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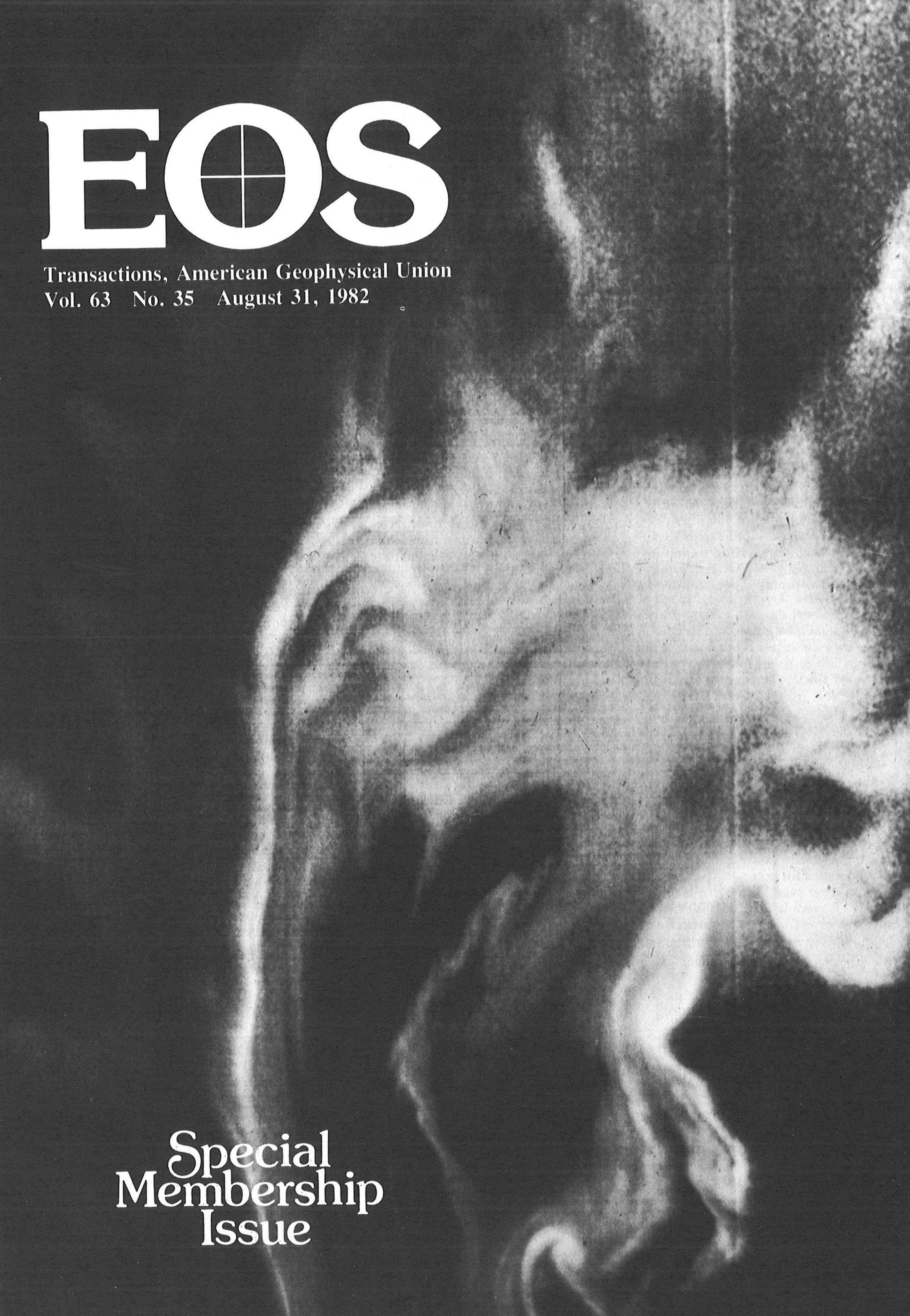

Special Membership Issue

The *Fram 3* Expedition

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Introduction

On the fourteenth of March 1981, *Fram 3*, the third in a series of four U.S. manned ice camps, was established in the eastern Arctic Ocean at 84.32°N, 20.07°E for oceanographic and geophysical research in the Eurasian Basin north of the Greenland-Spitzbergen Passage.

Investigators from several institutions in the United States, as well as from Canada and England, participated in studies of physical and chemical oceanography, low-frequency underwater acoustics, geophysics, and the mechanics and propagation of waves through sea ice. A Bell 204 helicopter and crew were stationed at *Fram 3* throughout the drift in order to support research efforts and camp operations. Several oceanographic buoys that used satellite telemetry were deployed during this time period.

