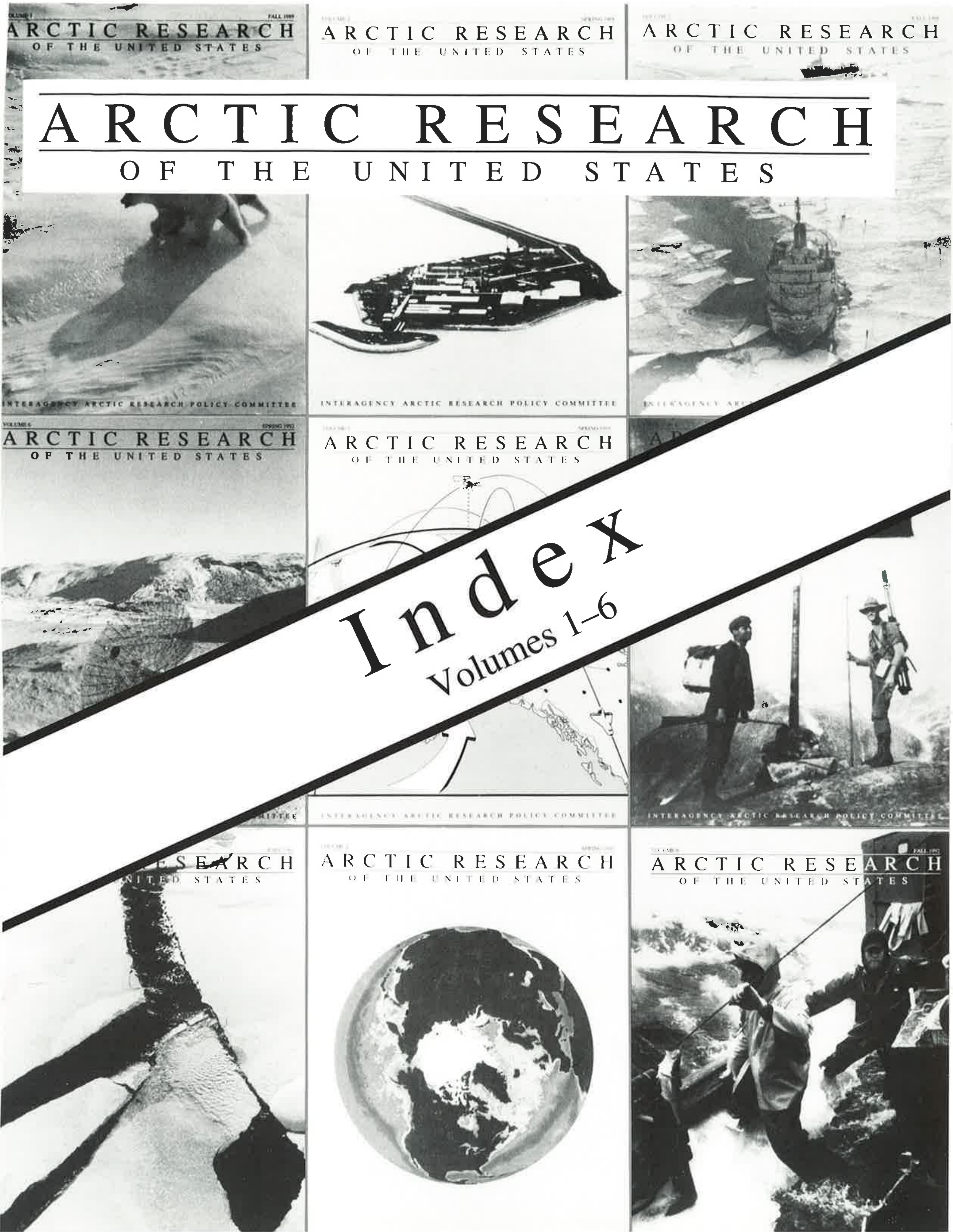

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Subject Index

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Title Index

Author Index

Conference Index

Acronym Index

AAAS	American Association for the Advancement of Science
AARC	Auroral Atmospheric Radiance Code
ABLE	Arctic Boundary Layer Expedition
ABSORB	Arctic Beaufort Sea Oil Spill Research Body
ACEC	Areas of Critical Environmental Concern
ACSYS	Arctic Climate System Study
ACUNS	Association of Canadian Universities for Northern Studies
ADAMHA	Alcohol, Drug Abuse, and Mental Health Administration
ADCP	Acoustic Doppler Current Profiler
ADEOS	Advanced Earth Observation System
ADF&G	Alaska Department of Fish and Game
ADGGS	Alaska Division of Geological and Geophysical Survey
ADI	Arctic Data Interactive
AEDD	Arctic Environmental Data Directory
AEDDWG	Arctic Environmental Data Directory Working Group
AEDS	Arctic Environmental Data System
AEIDC	Arctic Environmental Information and Data Center
AES	Atmospheric Environment Service of Canada
AEWC	Alaska Eskimo Whaling Commission
AF	Air Force
AFGL	Air Force Geophysics Laboratory
AFN	Alaska Federation of Natives
AFOSR	Air Force Office of Scientific Research
AFP	Alpha-fetoprotein
AFWRC	Alaska Fish and Wildlife Research Center
AG	Agriculture
AGASP	Arctic Gas and Aerosol Sampling Program
AGU	American Geophysical Union
AHAP	Alaska High Altitude Photography
AHD	Alveolar Hydatid Disease
AIDJEX	Arctic Ice Dynamics Joint Experiment
AIL	Arctic Investigations Laboratory
AINA	Arctic Institute of North America
AIS	Airborne Imaging Spectrometer
AIWEX	Arctic Internal Wave Experiment
ALASKA	Arctic Lands and Shelves–Key Assessments
ALERT	Arctic Long-term Environmental Research Transects
AMAP	Arctic Monitoring and Assessment Program
AMLR	Antarctic Marine Living Resources
AMMTAP	Alaska Marine Mammal Tissue Archival Project
AMPTE	Active Magnetospheric Plasma Tracer Explorers
AMQUA	American Quaternary Association
AMRAP	Alaska Mineral Resources Assessment Program
ANCSA	Alaska Native Claims Settlement Act
ANILCA	Alaska National Interest Lands Conservation Act
ANWR	Arctic National Wildlife Refuge
AOGA	Alaska Oil and Gas Association
AOR	Arctic and Offshore Research
AORIS	Arctic and Offshore Research Information System
AOSB	Arctic Ocean Science Board
APEX	Arctic Polynya Experiment
APOA	Arctic Petroleum Operators Association
APRISE	Assessment of Productivity and Recruitment in Subarctic Ecosystems
ARAMP	Arctic Remote Autonomous Measurement Platform
ARC	Arctic Radiation and Chemistry
ARCSS	Arctic System Science, NSF
ARCUS	Arctic Research Consortium of the United States
ARI	Accelerated Research Initiative
ARP	Arctic Research Plan
ARPA	Arctic Research and Policy Act
ARS	Agricultural Research Service
ASCE	American Society of Civil Engineers
ASF	Alaska SAR Facility
ASME	American Society of Mechanical Engineers
ASTF	Alaska Science and Technology Foundation
AVHRR	Advanced Very High Resolution Radiometer

