U.S. Office of Naval Research

NAVAL RESEARCH

REVIEWS

MAY 1976

AMERICAN REVOLUTION BICENTENNIAL 1776-1976

PROFILES IN SCIENCE

Dr. Norbert Untersteiner

Dr. Norbert Untersteiner is Professor of Atmospheric Sciences and Geophysics at the University of Washington. After studying under the late Albert Defant, he received his doctorate from the University of Innsbruck, with a thesis in dynamic oceanography. For lack of an ocean in the Central Alps, Dr. Untersteiner turned to glaciology in the mountains of Europe and Central Asia. While working as a research scientist, at the Central Establishment for Meteorology and Geodynamics in Vienna, he was invited to join the United States team of the International Geophysical Year and served as Scientific Leader of IGY-Drifting Station Alpha in the Arctic Ocean. Back in Austria after IGY, Dr. Untersteiner taught meteorology and glaciology at the University of Vienna. In 1963 he returned to the United States and the University of Washington to continue to work in the Arctic under a series of ONR contracts. After joining the teaching faculty in 1967, Dr. Untersteiner and several colleagues developed an interdisciplinary graduate teaching program in snow and ice research that has received high marks from the professional community. In 1969 he initiated, together with Kenneth Hunkins of Columbia University, the scientific plan for the Arctic Ice Dynamics Joint Experiment (AIDJEX), and has been its project director since 1971. Dr. Untersteiner has served on numerous national and international committees and is presently chairing a committee of the National Academy of Sciences charged with developing the scientific program for a repetition of Fridtjof Nansen's historic drift across the Arctic Ocean, this time with the safe platform of an icebreaker.

Naval Arctic Research Laboratory

CDR R. H. Schaus,* USN
Naval Arctic Research Laboratory

Introduction

The green-brown tundra with its myriad lakes slowly grew in detail as the nearly-new C-46 followed the shoreline of the Arctic Ocean in a long, gentle glide to a landing on pierced-metal matting laid on the coarse beach gravel. As the engines ticked slowly to a stop and the cargo door opened, the small party of scientists within was greeted by the utter silence of the Arctic. The sweet, fresh breeze that entered however, and the gentle sunlight even than near midnight on this August day of 1947 seemed to welcome these aliens to this traditionally harsh land and to bode well for their venture – for this marked the establishment of the Naval Arctic Research Laboratory at Barrow, Alaska, the northernmost point in the United States, 530 kilometers north of the Arctic Circle. Although the laboratory has acquired the respectable maturity of nearly 30-years of growth and dynamic operations, the above scene is hardly different from a typical arrival today. The C-46 has been replaced by C-47's and a small fleet of newer, specialized aircraft, but the landing is still made by flying the coastline approach to pierced-metal matting laid on the coarse beach gravel.

Prompted by the dearth of knowledge about Arctic areas in general, and by a lack of understanding of operational aspects in over 12.8-million square kilometers of Arctic seas in particular, the Office of Naval Research (ONR) organized both an Arctic research program as well as a laboratory to support it, shortly following WW-II. Now as then, the laboratory fulfills a unique role in the national interest by providing, through its strategic location, accumulated expertise and wide-ranging capabilities, a superb base from which to launch the accomplishment of basic and applied research, whether directed toward land, sea or atmosphere. With accelerating international interest in Arctic resources, Arctic naval operations and maritime commerce, native peoples and global climate modification, the laboratory can only be considered a unique and highly-valuable national asset (Figure 1).

At its inception, the Naval Arctic Research Laboratory (NARL) occupied a number of buildings within a Navy base camp constructed

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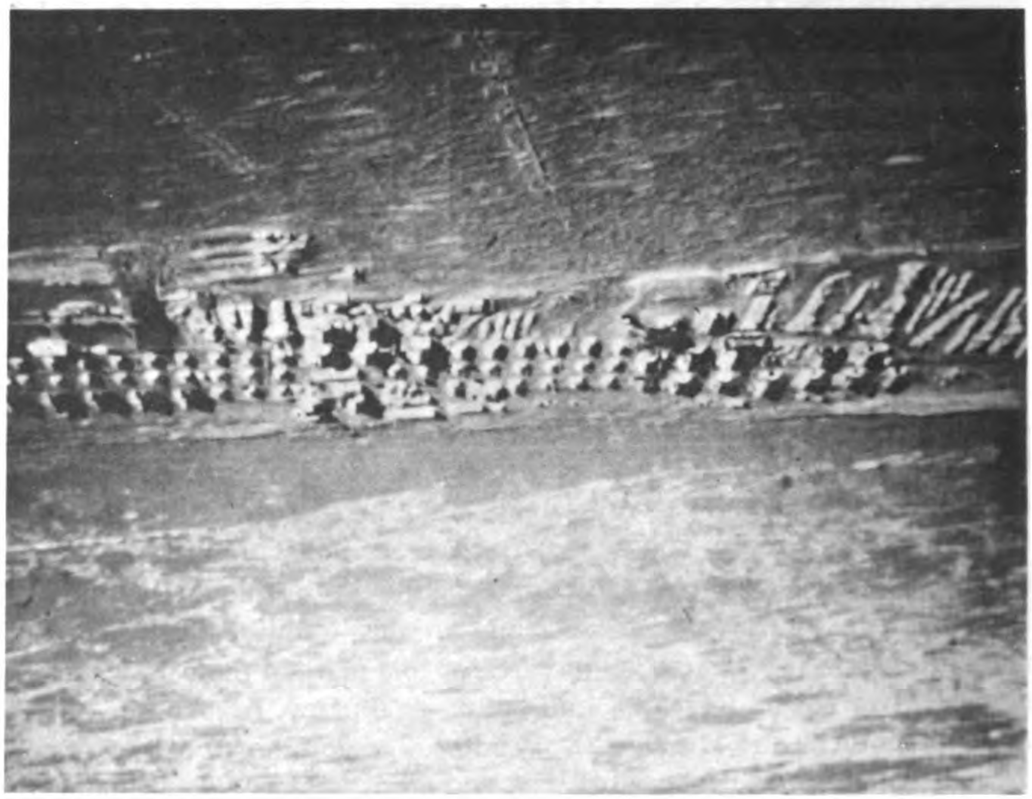

Figure 1 – Aerial view of NARL in October. Area of rough ice in background is the Chuckchi Sea.

to support oil exploration efforts on the huge Naval Petroleum Reserve No. 4 (NPR-4), later sharing these same facilities with the Air Force during construction of the Distant Early Warning (DEW) Line. Eventually, some 5,000 acres of NPR-4 lands were formally designated as the site of the Naval Arctic Research Laboratory, located on the shore of the Chukchi Sea between Point Barrow and the village of Barrow, the largest Eskimo settlement in North America. NARL itself is comprised of some 120 buildings housing, in addition to laboratories, resident personnel and visiting scientists, all services essential to a self-contained community, including all utilities, repair and construction shops and a complete air facility. In addition to the main laboratory, NARL operates a far-flung network of a dozen field research camps stretching across the entire North Slope of Alaska, from Canada on the East to the Bering Sea on the West and northward from the mighty Brooks Range. Additionally, since its beginning NARL has established a number of drifting research stations on the polar ice pack in pursuit of wide-ranging research objectives. Support and operation of these ice stations, which have drifted nearly to the Pole and as far East as Greenland, has proved to be a major feat in itself (Figure 2). Since nearly all support is accomplished by aircraft, specialized flying, navigation, landing and logistic

Figure 2 — Initial stage of construction of an ice station

support techniques had to be developed for these extremely demanding operations conducted on open pack ice, often during continuous darkness and always under some of Earth's harshest weather conditions (Figure 3). These many unusual demands have produced perhaps some of the most unique capabilities of any research support facility in existence: experienced personnel, equipment and techniques, for operating a multi-million dollar research program, comprising dozens of projects and agencies simultaneously, under weather and climate conditions always adverse and normally hostile to even man's basic survival (Figure 4).

The scientific administration of ONR's Naval Arctic Research Laboratory is a function of the Arctic Program Office, Earth Sciences Division of ONR. The laboratory is operated under contract to ONR by a Research Support Contractor, presently the University of Alaska, and by a Facilities Support (Operations and Maintenance) Contractor, presently Arctic Services Inc. of International Telephone and Telegraph. The mission of NARL is to provide all facilities and services for accomplishing programs of basic and applied research which contribute to successful Navy operations in the Arctic regions and environment, including the support of laboratory studies conducted at NARL as well as logistic support services to field research parties at outlying camps

Figure 3 — NARL aircraft on 3-meter thick polar ice 500 km from land at one of AIDJEX ice stations

and stations. While providing the above support is the primary mission of NARL, research facilities and support are frequently provided to other Federal agencies as well as to non-Federal institutions whenever such programs may be accomodated, depending upon the degree of relevance of a given program to the Navy's Arctic Program Objective.

Primary research efforts at NARL have traditionally encompassed the fields of Oceanography, Meteorology, Climatology, Ice-Physics, Hydro-acoustics, Geophysics, Atmospheric Physics and Marine Biology. With expanding interest in the Arctic, have come additional wide-ranging and dynamic programs involving Soil Engineering, Ecological studies, Contamination/Pollution studies, broad-based Biological studies and Anthropological and Sociological projects. With the ever increasing number of major national and international Arctic research interests and growing public and commercial interest in the Arctic, the unique location and capabilities of NARL may be expected to become rapidly more in demand to serve ever broadening national interests and concern.

Despite its remote and seemingly forbidding location, NARL is a hub of activity throughout the year and demands a high level of coordination and scheduling of support services. With permanent residents numbering nearly 200, the population at NARL soars throughout the period between

Figure 4 — Aerial view of a typical ice station. Layout of buildings is determined by functional efficiency as well as by dispersion and redundancy criteria for safety and survival in the event of fire or ice breakup.

March and October, with typically 700 scientists supported annually. Although non-resident research activity falls off during the deep winter months, this is the period when equipment and instrument inventories are repaired and refurbished and detailed preparations begun for the following year's flurry of research activity. In recent years, even during this period of continuous darkness, research activity has increased yearly as methodology and instrumentation become increasingly more flexible and allocation of support at NARL more dear. As an example of the science effort at NARL, the total number of mandays of science supported in 1973, 1974 and 1975 was about 14,000, 17,000 and 23,000 respectively. Of this effort, roughly 40% is solely Navy-sponsored, another 5% being jointly sponsored by the Navy and other agencies, and the remaining 55% being solely sponsored by other agencies.

Since research activity conducted away from the NARL laboratory must necessarily be supported by air, NARL aircraft and flight operations have evolved into a very specialized and highly-important integral part of all laboratory operations. The NARL aircraft inventory at present consists of two C-47 aircraft equipped with long-range fuel tanks, scheduled for replacement this year by C-117D aircraft, a DeHaviland twin-engine Otter, a DeHaviland single-engine Otter and four Cessna 180 aircraft. Unique uses and operating parameters have evolved for these aircraft since they are all called upon, generally at short notice, to operate from unprepared surfaces ranging from sea ice to gravel river bars to soggy tundra, at temperatures ranging from +65°F to −60°F, and with missions ranging from aerial photography to cargo and personnel transport to equipment and supply paradrops (Figure 2).

Remote sensing has become very important to research programs already underway at NARL and is destined to alter the entire complexion of Arctic research in the future. With recent quantum jumps in solid-state electronics, the techniques employed in sensing, data transmission, data processing and digital analysis of geophysical information have changed almost as rapidly as new innovations have appeared. The impact of remote sensing, particularly in Arctic research, may be appreciated when viewed in the perspective of today's research climate where man-hours, energy costs and increased specialization tend to diminish the science-per-dollar quotient. For many years satellite observations of Arctic phenomena have been employed and are proving ever more useful as refinements are developed. Recently the use of remote "buoys" or sensor packages deployed on and through the polar ice pack, either by air drops or manual placement, which continuously observe desired parameters, store the information and transmit their observations to a collating/processing center via satellite, is proving to be an exciting and extremely important technique. For instance, a network of very simple buoys deployed over a given areal expanse of polar ice, transmitting their individual geographic positions either automatically or on command over specified intervals of time, produces quantitative data on relative ice motion which is superior and cheaper than data obtained previously. Results using more sophisticated buoys have already produced truly spectacular results.

Results of research programs conducted at NARL include a long and distinguished list of advances and benefits. In addition to basic scientific knowledge gained, NARL research has figured prominently in landmark ecosystem studies and descriptions upon which were based Arctic sanitation, waste disposal/treatment and engineering standards; in physiological investigations leading to the development of new survival techniques; in nearshore oceanographic mapping of the Barrow Sea Canyon which allowed the first submarine access to the Arctic Basin from the West; in pioneering frostbite studies and in basic studies on sea ice and sea ice strength which furnished many of the design parameters for the SS MANHATTAN and the new USCGC POLAR STAR. Major programs underway or soon to be underway include the Arctic Ice Dynamics Joint Experiment (AIDJEX), the NOAA Outer Continental Shelf project (OCS), completion of geophysical explorations of Naval Petroleum Reserve No. 4, and the Nansen Drift Experiment.

Far from being a remote outpost in a polar no-man's-land, the Naval Arctic Research Laboratory is a dynamic and interesting research facilities tackling some of mankind's knottier and weightier challenges in what is certainly one of Earth's most fascinating frontiers.

Navigating Under Ice

Submarines navigate in the dark. Under the ice covered Bering and Chukchi seas, they must avoid colliding with sea ice ridges that sometimes dip down 80 to 100 feet in water that is only 150 feet deep. To navigate successfully, they depend on sound instead of sight. Dr. Allan Beal from the Arctic Submarine Laboratory explains it this way, "Sonar lets the submarines see the ice around them." Sonic waves reflect back from submerged objects and thereby indicate their location and allow submarines to steer around them. Low frequency and high frequency sounds are also used in submarine operations.

Special problems occur when navigating via sound in the Arctic Ocean. Between the Pacific and the Atlantic, there are about 900 miles of shallow water, which submarines must travel through. Oceanographers from the Naval Undersea Center in San Diego, the Polar Research Laboratory in Santa Barbara, the Applied Physics Laboratory in Seattle, and the Naval Postgraduate School in Monterey, are studying the characteristics of underwater sound in ice covered shallow waters of the Arctic Ocean. Since 1972, this study, named the Marginal Ice Zone Pacific (MIZPAC), has been supported by the Arctic Submarine Laboratory as part of its mission to increase submarine operating capabilities under the sea ice.

Dr. Beal, MIZPAC's Technical Coordinator, has spent over 20 seasons studying underwater acoustics and marine geology at the Naval Arctic Research Laboratory. He points out, "Everything in the ocean affects sound." For example, in the marginal ice zones of the Chukchi and Bering seas where ice is melting and mingling with warmer water, layers of warm and cold water develop. When sound waves pass through such layers they bend and may not return to the submarine to indicate the presence of an obstruction. One aim of this research is to determine where these warm and cold layers exist so that submarines can avoid them. In these same areas, where the ice cover is melting, levels of salinity fluxuate and this affects sound beams, although to a much lesser extent.

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The Arctic Ice Dynamics Joint Experiment (AIDJEX)

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Introduction

The Arctic Ice Dynamics Joint Experiment (AIDJEX) is a U.S. - Canadian cooperative research program aimed at advancing man's understanding of the large-scale response of sea ice to its environment. It is highly focused and coordinated program of data acquisition and mathematical modeling. It's specific purpose is to find a quantitative relationship between large-scale stress and strain fields in sea ice. The state of stress in the ice and the ice velocity fields can be determined given suitable methods of determining the external stresses exerted on the ice by wind and water currents. From this it will be possible to interpret a synoptic atmospheric pressure map diagnostically to estimate ice convergence, divergence, or shear - information which will be needed for off-shore drilling and surface shipping in ice covered seas. Using forecasts of atmospheric pressure fields, it also should be possible to predict ice motion and stress to the extent that atmospheric pressure fields can be forecast.

The dynamic ice model being developed by AIDJEX will be an important step toward understanding the long-term climatic interaction between the atmosphere, cryosphere, and hydrosphere, and hopefully provide the basis for a comprehensive analysis of the role of ice-covered seas in world climate. In addition to these major contributions to knowledge, AIDJEX is yielding scientific and technical information in the fields of energy transfer in a predominantly stable atmospheric boundary layer, heat and momentum exchange in the upper ocean, sea ice morphology, pressure ridging mechanics, and data buoy technology.

AIDJEX was conceived in 1969 when the Office of Naval Research contracted for Dr. Kenneth Hunkins of Lamont Doherty Geophysical Laboratory of Columbia University and Dr. Norbert Untersteiner of the University of Washington to prepare a design for a multi-station field research program in the Arctic Ocean. Their report was submitted

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in September 1969 and reviewed at a meeting of U.S. and Canadian arctic scientists two months later. At this meeting, J. O. Fletcher, then of RAND Corporation, was asked to coordinate preparation of a revised experimental design which was completed in May 1970. The National Science Foundation, in July 1970, contracted with the University of Washington to further develop and evaluate the scientific and operational plans for AIDJEX and coordinate the carrying out of the program by the cooperating U.S. and Canadian agencies and institutions.

As conceived, the AIDJEX program called for a series of pilot studies to resolve scientific and technical questions prior to the establishment of a year long, multi-station array in the Beaufort Sea area to obtain the data needed to develop and test the numerical model. The first of these pilot studies devoted entirely to oceanographic observations took place in March 1970 in the eastern Beaufort Sea at a sea ice camp operated by the Polar Continental Shelf Project (PCSP) of the Canadian Department of Energy, Mines, and Resources. This work by L. K. Coachman and J. Dungan Smith of the University of Washington was supported by ONR contract (AIDJEX Bulletin No. 4., 1971). A more ambitious pilot study program was carried out in 1971, again at a PCSP camp site. ONR again provided the principal support for the oceanographic observations under the direction of Coachman, Hunkins, and Smith. A rather ambitious program of remote sensing and ground truth observations was carried out under the direction of W. J. Campbell, USGS, and W. F. Weeks, U.S. Army Cold Regions Research and Engineering Laboratory using NASA aircraft overflights (AIDJEX Bulletin No. 8, 1971). In the spring of 1972 the third AIDJEX pilot study was conducted in the Beaufort Sea north of Barrow, Alaska. It was the most complex and sophisticated experiment ever performed on sea-ice up to that time, employing an array of manned stations and automatic data buoys utilizing some of the most advanced technology available. There were 26 field projects involved. The Naval Arctic Research Laboratory at Barrow (NARL) served as the principal shore base for the program, with additional support provided from the PCSP station at Tuktoyaktuk. Operations, preliminary scientific results, and data were reported in AIDJEX Bulletin No. 14, 1972.

A fourth pilot study, to provide additional information on the role of open water in leads in the total heat balance of the Arctic Ocean, was conducted in the spring of 1974 out of NARL.

Following the 1972 Pilot Study a revised Scientific Plan was published in AIDJEX Bulletin No. 15, 1972. It represented a further refinement and evolution of the initial version first prepared in 1969. The basic concepts of the original plan had met the test of real data from the Pilot Studies. However, in late 1972 budgetary limitations forced a revision of the plan for the main field experiment. A major change was the

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elimination of an important component of the original plan — a study of the shear zone, a region close to shore where (especially along the Alaska and Siberian coasts) a band of open water is frequently found in the summer. During the cold season, a zone of high shear deformation exists between the shore-fast ice and the more mobile ice 5-100 kilometers farther from shore. All previous attempts to model the dynamics of sea ice, including steady-state models, have suffered from a nearly total lack of knowledge of ice mechanics in the shear zone. Subsequent events related to the development of the resources of the off-shore areas have caused increased interest in the shear zone, and some data from this region will be acquired under a project funded by NOAA-BLM and coordinated through AIDJEX.

Development of Numerical Model

Before turning to the main field experiment, it might be well to discuss the development of the numerical model which proceeded in parallel with the experimental design. The AIDJEX modeling group was formed in 1971 at the University of Washington under a grant from the National Science Foundation. Though the AIDJEX modeling group has had the principal responsibility for constructing and testing the model, there has been a continuous exchange of ideas and information with scientists at CRREL, USGS, and a variety of other institutions. The approach taken in formulating the model is that it must:

1. Satisfy the equations of motion relating ice acceleration to all external and internal forces;
2. Employ a constitutive law combining a representation of small scale phenomena with a plausible continuous behavior on the large scale;
3. Contain an explicity formulation of the conservation of mass, and
4. Contain an explicit statement of the conservation of mechanical energy.

A model which meets these requirements has been developed and tested against data obtained in the 1972 pilot study and the first few months of the main experiment, under the direction of Dr. Max Coon. One important advance in the AIDJEX model over previous formulations is the introduction of the concept of "ice-thickness distribution" as a key state variable of the pack ice. The compressive strength of a large number of ice floes which make up the ice pack is determined by the portion of the total area covered by thin ice, since it is known that most pressure ridges are formed of thin ice. As thin ice is converted to pressure ridges, under continuing compression, a process similar to strain hardening sets in. On a larger scale the ice is assumed to contain enough fractures that there is no resistance to tension.