Oceanographically, the *Fram 3* region is of interest because of the proximity of the polar front, which separates the outflowing Arctic surface water from the inflowing Atlantic water in the Greenland-Spitzbergen Passage and northward. Significant amounts of heat and salt are transferred through this strait as compared to other passages into the Arctic Ocean, such as the Bering Strait and the Arctic Archipelago [*Aagaard and Greisman*, 1975]. Variations in these transports of heat and salt through the Fram Strait may prove to be a significant factor in climate change. Estimates of vertical fluxes in heat and salt were also part of the ongoing experiments of the *Fram* expeditions. These would help determine spatial variations of heat loss from the Atlantic water into the upper layers of the Arctic Ocean (less than 200 m). It was also hoped that data might also provide more insight into the origin and effects of the steep pycnocline that lies directly beneath the mixed layer (50 m) and the upper extent of the Atlantic water (200–500 m). Current theory suggests that this layer is the product of wintertime ice formation on the shelves surrounding the Arctic Ocean. The resultant cold, saline shelf water is later advected into the Arctic Ocean on surfaces of constant density that reside in the depth range of 50 to 200 m. Due to the very large gradients of temperature and salinity in this depth range, the vertical transfer of heat from the Atlantic water to the upper layers of the Arctic Ocean is effectively minimized. Mesoscale CTD (conductivity, temperature, and depth) surveys were also conducted by helicopter to depths of 500 m in order to expand the areas of observation as well as to map various features and their temporal variations on length scales of 10 to 300 km. A profiling current meter-CTD unit was also used at the main camp to study the response of the upper ocean to storms.

At camp, samples for chemical and biochemical analysis, ranging in volume from 1.2 to 100 l, were taken at many levels throughout the water column. Various projects were designed to study the concentrations of tritium, oxygen, alkalinity, nutrients, respiratory enzymes, trace metals, ammonia, dissolved silicon, and bomb-produced C-14.

Further geophysical information was also to be gathered in the areas of the Nansen Basin and Yermak Plateau. The Nansen Basin is of interest because of its thin oceanic crust, which is a result of the very slow spreading of the Arctic Mid-Ocean Ridge, located several hundred kilometers to the west. The Yermak Plateau may be continental in origin, however, it does not fit well into a reconstruction of the local continental land masses. In order to study these features, observations of heat flow, gravity, short sediment cores, seismic reflection profiles, and continuous precision depth recordings were made at *Fram 3*. Several seismic refraction lines were also conducted in the vicinity of the Yermak Plateau and within the Nansen Basin with the aid of the helicopter.

With all scientific goals accomplished, *Fram 3* was evacuated on May 13, 1981, at a position of 81°43′N and 3°15′E. The resulting net drift of 361 km proved to be much longer than that of *Fram 1* (163 km) and *Fram 2* (83 km) stations during the previous years. This not only allowed experiments to be carried out over a large geographical area but also

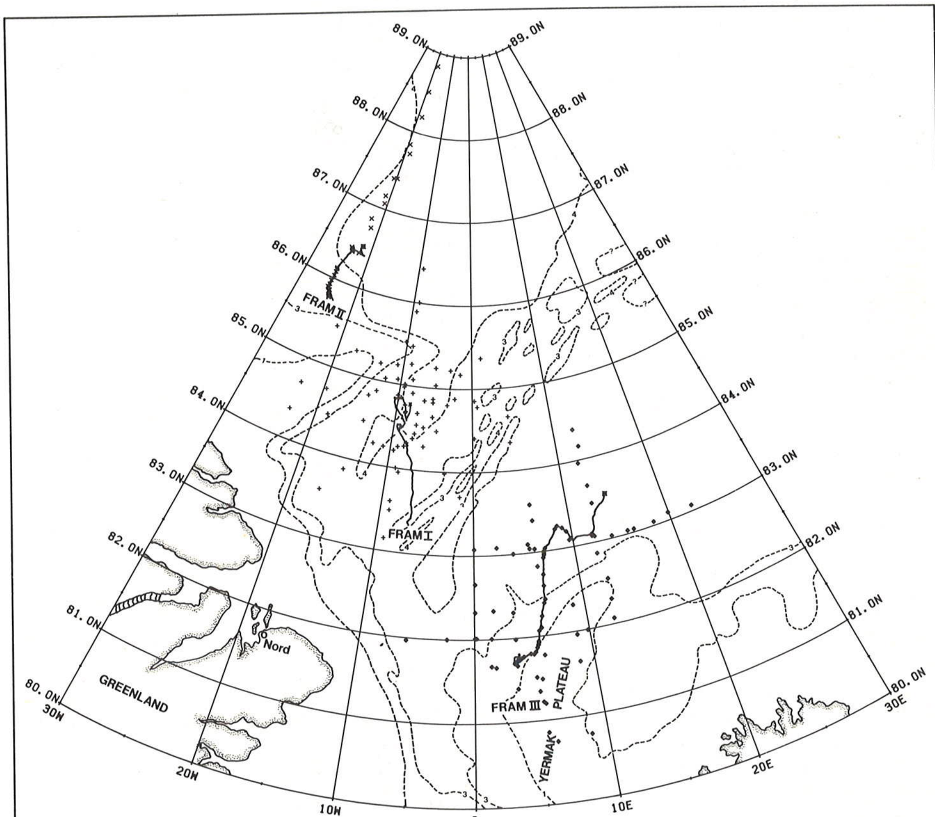

Fig. 1. Locations of all portable CTD stations taken during the *Fram 1, 2,* and *3* experiments. Drift tracks of the individual camps are also shown in reference to Greenland, Spitzbergen, and bottom topographic contours. The end of the drift track is labeled by the camp identification. Depths are given in kilometers.