AVIRIS	Advanced Visible and Infrared Imaging Spectrometer
AVO	Alaska Volcano Observatory
AWARE	Alaska Water Resources Evaluation
BCRST	Bibliography on Cold Regions Science and Technology
BIA	Bureau of Indian Affairs
BLM	Bureau of Land Management
BOM	Bureau of Mines
BOREAS	Boreal Ecosystem–Atmosphere Study
BOSS	Behavior of Offshore Structures
BPRC	Byrd Polar Research Center
BREW	Biosphere Research: Emissions from Wetlands
CAH	Central Arctic Herd
CAI	Comité Arctique International
CAMA	Central Arctic Management Area
CANQUA	Canadian Quaternary Association
CCAMLR	Convention for the Conservation of Antarctic Marine Living Resources
CCC	Cod and Climate Change
CCRS	Canadian Center for Remote Sensing
CD-ROM	Compact Disk–Read-Only Memory
CDC	Centers for Disease Control
CDMS	Cryospheric Data Management System
CEAREX	Coordinated Eastern Arctic Experiment
CEDAR	Coupling, Energetics and Dynamics of Atmospheric Regions
CEQ	Council on Environmental Quality
CES	Committee on Earth Science
CESAR	Canadian Expedition to Study the Alpha Ridge
CFU	Alaska Cooperative Fishery Research Unit
CG	Coast Guard
CIA	Central Intelligence Agency
CID	Center for Infectious Diseases
CIR	Color Infrared
CIRES	Cooperative Institute for Research in Environmental Sciences
COE	Corps of Engineers
COGLA	Canadian Oil and Gas Lands Administration
CONRIM	Council on Northern Resources Information Management
COOSRA	Canadian Offshore Oil Spill Research Association
COPE	Coordinated Observations of Polar Electrodynamics
CRBP	Cold Regions Bibliography Project
CRREL	Cold Regions Research and Engineering Laboratory
CRRES	Combined Release and Radiation Effects Satellite
CTD	Conductivity, temperature and depth
CZCS	Coastal Zone Color Scanner
DA	Department of Agriculture
DASA	Defense Atomic Support Agency
DC	Direct current
DE	Dynamics Explorer
DEC	Department of Environmental Conservation (Alaska)
DEW	Distant Early Warning
DFO	Department of Fisheries and Oceans (Canada)
DHHS	Department of Health and Human Services
DIAND	Department of Indian and Northern Affairs (Canada)
DMSP	Defense Meteorological Satellite Program
DNA	Defense Nuclear Agency
DNR	Alaska Department of Natural Resources
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOED	Department of Education
DOI	Department of Interior
DOS	Department of State
DOT	Department of Transportation
DOT&PF	Alaska Department of Transportation and Public Facilities
DPP	Division of Polar Programs
EBV	Epstein-Barr Virus
EC	Environment Canada
ECM	Electrical Conductivity Measurements
EEZ	Exclusive Economic Zone
EGC	East Greenland Current
EIS	Environmental Impact Statement
EM	Electromagnetic
EOS	Earth Observing System
EOSAT	Earth Observation Satellite
EPA	Environmental Protection Agency
ERS	European Remote Sensing (satellite)
ESA	European Space Agency
ESMR	Electrically scanning microwave radiometer
ESP	Environmental Studies Program
ESRF	Environmental Studies Research Fund
FAA	Federal Aviation Administration
FCCSET	Federal Coordinating Council for Science, Engineering and Technology
FCZ	Fisheries Conservation Zone
FE	Fossil energy
FERF	Frost Effects Research Facility
FIFE	First ISLSCP Field Experiment
FOCI	Fisheries–Oceanography Coordinated Investigations
FOFCC	Federal Oceanographic Fleet Coordinating Council