The process by which field data are converted to information suitable for use in the model to calculate the necessary variables to predict strain and rotation in the field of gridpoints, ice velocity, thickness distribution, and the state of stress in the ice is illustrated in Figure 1. The left column shows the data used in the model, the center column indicates the data in processed form, and the right column shows the components of the model. Some of the data are used to initiate model runs as well as provide input quantities such as air stress, while some data are used only to verify the quality of both the sub-models and the entire ice model. The remote sensed data, which include data gathered by satellite and aircraft as well as ground truth, allow the calculation of the ice thickness distribution and the strain of the ice cover. The area covered by open water or thin ice is used to check the part of the model that calculates the incremental thickness distribution. The strain is used to check the calculations of the entire model. Positions of the array of buoys are used to calculate the initial ice thickness distribution as well as the boundary velocity conditions for the area under consideration. The thermodynamic data, which include measurements of radiation, air temperature, and snow cover, are used to estimate the growth rates which, in turn, are used to compute the ice thickness distribution. Measured growth rates are used to check the thermodynamic model. The atmospheric input to the model is air stress obtained from pressure maps and geostrophic winds calculated from pressure data taken at the AIDJEX manned stations and data buoys, as well as from the U.S. Weather Service pressure maps. Profile measurements of velocity and temperature at the manned stations allow computation and verification of the drag coefficients that, together with the geostrophic winds, are used to calculate the air stress on the ice. The geostrophic flow of the ocean and the sea-surface tilt are calculated from long term averages, and the force exerted by the ocean on the ice is written in terms of the relative velocity of the ice and the geostrophic flow. The drag coefficients for these calculations are determined using velocity and density profiles from the manned stations.

A computation in the ice model is initiated with location and velocity of the ice, its internal stress and its thickness distribution (the percentage of the area covered by different ice thicknesses). From the ice motion, the velocity gradient, strains and rotations are calculated. The increment of internal stress is then found using the elastic-plastic constitutive equation and the thickness distribution is calculated. Using internal stress, air stress and water stress, a momentum balance is satisfied and an increment of velcotiy calculated. The new velocity then provides a new configuration or position. Outputs of the ice model are position, velocity, strain, rotation, stress, and thickness distribution.

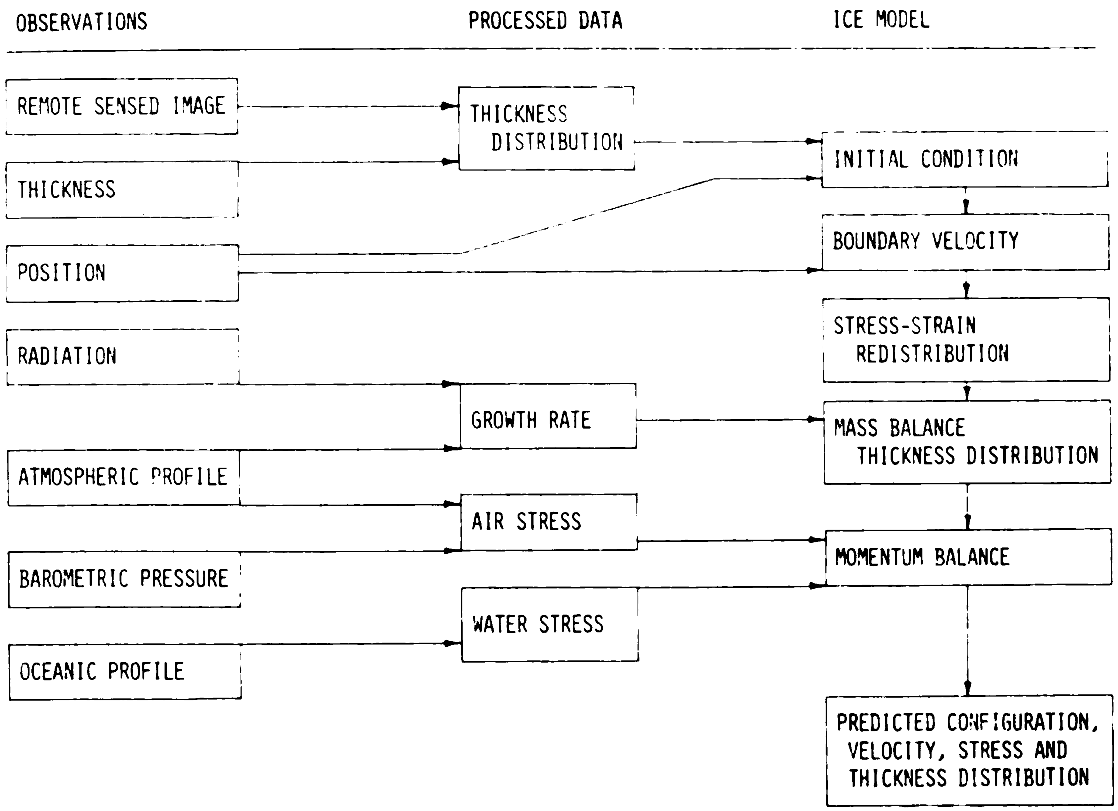


Figure 1 — The process by which field data are converted to information suitable for use in the model to calculate the necessary variables to predict ice strain and rotation, ice velocity, and thickness

Four Observation Stations

The development of the model in parallel with the series of pilot studies permitted a strong interaction between theoreticians and experimentalists in designing the optimal program of data acquisition for the main field experiment which was launched in March 1975. The basic design of the experimental array called for the establishment of four manned observing stations (three small stations forming a triangle with a central station also serving as a field logistics and support base) surrounded by a circle of automatic stations (data buoys) about 300 km from the central station. Surface observations were to be augmented by aircraft and satellite remote sensed data. The basic observational program at all four manned stations included position computed from the Navy Navigational Satellite System (NavSat), atmospheric pressure, wind vector, air temperature, ocean current profile in the mixed layer and ocean temperature and salinity to 1000 m. In addition, at the central station a more concentrated set of meteorological observations are conducted and solar and atmospheric net radiation are measured. Two sets of data buoys are employed, each reporting position, atmospheric pressure, and air temperature. One set of buoys uses NavSat to obtain position information and report data to the central station by HF radio. Eight of these buoys were deployed. The second set of data buoys uses the Random Access Measuring System (RAMS) to obtain position and transmit their data by NIMBUS F satellite. All buoys are battery powered.

The search for a site for the central camp commenced in early March. Bad weather and a paucity of adequate sites delayed the deployment until, on 12 March, after 16 search flights, totaling about 125 hours by Twin Otter aircraft from Mould Bay and R4D aircraft from NARL, a site was found at 76°N and 140°W. In the next few weeks about 900 metric tons of supplies were carried to the ice, primarily in L-100 aircraft under contract to NARL. The three satellite camps were established about 60 km from the central camp and were in operation by the end of the first week in April.

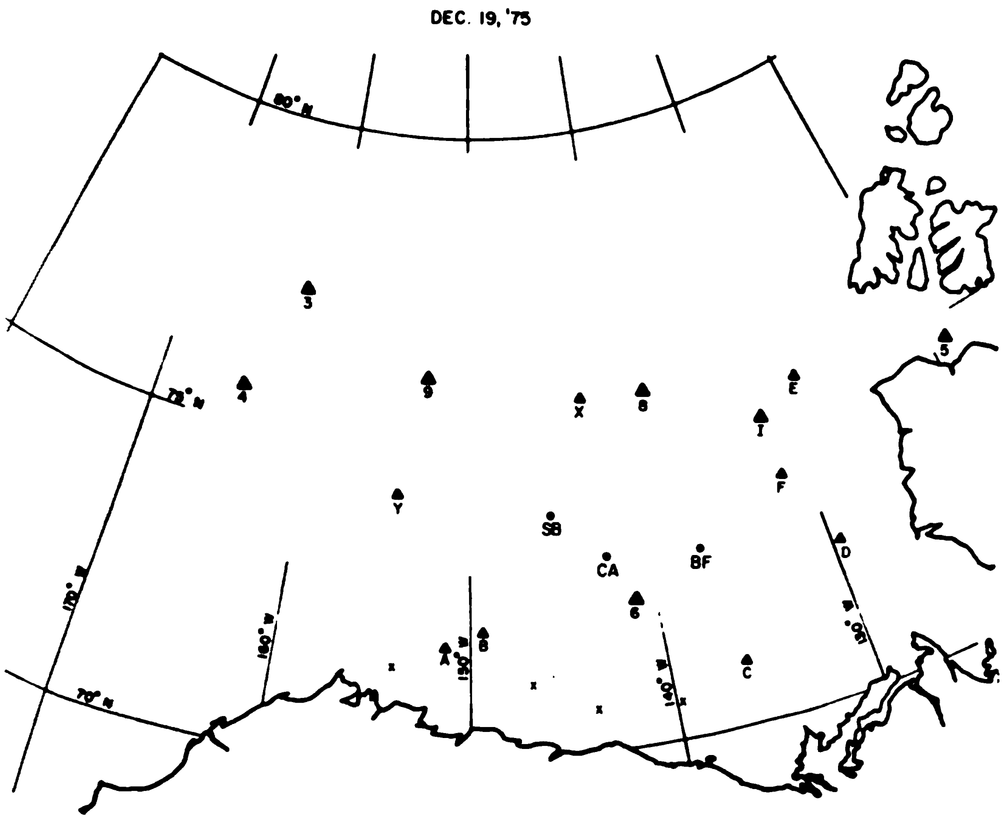
Data buoy deployment was essentially accomplished in two stages. In the first, eight of the buoys using the NavSat positioning system were installed on a ring about 300 km from the central camp. In the second stage seven RAMS buoys were deployed, one adjacent to each of seven of the NavSat buoys, and two others near the center of the manned camp array.

Use of the RAMS buoys had to await the launch of the NIMBUS F satellite. When the system began collecting data on 12 June, all nine buoys were being received by the satellite. In addition to observations taken from the surface, during April the NASA CV 990 aircraft made five remote sensing flights over the AIDJEX array to obtain microwave, IR and SLAR images, laser profiles, and visual photography. In addition, a Canadian Armed Forces Argus flew two missions with SLAR and IR imagers, and a Canadian Centre for Remote Sensing C-47 flew one mission to obtain scatterometer, microwave and IR imagery, and visual photography.

Data taken at the manned camps and by the NavSat buoys are flown to Barrow and sent to Seattle for processing and then placed in the AIDJEX Data Bank. Since flying conditions are poor and the ice surface is bare of snow, with numerous melt ponds, flights between Barrow and the AIDJEX camps are rare. The NARL operated Twin Otter made the last flight of the spring on 12 June carrying needed supplies and bringing out the latest data. A Twin Otter under PCSP contract made a flight in late August to ferry supplies and return data taken during the summer. A helicopter was stationed at the central camp through summer and carried out flights between the camps as weather permitted. Once during the summer, a NARL R4D made a parachute drop of food and necessary supplies at the main camp.

By late September ice conditions had improved enough to permit regular flights to resupply the camps, rotate scientific and technical personnel, and bring in equipment and personnel for the scheduled autumn programs. However, on 1 October a crack split the main camp and was followed by a series of further cracks which ultimately forced the abandonment of the main camp. On the first day of the breakup all personnel except for four support staff were evacuated. These four managed to salvage essential equipment and together with additional support personnel from NARL and PCSP managed to restore the camp to limited operation as a logistics base, but virtually all scientific activity stopped. Although the ice continued to deform, by nearly herculean efforts, camp personnel managed to salvage scientific equipment, fuel and buildings were flown to one of the satellite camps where a smaller logistics base was established. In the meantime the personnel associated with the data buoy program managed to conduct limited operations to refurbish some of the buoys which had failed during the summer and early fall. Using the new logistics base it was possible to continue to support the satellite camps which had continued their regular observations and data acquisition activities. By the middle of November, operations had become relatively routine, though on a somewhat reduced scale using three manned stations and a refurbished buoy network. The position of the camps and buoys on 19 December 1975 is shown in Figure 2.

Contrary to expectations, the general drift of the camps and most of the buoys was to the southeast throughout the summer and fall. The drift tracks through late October are shown in Figure 3.



• *Manned Stations*

CA – CARIBOU – central stations, BF – BLUE FOX – satellite station, SB – SNOW BIRD – satellite station

▲ *Buoys*

Numbered buoys are original array as deformed and represent both NAVSAT and RAMS platforms except 3 which is NAVSAT only and 6 which is RAMS only.

Lettered buoys are RAMS BUOYS. A, B and C report meteorological and oceanographic information. D, E and F are airdropped and report position only. X and Y report position and atmospheric pressure.

Small x's are planned positions of airdropped RAMS buoys to report position only.

Figure 2 – Position – AIDJEX Camps and Buoys, 19 December 1975

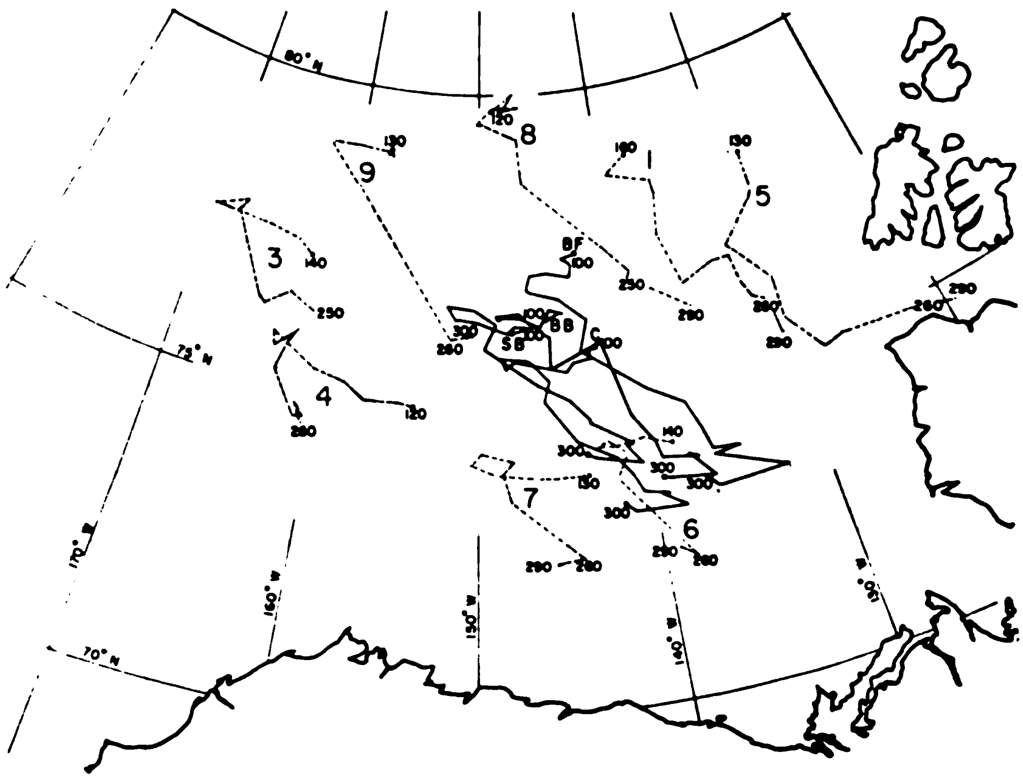


Figure 3 – Position History of AIDJEX Camps and Buoys

Position History of AIDJEX Camps and Buoys:

Day 100 is 10 April 1975
Day 260 is 17 September 1975
Day 300 is 27 October 1975

It is planned that the AIDJEX field program will conclude in April 1976. Data processing and modeling will continue into 1977.

In addition to the National Science Foundation, the Office of Naval Research, the Polar Continental Shelf Project, and the University of Washington, other agencies and institutions which are or have participated in AIDJEX include Columbia University, Oregon State University, McGill University, University of Alaska, Bedord Institute of Oceanography, Scripps Institute of Oceanography, University of California at Davis, U.S. Army Cold Regions Research and Engineering Laboratory, U.S. Geological Survey, National Aeronautics and Space Administration, National Oceanic and Atmospheric Administration, National Center for Atmospheric Research, Environment Canada, and the Canadian Geological Survey.

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Low frequency underwater sounds are also being studied as these sounds are used to detect the presence of another submarine. Such sounds include the noise another submarine makes as it operates underwater. How far low frequency waves travel in the marginal ice zone at different times of the year depend on ice cover, structure of the water, and characteristics of the ocean floor. The low frequency phase of MIZPAC is being conducted by the Polar Research Laboratory at an offshore ice camp. The camp consists of a main site, named "Pitcher," and remote instrument sites arranged in the shape of a baseball diamond around "Pitcher" camp. Radio transmitted acoustic signals are picked up by receiving hydrophones under the ice at the remote sites and telemetered to "Pitcher" for recording. These experiments are designed to measure low frequency transmission loss under the water.

Scientists from the Applied Physics Laboratory at the University of Washington are carrying out high frequency acoustic research for MIZPAC. Working out of pre-fabricated wanigans built at NARL and transported to an offshore ice camp, four men studied the effects of ice on high frequency sounds. Such information is necessary when using acoustic torpedos that require high frequency signals to locate their targets.

The Naval Arctic Research Laboratory at Barrow is the logistics base for MIZPAC-76. NARL provided ice reconnaissance flights and carried out the establishment, supply and evacuation missions for the ice camps.

This is the first large-scale winter study of the shallow Chukchi Sea. In the past, considerable underwater acoustic research has been done in the central Arctic Ocean where the water is deep and sound propagation is good. That area does not cause submarines any great difficulties. "Today the marginal ice zone," according to Dr. Beal, "has become the significant area for underwater acoustic research."

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What Have We Found at the Seventy-First Parallel and Where Do We Go From There

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Office of Naval Research

The remote, barren, Arctic regions of the world have suddenly achieved tremendous economic, political and military importance due to energy resource development. Areas once considered to be of little economic importance and which were formerly inhabited only by small groups of Eskimo hunters and whalers have attained an inestimable value to the continued prosperity and well-being of the United States. The national requirements for development of resources in this inhospitable environment have created urgent needs for research and technology specifically oriented to civilian and military operational requirements in the Arctic. These research and technology requirements encompass all of the academic and engineering disciplines essential to modern industrial technological development and military defense, such as communications, transportation, habitation, construction, geology, and climatology. Basic to the success of any such technological enterprise, particularly in the Arctic, is the capability of man to operate and function efficiently under such adverse environmental conditions. The specifically human problems associated with large scale development of Arctic resources and the importance of learning to cope with the special problems of the Arctic were recognized and anticipated twenty years ago by Dr. Lawrence Irving when he said,

> "Some white people live productively in the Arctic, but others will not adapt due to disposition or lack of knowledge. So far, exploration, science, government, and other avenues of exploitation of the arctic have been excessively burdened by the unfitness of such personnel. I recommend that serious attention be given to physiological accounting in determining the fitness of prospective workers in the Arctic, and the cost of maintaining them when viewed with their potential productivity in mind." (Irving, 1954).

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†Dr. Callahan is Program Director for Medical and Dental Sciences at the Office of Naval Research. Recently he has been studying the physiological and biophysical mechanisms of cold injuries at NARL.

The Arctic's newest resident, temperate or urban man, is now grappling with problems peculiar to life at the seventy-first parallel. Man is trying to understand and cope with long periods of extreme cold, unusual day/night cycles and the stresses of living in a remote area. The economics, for the Navy, and, more recently, for the oil industry, of assessing and optimizing Arctic adaptability are obvious. One has only to witness the "turnover" rates of workers in remote Arctic sites, despite high wages, to realize the value of such knowledge.

The study of human adaptation and operational capability in a specific environment should not neglect a study of the environment itself. It is not only the effects of environment on the man, but the effects of man on the environment which will determine the success or failure of an adaptive process.

> "By learning how native animals and plants survive under adverse conditions, through adaptations to the environment, hints will undoubtedly emerge facilitating human survival as well." (Dale M. Arvey, 1964).

The Arctic should be considered a specialized, unique ecosystem rather than merely a remote geographic area. It is characteristic of such sensitive ecosystems that perturbation of any of its elements produce unpredictable alterations in the total system (Figure 1).

With this objective in mind Dr. Lawrence Irving and his associates initiated the first research program at the Naval Arctic Research Laboratory (NARL) collecting information on metabolic activity, bird physiology and navigation, vitamin content of Arctic flora and fauna, health of indigenous people, and Arctic geophysics and ecology during NARL's first season in support of science. Since its beginning in 1947, scientists from a variety of disciplines have come to NARL to continue the study of the adaptations which indigenous flora, fauna and people have made to this unusual environment.

A decade ago, Dr. Max Britton, then Director of Arctic Programs for the Office of Naval Research, made this observation, "In the Arctic there is yet an opportunity to find the answers before the inroads of civilization disrupt if forever." (Britton, 1964). Since that time, the discovery of vast reserves of oil on the north slope of Alaska is bringing the inroads of civilization to the Arctic with potentially overwhelming consequences. In many cases, the only reliable knowledge serving to guide us in this onslaught of civilization comes directly from research accomplished at NARL. Practical uses for scientific data are many. The information gathered at NARL on the nature of permafrost resulted in new construction and design techniques for the Arctic. This knowledge greatly facilitated the construction of the DEW-line sites. The nature of the tundra as described in early biological surveys led to an understanding of the fragility of the tundra. Special procedural techniques and vehicles,

Figure 1 – At 30°F below zero, work of loading drums of fuel for Project AIDJEX proceeds

i.e. the surface effects vehicles, were designed to minimize the effects of operations on the land. Extremely slow rates of biodegradation, discovered through biological research, necessitated modifications in (solid waste) treatment facilities for old and new communities in the arctic.