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Cover. Photograph of equatorward boundary of diffuse aurora taken over South Pole by DMSP-F1 satellite on June 26, 1978 (local noon at bottom, local dusk on left). Photograph rotated 180° was published as Figure 1a in a paper by Liu et al. (JGR, *87*, 2385). Paul Mizera and staff at Aerospace Corporation have pointed out the face of a creature of the aurora. Although there are many opinions, most seem to center on the canine family.

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over a range of ocean depths, from a maximum of 4088 m in the Nansen Basin to a minimum of 727 m above the Yermak Plateau. Figure 1 shows the drift tracks of the three *Fram* stations superimposed on the general bathymetry of the Arctic Ocean.

Background

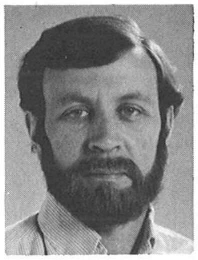
After completion of the Arctic Ice Dynamics Joint Experiment (AIDJEX) in the Beaufort Sea in 1976, where ice mechanics in the central pack was emphasized, the United States made a concerted effort to begin geophysical and oceanographic investigations in the eastern Arctic Ocean. The *Fram* expedition series of short-duration manned camps located on the drifting pack ice north of Greenland has been the focus of this effort. Cooperation and participation from Norway, Denmark, and Canada in several of the expeditions have been an important aspect in these projects.

The project name *Fram* echoes that of the specially designed ship that was frozen into the pack ice of the Arctic Ocean near the New Siberian Islands by the Norwegian explorer Fridtjof Nansen, in a milestone of polar scientific exploration. During the drift of the original *Fram* (1893–96), an unprecedented amount of information was collected over the deep ocean of the Eurasian Basin.

The first of the modern *Fram* camps was established on the drifting ice at a position of 84°24′N, 6°00′W, on March 11, 1979 (Figure 1). *Fram 1* was a U.S. drifting ice station that had scientific and logistic participation by Norway, Denmark, and Canada. Away from the main camp a CTD survey, seismic refraction lines, microearthquake investigation, and polar bear migration studies were supported by helicopter. At the main camp there were programs in physical, chemical, and biological oceanography, as well as surface weather monitoring. Although the drift of the camp did not reach its anticipated destination by evacuation time, a large amount of geophysical and oceanographic data were obtained [*Kristoffersen*, 1979; *Hunkins et al.*, 1979*a, b*].

Preliminary scientific results from *Fram 1* were presented at the special session 'Arctic Geophysics and Oceanography: LOREX and *Fram 1*' during the American Geophysical Union Spring Meeting 1980. Interesting results suggest that the crust in the Amundsen Basin is less than 3 km thick and is related to the slow spreading rate of the Arctic Mid-Ocean Ridge. *Reed and Jackson* [1981] have also formulated a theoretical model for the relationship between crustal thickness and spreading rate for the ridge. Data not only from the *Fram* expedition but also from numerous areas around the world agree with the model. Also observed on one of the refraction lines was a local hot spot over which the crust was significantly thicker, 8 km [*Jackson et al.*, 1982].

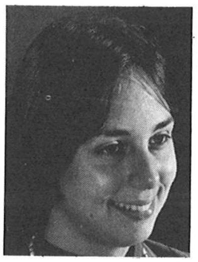
Although baroclinic eddies of the type highly prevalent in the Beaufort Sea north of Alaska [*Manley*, 1981; *Dixit*, 1978; *Hunkins*, 1974; *Newton et al.*, 1974] were not observed, a prominent front was found in the mixed layer. Heat flux from the Atlantic water into the surface mixed layer is effectively minimized by the steep pycnocline overlaying the Atlantic water, even close to the main polar front region [*Aagaard et al.*, 1979; *McPhee*, 1980*a*]. Both portable and camp-based CTD measurements documented a type of frontal



James Morison *is a physical oceanographer at the Polar Science Center, University of Washington, Seattle. He holds a B.S. and an M.S. (mechanical engineering) from the University of California at Davis and received a Ph.D. in geophysics from the University of Washington in 1980. He is a member of Sigma Xi, the American Geophysical Union, and the Current Meter Technology Committee of the IEEE Council on Oceanic Engineering. His current research interests are in experimental and theoretical studies of the dynamics and thermodynamics of the upper Arctic Ocean and marginal ice zones.*

Peter Wadhams *is assistant director of research at the Scott Polar Research Institute, University of Cambridge, England, and leader of the Sea Ice Group there. His research interests include the topography and thickness distribution of sea ice in the Arctic Ocean, the interaction of ocean waves with sea ice, and the dynamics of ice edge processes such as band and eddy formation. From 1980–81 he was visiting professor at the Naval Postgraduate School, Monterey, and he is involved with the planning of the MIZEX ice edge experiment.*