FS	Forest Service
FWS	Fish and Wildlife Service (also USFWS)
GCM	General Circulation Model
GEM	Geospace Environment Modeling
GEOSAT	Geostationary Satellite
GIFA	Governing International Fishery Agreement
GIS	Geographic Information System
GISP	Greenland Ice Sheet Program
GISP II	Greenland Ice Sheet Program II
GLORIA	Geologic Long Range Inclined Asdic
GMCC	Geophysical Monitoring for Climatic Change
GOES	Geostationary Operational Environmental Satellite
GOFS	Global Ocean Flux Study
GPS	Geophysical Products System
GRIP	Greenland Icecore Program
GS	Geological Survey
GSC	Geological Survey of Canada
GSP	Greenland Sea Project
GTE	Global Tropospheric Experiment (NASA)
GTF	Governor's Task Force
HF	High frequency
HAARP	High-frequency Active Auroral Research Program
HIRIS	High-Resolution Imaging Spectrometer
HRPT	High-Resolution Picture Transmission
HRSA	Health Resources and Services Administration
HRV	High-resolution visible
IAOE	International Arctic Ocean Expedition
IAPG	Interagency Arctic Policy Group
IAPP	International Arctic Polynya Project Program
IARCC	Interagency Arctic Research Coordinating Committee
IARPC	Interagency Arctic Research Policy Committee
IASC	International Arctic Science Committee
IAWG	Interagency Archeology Working Group
IBR	Information Base Review (MMS)
ICAM	International Conference on Arctic Margins
ICC	Inuit Circumpolar Conference
ICECAP	Infrared Chemistry Experiment Coordinated Auroral Program
ICES	International Council for the Exploration of the Sea
ICSU	International Council of Scientific Unions
IGBP	International Geosphere–Biosphere Program
IGY	International Geophysical Year
IHP	International Hydrological Program
IHS	Indian Health Service
IIAS	Interactive Image Analysis System
IMF	Interplanetary Magnetic Field
IMPROVE	Interagency Monitoring of Protected Visual Environments
INQUA	International Union for Quaternary Research
INSTAAR	Institute of Arctic and Alpine Research
IPA	International Permafrost Association
IR	Infrared
IRIS	Imaging Riometer for Ionospheric Studies
ISCCP	International Satellite Cloud Climatology Program
ISGF	International Symposium on Ground Freezing
ISHTAR	Inner-Shelf Transport and Recycling (NSF)
ISLSCP	International Satellite Land Surface Climatology Program
ISTP	International Solar-Terrestrial Program
ITEX	International Tundra Experiment
ITM	Information Transfer Meetings (MMS)
IUCH	International Union for Circumpolar Health
IWC	International Whaling Commission
IWGDMGC	Interagency Working Group on Data Management for Global Change
JGOFS	Joint Global Ocean Flux Study
JIC	Joint Ice Center
JIWG	U.S./Canada Joint Ice Working Group
JOI	Joint Oceanographic Institutions, Inc.
JPL	Jet Propulsion Laboratory
JRS	Japanese Remote Sensing (satellite)
KANA	Kodiak Area Native Association
LAII	Land–Atmosphere–Ice Interactions
LEADEX	Lead Experiment
LIGG	Lanzhou Institute of Glaciology and Geocryology
LME	Large Marine Ecosystem
LOREX	Lomonosov Ridge Experiment
LRV	Low Resolution Visible
LTER	Long-Term Ecological Research
MAB	Man and the Biosphere
MAP	Middle Atmosphere Program
MARAD	Marine Administration
MFCMA	Magnuson Fishery Conservation and Management Act
MIZ	Marginal ice zone
MIZEX	Marginal Ice Zone Experiment
MMS	Minerals Management Service
MOS	Model output statistics
MOU	Memorandum of understanding
MSA	Methanesulfonic acid
MSS	Multispectral scanner
MST	Mesospheric–stratospheric–tropospheric