Though the years the Office of Naval Research has supported Arctic research which has anticipated by many years, the need to develop capabilities for operating effectively in that area of the world. NARL has become the headquarters for such endeavors and is the only facility to accommodate on-site Arctic science in the United States. The broad biological and environmental research interests reflects the original purpose of NARL as expressed by Vice Admiral H. B. Bowen, Chief of Naval Research in 1946, when he proposed a laboratory to conduct effective investigations on Arctic environments.

The Biological Research Program

NARL is operated on a year round basis providing the opportunity for the full spectrum of biological research. The program has been organized under two main categories of research; environmental sciences and physiological sciences. It is only by studying both man and the environment that an adequate understanding of either can be obtained.

According to Dr. G. Edgar Folk, a veteran Arctic physiologist, "only a small fraction of the information needed on Arctic cold weather physiology has been obtained. There is a conspicuous increase in public interest in biological adaptations and thus more interest in biology in the Arctic than ever before." (Folk, 1969).

The physiological sciences program at NARL is primarily concerned with mechanisms of adaptation to extreme cold, particularly as it applies to humans. The research centers around the biophysics of adaptation to extreme cold and includes studies of comparative metabolism, blood chemistry, thermoregulation and thermogenesis. It is known that seasonal cold induces changes in energy requirements, blood composition and regional flow patterns and thermoregulatory capabilities. Adaptation is clearly a function of the animal's ability to make those adjustments. The overall objective of this research is to understand the degree to which and the mechanisms whereby adjustments are made in Arctic forms.

In response to increasing requirements for additional research on Arctic adaptation which have been stimulated by the increase in human activity in the Arctic, a new "core" program in environmental biophysics has been established by Dr. L. S. Underwood, Assistant Director for Science at NARL. This "core" program, which was started in 1975, provides support for several resident scientists to spend one to two years in research in environmental biophysics at NARL.

The "core" program exemplifies a trend toward year round research in the Arctic. Over the years, the main research "season" at NARL comprised the more temperate months of June, July and August. Biologists and physical scientists recognized the need for winter data and have begun designing year round programs in order to study the interplay of adaptive mechanisms and extreme seasonal variations in temperature.

Dr. Jim Mosher, formerly at Brigham Young University, was awarded the first of the "scientific residencies" to establish and utilize a metabolic laboratory at NARL. Dr. Mosher explains, "The primary goal of my research program is to identify and describe mechanisms by which Arctic animals have adapted metabolically to the environmental extremes of temperature and photoperiod." Thus, using modern, "state of the art" research techniques, he will expand upon the baseline data collected in the early days of Arctic physiology.

Under the direction of Dr. Mosher and Dr. Underwood, a highly sophisticated metabolic study facility has been established at NARL during the past year.

Considerable specialized equipment has been acquired and assembled to provide continuing capability to study the problems of metabolic responses to cold in animals and to determine metabolic rates by measuring the amounts of oxygen an animal uses and carbon dioxide it produces over a wide range of environmentally appropriate temperatures. The "metabolic laboratory" includes a specially designed environmental chamber which controls temperature from −80°F to +50°F and various analysis and recording instruments. There will also be a fully automatic facility for measuring the heat of combustion of biological materials and soxhlet extraction systems for determination of body composition of small to medium sized animals. Additional equipment for remote monitoring of microclimates in the field is being prepared. Such equipment will facilitate obtaining information that demonstrates the energy costs of activity at low temperatures, the limits within which activity is practicable, and an understanding of successful adaptations to Arctic life. Such sophistication and technology in physiological research has launched the experimental period in arctic biology (Figure 2).

The program's second resident fellow, Dr. Tim Casey, from the University of California at Los Angeles is looking into thermoregulation and respiration in Arctic mammals. He plans to compare Arctic species responses with temperate zone animals to determine differences and similarities in physiology. Dr. Casey will carry out respiration studies in the winter to study seasonal variations in thermoregulation and respiration.

Also included in the "core" program is a project entitled "Veterinary Research in Arctic Animals" which is being directed by the attending veterinarian to NARL, Captain Michael Philo, VC, USA. Dr. Philo

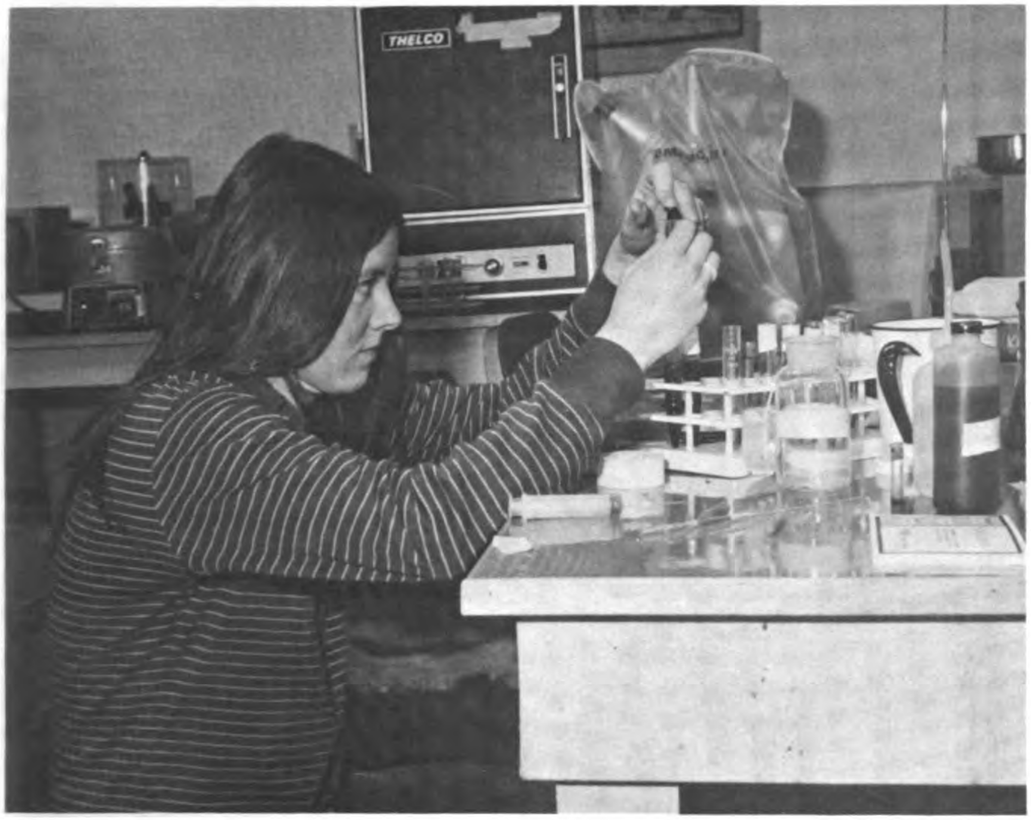

Figure 2 — Katie Persons, Biological Technician preparing blood serum at Animal Research Facility Hematology Laboratory

is concerned with three main areas of research: (1) to determine the possible existence of sub-clinical rabies in Arctic fox, (2) to determine hemotological changes in Arctic adapted animals caused by use of various anaesthetic drugs, and (3) to continue frostbite injury research started at the Army Research Medical Laboratory-Alaska, in Fairbanks (Figure 3).

Dr. Philo is working to determine nutritional requirments of laboratory animals experiencing Arctic conditions. Food consumption, weight change and changes in blood chemistry data are collected on all animals in the research facility.

Dr. L. S. Underwood who, in addition to his activities as Assistant Director for Science at NARL, directs the core program in environmental biophysics, has been active in year round research in Arctic adaptation at NARL since 1968. Dr. Underwood has specialized in cold adaptation in the Arctic fox, paying particular attention to changes in insulative quality of the fur, food consumption, metabolic responses to environmental temperature and overall energy requirements. Dr. Underwood was initally interested in the question of how the Arctic fox was able to produce sufficient metabolic heat during the winter when the food supply was inadequate to permit "stoking of the metabolic furnace."

Figure 3 – Dr. Michael Philo (left), resident veterinarian at NARL conducts regular immunization programs in clinic of Surgical Research Building

He discovered that the insulative properties of the fur was seasonally related to the abundance of the food supply and environmental temperature. This relationship not only obviates the necessity for increased caloric intake by the fox but actually permits it to survive on a reduced caloric intake during periods of the most severe cold stress.

In addition to the "core" program in environmental biophysics which utilizes full time resident scientists; the research effort is supplemented by the visiting scientist program. Under this arrangement, scientists from academic institutions visit the laboratory for short periods of time during the year to collect data or use the unique animal research facility at NARL.

Among the various research efforts underway by visiting scientists is a study by Dr. G. Edgar Folk of the University of Iowa which is concerned with the quantification of energy conservation mechanisms in hibernating Arctic mammals. Dr. Folk has worked at NARL for many years in such areas as biotelemetry of physiological responses to extreme cold, and the biochemistry of cold adaptation.

Dr. Theodore Malinin, University of Miami Medical School is currently involved in a study on the hormonal regulation of body calcium in animals under acute cold stress.

Other investigators are grappling with the problem of the role of body water and electrolytes (salts) under severe cold stress. The concentrations of electrolytes dissolved in body water are normally maintained within rather narrow limits. The observation that exposure to severe cold results in the loss of body water, raises several important questions as to whether body electrolyte levels decrease proportionally to body water loss or are maintained at normal levels. A change in either electrolyte level or electrolyte concentration could affect the functioning of various physiological mechanisms within the body. A primary goal of this research in addition to the quantification of the phenomena is to ascertain the significance of this dynamic process in cold adaptation.

The second major area of investigation at NARL, environmental research, is crucial to the Navy's role in the Arctic: "every aspect of the Arctic environment ashore must be understood if operations (Navy) are to proceed on a rational basis with some guarantee of success." (Hayes, 1964).

The importance which is attached to the environmental phase of Arctic research is demonstrated by a number of funding sponsors for this research at NARL. These sponsors include the following: Bureau of Land Management (BLM), National Oceanographic and Atmospheric Administration (NOAA), Energy Research and Development Administration (ERDA), Office of Naval Research (ONR) and the National Science Foundation (NSF).

Oil development has brought renewed interest in Arctic environmental science. As a result several new biological programs are active in the Arctic and relying on NARL for their logistical support. Under the Outer Continental Shelf Lands Act of 1972, the Bureau of Land Management (BLM) is responsible for monitoring the environmental impact of industry in the area three miles offshore of the United States. The Offshore Coastal Study (OCS) project, funded by the BLM and National Oceanographic and Atmospheric Administration (NOAA), plans to assess environmental conditions in the littoral environment. Interrelationships between the land, sea and air will be examined in order to understand the ecology of the region. The Beaufort and Chukchi Sea phase of OCS involves fifty different investigations along the Arctic coast from Barrow to the Canadian border involving a total of 350 scientists and support personnel. Plans for 1976 call for expansion of the study area westward along the Chukchi Sea coast. NARL is the primary staging area for OCS field camps.

A veteran of 20 summer seasons studying bird and lemming ecology in the Arctic, Dr. Frank Pitelka, University of California at Berkeley,

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began working with a team of OCS biologists in 1975 stockpiling baseline data needed to determine the possible effects of man-made disturbances on animal life along the Beaufort Sea coast. At Barrow, which provides nesting habitat for approximately 16 species of shorebirds, Pitelka and his colleagues are trying to assess the importance of different types of shorelines for various species utilization so that they can understand how offshore oil development might affect the Arctic's shorebird populations.

Another OCS project related to the shorebird study is headed by Drs. Carter Broad and David Mason from Western Washington State College. Their teams are surveying the shallow waters of the Beaufort Sea to determine what plants and animals live there. They have found that, although the nearshore waters do not support a very rich fauna or flora, they do provide food enough to support a great many birds. Oil contamination at certain times of the year could affect these littoral feeders. Such studies will be incorporated into the entire OCS effort to create what Dr. Pitelka calls a "big picture" describing the general ecology of the area.

The United States Energy Research and Development Administration (ERDA) is also spurring new environmental research in the Arctic. In 1975, ERDA sponsored a data collection project on abundances and distribution patterns of shorebirds during and after the breeding season on tundra habitats away from marine shores. Again the goal is to anticipate environmental problems before they occur, and Barrow provides a particularly good study site due to its geographic position between the Beaufort and Chukchi seas where the effects of nearshore ocean currents on animal life can be easily measured. An ERDA sponsored team of biologists working out of NARL is looking at the effects of road construction and oil spills on the numerous lakes and ponds which characterize the arctic tundra. These researchers will analyze all of the plant and animal populations within the ponds and lakes to determine the impact of oil spills and road dust on them. Particular attention is given to existing lakes as well as lakes created by roads at Prudhoe Bay and along the trans-Alaskan pipeline. This project brings together specialists in algal production, bacterial dynamics, zooplankton, nitrogen dynamics, bottom dwelling inverterbrates, fish populations and oil degradation.

The Office of Naval Research, anticipating possible oil spills on Navy controlled lands on the North Slope, is supporting microbiological research into biodegradation of crude oil. Dr. Ronald Atlas, a microbiologist from the University of Louisville in Kentucky, during his third field season at NARL (1975) tested an oleophilic (oil-sticking) fertilizer which he developed to stimulate the rate of biodegradation of crude oil. Dr. Atlas and his assistants will simulate as many natural conditions surrounding an oil spill as possible. They will do extensive experiments during both summer and winter and will examine what happens to oil on the surface of the water or the ice, as well as what happens to oil on the ocean floor. At the present time, the Navy has a patent pending on Dr. Atlas's oleophilic fertilizer.

Tackling the problem of oil contamination on terrestrial areas, scientists sponsored by the NSF initiated a program of Research on Arctic Tundra Environments (RATE). They are determining what might happen if the trans-Alaskan pipeline were to break, flooding the surrounding tundra with oil. Would tundra vegetation die out, or would it flourish on the carbon of the oil? Dr. Gary Laursen from the Virginia Polytechnic Institute is investigating these questions for RATE. Using sites studied extensively by the Tundra Biome Program from 1970-74, Dr. Laursen is spilling oil in five and twelve liter/square meter concentrations on five different types of tundra habitat, and is monitoring changes in the microflora (minute plants). Specifically, he is looking for changes in biomass density and plant respiration. He has found that the plant population decreases with an increase in oil concentration. Also, respiration rates of individual plants fall off. In studying the ability of higher vascular plants of typical tundra vegetation, such as willow and grasses, to adapt to their cold environment, Dr. Laursen has found that almost all dominant plant species are "microrrhizal"—that is, they have a close and very delicate relationship with fungi. Through this symbiotic relationship (as Dr. Laursen calls it) the fungi enables the plant to obtain certain important nutrients from the soil. Dr. Laursen has discovered that oil kills fungi, destroying this symbiotic relationship, and thus decreases the plant's chances of surviving cold. In winter, the above-ground parts of vegetation die but the root system persists in the top five centimeters of soil. Snow actually acts as an insulator and top surface soil temperatures may be +30°F in the dead of winter. However, oil tends to increase the depth of thaw in summer permitting the permafrost, in time, to kill off these root systems effectively ending plant life in the area. Eventually the area may revegetate. If Dr. Laursen can continue his study two more summers, seven years worth of information will have been obtained to deal with the problem of oil perturbation of the tundra ecosystem.

The major research program in arctic environmental research was begun in 1970 by scientists in the International Biological Program (IBP). The RATE study picks up where IBP left off. Current research is concentrating on the interactions between the major ecosystem components in the tundra: (1) primary producers, (2) decomposers, and (3) animal consumers. Meade River, a NARL field station, was chosen as the primary research site for the RATE project because it represents a greater diversity of plant and animal life, and because of its location in typical inland tundra as opposed to the littoral tundra of Barrow. Meade River site is established and supported by NARL and will be active at least two more years, at the end of which man's knowledge of Arctic ecosystems will be further advanced. RATE represents a major cooperative effort between the Office of Naval Research and other federal funding agencies bringing together a team of biologists in the best tradiation of the early research programs at NARL.

Facilities for Biological Research at NARL

The Naval Arctic Research Laboratory has made scientific research not only possible in the Arctic but, over the years, has introduced improvements in techniques, equipment and experience to make Arctic science more attractive to larger numbers of scientists. In other words, to collect scientific data in the Arctic one no longer has to be an "Arctic hero" to the extent that was necessary in the early days when "camping out" constituted the only means of performing biological research in the field.

At NARL's headquarters about five miles north of Barrow, the facility has come a long way from the 40-by-100 foot, two story quonset used in 1948 to the present modern laboratory and housing complex completed in 1968. The new scientific center has approximately one acre of floor space under one roof. It serves as a laboratory-administration-billeting building with forty-six modern, fully equipped laboratory spaces, sleeping quarters for one hundred persons, administrative offices, a lounge and a game room, a museum of Arctic fauna and archaeology, and an excellent library. The research laboratories are supported by a wide variety of modern electronic and scientific instrumentation necessary to perform a wide spectrum of biological research projects in a variety of disciplines including biochemistry, physiology, biophysics, ecology and hematology. A well-equipped laboratory stock room provides ready access to practically all standard laboratory items of glassware, chemicals and hardware. In addition to the main laboratory facility, NARL operates field stations of varying size and refinement for researchers to use at over a dozen sites spanning the Alaskan north slope from the Brooks Range north to the Arctic Ocean. Food, fuel, equipment and personnel are flown in by NARL aircraft. For example, in June 1975, scientists of the RATE study began their investigations out of the Meade River Field Camp operated by NARL. Located sixty miles south of NARL the site consists of ten wooden buildings, including a kitchen and three dormitory buildings sleeping six each, and a 1500 foot runway which is adequate for NARL's Cessna 180's and Single Otter aircraft. The camp supported 21 researchers throughout the summer who were working on ten different projects dealing with the tundra ecosystem. Meade River site will be used for two more years before it is brought back to Barrow via a winter "Cat" (caterpillar) train. During the summer of 1975, approximately half of the investigators working out of NARL were at various field camps. Five permanent terrestrial field stations and two temporary ones were active at that time.

A unique feature of the biological research capability at NARL is the Animal Research Facility.

Animal physiology has always been an important mainstay of the biological research program at NARL. In the early days of the laboratory, the animals required for specific studies were maintained only until the research project was completed. They were then either released or terminated. A variety of animals have been housed at NARL for the use of scientists including ground squirrels, wolverine, flying squirrels, porcupine, Arctic fox, snowy owls and ermines. The first wolf, Lobo, which was brought to the laboratory by Eskimo trappers in 1957 was raised by the family of the then director, Dr. Max Brewer (Figure 4).

Figure 4 — Gary Seiler, Animal Research Facility staff member transporting diet to wolf pack. Wolf cages are covered with canvas during winter period to minimize snow accumulation and provide protection from winds.

The continuous acquisition of new animals was not only expensive but very seasonally dependent. On various occasions a required species could not be obtained in time to coincide with research schedules. An additional problem involved the fact that recently captured wild animals are variable in regard to age, health and metabolic balance and are consequently poor specimens for laboratory studies. In 1963 the laboratory established facilities to accomodate on a permanent basis some of the indigenous Arctic species for use by researchers.

In 1974, in order to facilitate response to increasing emphasis on biological research, Dr. Warren Denner, director of the laboratory and Dr. Larry Underwood undertook a program of improvements to the NARL Animal Research Facility. The facility improvement program was multifaceted and included increase in laboratory space, improvement in animal care techniques, record keeping, staff efficiency and operational effectiveness.

At present these improvements are nearing completion and the Animal Research Facility has grown from a 20-by-40 foot quonset used as a physiological laboratory in 1947 to an extensive animal research complex spanning approximately two acres. Today this facility is staffed by professional technicians and research aides who reflect both Arctic and scientific experience to complement the work of the scientists. A six foot high chain link fence encompassing the entire animal facility (ca. 1,300 feet) has been completed. The fence serves to isolate the laboratory animals from wild species and thus decrease the possibility of any diseases being transmitted into the colony. It also minimizes vehicular and pedestrian traffic which could disrupt research and adversely affect animal behavior and physiology. Finally, the fence provides a measure of safety for any laboratory animal which may inadvertently escape from it's cage by confining it to the animal facility area. The completion of this project required augering nearly 100 post holes into frozen ground and inserting fence posts during very cold weather (Figure 5).

A new surgical suite has been completed which includes; a surgical preparation room featuring a scrub sink for the surgeon and storage areas for sterile packs; and a surgery room which can be completely closed off and is equipped with a stainless steel surgical table, a surgical light, a gas anaesthesia machine, an I.V. drip stand, and a cart for emergency equipment. The suite accommodates small to wolf-sized animals. New facilities have been added for the isolation and treatment of animals and a recovery room for post-operative treatment. In-cage environment for all species of experimental animals resident in the facility have been upgraded.