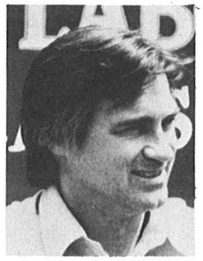
Stuart Moore *is a research technician at the Scott Polar Research Institute, working primarily for the Sea Ice Group. He is involved mainly in the design and development of field and laboratory equipment and has participated in numerous Arctic and Antarctic field experiments.*



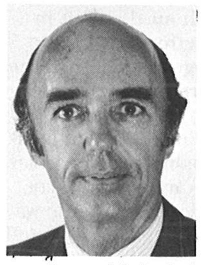
Valery Lee, *B.S. (earth and planetary sciences) M.I.T., M.S. (physical oceanography) University of Miami; a newcomer to arctic research and ice camps, she says she's already hooked. Valery is working with the Tritium Lab in Miami, where they do proportional gas counting to measure tritium and radiocarbon levels in the ocean. She likes to get out in the field and do some hands-on oceanography so as not to lose touch with 'what it's all about.' Sailing her 15′ knockabout in Biscayne Bay provides an excellent antidote for those ice-camp blues.*

Lou Codispoti *is a principal investigator at the Bigelow Laboratory for Ocean Sciences. He received his B.S. in chemistry from Fordham University and his M.S. and Ph.D. in oceanography from the University of Washington. He is a member of the American Geophysical Union, the American Society of Limnology and Oceanography, and the Arctic Institute of North America. His research interests include nutrient and carbon dioxide chemistry in highly productive regions, the nitrogen cycle in oxygen deficient waters, and the chemical oceanography of the Arctic Ocean.*

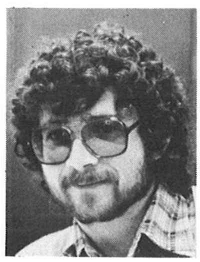
H. Ruth Jackson *received a B.Sc. from Dalhousie University and an M.Sc. in geophysics from Durham University in 1978. She is employed by the Atlantic Geoscience Centre of Bedford Institute of Oceanography. She participated in the Fram 1, 2 and 3 expeditions and is involved in tinuing research in the arctic.*



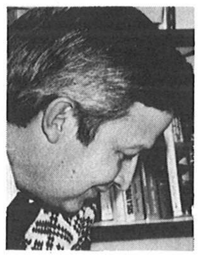
Ted Packard *is a principal investigator at the Bigelow Laboratory for Ocean Sciences. He received his B.S. in life sciences from M.I.T. and his M.S. and Ph.D. in oceanography from the University of Washington. His research is focused on biologically regulated chemical reactions in the ocean. He is a member of the American Chemical Society, the American Geophysical Union, the American Society of Limnology and Oceanography, and the Catalan Biological Society.*



Kenneth Hunkins *is a senior research associate at Lamont-Doherty Geological Observatory and an adjunct professor in the Department of Geological Sciences at Columbia University. His polar research centers on currents of the Arctic Ocean and their driving forces of wind and gravity, and it includes spatial scales ranging from the large-scale mean circulation through mesoscale eddies to small-scale processes and internal waves. He is also studying current behavior in submarine canyons of the East Coast with an array of moored oceanographic sensors. He lives in Nyack, New York.*



Thomas Manley *received a B.S. in mathematics and geology at Kent State University in 1974. Further graduate degrees (M.A., 1976; M.Phil., 1978; and Ph.D., 1981) were earned through Lamont-Doherty Geological Observatory of Columbia University in the field of physical oceanography. His dissertation dealt with mesoscale eddies of the Arctic Ocean and their characteristics and effects on energy, heat, and salt balances. Research interests include all facets of physical oceanography in the Arctic Ocean.*



Peter Jones *obtained his education at the University of British Columbia, receiving a Ph.D. in 1963. Since 1973 he has been at the Bedford Institute of Oceanography, where much of his work has focused on the chemical oceanography of arctic regions.*

intrusion of colder, more saline water from the south and may have originated from the arctic continental shelves [*Aagaard et al.*, 1979; *Hunkins and Manley*, 1980; *McPhee*, 1980*b*].

In the following spring, *Fram 2* was established on March 14 for the study of long-range, low-frequency, underwater acoustics, and later its two manned satellites, camp 1 and camp 2, were also set up [*Allen et al.*, 1980]. Marine geophysics and physical oceanography were conducted at the main camp as well as along lines radiating away from the station, using a Bell 204 helicopter as in the *Fram 1* experiment. Scientific objectives and preliminary results of the underwater acoustic program are given by *Dyer and Baggeroer* [1980] and *Baggeroer and Dyer* [1982]. Some of the more notable results were the highly variable ambient noise conditions and good signal-to-noise ratios from backscattering of signals by features as far away as the Chukchi Sea. Seismic refraction work at *Fram 2* indicates that 2 to 3 km of sediment overlay a crust of less than 5 km, agreeing fairly closely with the *Fram 1* results [*Duckworth et al.*, 1982].