NAD	Nansen Arctic Drilling Program

NARL	Naval Arctic Research Laboratory
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency
NAVSEA	Naval Sea Systems Command
NCAR	National Center for Atmospheric Research
NCP	National Climate Program
NEIC	National Earthquake Information Center
NEPA	National Environmental Policy Act
NEPERF	Naval Environmental Prediction Research Facility
NESDIS	National Environmental Satellite, Data, and Information Service
NEW	Northeast water polynya
NGO	Non-governmental organization
NIAID	National Institute of Allergies and Infectious Diseases
NICCF	National Ice Core Curatorial Facility
NIH	National Institutes of Health
NILU	Norwegian Institute of Air Research
NIMH	National Institute of Mental Health
NIST	National Institute of Standards and Technology
NLC	Northern Libraries Colloquy
NMC	National Meteorological Center
NMD	National Mapping Division (Amundsen–Scott South Pole Station)
NMFS	National Marine Fisheries Service
NMML	National Marine Mammal Laboratory
NOAA	National Oceanic and Atmospheric Administration
NOGAP	Canadian Northern Oil and Gas Action Program
NOGAPS	Naval Operational Global Atmospheric Prediction System
NOW	North water polynya
NPC	Nasopharyngeal cancer
NPFSC	Interim Convention on Conservation of North Pacific Fur Seals
NPOC	Naval Polar Oceanography Center
NPRA	National Petroleum Reserve–Alaska
NPS	National Park Service
NRC	National Research Council
NRL	Naval Research Laboratory
NS&T	National Statutes and Trends
NSDD	National Security Decision Directive
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSN	Northern Science Network
NWAFC	Northwest and Alaska Fisheries Center
OAII	Ocean–atmosphere–ice interactions
OAR	Oceans and Atmospheric Research
OAS	Office of Aircraft Services (Alaska)
OCEANAV	Oceanographer of the Navy
OCI	Ocean color imager
OCLC	Online Computer Library Center (formerly Ohio College Library Center)
OCS/EEZ	U.S. Outer Continental Shelf/Exclusive Economic Zone
OCS	Outer Continental Shelf
OCSEAP	Outer Continental Shelf Environmental Assessment Program (NOAA)
ODP	Ocean Drilling Program
OHMSETT	Oil and Hazardous Material Simulated Environmental Test Tank
OIES	Office of Interdisciplinary Earth Sciences
OMAE	Offshore Mechanics and Arctic Engineering
ONR	Office of Naval Research
OSTP	Office of Science and Technology Policy
PALE	Paleoclimates of Arctic Lakes and Estuaries
PCH	Porcupine Caribou Herd
PICES	Pacific International Council for the Exploration of the Sea
PICO	Polar Ice Coring Office, University of Alaska Fairbanks
PIPOR	Programs for International Polar Oceans Research
PIPS	Polar Ice Prediction System
PM	Passive microwave
POAC	Port and Ocean Engineering under Arctic Conditions
PRB	Polar Research Board
PRECP	Processing of Emissions by Clouds and Precipitation
PROBES	Processes and Resources of the Bering Sea Shelf
PROFS	Program for Regional Observing and Forecasting Services
PSC	Polar stratospheric cloud
PTWG	Polar Technology Working Group
PYK	Porcupine–Yukon–Kuskokwim
R-TEAM	Real-Time Environmental Arctic Monitoring
R4D	Response, Resistance, Resilience and Recovery from Disturbance
RAF	Research Aviation Facility
RAPS	Resource Apprenticeship Program for Students
RISP	Ross Ice Shelf Project
ROV	Remotely operated vehicle
RSP	Regional Study Plan (Alaska)
SAD	Seasonal affective disorder
SAR	Synthetic aperture radar
SARSAT	Satellite Search and Rescue System
SBIR	Small Business Innovative Research