One of the more significant improvements at the Animal Research Facility has been in the area of staffing.

Figure 5 — Feeding time for Arctic wolves at NARL Animal Research Facility. Dominant wolf (right) in pack social hierarchy feeds first.

The Animal Research Facility for the first time has a resident veterinarian, CAPT L. Michael Philo, VC, USA assigned to NARL by the U.S. Army. Dr. Philo has the responsibility for the provision of veterinary support for authorized, on-site research projects in the Animal Research Facility. Such support includes performing all surgery and anaesthesia on the animals, advising the animal facility staff on policies and improvements for the facility (mainly diet and expansions), and supervision of the animal health care program. According to Dr. Philo, "NARL's animals are in excellent physical condition. Our goal is to improve the facility until it meets the standards of the American Accrediting Association of Laboratory Animal Care."

Mr. Derek Craighead, Animal Facility Supervisor, holds a Bachelor of Science degree in Wildlife Biology and has had much research experience working with his father, Dr. John Craighead, on various animal physiology studies.

Maintaining healthy populations of animals under Arctic conditions has not been without its challenges throughout the years. The battle against cold, wind and snow presents continuous problems in the maintenance of the Animal Research Facility. There are no textbook rules available on methods of maintaining an Animal Research Facility in the severe Arctic environment. It is necessary therefore to experiment with new ideas and techniques in animal maintenance. For this reason, Dr. Philo, Dr. Underwood and Mr. Craighead have established an "in-house" research program within the Animal Research Facility to experiment with diets, caging materials, improvements in the in-cage environment, and animal care techniques with particular attention to those problems inherent in the Arctic. However, NARL does not rely only on its "in-house" expertise to solve animal care problems. Valuable suggestions have come from a variety of experts such as Dr. Theodore Reed, Director of the National Zoo, whose visit to this facility as a consultant in 1973 resulted in several areas of improvement. Advice has also been obtained from Armed Forces Institute of Pathology, San Diego Zoo, National Science Foundation, Subcommittee on Laboratory Animals, Institute of Laboratory Animal Resources of the National Research Council and the Animal Resources Branch of the National Institutes of Health.

Staff members and technicians of the Animal Research Facility are encouraged to submit suggestions for improvements to Dr. Underwood.

Strict operational procedures for the use of animal resources at the Animal Research Facility have been instituted. Research protocols involving use of laboratory animals by investigators must now be submitted in advance and an Animal Use Review Panel has been established to review these protocols to insure that proposed methodologies are consistant with the regulations established by U.S. Government agencies.

Scientists now program animal use through the facility staff who prepares the animal for whatever research is intended, carry out all surgical procedures (with assistance from the scientist), and is responsible for all post-research care. Health records are kept on all NARL animals enabling the scientists to know the age, sex and general condition of the animals they intend to use. Whenever it is necessary to immobilize and anaesthetize an animal, its general physical condition is checked and monitored while data are being collected.

Every effort has been made to bring the Animal Research Facility into complete complicance with the guidelines established by the Committee on Revision of the Guide to the Care and Use of Laboratory Animals of the Institute of Laboratory Animal Resources, National Research Council.

At the present time, the animal facility supports a population of approximately 300 individuals and 21 species, including one polar bear, 20 wolves, 4 wolverines, 1 lynx, 4 Arctic foxes, 2 golden eagles, 2 jaegers, several snowy owls and a variety of small mammals indigenous to the Arctic (Figure 6).

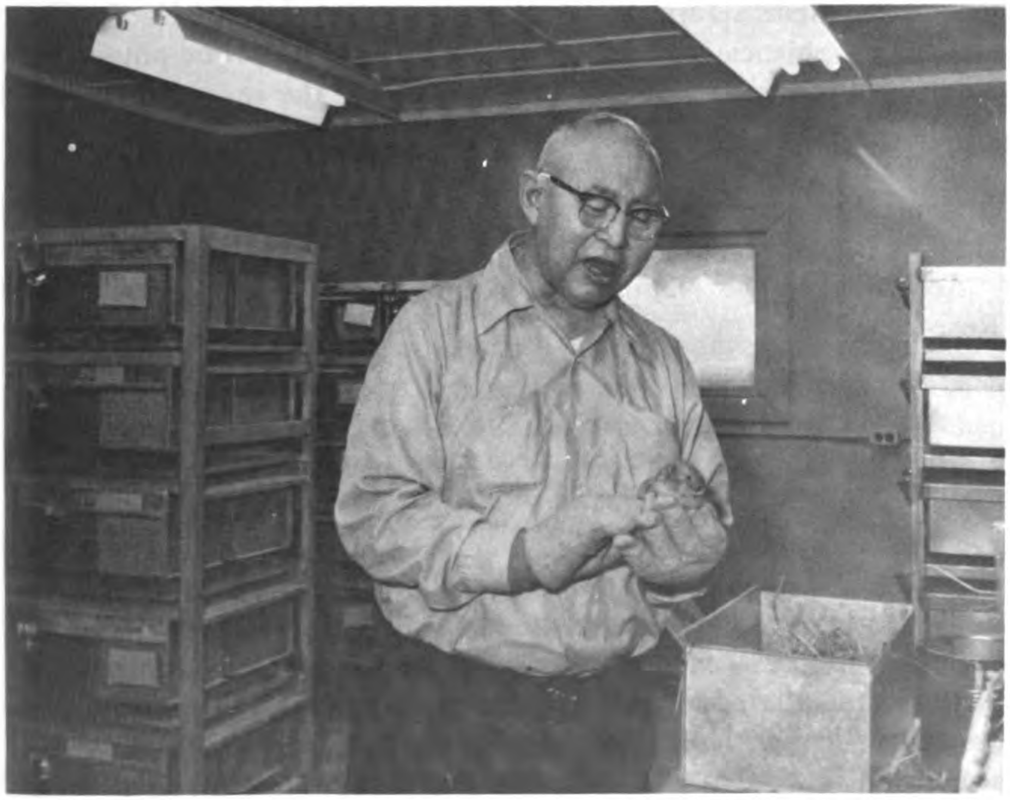

Figure 6 — Mr. "Pete" Sovalik, animal caretaker, and most senior staff member at NARL discusses the lemming population in the modern small animal building

The Animal Research Facility at NARL has been described as "the only facility in the free world that maintains Arctic species under relatively natural envrionmental conditions." As a result of a recent upgrading of the facility it is now possible to not only provide investigators with common Arctic species on demand, but to have the animals in a uniform, healthy, and biologically balanced condition. The Animal Research Facility at NARL remains the singularly unique facility in the world for the conduct of Arctic biology of broad scope and high quality (Figure 7).

Conclusions

In 1895, Fridtjof Nansen made this observation while travelling in the Arctic,

> "I was not a little surprised when I suddenly saw a track of an animal in the snow. It was that of a fox...What in the world is that fox doing here?...a warm blooded mammal on the eighty fifth parallel?" (Wiggens, 1967).

Today biologists are trying to fathom that question as it relates to man's settlements on the seventy-first parallel, the furtherest north land in

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the United States. For the first time, scientists are provided with the technical sophistication and the on-site facilities to probe physiological, biomedical and even psychological problems at the seventy-first parallel and beyond. The possibilities for living in outer space or under the sea loom before us. Not unlike life in present day polar regions, future communities may take man to remote and environmentally stressful areas of our universe.

According to the National Research Council's Committee on Polar Research,

> "The flora and fauna of the polar regions are known in sufficient detail that efforts of botanists and physiologists can be applied to special problems...The physiological mechanisms underlying adaptations to cold are now understood only to the extent that many kinds of such adaptations have been recognized and have excited the interest of the observers."

Largely because of the presence of the Naval Arctic Research Laboratory, biologists have an opportunity to explore, with more systematic methods and a greater degree of accuracy, the new field of cryobiology, as well as human biology and psychology as these relate to the polar regions. It is necessary to apply our knowledge of animal physiological adaptations to extreme cold to temperate man—now a resident of Arctic regions.

While Nansen asked, "What in the world is that fox doing here?" We can ask ourselves, "What are we doing here and can we do it better, more safely and with greater efficiency?"

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Arctic Coastal Processes: An Overview

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Introduction

In recent years, interest in Arctic coasts has grown rapidly, both for reasons of national security and because of the reserves of hydrocarbons discovered there. It quickly became apparent that our understanding of this region is insufficient to meet military and industrial requirements. Ice gouging of bottom sediments, for instance, presents a serious danger to pipelines, well heads, and bottom-mounted acoustic monitors, yet we know very little about either the mechanics or statistics of the process. The formation and migration of nearshore bars, a significant danger to all but very shallow draft boats, and storm surges which cause rapid erosion and undercutting of coastal installations are two more processes receiving much attention in recent Arctic coastal research.

Much of the following description of coastal processes has been derived from personal observations on the Alaskan North Slope. We have attempted, though, to specify those statements which apply only to the Alaskan Arctic as opposed to those which are felt to have more general applicability. Most of the processes to be described occur on small to intermediate time and length scales; e.g., storm surges last only one or two days and affect only a few hundred kilometers of coastline, whereas ice gouging may be completed within a few minutes and influence only a few tens of meters of bottom sediment. At these scales, there is very little feedback from the coastal processes to the annual temperature cycle, but the temperature cycle significantly influences the coastal processes. Therefore, the processes and interactions are arranged below in a chronological format, beginning during the winter months, when the nearshore waters are ice covered, proceeding through breakup and the open-water season, and terminating with freezeup, which completes the annual cycle.

The Winter Season

Our knowledge of coastal processes occurring during the winter months is probably more meager than for the other seasons. During

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this time the beach foreshores are covered by a thick blanket of ice and snow which protects them from eolian reworking. The nearshore waters are covered by shorefast ice some 2 meters thick. This ice cover effectively eliminates the direct forcing of nearshore currents and waves by wind during the winter. At these times, tidal currents, geostrophic currents, and currents driven by lateral friction appear to be dominant. That tides are still important has been clearly shown by the few measurements made beneath the shorefast ice (1). In isolated pockets, such as in lagoons, brine exclusions during the formation of the surface ice may cause bottom salinities to increase significantly above normal coastal, and even open ocean, values.

Approximately 2 meters of new ice are formed each winter; thus, where the normal water depths are less than 2 meters, the ice will typically extend to the bottom. A thin layer of surface sediment will be incorporated into the ice cover when the interstitial water freezes. During a rise in sea level, such as might be caused by a drop in atmospheric pressure, the ice-sediment will float on a thin layer of water which will intrude between the ice and the seabed. As this water freezes, another layer of sediment may be incorporated into the ice cover. In this fashion, a significant amount of surface sediment may be adfrozen to the shorefast ice. During breakup, this ice and sediment will float offshore, where the rafted sediment will fall to the bottom when the ice melts.

Ice gouging also affects the nearshore sediments during winter. Barnes and Reimnitz (2) point out that, in the Beaufort Sea, the shorefast ice extends offshore to the location of the 10- to 20-meter depth contour. Beyond this point lies a shear zone, up to 20 km wide, where the moving ice pack meets the shorefast ice. This seems to be an area of active ice gouging of the bottom sediments, a process which will be discussed more fully below.

Breakup

As air temperatures rise above freezing, snow melt, initial thaw of the active surface layer of the tundra, and melt of river ice cause flow to begin in the rivers of the Alaskan North Slope. In ths region, the freshet arrives at the coast at approximately the same time that the daily average temperature rises and remains above freezing. For those rivers initiating in continuous permafrost areas, the freshet is the first flow of the year. It also represents a major portion of the total transport of the river in terms of both water and sediment (3, 4). The river flow runs over the shorefast ice until it reaches the location of the 2-meter depth contour. It then flows through the ice and forms a broad, fan-shaped lens of fresh water between the ice and underlying seawater.

Numerous smaller melt water streams occur along the tundra coastline. Flow from these streams is essentially confined to the breakup period.

The shorefast ice begins to break up near the time river flow first reaches the coast. Wind stress on the ice represents a horizontal force on the ice which is an important contribution to the breakup process. This stress, τ, has typically been assumed to be due to skin drag and is related to the wind speed, U, by a bulk drag coefficient, C_d, through the formula

$$\tau = \rho C_d U^2,$$

where ρ is the air density. To be a useful predictor of stress over a sizable area, this formula requires that C_d be well known and be characteristic of the entire area under discussion. The variety of small-scale features such as ridges, leads, melt pools, and blowing snow which are present in the nearshore zone preclude a good definition of the drag coefficient at this time (5). Furthermore, form drag, as well as skin drag, may make a significant contribution to the total drag on the ice (6, 7).

While the nearshore ice is breaking up under the influence of wind stress, solar heating, and melt as a result of the warm runoff from the spring freshets, ice and snow which were incorporated in the beach the previous fall are also melting (8). When snow covered, the beach was easily traversible by foot or by snowmobile. During the breakup season, the melt of ice and snow within the sediment causes numerous collapse features to form on the beach. The sand also becomes extremely moist. The resultant beach assumes a very irregular, pitted aspect, and it is extremely difficult to move about upon (Figure 1). The beach continues in this state until it is dried and packed by eolian action or until it is reworked and packed by waves during a large storm.

The Summer Season

Within one or two months after breakup begins, the shorefast ice has normally been completely effaced and a band of moderately ice-free water has developed within 15 km or more of shore. During the one to four months when this band of open water exists, coastal processes in the Arctic bear the greatest resemblance to similar processes in temperate regions. Process modification, though, occurs because of factors unique to the Arctic such as the presence of an offshore ice pack, the presence of permafrost, and the unique hydrologic regime.

The dominant winds along the Alaskan Arctic coastline blow from the northeast. It is not uncommon for these winds to blow at speeds of 8 to 10 m/s for more than a week at a time. Storm winds may blow

Figure 1 — An example of an Arctic beach during breakup. Note the collapse feature where the underlying ice has melted. The mass of ice in the section through the beach is approximately 40 cm thick.

from any direction, but the most important for coastal processes are those which blow from the southwest. These winds have a long fetch of open water across the Chukchi Sea available to them before they reach the coast, and, since they may commonly attain speeds of 20 m/s or more, they are capable of causing serious modification of the coastal morphology. The general lack of beach vegetation permits the wind to winnow out the fine fraction from the sediments, leaving low barriers armored with gravel pavements. Other than this, though, direct modification by eolian action appears minimal, but reworking of beaches and coastal erosion by a combination of wind-driven waves, currents, and storm tides is severe.

Surface waves are usually fetch limited in the Alaskan Arctic by the presence of pack ice. Wave heights are typically bounded below 1 meter, although storm waves of 2-meter height have been observed in both the Chukchi and the Beaufort Seas. These larger waves would appear to be more common in the Chukchi Sea, where the greater expanse of open water increases the possibility of a significant fetch for wave generation.

The same winds that generate the surface waves also drive strong coastal currents. Within the nearshore region, the currents generally flow along the coast at speeds greater than 0.5 m/s in the direction toward which the wind is blowing. A slight onshore-offshore component of flow tends to raise coastal sea level when the shoreline is to the right of the direction of the current and to lower it in the opposite case. The magnitude of these storm surges is inversely affected by water depth. Thus, the broad, shallow shelves surrounding the Arctic Ocean are conducive to large surges. Surges of 1 to 3 meters are not uncommon in Alaska (9) (Figure 2). The import of these storm surges for the coastal geomorphology will be dealt with further below.

After the spring freshet, there is a large volume of fresh water in the nearshore region. In the shallow nearshore waters and lagoons behind the barrier islands this water is heated by solar radiation. Those currents which tend to raise coastal sea level also pile the warm, fresh water against the shore. In cross section it forms a wedge. The currents which lower coastal sea level also carry the fresh water offshore in the form of a surface lens and upwell colder, saltier water against the coast (10) (Figure 3). Both the current system described in the preceding paragraph and the coastal water property variations are very reminiscent of the coastal jets which Csanady (11) has described in the Great Lakes. During the summer, after the transport of the rivers has dropped to its small post-breakup value, the changing coastal winds cause mixing of the nearshore waters with the shelf waters and a lessening of the density difference between the two water masses.

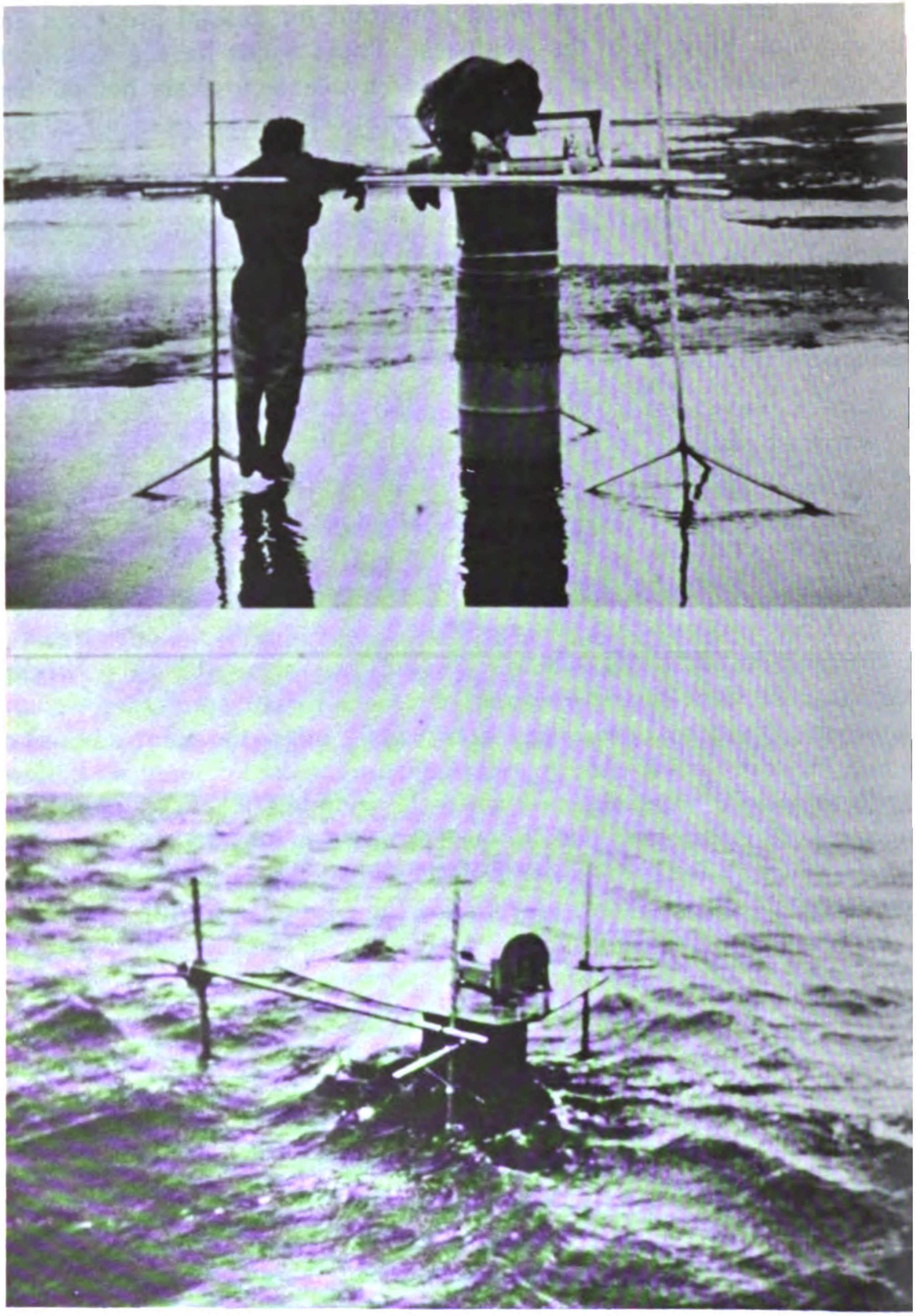

Figure 2 — Two views of the same portable tide gauge installation. Top: water level i slightly below normal. Bottom: water level is high because of a storm surge.