A subsurface mesoscale eddy was observed on a helicopter traverse to camp 1 from *Fram 2*. This is only the second observation of a subsurface mesoscale eddy in the Eurasian Basin. The first observation of such a feature was made by Shirshov in 1937 from the Soviet drifting ice station *NP-1* [as reported by *Belyakov*, 1972]. Thickness of the eddy was about 175 m and was in the depth range of 50 to 225 m. The depth of maximum angular velocity was calculated to be at 90 m. These characteristics are similar to those observed in the Beaufort Sea during the main AIDJEX experiment.

Staging of *Fram 3*

In late February of 1981 the advance team for *Fram 3* accompanied a group of U.S. Army parachute riggers from the 612th QM Company of Fort Bragg, North Carolina, as well as the support crew and officers of three U.S. Air Force C-130 Hercules transports from the 317th Tactical Air Wing of Pope Air Force Base, North Carolina, to Thule, Greenland. These C-130's were then used to transport all scientific and logistic gear to the Danish base at Nord on the northeast corner of Greenland, while the Army riggers at Thule prepared the necessary lumber, fuel, and explosives for eventual C-130 paradrops over *Fram 3*.

A DeHavilland Twin Otter and a specially modified DC-3 'Tri-Turbo' were then used for location, establishment, and support of the drifting ice camp. On March 13, *Fram 3* was established on a large multiyear floe that measured 3 km by 5 km and had an average thickness of 4 m. Bad weather and radio communications prevented further flights to *Fram 3* until 5 days later.

By mid-April, 203,000 pounds of fuel, lumber, and explosives were paradropped to *Fram 3* by the C-130's. An additional 75,000 pounds of scientific and logistic gear were landed at *Fram 3* by way of 24 Twin Otter and five 'Tri-Turbo' flights. From April 6 to May 5 (last day of the scientific program) an average of 19 people were stationed at the camp. By the end of the manned drift, a total of 895 'man days' had been logged at the camp.

Final evacuation from *Fram 3* was on May 13, at a position of 81°43′N, 3°15′E, 61 days after the first landing. The net drift of the ice station was 361 km to the southwest at an average drift rate of 5.9 km/d. Due to the meandering of the camp along the drift track, the total distance covered was 505 km, with a computed average drift velocity of 8.3 km/d.

Following a few days of packing at Nord, two C-130s from the 36th TAS of McChord Air Force Base, Washington, removed all remaining gear and personnel from Nord to Thule Air Force Base and then back to the United States.

Fram 3 Scientific Programs and Preliminary Results

The institutions involved in scientific programs on *Fram 3* and available preliminary results are listed below.

Lamont-Doherty Geological Observatory

Station physical oceanography. Profiles of conductivity, temperature, and oxygen were made to depths of 1000 m at least three times each day, using a Neil Brown CTD equipped with an oxygen sensor. Stations to the bottom of the ocean were taken on a weekly basis. A pinger mounted on the CTD permitted data to be taken within a few meters of the bottom. A 12-bottle rosette sampler and reversing thermometers were used to obtain temperature, salinity, and pressure data for later calibration.

Additional CTD stations were taken to provide geochemists with small 1.2-l samples of water for the study of tritium, oxygen, dissolved nutrients, and gases within the water column; to provide intercalibration stations between the portable ODE (ocean data equipment) and Neil Brown CTD's; and to provide a concurrent station at *Fram 3* at those times that the portable CTD was away from camp on a helicopter transect.

Preliminary results show passage of the main camp through the polar front, a somewhat linear surface feature on the order of 100 km wide and extending to a depth of roughly 300 m. Large temperature and salinity variations were observed frequently within this depth range. Fine structure was also highly variable in this area. Yo-yo CTD stations that were taken every 20 min to depths of 400 m were, in several cases, inadequate for keeping track of the individual fine-structured features. Well-mixed boundary layers were also observed at abyssal depths as well as along the slope and top of the Yermak Plateau.

Mesoscale helicopter oceanographic survey. Helicopter mobility provided the means to study mesoscale features and their spatial variability in the upper 500 m. This was accomplished by using a portable CTD, as in the *Fram 1* and *Fram 2* expeditions. Figure 1 shows the positions of the CTD stations taken in the vicinity of each of the *Fram* ice camps. A major objective of this program was to map the polar front in the vicinity of the *Fram 3* drift track. Another objective was to study any eddies within the region. It is hoped that further knowledge about these features will aid in the understanding of lateral mixing within the Arctic Ocean and of transport processes across the polar front. The camp passed over two features, 15 and 25 km across, of anomalously high salinity and temperature, which had apparently originated from Atlantic water. They appear to be eddies shed by the polar front. Work done by *Hunkins* [1981] indicates that this region is baroclinically unstable and that features with a scale of approximately 30 km are the fastest growing (doubling time of 2 weeks).

Alignment of the polar front was generally NE-SW. Its location, on the basis of salinity, was fairly stationary over the 1-month observation period, although temperatures showed a more variable pattern.