SCAR	Scientific Committee on Antarctic Research
SCAT	Scatterometer
SCOR	Scientific Committee for Ocean Research
SCS	Soil Conservation Service
Sea-WiFS	Wide-Field Sensor
SEL	Space Environment Laboratory
SGC	Salivary gland cancer
SHPO	State Historical Preservation Office
SHRP	Strategic Highway Research Program
SI	Smithsonian Institution
SISEX	Shuttle Imaging Spectrometer Experiment
SIZEX	Seasonal Ice Zone Experiment
SLAR	Side-looking airborne radar
SLIP	St. Lawrence Island Polynya
SME	Solar Mesospheric Explorer
SMMR	Scanning multichannel microwave radiometer
SMO	Science Management Office, GISP II, University of New Hampshire
SPOT	Systeme Probatoire d'Observation de la Terre
SSC	Science Steering Committee
SSM/I	Special sensor microwave/imager
SSWG	Social Science Working Group
STEP	Solar–Terrestrial Energy Program
STTP	Solar–Terrestrial Theory Program
TA&R	Technology Assessment and Research
TACT	Trans-Alaska Crustal Transect
TAGS	Trans-Alaska Gas System
TALI	Trans-Alaska Lithosphere Investigation
TCCRE	Technical Council on Cold Regions Engineering
TGCM	Thermospheric General Circulation Model (TGCM)
TM	Thematic mapper
TRAPOLEX	Transpolar Expedition
UAA	University of Alaska Anchorage
UAF	University of Alaska Fairbanks
UARS	Upper Atmosphere Research Satellite
UCAR	University Corporation for Atmospheric Research
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNL	University of Nebraska–Lincoln
UNOLS	University National Oceanographic Laboratory System
URI	University Research Initiative
USARC	U.S. Arctic Research Commission
USCG	United States Coast Guard
USDA	United States Department of Agriculture
USFWS	U.S. Fish and Wildlife Service (also FWS)
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
UV	Ultraviolet
VERLORT	Very long-range tracking (radar)
VHRR	Very high resolution radiometer
VLF	Very low frequency (radio waves)
WAH	Western Arctic Caribou Herd
WDO	Winter Drift Operation
WINE	Winter in Northern Europe
WLN	Western Libraries Network
WOCE	World Ocean Circulation Experiment
WP	Weather plane
WRD	Water Resources Division
WSC	West Spitzbergen Current
YPLL	Years of potential life lost

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