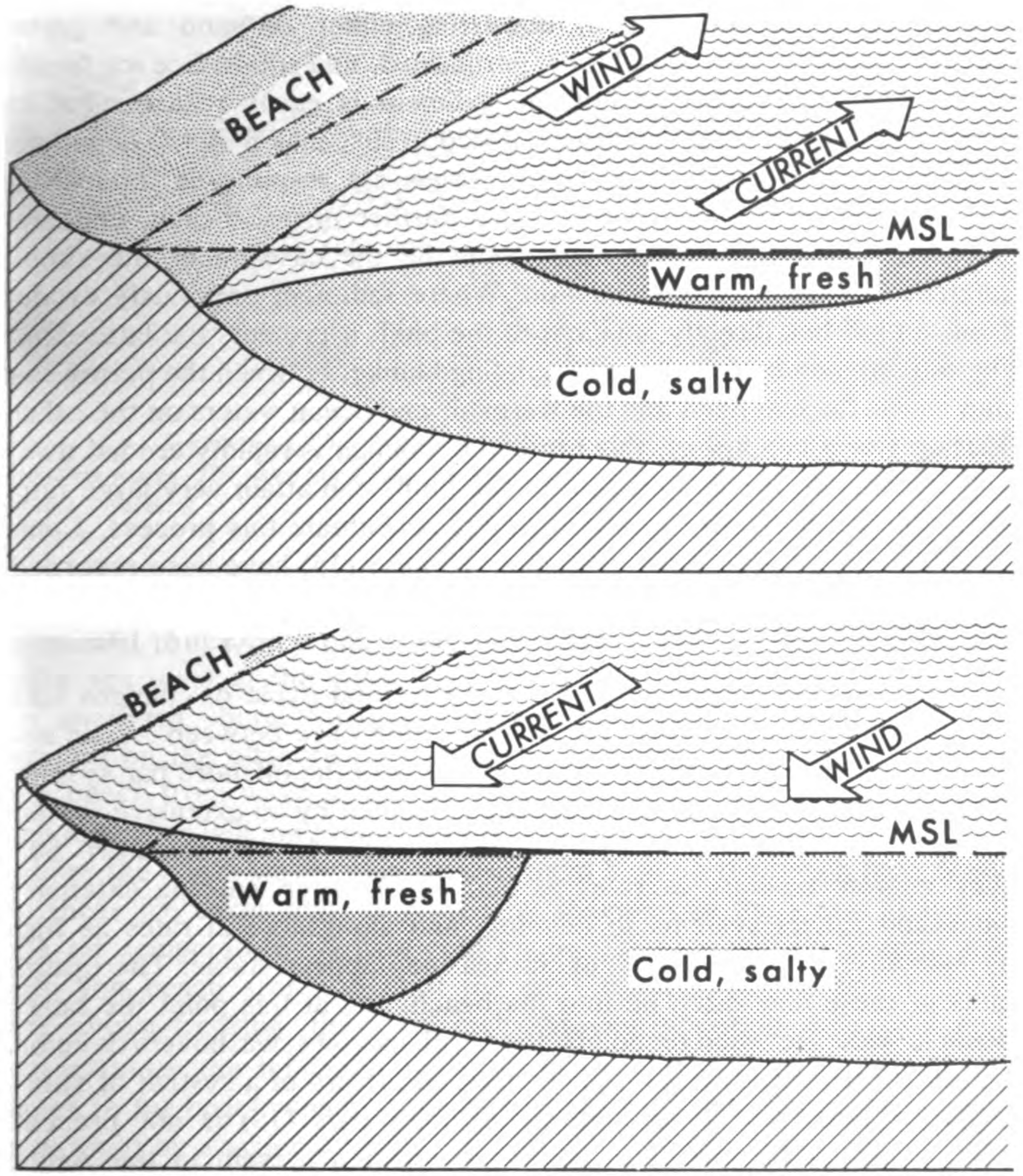

Figure 3 – Top: winds which blow with the coast to the left lower sea level and move the fresher waters offshore. Bottom: winds which blow with the shore to their right raise sea level and press the fresher water against the coast.

Astronomical tides in the Arctic Ocean are driven by the tides in the Atlantic (12). They are semi-diurnal in nature and of small amplitude by the time they reach the Alaskan shore. Generally, their amplitude is less than 0.5 meter. The Coriolis parameter, though, is close to the semi-diurnal frequency at these latitudes, and resonances may cause tidal currents to be important away from the sea surface or under the shorefast ice where wind-driven currents are unimportant (12, 13).

The capacity that waves and currents have for erosional activity is greatly enhanced because coastal sediments along the Alaskan Arctic are generally unconsolidated, consisting either of sand and gravel barrier islands or of tundra bluffs, permafrost, and subsurface ice formations. The unconsolidated bottom sediment is easily resuspended by wave and current action and then carried in suspension by the nearshore currents. The frequent large storm surges are responsible for moving the location of the surf plunge point farther up the beach, exposing a broader area to erosion than would be the case under the simple influence of the astronomical tide. Where sediment previously eroded from a bluff lies directly adjacent to the bluff, it protects the latter from thermal erosion by forming an insulating blanket between the permafrost and ice on the one hand and the warm air and ocean waters on the other. During storm conditions, this protective blanket is rapidly eroded away and subsequent thermal erosion of the bluffs can attain very large rates (14). The warm, fresh nearshore waters accentuate this process. Long-term thermal erosion rates as high as 10 m/yr (15) have been recorded, while a single storm may cause many meters of bluff cutback (16). More typical rates, though, appear to be between 1 and 4 m/yr (15, 17).

Beach processes appear to follow the normal cycle of changes seen on temperate beaches (18). The primary difference between Arctic and temperate beaches seems to be associated with the offshore bar system. Much of the Alaskan Arctic shoreline is fronted by an extensive system of bars. These are long, continuous features. In the Beaufort Sea, they migrate onshore at rates as high as 70 m/yr, causing extensive ridge and runnel systems to develop, and alongshore at rates as high as 300 m/yr, while in the Chukchi Sea they appear stable. The updrift ends of these bars often tie into the beach, and at this point the beach plane is wide. Between tie points, the beach narrows, washovers develop, and tidal inlets tend to form. The classical picture of a system of short, rhythmic inner and long, continuous outer bars (19) is not present. This seems to be related to the wave regimen present in the Arctic (20). The circulation patterns associated with outer bar systems extend almost to the subaerial beach because of the normal low wave action, and thus there is no room for an inner bar system to develop (6). The formation and position of the bars may well be related to the occurrence of long-period infragravity waves. Groups of storm waves approaching a beach will cause a system of long-period standing waves to occur in the onshore-offshore direction. The secondary flow patterns associated with these waves will cause suspended sediment to accumulate under the antinodes of the standing waves (Figure 4). The location of these antinodes depends upon the mean nearshore bottom slope and the mean storm wind speed. Predictions of antinode location correlate well with the offshore bar locations at many sites along the Alaskan Arctic coast (21).

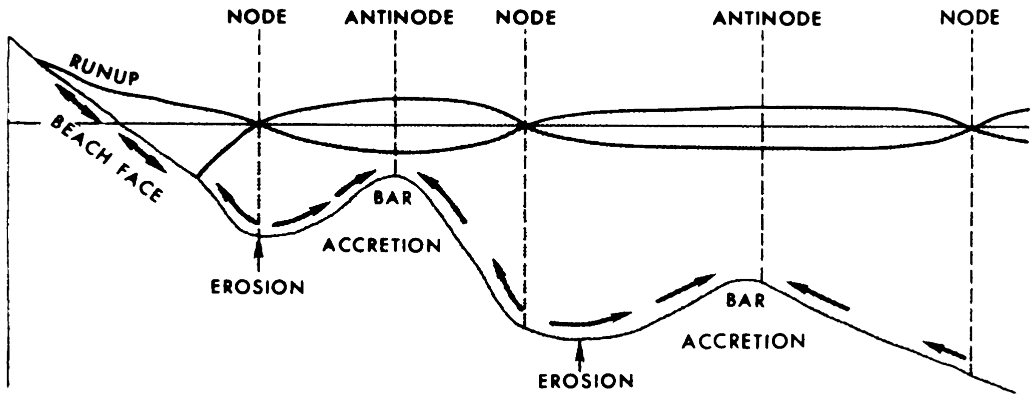

Figure 4 — Schematic of bar formation: storm waves set up a system of long-period standing waves. The associated motions cause sediment accumulation under the antinodes of this system.

Another feature of the summer beach which is unique to the Arctic is related to the presence of ice on the ocean surface. The winds which raise sea level at the coast may also cause the edge of the pack ice to approach shore. Small cakes of ice and ice boulders sometimes ground on the offshore bars and form a natural breakwater, protecting the beach from wave action. If the water level is high enough, though, the ice cakes will not ground on the bars but will be carried to the beach, where the storm waves may deposit them high on the beach face. Some of these ice cakes may be buried by sediment as the storm abates. If the air temperatures remain cold enough, the ice will be incorporated into the beach structure until the next summer. If the temperatures are above freezing, they will melt. Moving about in their own melt water under the influence of the wind, they then excavate small pot holes in the beach which also may be preserved until the beach is again reworked by a major storm.

The larger ice cakes which approach the beach during a storm may ground on the bottom proper rather than on a bar. If they do, they often excavate a gouge in the sediments. These gouges may also take many shapes but are often long and narrow. Such bottom gouges may also form during the winter owing to shear and pressure ridging, as mentioned above. The bottom gouges may achieve densities of 300/km of ship track and depths of 5.5 meters or more, although 0.5 to 1.5 meters is more typical (22, 23).

On a longer time scale and larger spatial scale than the beach changes, major coastal features such as inlets and barrier islands are also changing. In the Chukchi Sea, where open water during the summer months has, over extended periods of time, permitted significant reworking of the coastal sediments by storms, the barrier islands appear to be in dynamic equilibrium. Tidal inlets along the island chains, though, are often ephemeral or migratory. On the Beaufort Sea, though, where the presence of pack ice has restricted the amount of wave action available to rework the shoreline, the islands do not yet appear to have attained an equilibrium state. Major changes in island shape are still occurring, and a general westward migration of the islands seems to exist. The rate of this migration is estimated at between 7 and 25 m/yr, and rates during a single year achieve values an order of magnitude larger.

Freezeup

As the temperature begins to fall below freezing, ice forms on the rivers, lakes, lagoons, and, finally, on the nearshore waters. The oceans do not freeze as rapidly as breakup appeared to occur. During breakup, as soon as fresh water, resulting from melt of the snow and ice over land, begins to flow, the ice on the lagoons, in the inlets, and in the nearshore area begins to deteriorate. During the summer months, though, vast quantities of heat are stored in the waters overlying the continental shelves. This heat must be lost to the atmosphere before freezeup can be completed. Stratification somewhat lessens these requirements, but, as mentioned above, the majority of the freshwater input responsible for the coastal stratification occurs during the spring freshet, and the resultant halocline has normally been significantly eroded by the time freezeup begins except near the major river mouths.

Ice normally forms first on the lagoons behind the barrier islands. These are the areas of shallow, fresh water where the heat flux to the atmosphere is most efficient in cooling the entire water column to its freezing point. Quite often, at this time, there are strong currents flowing out of the inlets to the lagoon. These currents may either be tidal or the result of wind set-down. In either case, large volumes of ice slush are swept out of the lagoons and into the nearshore areas. In response to rising and falling sea levels, onshore winds, and wave action, this ice slush is often deposited on the beach face in the form of an ice slush berm or an ice-foot. During storm conditions, this ice may then be covered with sediment and incorporated into the beach structure. Alternating layers of ice and sediment thus formed are referred to as "kaimoo" (24, 25).

Somewhat later in the freezeup season, as the air temperature continues to drop, the lagoons become totally ice covered. At this time, the nearshore waters are cold enough so that the waters in the swash zone may freeze on the beach surface during swash backwash. A thin veneer of ice forms on the beach face. As this layer builds up, it forms an ice-foot which may attain thicknesses of tens of centimeters, depending upon the amplitude of wave action and tides. If this ice-foot is broken up by a sudden rise in sea level which produces buoyancy forces stressing the ice-foot, the resultant ice cakes and ice boulders will then wash ashore and become incorporated in the beach (Figure 5).

Later still, frazil and ice slush form on the nearshore water surfaces. Winds that tend to raise coastal sea level also cause currents which in conjunction with wind stress, drive the frazil and ice slush against the shore, compacting it and, under storm conditions, throwing it up on the beach to form a storm ice-foot. Winds which tend to result in a lowering of coastal sea level also result in a dispersion of the frazil and ice slush. When the ice slush is thick near shore, it filters out all but the longest waves. If this occurs during cole, reasonably calm conditions, the slush may solidify and form shorefast ice. The final aspect of the freezeup process then occurs when the pack ice moves into a position near shore. This completes the cycle of nearshore processes in the Arctic.

Conclusions

It is apparent that the Arctic coastline cannot be characterized as a frozen, stagnant region. The variety of dynamic processes active in the Arctic nearshore zone is large. In winter, not only are the under-ice currents still active, but the ice itself is interacting with the bottom both through adfreezing of sediment and gouging. Breakup causes a total

Figure 5 — Photograph of a storm ice-foot. The blocks of ice in the foreground are due to the destruction of an ice-foot which was built under low tide and low wave conditions

change in the coastal region: melt of ice in the sediments results in beach changes as large as any seen during the open-water season, and the removal of the shorefast ice permits wind stress to generate strong currents in the nearshore area. During the summer, it is the storm surges, which result in large rates of erosion and sediment transport, that are the important process. At the time of freezeup, the rapid beach accretion caused by interactions of the beach with the freezing ocean is an important dynamic feature of the region. From the few sets of data collected in the area and comparison with processes active on temperate beaches we can begin to understand and predict the interactions which take place there. We still lack considerable knowledge of those processes which are distinctly Arctic, such as the effects of permafrost on beach and nearshore processes and the dynamics of an ice-covered nearshore and inner-shelf region.

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Modeling Ice Thickness Dynamics and Energy Exchange in the Arctic

ONR investigator Dr. G. Maykut under contract is making steady progress toward modeling ice thickness dynamics and energy exchange in the Arctic. Based on laboratory experiments and field data from three simultaneous manned drifting stations in the central Arctic, an improved model of the thickness distribtuion of sea ice has been formulated. The theory models the changes in thickness due to melting and freezing and the rearrangement of existing ice to form leads and pressure ridges. The model was found to favorably compare with published submarine values of ice thickness.

In a related study by Dr. S. Martin, a simple model of heat transport in young sea ice has been combined with climatological data on air temperatures and incoming radiation fluxes to predict how each component of the heat balance in the central Arctic is affected by the rapid growth of ice in leads. It was determined that the total heat input to the atmospheric boundary layer from regions of young ice is equal to or greater than that from regions of open water or thick ice.

Recent Advances in Arctic Hydroacoustics

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Naval Ocean Research and Development Activity

Introduction

The two features peculiar to the polar environment that most strongly influence underwater sound are the permanent ice cover and the sound speed structure in the water. The water column is relatively stable and nearly isothermal, whereas both the physical and statistical characteristics of the ice canopy are highly variable in both time and space (1). Due to the essentially positive sound speed gradient in the water column, acoustic ray paths are generally upward-refracted and supsequently reflected and/or scattered from the rough ice-water interface (2). In addition, the principal source of ambient noise in Arctic and subarctic waters is large scale deformation of ice floes (3).

Between 1970 and 1975 the Naval Oceanographic Office conducted an environmental acoustic experimental research program directed at establishing causal relationships between environmental features, in particular sea ice properties, and underwater acoustic ambient noise and transmission loss in the Arctic Ocean (4). All measurements were made from aircraft. Acoustic measurements were made using sonobuoys and signal underwater sound charges, vertical temperature profiles were measured using airborne expendable bathythermographs, and the statistical properties of sea ice roughness were determined using a laser profiler.

The purpose of this paper is to review the most significant advances in our understanding of ice-related underwater acoustic phenomena which resulted from this research program.

Synoptic Ambient Noise Measurements

Quasi-synoptic measurements of ambient noise levels in the vicinity of the ice-water boundary were made in the vicinity of the sites shown in Figure 1. The measurements were acquired by deploying calibrated

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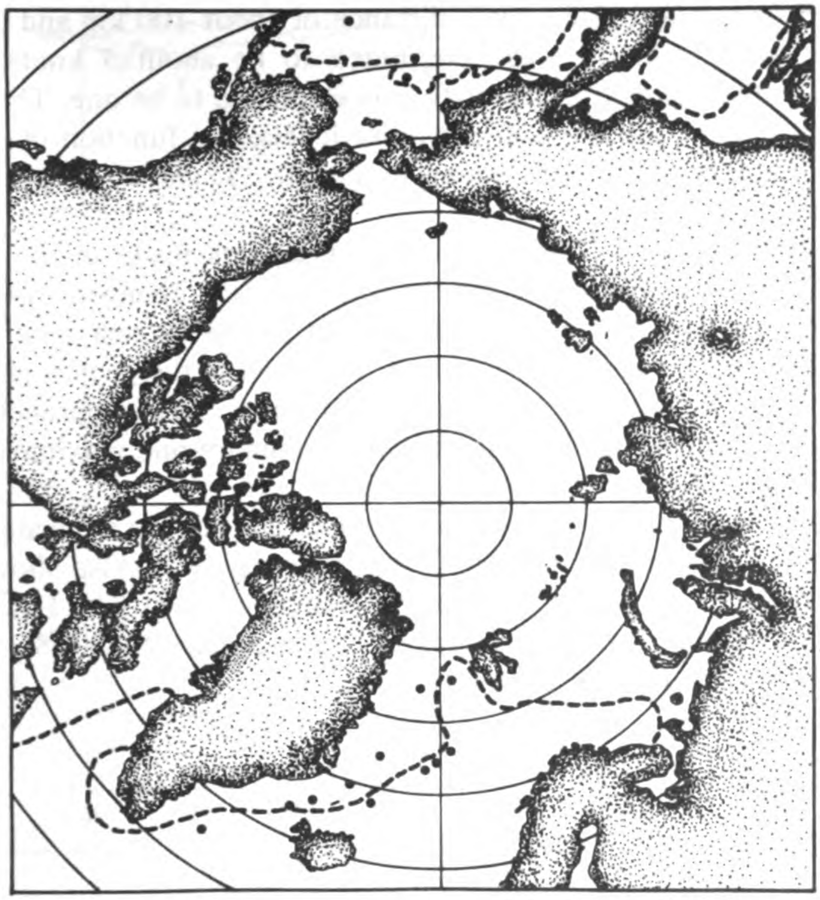

Figure 1 — Approximate locations of measurement sites (●) and ice-water boundary (- - -)

sonobuoys from aircraft into open water and into water openings in the ice field along tracks normal to the ice-water boundary.

The most pronounced feature of the measurements, which appears to be a universal property of the ice-water boundary, is anomalously high ambient noise levels at the boundary relative to noise levels in totally ice-covered and ice-free waters (5). Hypothetically, the mechanisms responsible for high ambient noise generation at the ice-water boundary are related to wind-generated ocean wave interactions with sea ice at the boundary.

To determine the relative magnitudes of physical phenomena characteristic of marginal sea ice areas on the generation of ambient noise, several sets of measurements of the spatial variability of ambient noise were made under the following environmental conditions: compact and diffuse boundaries, and high and low sea states.

Quasi-synoptic ambient noise measurements were made in the vicinity of a diffuse boundary in April 1972 (6). At this site, the ice concentration changed from 1/8 to 7/8 over a distance of about 100 km and the geostrophic wind velocity was determined to be about 3 knots, nearly normal to the boundary. Sea state was estimated to be one. The spatial variability of the median ambient noise levels as a function of distance from a diffuse boundary for frequencies of 100, 315 and 1000 Hz is shown in Figure 2.

For comparison, ambient noise measurements made in the vicinity of a diffuse boundary where the ice concentration changed from 1/8 to 7/8 over a distance of about 100 km, but where the sea state was estimated to be 5, is shown in Figure 3. In this case the geostrophic wind velocity was determined to be about 20 knots, nearly parallel to the boundary. Figures 2 and 3 illustrate the minimum and maximum levels measured at diffuse ice-water boundaries.

A comparison of noise levels at compact and diffuse ice-water boundaries at a frequency of 315 Hz is shown in Figure 4. Also shown here are noise levels in totally ice-covered waters (2,7) at 315 Hz (on the left), and Wenz' familiar "standard" open-ocean levels (8) for sea states 1-5 at 315 Hz (on the right).

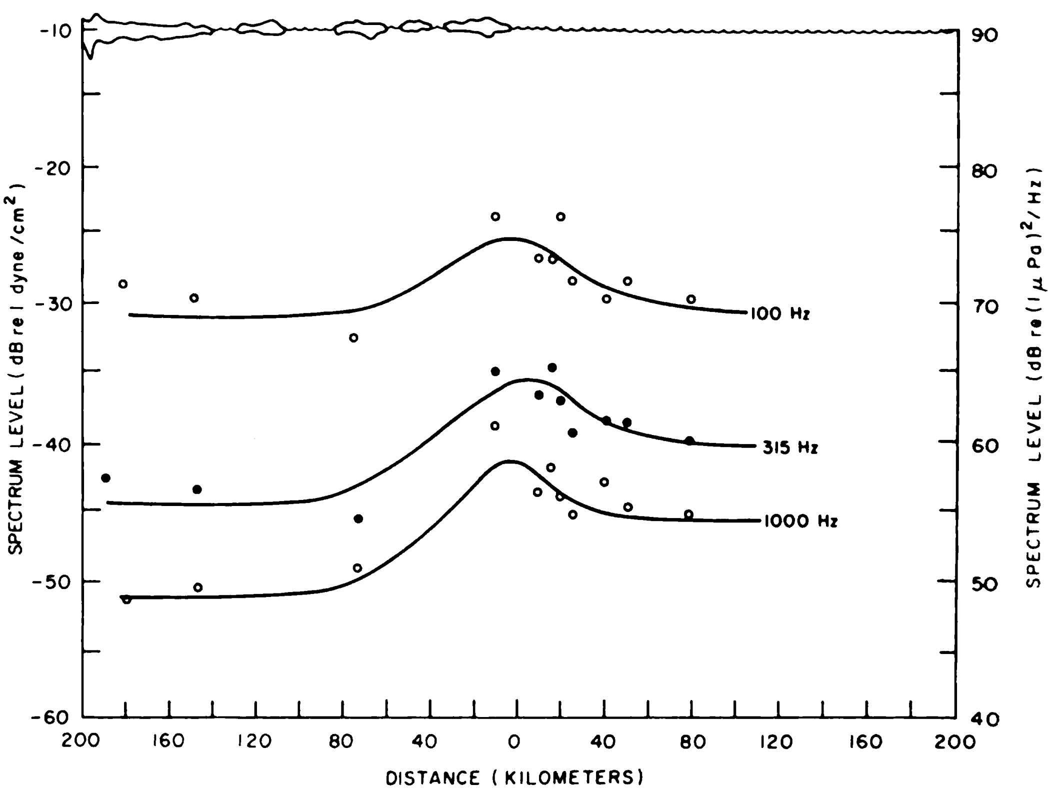

Figure 2 — Variations of median ambient noise sound pressure spectrum levels with distance from a diffuse ice-water boundary for frequencies of 100, 315, and 1000 Hz. Sea State: 1.