Ocean currents. The properties of inertial and internal waves were investigated with an array of five Aanderaa current meters equipped with conductivity, temperature, and pressure sensors. Two strings of current meters were deployed—one in a lead at the edge of the large *Fram* ice floe, 5 km from the camp; and one at camp itself. The 'lead string' had instruments suspended at depths of 25 and 100 m, while the 'camp string' had instruments at 25, 100, and 480 m.

The 100-m lead instrument documented the passage of the camp through part of the frontal zone. Superimposed upon the frontal transition of temperature and salinity along the steady southwest movement of the camp

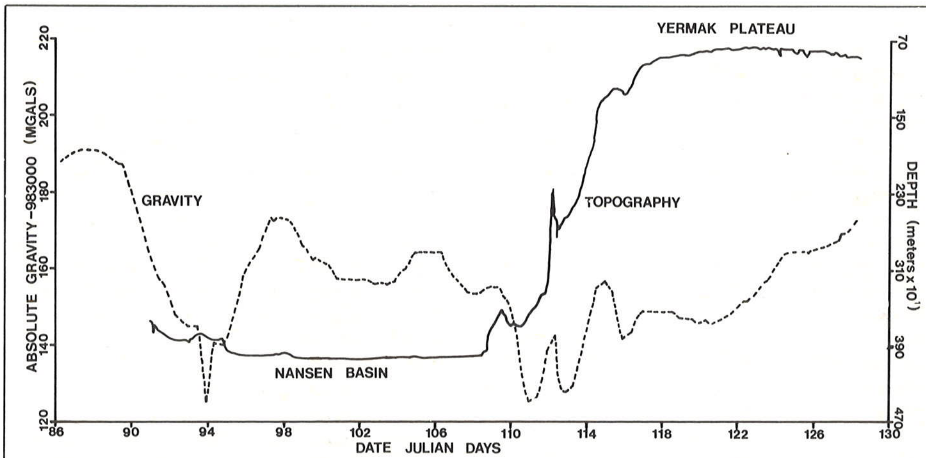


Fig. 2. Temperature and salinity time series recorded at the edge of the large *Fram 3* ice floe. Data were taken by an Aanderra current meter suspended at a depth of 100 m.

are the signatures of the anomalous intrusion of warmer, more saline water (Figure 2), previously described in the mesoscale helicopter oceanographic survey. Data from two Aanderaa current meters (25-m lead, 480-m camp) were discarded because of flooding and circuitry problems.

Hydroacoustic observations. Studies of underwater sound propagation were conducted by using sensitive hydrophones and a single geophone. Hydrophones were placed at 1 km and 3 km away from the camp and at depths of 46 m and 60 m, respectively. The geophone was placed on the surface of the ice at a distance of 1.5 km away from the camp. Data were continuously recorded on Hewlett-Packard FM recorders.

Single earthquakes, as well as earthquake swarms, were recorded frequently, with one earthquake recorded every day on the average. Although epicenters of the earthquakes could not be fixed because of the single recording site, most of them apparently originated from the Arctic Mid-Ocean Ridge.

Geophysical observations. A marine geophysical program provided background data on position, depth, magnetic declination, floe azimuth, and gravity. A geophysical data report summarizes these results [*Hunkins et al.*, 1981]. Figure 3 shows the depth and gravity field along the drift track of *Fram 3*.

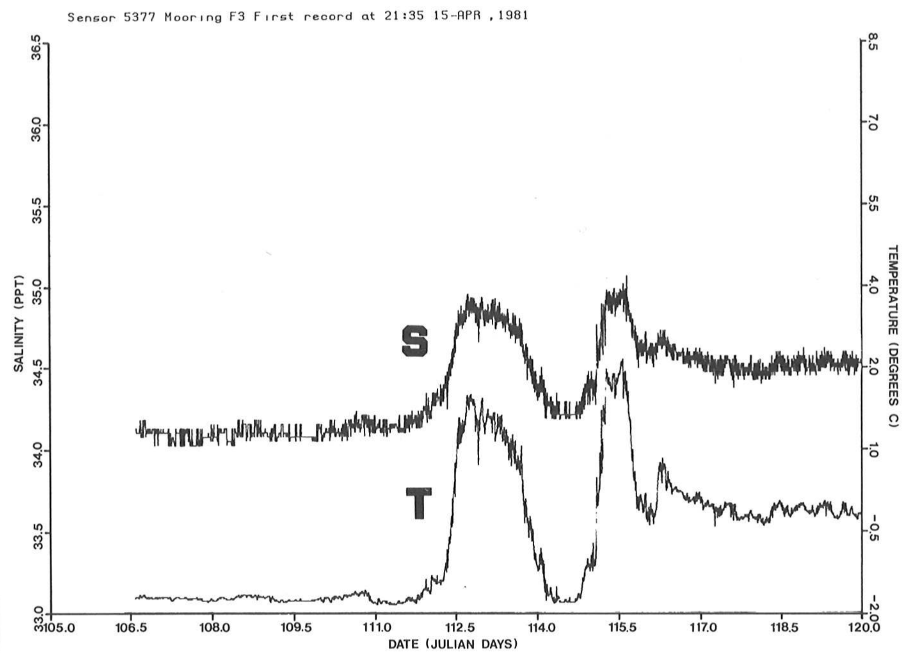


Fig. 3. Gravity and topography along the drift track of *Fram 3*.