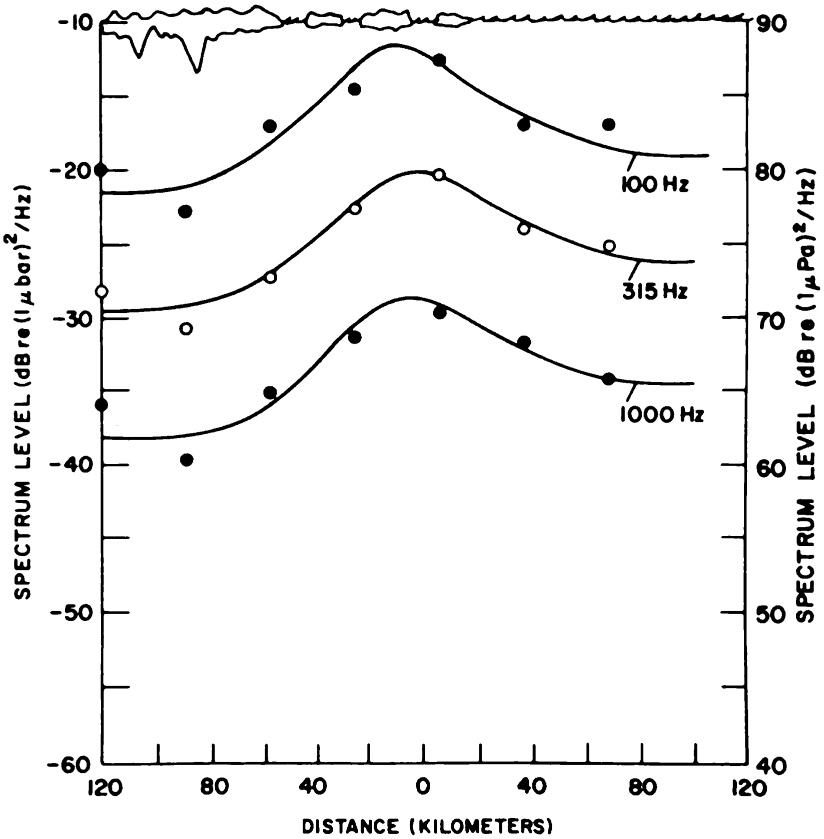

Figure 3 — Variations of median ambient noise sound pressure spectrum levels with distance from a diffuse ice edge for frequencies of 100, 315, and 1000 Hz. Sea State: 5.

In the case of the compact ice edge the ice concentration changed from 1/8 to 7/8 over a distance of about 1 km. The estimated geostrophic wind velocity for both data sets was about 10 knots, and the sea state of the contiguous open ocean was 2. From this figure it is evident that noise levels at a compact ice-edge are much higher than at a diffuse ice edge, and that noise levels appear to be much higher at the ice edge than in the totally ice-covered Arctic Ocean for the same wind velocity.

The noise levels shown on the left side of the figure illustrate a peculiar feature of ambient noise in totally ice covered waters, viz. that noise levels under the sea ice canopy are strongly dependent on the ice regimen. As an example, for the same wind velocity of 10 knots, the noise level at a frequency of 315 Hz in the central Arctic, where ice floes are between .1 to 10 km in length, is 15 dB higher than the noise level in a fast-ice regimen, such as is found in the Canadian archipelago during the winter season.

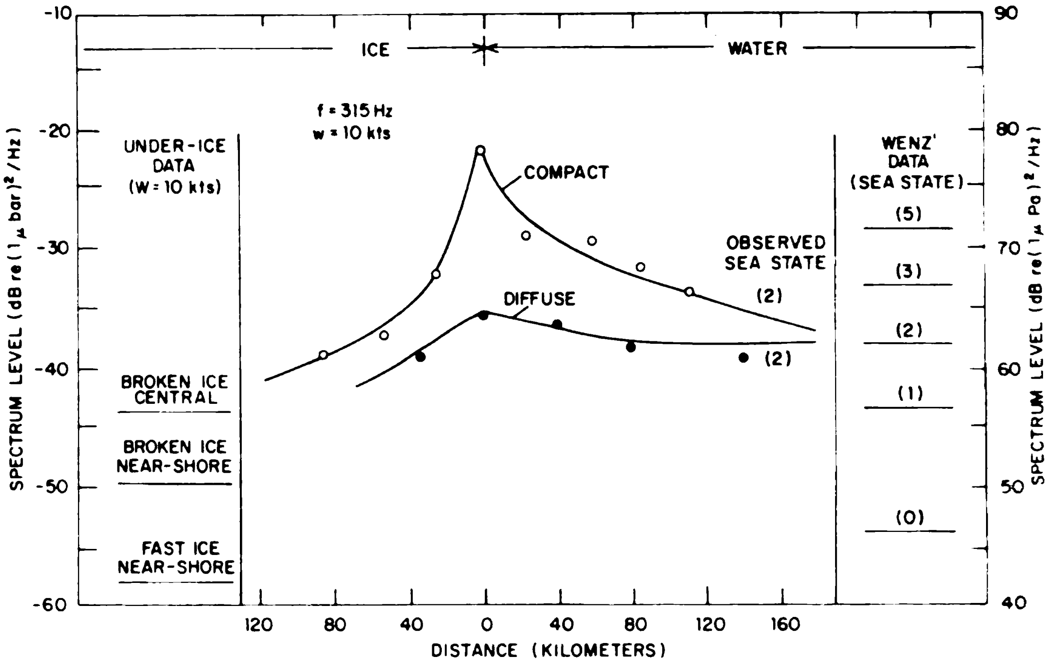

Figure 4 — Variations of median ambient noise sound pressure spectrum levels with distance from a diffuse and a compact ice edge. Sea State: 2. Under-ice levels on the left. Open ocean levels on the right.

Long Range Propagation of Ice-Edge Noise

Theoretically, the shapes of the ambient noise with distance curves are a function of sound propagation conditions which, in turn, are a function of ocean depth, sound speed structure, and the nature of the ocean boundaries. Sound propagation from a near-surface source in the subarctic occurs primarily by refracted-surface-reflected paths, and the signal attenuation with distance at high frequencies (> 100 Hz) is controlled by reflection losses from the wind-swept sea surface and from the ice-water interface. The latter are generally much higher than reflection losses from the sea surface, an observation which may account for the difference in the rate of change of ambient noise level vs. distance in the ice-covered and ice-free sides of the boundary.

To illustrate the effect of transmission loss on the shapes of the ambient noise vs. distance curves quantitatively, one set of coincident measurements of the spatial variability of ambient noise, transmission loss, and temperature structure will be considered in some detail. The measurements were made along the 400 km open water track normal to the ice-water boundary in the East Greenland Sea, which is illustrated in Figure 5. The measurements were made from two aircraft. Attenuated sonobuoys, deployed at the ice edge, were monitored from one aircraft, while explosive sound signals were deployed every 7 km, and ambient noise sonobuoys and airborne expendable bathythermographs were

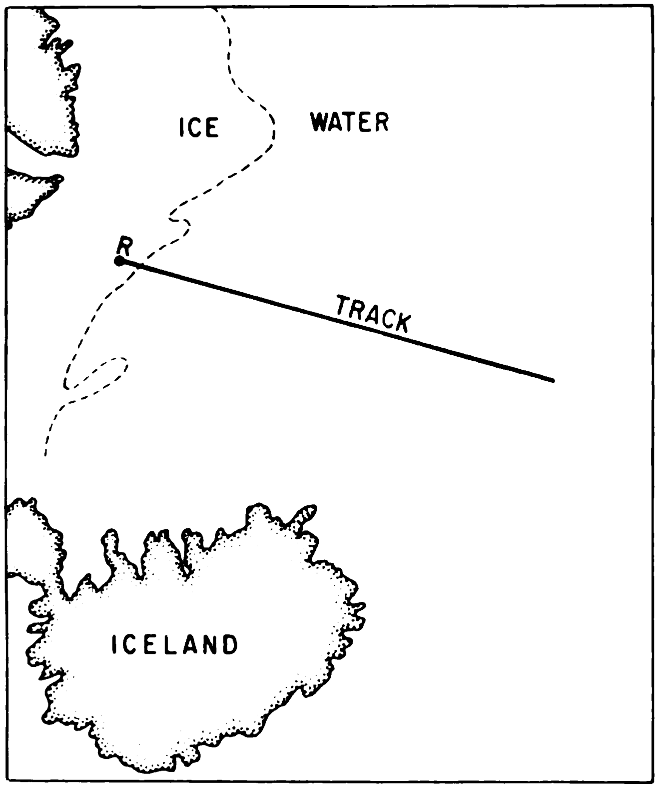

Figure 5 — Location of track for synoptic measurements of ambient noise, transmission loss and temperature structure. Signals detected at R.

deployed and monitored every 70 km from the second aircraft. To approximate the depth of the source of sound at the ice-water boundary, viz., zero depth, the explosive sound signals were set to detonate at a depth of 18 meters. The hydrophone depth was also set at 18 meters. The ocean depth at the measurement site was approximately 1000 m. The entire measurement time lasted 4 hours.

The results of the temperature measurements and the corresponding ray diagram are shown in Figure 6 and 7 respectively.

The recorded explosive sound signals were filtered and integrated, and transmission loss was computed in 1/3 octave frequency bands over the frequency range 50-1000 Hz. Median ambient noise spectrum levels were also computed over the same frequency range. Results of the transmission loss and ambient noise measurements at a frequency of 100 Hz are shown in Figure 8. Also shown in Figure 8 are range-dependent ray theoretical (10) and parabolic equation method (11,12) computations of transmission loss. Both sets of computations appear to be in reasonably good agreement with the data. The departure from cylindrical spreading is represented by the curve labeled T.L.-C.S. (in relative dB). At lower frequencies the data are complicated by

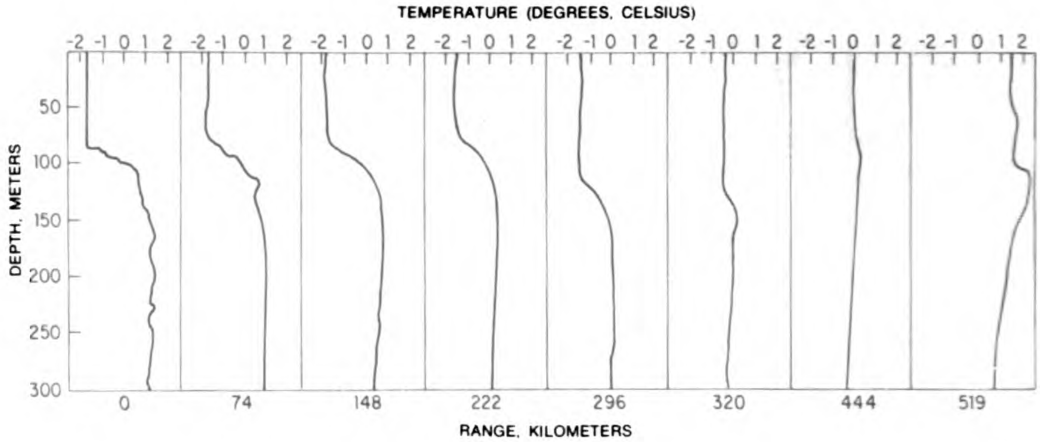

Figure 6 — Airborne expendable bathythermograph (AXBT) measurements

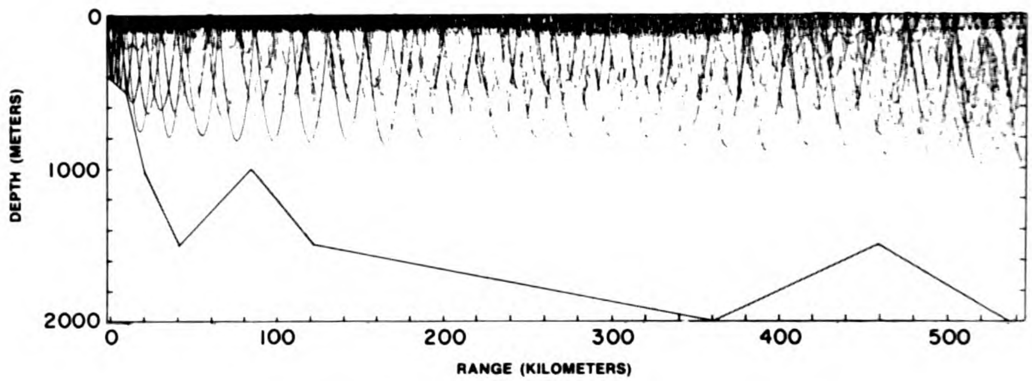

Figure 7 — Ray trace based on AXBT measurements

bottom effects and source level uncertainties, whereas at higher frequencies the data are complicated by sea-surface scattering and mid-water absorption, and will not be considered here.

Hypothetically the sound generated at the boundary may be considered as a line source of sound when the measurement distances from the boundary are large compared to the magnitude of ice-edge irregularities (9). Hence, at measurement sites which are far from the ice edge, sound propagating from the ice edge should be expected to experience plane wave propagation, i.e. no attenuation with range due to geometrical spreading loss if the sound speed structure does not vary appreciably with range. The sound speed structure, however, varies considerably with range (shown in Figure 6) resulting in a significant departure from cylindrical spreading, as illustrated by the curve labeled TL-CS in Figure 8. It was hypothesized that this departure from cylindrical spreading could be used to "predict" the rate of change of ambient noise level with range. As illustrated in Figure 8 the "predicted" and measured rate of change of noise level with distance from the ice-water boundary are in excellent agreement at ranges beyond 50 km from the ice-water boundary. For comparison, current and historical estimates of "low-shipping" noise levels at 100 Hz are also shown in Figure 8 (8,13). From this figure it appears that for the environmental configuration at this particular measurement site ice-edge noise is evident at ranges up to 400 km from the ice edge.

The foregoing discussion illustrates the particulars of the problem of determing long range ice-edge noise effects. The "range" of ice-edge noise depends on the "source level" of the noise which is a function of sea state, transmission loss which at moderately low frequencies in ice-free water is controlled by the sound speed structure, and the "asymptotic" ambient noise level far from the ice-water boundary which at low frequencies is controlled by shipping density.

Transmission Loss in Ice-Covered Waters

In ice-covered waters the analysis of transmission loss is generally simplified by the relative uniformity of the sound speed structure, but severely complicated by under-ice scattering losses, even at moderately low frequencies.

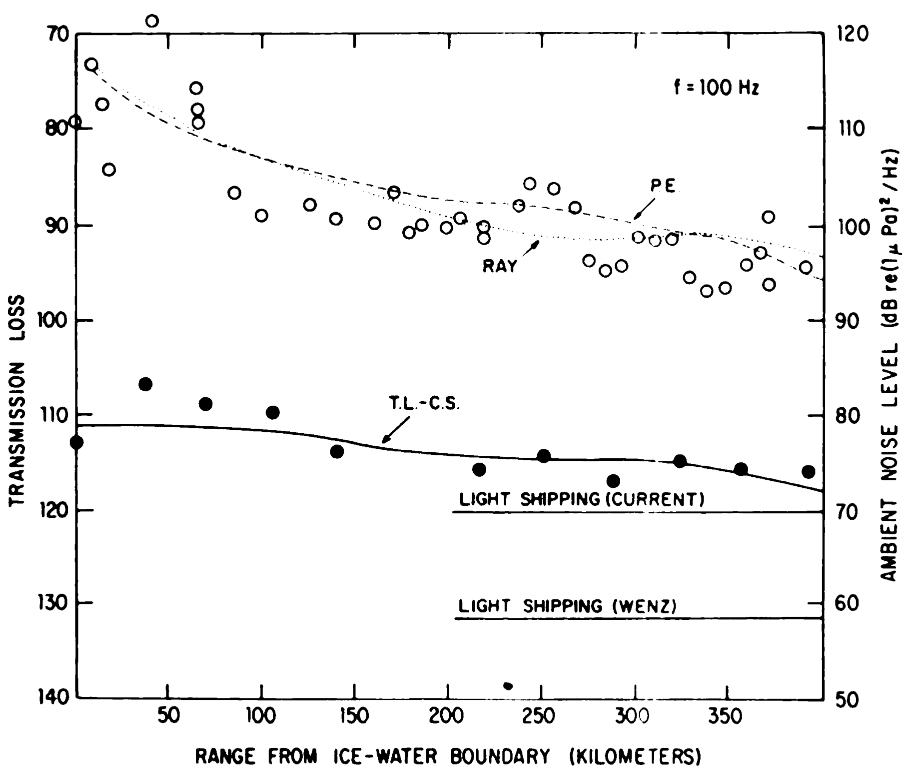

Figure 8 — Analysis of relationship between ambient noise and transmission loss data

It has been hypothesized by many previous investigators (2,3,7,14) that under-ice reflection loss and scattering strength are primarily controlled by the "roughness" of the ice. Recently, however, it has been qualitatively but convincingly demonstrated that backscattering strength is controlled virtually exclusively by the size and number of sea ice ridges (15). In accordance with this concept, an analytical model of scattering loss has been developed, which expresses under-ice reflection loss as a function of the number and average depth and width of sea ice ridges.

Sea ice ridges are rubble piles formed by collisions and shear interactions between adjacent floes. Ridge dimensions vary widely but are nominally about 1 m high, 4 m deep and 12 m wide, with the ridge length generally being much greater than the depth or width. A representative average spacing between ridges, which is random, is about 100 m. The effective orientation of a large number of ridges is also generally random. The cross-sectional contours of ridge sails and keels, the result of a random process, are highly variable.

Examples of measured cross-sectional ridge contours (17,19) which are shown in Figure 9, illustrate the following features of sea-ice ridges: (a) a majority of ridge keels are flattened at the bottom due to ablation, and approach the ice-water interface at a relatively steep angle; and (b) the shapes of ridge sails are highly variable, although in many instances a narrow protuberance is evident near the center of the ridge.

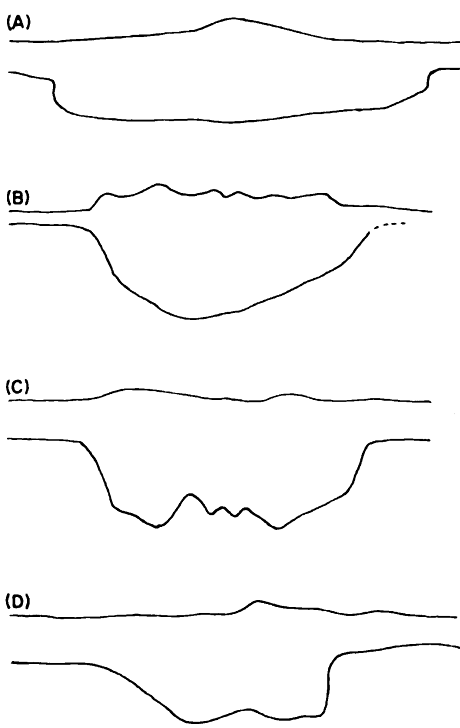

Figure 9 – Ridge profile measurements by Kovaks (A and B) and Francois (C and D)

A comparison between measured contours and simple geometrical shapes suggests that ridge keel contours may reasonably be represented by a half-ellipse.

Measurements of the keel-depth-to-sail-height ratio, R, of previously reported contours (17,21) vary between 1/3 and 8, and average 4.0 ± 0.5, as illustrated in the histogram in Figure 10. In this figure the number of observations is shown as a function of the estimated keel-depth-to-sail-height ratio of the examined contours. Another estimate of R, based on a statistical analysis (22) of a set of near-coincident measurements of about 100 keel depths and sail height, results in $R = 4.0 \pm .3$, which is in good agreement with the results in Figure 10. In addition, it is noteworthy that the ratio between the deepest keel and the highest sail reported in the literature (23) is equal to 3.6.

Prior to a theoretical interpretation of the relationship between the statistical properties of sea-ice ridges and under-ice reflection loss, a few relevant theoretical aspects of acoustic reflectivity from sea ice will be mentioned.

Rays which propagate to long distances (greater than 30 km) in Arctic waters reflect from the ice-water interface at grazing angles, ϕ, which are generally smaller than 15°.

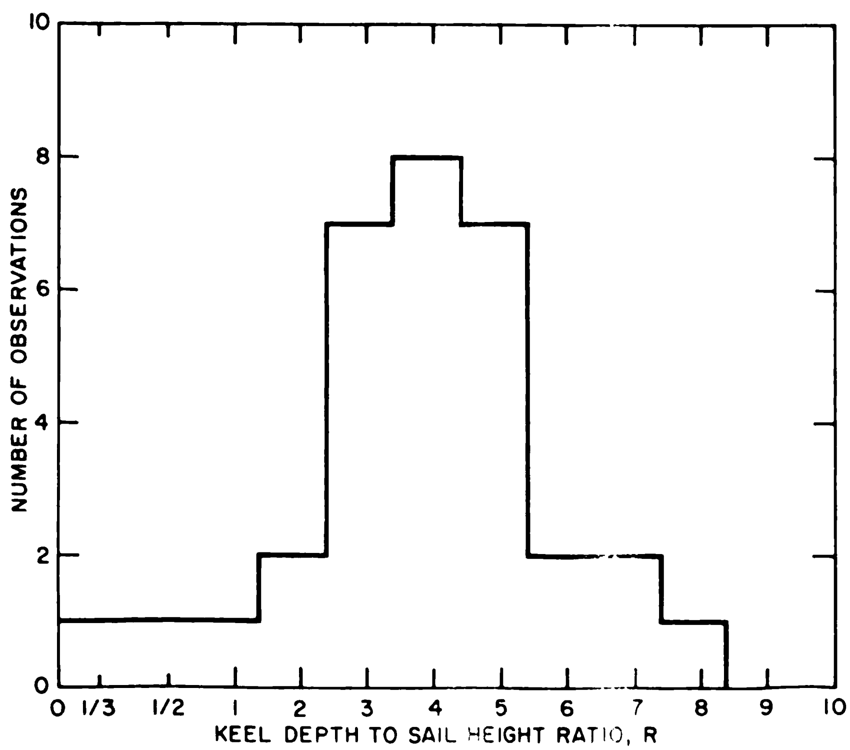

Figure 10 — Histogram of the number of observations vs estimated keel depth to sail height ratio

Representative values of the shear wave velocity (23) in bulk ice vary between 1500 and 1860 m/sec. If the lowest measured shear wave velocity is considered, the smallest possible shear critical (grazing) angle according to Snell's Law is 20°. Hence, if a simple ice-water interface is assumed, the theoretical reflectivity (24) at high frequencies in the angular range of interest is presumably unity over the reported range of sea-ice velocities. Consequently, if the ice-water interface were perfectly smooth, the measured under-ice reflection loss might be expected to be zero. The sea ice canopy, however, is generally interspersed with ridges, and the estimated reflection loss is generally greater than zero.

A theoretical model of reflectivity from a distribution of parallel, randomly spaced protuberances at a perfectly reflecting boundary has been developed by Twersky (25,26). The model considers a plane acoustic wave incident on a one-dimensional distribution of protuberances, which may be either identical or non-identical, and either elliptic or circular half-cylinders situated at the surface of a perfectly reflecting half-space, as illustrated in Figure 11.

The nature of "randomness" required is essentially that the average separation of the scatterers be large compared to the width of the feature, a condition that is generally satisified by sea ice ridges. Based on the geometrical and statistical models discussed previously, the spacing-to-ridge-width ratio of sea-ice ridges is estimated to be generally between 5 to 10, except in extremely rought near-shore areas during the winter season where this ratio may approach (2).

Approximate and relatively simple solutions for reflectivity have been derived by Burke and Twersky (26) as a function of grazing angle, ϕ, acoustic wave number, k, number of protuberances per unit distance, N, protuberance half-width, w, and depth, d, for cases where the wavelength is either large or small compared to protuberance dimensions. Theoretical solutions were derived for identical scatterers, but are equally valid for average values of d and w of non-identical scatterers.

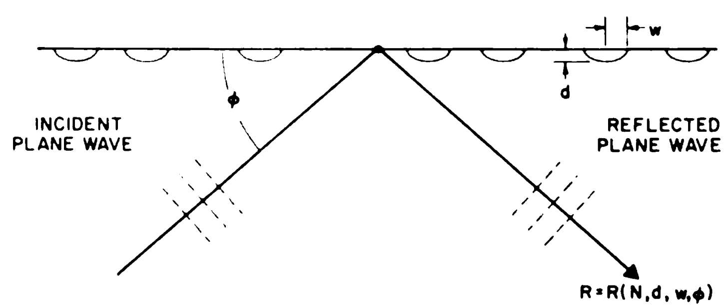

Figure 11 — Graphical representation of plane wave sound reflection from a random distribution of elliptical half-cylinders

To simplify the analysis of under-ice reflectivity in both the high and low frequency limits, the protuberance above the air-ice interface will be disregarded. Furthermore, at frequencies corresponding to wavelengths comparable to the modal thickness, complications caused by mode conversion to Lamb modes in the ice plate (27) will also be dismissed. Assuming the geometrical model in Figure 11 to be a good approximation of the spatial configuration of a large number of sea-ice ridges, application of Twersky's theory leads to the derivation of the following equations:

CASE 1: $kd > 1$

In this case the reflectivity from a distribution of widely spaced elliptical half-cylinders is independent of frequency; the wavelength is assumed to be smaller than the average ridge depth, d; and the plate thickness is assumed to be infinitely large. The energy reflectivity, R, from a perfectly reflecting ridged surface is expressed by:

$$R = \left[\frac{1 - xNd/\phi}{1 + xNd/\phi}\right]^2, \tag{1}$$

where x may be interpreted as a correction for the eccentricity of the half-ellipse. For the geometrical model of ridges under consideration and in the angular range of interest, x is approximately equal to 1.0.

CASE 2: $kd < 1$

For the case where the wavelength is greater than the average ridge depth and the plate thickness is assumed to be negligibly small, the energy reflectivity from a perfectly reflecting ridged surface is given by the expression:

$$R = 1 - \pi^2 (Nd)\, k^3 \left[d \left(\frac{d + w}{2}\right)^2\right] \phi \tag{2}$$

This equation is an approximate expression which is valid only for relatively small reflection losses.

To investigate the accuracy of the predictions of this model a number of experiments were conducted (28), in which transmission loss and topside sea-ice profiles were measured coincidently from aircraft. Transmission loss was measured using SUS charges directed into water openings in the ice field; topside sea-ice profiles were measured using an airborne laser profiler. Average bottomside ridge features were then inferred from topside measurements using a keel-depth-to-sail-height ratio of 4.0, as suggested by the data shown in Figure 10.

An example of a comparison between measured and computed transmission loss which includes a surface reflection loss computed from equations (1) and (2) and laser measurements of ridge characteristics is shown in Figure 12. The water depth at this measurement site was

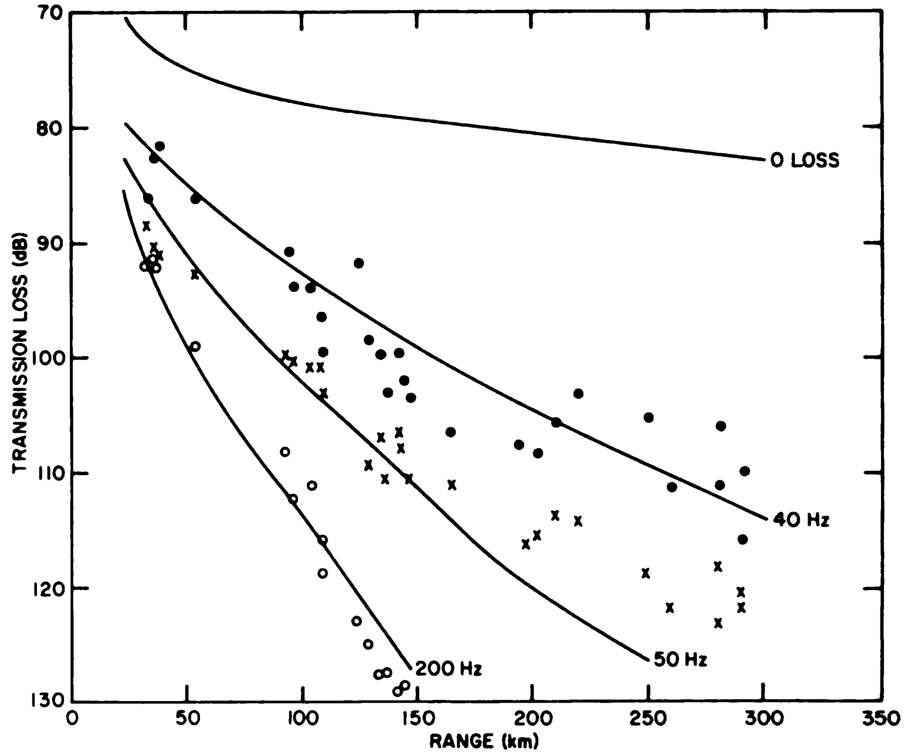

Figure 12 – Comparison of theoretical predictions (——) and experimental measurements at frequencies of 40 Hz (●), 50 Hz (x) and 200 Hz (o) along tracks 18 and 20

approximately 1000 m, and the source and receiver depth were 240 m and 60 m respectively.

The good agreement between the spatially averaged ray theoretical computations and measurements at frequencies of 40, 50 and 200 Hz demonstrates the accuracy of the predictions of the heuristic reflection loss model described above. At frequencies above 200 Hz, the measured transmission loss was essentially independent of frequency in accordance with predictions of the reflection loss model. A comparison between theory and data below 40 Hz is not shown, since accurate computations of theoretical transmission loss at such frequencies requires wave theory techniques.

Conclusions

As a consequence of the Naval Oceanographic Office's Arctic Acoustic Program a number of significant advances were made in our understanding of Arctic underwater acoustic ambient noise and transmission loss. Using a synoptic airborne environmental and acoustic measurement techniques it was shown that (1) a virtually universal feature of the marginal sea ice zone environment is a relative maximum in ambient noise levels at the ice-water boundary, and that the absolute magnitudes of noise levels at the boundary appear to be a function of the state of the contiguous open ocean, and the rate of change of ice concentration at the boundary, (2) the ice edge may, to a first approximation, be considered as a line source of sound, and that the rate of change of noise levels with distance far from the boundary may be related to the systematic departure of transmission loss from cylindrical spreading, and (3) under-ice reflection loss may be reasonably accurately estimated from theoretical equations based on the assumption that sea ice ridges may be described as parallel, randomly spaced, infinitely long, elliptical half-cylinders.

Future Research

Logical extensions of the research discussed here would include investigations of

(a) the relationship between ocean wave spectra and the spectrum of the noise generated at the ice-water boundary.

(b) the horizontal and vertical directionality of ambient noise fields as a function of distance from the ice edge.

(c) ridge effects on transmission loss, based on coincident submarine sonar measurements of keel parameters.

(d) theoretical and experimental transmission loss in environments characterized by range-dependent under-ice reflection loss and sound velocity structure.

(e) the variability of the "effective" shape and statistical characteristics of sea ice ridges as a function of the age, temperature and salinity of the ice.

(f) theoretical reflectivity from randomly oriented, randomly spaced elliptical half-cylinders.

(g) the effect of under-ice scattering losses on the normal modes which characterize long range propagation at low frequencies (mode stripping), and on signal coherence.

(h) sound propagation in shallow ice-covered waters.

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Up in a Haze

In the past, pilots flying around Barrow have reported a recurring band of yellowish-brown haze like that found over cities. Whether this haze is natural or the result of pollution is unknown. Dr. Glenn Shaw, University of Alaska, and Dr. Kenneth Rahn, University of Rhode Island, are interested in this question, and have been funded by the Office of Naval Research to study the phenomenon. Working under Dr. Rahn, Mr. Randy Borys is presently working out of the Naval Arctic Research Laboratory to gather aerosol samples from the haze. The haze generally has been detected at altitudes between six and seven thousand feet, and is about two to three thousand feet thick, according to Randy. It also generally occurs with a southerly or southeasterly wind. Some crude trajectory analysis of air mass movement indicate that the haze may be originating in Europe or the Eastern United States. Chemical analysis of the aerosol samples collected will reveal whether the haze is natual or caused by man.

Utilizing a NARL pilot and a Cessna 180, Randy flies around Barrow to take the air samples. While the Cessna climbs into the sun, Randy monitors a photometer until a sharp change occurs, an indication of the haze. The plane then levels off and flies at that altitude for four hours. Randy also monitors a particle counter that counts the number of particles per cubic centimeter of air. He is trying to correlate the particle counts with the photometer readings.

Three vacuum pumps equipped with different filters are used to accomplish the sample collection. According to Randy, the air in the arctic is so clean that it is necessary to fly four hours at a time in order to gather enough particulate matter from the air that can be analyzed. Clean air in Barrow normally contains less that 100 particles per cubic centimeter, as compared to 3,000 or more particles per cubic centimeter found outside of cities. Even with the haze in the Barrow area, particle counts have only reached 500 particles per cubic centimeters so far. Randy collects samples every day, or as often as weather permits. If there is no haze, samples are still taken for use as a local "background" sample. The haze can only be detected from the air, necessitating a lot of flying.

Three different filters are used so that the air particles can be examined in a variety of ways. A high-volume filter will be analyzed to determine the chemical constituents of the particles. A smaller filter will be examined under a scanning electron microscope, and the last filter will be analyzed for ice nuclei, a necessary ingredient for ice crystal formation.

Dr. Glenn Shaw of the University of Alaska will be coming to Barrow to measure the possible effects of the haze on solar radiation levels. He is interested in the question of whether the haze is affecting solar radiation that reaches the ground, and will train Randy to take radiation measurements.

The Fridtjof Nansen Drift Station

Leonard Johnson*
Office of Naval Research

A century ago there was speculation and debate on the possible existence of an open polar sea. Lt. deLong, USN, was commissioned to take the USS JEANNETTE through Bering Strait and westward of the Chukchi Sea along the Siberian coast to investigate the possibility. He began his voyage in the late 1870's and eventually forced his ship past the New Siberian Islands and into the Laptev Sea, where he lost her to the crushing forces of the ice. A retreat over the ice to the Lena Delta resulted in the starvation and eventual death of most of the crew, including deLong.

This episode took on greater significance upon the discovery of debris from the JEANNETTE along the southwest coast of Greenland just three years after her loss. The discovery caused considerable speculation in the Scandinavian countries, where academic interest in polar seas was strong, on the possible existence of a transpolar "Jeannette Current." Fridtjof Nansen, fresh from the acclaim of his traverse across the central Greenland ice cap, determined his next endeavor would be to cross the Arctic Basin by boat. He designed both the vessel and the scientific program and even more remarkably found financial backers for his experiment. Nansen sailed his copper clad, wooden, round hull FRAM eastward through the Barents Sea and into the Laptev Sea where he inserted her into the ice in 1893 in the general vicinity of the crushing of the JEANNETTE. In less than three years, the FRAM drifted westward and came out of the ice northwest of Svalbard. Duplication of Nansen's drifting scientific platform have been intermittently discussed in the past. In 1958, Dr. Louis Quam, the past director of the ONR Arctic Program, proposed the strengthening of a fleet oiler for a transpolar drift. The idea was to provide a sufficient source of fuel oil for the scientific party for a period of years. In another region the idea was suggested to adapt a surplus ice-breaker (by adding a center well) and to use it to study the high latitude Baffin Bay open-water anomaly known as "North Water." The U.S. National Academy of Sciences' Committee on Polar Research, now the Polar Research Board, recommended in 1963 that support be given to a plan to freeze a ship into the Arctic

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pack ice. There have also been NSF sponsored studies of possible platforms for scientific purposes on the sea ice.

The concept of modern duplication of the FRAM drift by freezing in a decommissioned Coast Guard *WIND*-class icebreaker developed in the Office of Naval Research within the divisions of Terrestrial and Ocean Sciences. It was decided that an icebreaker would be preferable to an ice island because of its stability, maneuverability, and versatility. This sparked a series of workshops in late 1974-75 to define the scientific objectives to be addressed by the drift. The Polar Research Board of the National Academy of Sciences was commissioned on 16 May 1975 to hold a workshop to review and augment the existing scientific plan. A Polar Research Board Committee on the Nansen Drift station Project was appointed and with the help of several working groups, a scientific plan for crossing of the Arctic Ocean's Eurasian Basin along a track approximating that of the FRAM was drawn up. The committee, chaired by Dr. Norbert Untersteiner, professor of atmospheric sciences, of the University of Washington, is scheduled to issue its report in June of 1976.

As a parallel action, the Commandant U.S. Coast Guard, as the other mission agency in the federal government that has a long tradition of interest and capability of operating in the polar regions, was requested by the Chief of Naval Research to work cooperatively in this endeavor. The Commandant subsequently replied with conceptual approval on 2 April 1975. Since then, informal discussions have identified the USCG BURTON ISLAND (Figure 1) as the platform.

It is expected that the scientific program will be multidisciplinary, ranging from study of plate tectonics to the study of effects of high-energy solar particles on the earth's magnetosphere. The platform's anticipated path would be over the locale of mid-ocean sea-floor spreading, of particular interest in global tectonics. Due to the low sedimentation rate in an ice-covered ocean, long piston cores would be able to provide new paleoclimatic information otherwise unobtainable. While the physical oceanography of the Arctic Ocean's Canadian Basin is relatively well understood, little information is available on the Eurasian Basin, where sea-ice-atmosphere interaction may be especially intense and of significance to global climate.

As now envisioned, the station would begin its two-to-three-year passive drift late in 1977, along a track approximated in Figure 2. This raises possibilities for merging observational programs with those of POLEX and also portions of the 1976-1978 International Magnetospheric Study.

It is expected that the project will be a multiagency U.S. program with participation open to all and that all research data from such a project would be made publicly available placed in the appropriate data banks.

Figure 1 – USCG Burton Island

Scientific Program

Since this will be such a unique experiment in a region where scientific data from all disciplines is almost totally lacking to scientists of the western world, a highly sophisticated scientific program is highly desirable. The program described below is a synopsis of the recommendations by scientists within each discipline, to the Polar Board of the National Academy.

Marine Geology and Geophysics

The Nansen Ridge and Eurasian Basin have a number of unique aspects which are of great potential significance to the understanding of global dynamics and the processes of ocean basin formation and continental tectonics.

Utilizing the ice cover it will be possible to do thorough closely spaced sampling that is not possible nor economical in other of the world's oceans. In realizing the following objectives, there is the possibility of obtaining a clearer understanding of the dynamics of the

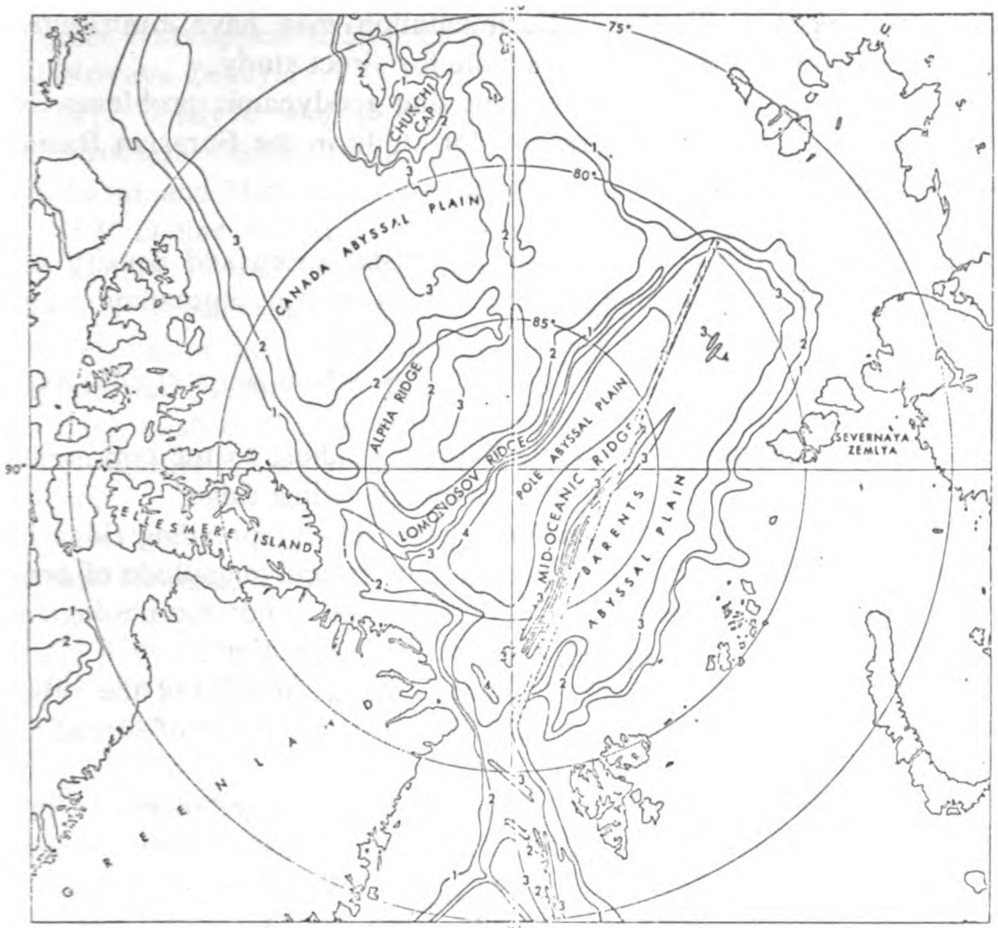

Figure 2 – Bathymetric chart of Arctic Basin with projected Nansen Drift track shown as heavy black line

processes that function in the crust and upper mantle of the earth as well as the sedimentological and paleontological factors that have modified the ocean floor. This work will directly supplement work done from ice-island T-3 during the past 15 years in the Amerasian Basin.