Bedford Institute of Oceanography

Chemical oceanography. The Bedford Institute of Oceanography's primary program for chemical oceanography included measurements of oxygen, salinity, alkalinity, nutrients (nitrate, phosphate, silicate), trace metals (Mn, Fe, Ni, Cu, Zn, Cd), and radionuclides (Cs-137, Sr-90). The goal in measuring the first group of components, oxygen, salinity, alkalinity, and nutrients, was to characterize the water in the Eurasian Basin and above the Yermak Plateau and to study chemical processes, e.g., nutrient regeneration, that occur in the Arctic Ocean. More than 100 samples were collected at fairly closely spaced depth intervals from 3800 m to the surface, as the ice camp drifted toward and over the Yermak Plateau. For radionuclides and trace metals the goal was to characterize the water column and to see if there were any near-surface higher concentrations associated with Bering Sea water, as has been observed near the North Pole on the 1979 LOREX expedition [*Weber*, 1979]. Because sample collection was more difficult, especially for the radionuclides that required 100 l of water, fewer samples were collected. About 20 samples for trace metals and 15 for radionuclides were collected between depths of 2500 m and the surface.

A secondary program was to collect ice samples for analysis of alkalinity and some major ions (Ca, Mg, Cl, and SO_4). The goal of this program was to analyze the ice to detect chemical differentiation of ions, which occurs during freezing, and hence possibly to be able to predict ice meltwater content in near-surface seawater from an analysis of major ion content. Altogether, about 15 different ice samples were collected from leads, pressure ridges, and one ice core.

Analyses of the samples are presently underway, and most should be complete within about 3 months. Detailed interpretation of the results will take longer and will be done in conjunction with the physical oceanographic measurements.

Seismics and heat flow. The Atlantic Geoscience Centre of Bedford Institute of Oceanography ran a geophysical and geologic sampling program on *Fram 3* that consisted of seismic refraction, seismic reflection, heat flow, and coring.

The seismic refraction program involved the use of a tethered ocean bottom seismometer. The sound source was from 20- to 100-kg TNT charges carried away from the receiver by helicopter and detonated in areas where thin ice made access to the water possible. A 150-km line along anomaly 7 (26 m.y.) in the Nansen Basin was completed in an area where oceanic crust formed by slow spreading could be investigated. Three lines were run on the Yermak Plateau. Line 2 was run in water depths of about 2000 m on the slope of the Yermak Plateau. Line 3 was parallel to line 2 but on the top of the plateau, and line 4, also on the plateau, was run perpendicular to line 3.

The reflection profiling system was in operation at *Fram 3* from April 11 to May 5, 1981. The ocean bottom seismometer (OBS) was deployed at camp, but the refraction profiles generally ran parallel to structure and were shot away from the seismic reflection line at large angles. The reflection records provided information on the thickness of sediment below the OBS and a cross section across a portion of the Nansen Basin and the Yermak Plateau. The 9000-J Edgerton sparker provided a clear record of sedimentary layers with varying dips on the plateau, but only a minimum thickness of sediment in the basin because oceanic basement is not obviously recorded.

Along the reflection profile, 10 heat flow measurements were recorded with a 2.5-m Applied Microsystems probe, and 10 accompanying short gravity cores of about 30 cm were taken. The heat flow measurement and cores were done at water depths from 3675 to 795 m, accomplishing a line from the edge of the Nansen Basin to the top of the Yermak Plateau.

Refraction lines in the vicinity of the Yermak Plateau indicate that its northern tip is predominantly of oceanic origin, whereas the broader, more southern segment is of continental origin.

Bigelow Laboratory

Chemical and biochemical oceanography. During the first half of the *Fram 3* experiment, observations of the chemical and biochemical properties of the water column were made. These included on-site analyses for dissolved oxygen, ammonia, dissolved silicon, nitrate, nitrite, and reactive phosphorus from samples collected directly beneath the ice cover to a depth of 4000 m. On-site determinations of the activity of the respiratory electron transport system (ETS) were also made on eight samples taken from depths as great as 2000 m. Preserved samples were returned to the Bigelow Laboratory for examinations with a scanning electron microscope and for determination of their nutrient, chlorophyll, phaeophytin, particulate nitrogen, and particulate carbon contents.

With the exception of the scanning electron microscope examinations, all of the laboratory work has been completed. Initial analysis indicates that metabolic rates in the *Fram 3* water column are extremely low. Nitrite and ammonia concentrations were zero or very close to zero throughout the water column, and ETS activities were low in the upper 125 m and undetectable below that depth. This was the first time that ETS activity could not be detected in the deep-sea samples. While these results were not surprising, they will prove useful (when combined with data from other regions) in clarifying the relative importance of the processes that feed the 'deep metabolism' and in constructing an inorganic nitrogen budget for the Arctic Ocean. Although some weak maxima and minima were observed in the vertical dissolved silicon, reactive phosphorus, and nitrate distributions, there was no evidence for the presence of substantial amounts of the high nutrient waters that enter the Arctic via the Bering Strait. In addition, these data do not suggest a large contribution to the subsurface layers from waters formed over the continental shelf during the ice formation season.