The Ridge is one of the few crustal plate boundaries that approaches its own locus of rotational opening. The consequent low spreading half-rates (0.5 - 0.8 cm./yr.) and the likely significant change of rate with increasing distance from the pole make the Eurasian Basin-Nansen Ridge an ideal laboratory for studying the implications of different geodynamic models and the morphology and crustal structure produced at various accretion rates.

The very slow rate of sedimentation in the Eurasian Basin should make it possible to observe the physiographic expression of different parts of the ridge system, and to make measurements of heat flow and magnetic characteristics uncomplicated by the insulation of a thick sedimentary blanket. The slow sedimentation may have contributed to the preservation of deep rifts available for direct study.

Some of the most important tectonic and geodynamic problems for which there is an unique opportunity for study in the Eurasian Basin-Nansen Ridge area include:

(1) What are the manifestations of crustal strain and density redistribution near the termination point of an actively spreading ridge where it abuts a continental block?

(2) What is the pattern of fracturing by which an accreting sea-rotational opening at very low spreading rates.

(3) How does the crust-mantle boundary adjust to the continent-ocean floor boundary at the end of a slowly spreading ridge?

(4) What is the fine structure of a very slowly spreading ridge in terms of intrusion sequence and spacing, pattern and magnitude of geothermal heat release, magnetic characteristics, and morphological development under conditions of very slow sedimentation?

(5) What are the longitudinal changes along the axis of the ridge with distance from the locus as a function of increased rate of spreading and/or increased time of spreading?

(6) What are the characteristics, both crustal and sedimentological, of the junction of the ocean's crust with the main mass of the continent (e.g. the Eurasian block at the edge of the Kara and Barents continental shelves) as compared with its junction with an isolated and splayed submerged fragment of continental crust (Lomonosov Ridge)?

(7) What is the internal structure and nature of the "basement" of the Lomonosov Ridge and how does it terminate against or near the North American continent?

(8) What is the sequence and magnitude of motion on the fracture systems bounding the Svalbard block, the Yermak Plateau and the northeastern part of Greenland, and what is their relation to the fault systems of the mid-ocean ridge system as is passes through the junction between the Greenland Sea and the Arctic Ocean?

(9) What was the configuration of the continental masses around the north Atlantic Ocean area prior to the development of the Alpha Ridge and of the sedimentary basin in which the rocks now underlying the Arctic continental shelves were formed?

(10) What are the relationships between the geosynclinal belts and fold systems of northeastern North America and those of Svalbard, Franz Josef Land and Novaya Zemlya? For example, the fossils of East Greenland Mesozoic rocks are related to both Europe and to the rest of North America, except during the Cenomanian stage when there appeared to be direct affinitives to Europe but not to fossils in strata of the same age in nearby Canada; however, Innuitian and Greenland

orogenic belts appear to have counterparts (or continuation?) in Svalbard and Novaya Zemlya.

(11) Analyze and describe the regional geological framework and structural history of the Eurasian Arctic in terms of shelf, slope, rise, basin, and Mid-Ocean provinces.

(12) Define the Arctic Mid-Ocean Ridge geometry, tectonic style and history of the adjacent Arctic basins and intrabasinal tectonic elements through the integration of geophysical profiles with surface and subsurface geological information provided by surface geological mapping and subsurface studies of cores and dredges.

(13) Analyze the depositional, structural and paleontologic history of sedimentary basins of the shelf, slope, rise, and basin.

Physical Oceanography

The goal of the physical oceanography program is to provide high quality measurements of those oceanographic parameters which will enable us to understand the circulation, heat exchange and mass exchange of the waters of the Eurasian Basin.

The objectives are to:

(1) Map oceanographic properties of the Eurasian Basin on a large scale. These fields include temperature, salinity, density (a derived quantity), and certain chemical parameters, including a number of radioisotopes. This mapping will provide basic information on the basin's circulation and will also establish a climatic baseline.

(2) Make direct measurements of the velocity field in the Eurasian Basin. Continuous measurements of currents over time periods as long as possible will help define the mean circulation as well as the fluctuations.

(3) Investigate the processes which modify the waters of the Eurasian Basin. The processes include vertical exchange with the ice and the atmosphere and mixing between layers as well as horizontal exchange around the margins of the basin. The growth of sea ice and its influence on vertical exchange is a special Arctic Ocean problem. The effect of freezing and melting on water properties should receive contiued study. The exchange of water, heat and salt across the continental margin bordering the Eurasian Basin should be investigated, including especially the role of canyons.

Biology and Biochemistry

The research problems of interest to biologists on the Nansen Drift focus on contributing to our understanding of the marine ecosystem of the Eurasian Basin.

The biological and environmental results can be used to describe relatively undistrubed conditions in the least productive ecosystem in the world ocean. The biological baselines drawn from the Nansen Drift can document present levels of pollutants and the status of rare and endangered species. The increased understanding of species populations, communities, feeding relationships and environmental controls and interactions will broaden the knowledge base for comparative studies of ocean ecosystems.

The biological results are inseparably related to the work of other disciplines that will measure aspects of the environment such as insolation, submarine radiation, ice thickness and ice cover, ocean currents and water masses, water chemistry, suspended materials, bottom sediments, and marine acoustics.

Marine Acoustics

Virtually no acoustic data exist from the Eurasian Basin. Specifically the following important gaps exist at the present time and will be addressed.

(1) No concurrent measurements of propagation loss and environmental measurements in the Eurasian Basin exist.

(2) Propagation loss in the infrasonic frequency band from 2 to 10 Hz has not been measured.

(3) Propagation loss to geophones in the ice has not been measured nor have the effects on loss of geophone location near pressure ridges and leads been measured.

(4) The under-ice reflection loss model requires validation at low frequencies, with under-ice ridge characteristics extracted from submarine SONAR under-ice profiles coincident with the loss measurements.

(5) A theoretical model of under-ice sound propagation which can accommodate spatial variability of sound velocity structure, ocean depth and surface reflection loss has not yet been tested.

(6) Bottom loss in ice-covered waters has not been investigated.

(7) The mid-water absorptivity at frequencies of the order of 1 kHz has not been accurately measured nor has it been related to the chemical composition of water masses in the field.

(8) The strong bottom reverberation in the band 4 to 20 Hz commonly observed in long-range explosive propagation has not been investigated quantitatively.

(9) No measurements of ambient noise exist in the Eurasian Basin, and only now are experiments being carried out in connection with the AIDJEX Program to relate ambient levels to large scale ice deformation in the Amerasian Basin.

(10) The source levels and radiation patterns of various types of ice deformations have not been determined.

(11) Acoustic signals emitted by marine mammals have not been quantitatively related to the behavior and migration patterns of marine mammals in ice-covered waters.

(12) The vertical directivity of the ambient noise field has not been measured and only limited experiments on the horizontal directivity have been made.

(13) The effects of anisotrophy of ambient noise and signal incoherence on the array gain of large aperature, low frequency arrays have not been measured.

(14) Only limited under-ice backscattering measurements from directional sources have been made.

(15) Reflectivity at the flat ice-water interface needs to be measured virtually continuously with angle, for several different ice types. The seasonal variability is not known.

(16) Spatial and temporal signal fluctuations and coherence have not been investigated.

(17) The existence of the deep scattering layer in the Eurasian Basin is unknown nor have quantitative volume reverberation measurements been reported for the Eurasian Basin.

(18) Vertical profiles of the longitudinal and shear wave velocity in sea-ice have never been measured as a function of temperature and salinity in the ice.

(19) The velocity and absorptivity of sound in the "slush layer" at the ice-water interface has never been determined.

(20) No backscattering measurements from the sea floor have been made.

(21) Coupling of propagation from shallow to deep water and vice versa has not been investigated quantitatively.

Sea-Ice Air Interface

The primary goal of this program is to determine the heat and mass balance of the ice cover in the Eurasian Basin. Observations will be carried out over a range of ice thicknesses and the results combined with strain data derived from positions of the large-scale data buoy array to make theoretical calculations of the ice thickness distribution within the region throughout the period of the drift. Predicted thickness distributions will be compared with satellite and airborne imagery when available.

An important part of the program will be to monitor mass changes at the bottom of the ice and heat conduction within the ice, allowing us to estimate the oceanic heat flux as a residual. During the winter and spring the oceanic heat flux will reflect the rate at which the Atlantic layer is losing heat; during the summer and fall the oceanic heat flux should contain a large contribution from the absorbed short-wave radiation, and it will be necessary to use information on the thickness distribution to separate the two components. In order to estimate the total amount of heat that the mixed layer supplies to the ice, measurements of ablation on pressure ridge keels will also have to be made. Comparative data on keel ablation and ablation/accretion on the underside of undeformed ice will also provide a basis for estimating the lifetime of pressure ridges, a vital step in achieving an understanding of the total mass balance of the Arctic Basin.

The accretion and energy flux data will allow us to calculate growth rates for all thicknesses of ice and, since the rate at which salt is initially rejected by sea ice is related to the rate at which it grows, it should then be possible to estimate salt rejection as a function of ice thickness.

The optical properties of sea ice influence not only reflected short-wave radiation, but also the amount of energy transmitted to the ocean. In the spring and fall the interaction between solar radiation and the ice cover is relatively simple, with only snow-free young ice exhibiting significantly different optical properties; in contrast, the rapidly changing amounts of snow, bare ice, melt ponds, and open water during the melt season give rise to large spatial and temporal variations in the short-wave balance. To determine the effect of these variations on the regional heat exchange, periodic surveys of albedos and extinction coefficients in all types of ice will be made throughout the summer. Melt pond coverage and ice structure will also be monitored. It is hoped that changes in the optical properties of the ice can be related to changes in its structure caused by internal melting. Because spectral albedos and the spectral composition of light transmitted to the ocean beneath bare ice, melt ponds, and leads are significantly different, spectrophotometer data will be used to supplement the bulk radiation measurements.

Movement, Stresses, and Distribution of Thickness in the Ice Field at Various Scales: Observations and Predictions

A study of the ice motion in the Trans Polar Drift stream will include observations at the scale of the overall drift as well as measurements at smaller, local scales. As a central point for such observations, large scale and small scale measurements of ice movements can be made at the same time in the same region. Correlation of measurements at different scales will advance the present understanding of pack ice internal resistance, and will improve the existing capability for developing predictive models. The ability to carry out these measurements throughout the drift, in which the ice changes from thin first year ice to thick multi-year ice, will permit a comparison of the constitutive properties of these different types.

Detailed measurements of ice motions in the Trans-Polar Drift stream for an extended period of time have yet to be carried out. Such measurements are currently being made by the AIDJEX program over a region of approximately 800 km in the Pacific gyre. It will be of great value to have corresponding sets of data on these two main features of the Arctic Basin. A knowledge of pack rheology in these two main features will allow for more accurate modeling of the entire Arctic Basin.

In addition to simply observing the motions of the ice field, there will be great interest in improving predictive models for motions, stress states, and the distribution of thickness in various regions of the Arctic Basin.

Physical Properties of Sea Ice

A comprehensive description of the mechanical properties of sea ice has yet to arise out of the many investigations which have been carried out over the past 20 years, but the variability of conditions and testing procedures has made uniform interpretation difficult. Certain principles have been established, such as the dependence of strength and modulus on brine volume. Other effects, such as dependence of strength upon load rate and sample size have yet to be satisfactorily quantified for any kind of practical application. Comprehensive fracture criteria, and the influence of stress concentration, have yet to be established.

Other significant gaps in our existing state of knowledge include the properties and mechanisms by which the salt content varies with time (desalination) and the radiative properties of sea ice in the microwave part of the spectrum. It has been suggested that the unexpected radiative differences in sea ice are related to the age of the ice, which would correlate with physical factors such as salt content and crystal structure.

Planetary Boundary Layer (PBL) and Troposphere

The objectives suggested for the tropospheric research program are:

(1) To determine the mean vertical transfers of momentum, heat, and water vapor in the surface layer including their relation to the mean state of the surface and atmosphere, and their variation with season, time of day and geographic location.

(2) To determine the vertical distribution of temperature, velocity and humidity in the PBL and its relation to surface transfers, synoptic conditions and season.

(3) To determine the macrostructure of fog and low stratus clouds and its relation to surface transfers, PBL structure, the radiation field and microphysical properties.

(4) To determine optical properties of arctic haze and to estimate the effect of haze on radiative transfer.

Achievement of the above objectives will contribute to our fundamental understanding of PBL dynamics, physics of fogs and stratus clouds, and the nature and effect of haze, as well as elucidating those features which are peculiar to the Arctic. Achievement of the objectives will also lead to improved models and parameterizations of heat, mass and momentum transfers in the Arctic and will aid the modeling of the Arctic climate, e.g., in general circulation models of the atmosphere.

Upper Atmosphere and Ionosphere

The most significant problem concerns the mechanisms which convey energy from the sun through the magnetosphere to the lower ionosphere and atmosphre. Specific aspects of this enormously complex problem include the following:

Substorm phenomena: what is the spatial distribution of energy deposited by energetic particles (and the associated visual auroral emissions and geomagnetic disturbances) during various phases of substorms?

Particle entry through the magnetospheric cusp: where is the cusp, what particle flux variations occur within it, how far in local time does it extend in local time, and what are the variations with geomagnetic activity?

Convective electric fields across the polar cap and their connection to the global ionospheric potential: can separated ground based static electric field measurement be used to monitor trans-polar electric fields and related to interplanetary phenomena such as the direction and intensity of the interplanetary magnetic field?

Maintenance of the polar nighttime ionosphere: in the absence of solar radiation during long polar nights, what are the important ionization sources?

Minor species in the polar cap atmosphere: what is the effect of prolonged periods of sunlight or darkness on the abundances of 0_3, $N0$, or 0_2 for example?

Effects of solar activity on surface weather: is particle bombardment of the polar cap, field-aligned current systems in the auroral region, or polar cap convective electric fields associated with major meteorological patterns?

Upper atmospheric dynamics: what plasma motions and wind velocity patterns prevail over the polar cap?

Plasma instabilities: what is the geographic extent of intense plasma irregularities which develop with the ionosphere due to electric fields?

Survey of electromagnetic distrubances in the polar cap region: how effective are various ground-based and satellite communication and navigation systems from ELF to VHF frequencies in the polar cap region, how do a variety of AIM phenomena affect these systems, does the vastly different conductivity of deep ice (in comparison to sea water) significantly affect the reliability and accuracy of these systems?

Remote Sensing

The NDS will be frozen into the pack ice of the Arctic Ocean north of the Lena Delta, and it will then drift over the North Pole and exit from the pack via the East Greenland Drift stream. During this drift the NDS will transit the complete length of the Trans Polar Drift Stream which is the major feature in the Arctic Basin. During the 2 to 3 years that it takes for this transit, the young, saline, lightly deformed ice of the Siberian Shelf is gradually transformed into the thick, low salinity, highly deformed ice that is observed exiting the Arctic Basin east of Greenland. Inasmuch as the NDS will move with the ice it will serve as an excellent platform from which both the metamorphism of the ice and the ice-dynamics en route can be studied. The following types of remote sensing information will be collected.

(1) Sequential imagery can be used in conjunction with the movement of the data buoys and radar transponders to define the ice drift and deformation field in considerable details.
This is important in advancing our understanding of the geometry of the large scale deformation processes that occur within the ice pack. Of particular interest here are the changing patterns of leads and of areas of recently deformed ice as well as the homogeneity of the deformation as viewed on different scales. Also of interest will be contrasts between the tectonic style of the ice deformation within the Trans Polar Drift Stream as viewed from the NDS and the ice behavior within the Pacific gyre as investigated by AIDJEX.

(2) Direct measurement of the ice thickness distribution G. To accomplish this one must be able to make accurate estimates of the areal percentage of ice of different thicknesses within the study area. Of particular interest are estimates of the amount of thin ice and open water present at any given time. It is currently believed that the ice thickness distribution is the most important single parameter in controlling the rheological response of the ice pack to the external forces that are imposed upon it. However, if G is known at one instant in time,

the changes in the thickness distribution caused by mechanical and thermodynamic effects can be calculated. Therefore, one needs to measure G only occasionally in order to initialize and verify such calculations. This is fortunate because good estimates of G are difficult to obtain for the wide expanses of ice that are of interest here. A considerable portion of this difficulty is caused by the fact that there currently is no simple direct method for determining the thickness of sea ice via remote sensing techniques.

(3) Direct determination of ice types within the study area as well as the physical state of each of these types. Admittedly, valuable information on the nature of the ice in any given area is provided by knowing its thickness (i.e., the G function). Nevertheless, it is useful to have independent methods for estimating ice age and properties.
Of particular importance in fixing the properties of the ice are its age, salinity and temperature.

(4) Top and bottom roughness of the ice pack. Accurate estimates of these pertinent roughness parameters are required if one wishes to calculate the wind and water stresses that are transmitted to the ice pack.
It is to be expected that significant changes in the top and bottom roughness of the ice pack will occur from the time that the ice first forms over the Siberian Shelf to the time when it exits from the Arctic Basin via the Greenland Sea. Also of interest is the modification of existing roughness elements during the summer melt season.

Sea Ice Research

Dr. Tadashi Tabata of the Institute of Low Temperature Science, Hokkaido University, is here at the Naval Arctic Research Laboratory to study sea ice. He has been studying sea ice for 31 years, and has done research at NARL seven times since 1969. Dr. Tabata is head of the Oceanography Section and the Sea Ice Research Laboratory at the institute, which is one of the three largest research facilities in the world that study snow and ice. Working with him are Drs. Nobuo Ono, Masaaki Aota, Toshiyuki Kawamura, Takatoshi Takizawa, and Masao Ishikawa. Their project, named the Japan Arctic Sea Ice Project, is aimed at determining the relation between structure and strength of sea ice.

Many scientists have studied sea ice strength in the past. However, in each case parameters such as sample size, temperature, salt concentration, density, and rate of loading varied, resulting in differing results. The mechanical properties of sea ice became increasingly unclear. In August of 1975, a committee of the International Association of Hydrologic Research met to discuss this problem and made recommendations for standardized methods of measurement. Dr. Tabata is at NARL to investigate sea ice using these methods of measurement, and will report his results to the committee.

U. S. GOVERNMENT PRINTING OFFICE : 1976 O - 207-933

Four major tests are presently being performed. The crushing strength of sea ice is determined by cutting a core out of the ice, then subjecting it to compression from a machine. Forces of up to 70 kg/cm^2 are applied. Different temperatures, loading rates, and core lengths will be used in these measurements.

The tensile strength of sea ice is determined by cutting "bars" out of a block of ice. The bars, measuring 2.5 by 5 by 30 cm, are cut every 3 cm from the block of ice to a depth of 70 cm. The bars are then bent by the compression machine to measure flextural strength. In every layer ten samples are taken, necessitating the measurement of some 200 samples.

According to Dr. Tabata, the structure of sea ice (i.e. size of ice crystals, their arrangement, ice salinity, air bubbles within the ice, and temperature) is an important factor in determining its strength. Many previous ice studies did not measure all these factors. Dr. Tabata and his group will attempt to measure as many parameters as possible in order to obtain a complete description of sea ice structure.

Other properties of sea ice will be studied during the group's two month stay in Barrow. The stress and strain in sea ice by wind, temperature, water stress, and thermal expansion are being investigated. Working from a hut about 150 meters offshore on the sea ice, the scientists are measuring ice deformation using pressure transducers frozen in the ice. Data is recorded on a digital readout system and on a strip chart recorder, along with information on wind speed and direction, and temperature. Heat flux in the ice is measured with a radiation meter, and a heat budget (the amount of heat gained and lost through radiation) will be determined.

NAVAL RESEARCH REVIEWS publishes highlights of research conducted by Navy laboratories and contractors and describes important naval experimental facilities. Manuscripts submitted for publication, correspondence concerning prospective articles, and changes of address, should be directed to Code 730, Office of Naval Research, Arlington, Va. 22217. Requests for subscriptions should be directed to the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402. Subscription price: $6.50 per year in the U.S. and Canada; $8.15 per year, foreign; $0.55 per individual copy. The issuance of this periodical approved in accordance with Dept. of the Navy publications and printing regulations.

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NAVSO P-510

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IN THIS ISSUE

VOL. XXIX, NO. 5

Note:

The articles for this special issue on The Naval Arctic Research Laboratory were assembled by Dr. G. Leonard Johnson, Office of Naval Research.

Cover Caption

Arctic diver in scuba equipment preparing to submerge

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OFFICE OF NAVAL RESEARCH
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