Tritium Laboratory, Rosenstiel School of Marine and Atmospheric Science

Chemical Oceanography. Detailed profiles of water samples were collected at three points along the drift track for later analysis of their tritium and ^{3}He content. Results from the earliest samples show highly tritiated water above the halocline, indicating that, at this early stage in the drift, *Fram 3* was situated in a region of outflow from the Arctic Basin. The tritium-salinity relationship of these samples seems to uphold the view that, below the upper mixed layer, Nansen Basin water is composed of binary mixtures of Atlantic source water and predominantly meteoric freshwater [*Ostlund,* 1982]. The derived tritium values of the freshwater source imply an approximate 10-year residence time for the freshwater component in the East Arctic Basin. *Fram 3* tritium-^{3}He ages, which provide an essentially independent estimate of residence time, corroborate this result.

A profile of large-volume water samples was obtained by using a 100-l General Oceanics Go-Flo Sampler. Carbon dioxide gas was extracted from these samples at camp for later radiocarbon analysis. Samples down to 1250 m show a definite presence of bomb-produced ^{14}C; deeper layers show what is most likely some bomb contribution. There is measurable tritium all the way down to 3500 m, indicating that there have been contributions at these depths of water that have been at the surface within the last 20 years.

Polar Science Center—University of Washington

Current velocity-CTD profiling, oceanographic buoys, meteorology. The scientific group from the Polar Science Center carried out three main experiments at *Fram 3*. First, a new Arctic Profiling System (APS) was used during the experiment to examine the response of the upper ocean to storms. An additional goal was to use this device to study the vertical and horizontal circulation patterns within leads. The new APS was built by the Applied Physics Laboratory of the University of Washington and is a more compact version of an earlier instrument described in *Morison* [1980]. The device is a wire-lowered instrument that measures continuous profiles of conductivity, temperature, and velocity. During the experiment, there were three storms for which good records were obtained. During these storms, casts were made to 300 m every half hour. One such sequence of profiles measures the development of a 35-m-thick mixed layer from an initially stratified condition and should provide an especially good basis for comparison with mixed layer theories. Conditions at *Fram 3* were highly variable, and dramatic changes in the water structure, especially temperature, were quite common. The variations are related to the location of *Fram 3* near the ice edge, and the data will be compared to those obtained during a previous cruise (NORSEX 79) in the same region made during the fall of 1979. Unfortunately, no leads opened near camp, and the goal of studying lead circulation was not achieved.

The second experiment involved the deployment and testing of two new oceanographic buoys built by the Polar Research Laboratory. The buoys are being developed to provide a means of gathering long-term hydrographic data in the upper Arctic Ocean. One buoy is a thermistor buoy (T-buoy) and the other is a temperature-conductivity buoy (T-C buoy).

The T-buoy incorporates an electronics/ARGOS transmitter package in an aluminum tube and a Kevlar cable with thermistors imbedded in it every 20 m, hanging to a depth of 200 m. The buoy transmits temperature from all the sensors through the ARGOS satellite system four times per day.

The buoy was installed at *Fram 3* and left there after evacuation. The primary objectives were to perform intercalibrations with the APS and T-C buoy, provide a picture of the thermal structure in the East Greenland Drift, and test the survivability of the design. Data gathered simultaneously with the APS and the T-buoy generally agree.

After the end of the experiment, the T-buoy drifted south along the coast of Greenland and through Denmark Strait. Figure 4 shows the drift track of the buoy. It is noteworthy that the T-buoy remained in a fixed relation with the three other buoys left at *Fram 3* (two from the Polar Research Laboratory and one from the Norsk Polarinstituit) until just north of Denmark Strait, indicating the *Fram 3* ice floe maintained its integrity for a remarkably long time. The T-buoy ceased functioning on August 22, near the ice edge at 67°35′N 25°41′W.

The temperature profiles in Figure 4 show characteristic thermal regimes in the drift. The first shows a deep thermocline, indicating the buoy was on the cold side of the polar front. The second and third regimes show a shallow thermocline, indicating the buoy was on the warm side of the front, in spite of being 50–100 km from the ice edge. In the fourth regime the thermocline is again quite deep, but surface heating appears to be important. Fluctuations in the temperature records on the time scale of a couple of days suggest the presence of meanders or eddies near the front. The continued survival of the instrument, even in the rigorous ice edge region, bodes well for the survivability of such buoys in the pack ice.

The T-C buoy was developed as a step toward remotely measuring both temperature and conductivity for the study of the mixed layer in the Arctic. It incorporated three temperature and conductivity sensor pairs at 15 m, 30 m, and 50 m, suspended below a surface electronics package. In this buoy, temperature and conductivity are averaged over 3-hour periods. The average values are then transmitted during a once daily, 5-hour transmission window.

The buoy was operated at *Fram 3* for the purposes of testing and intercalibration with

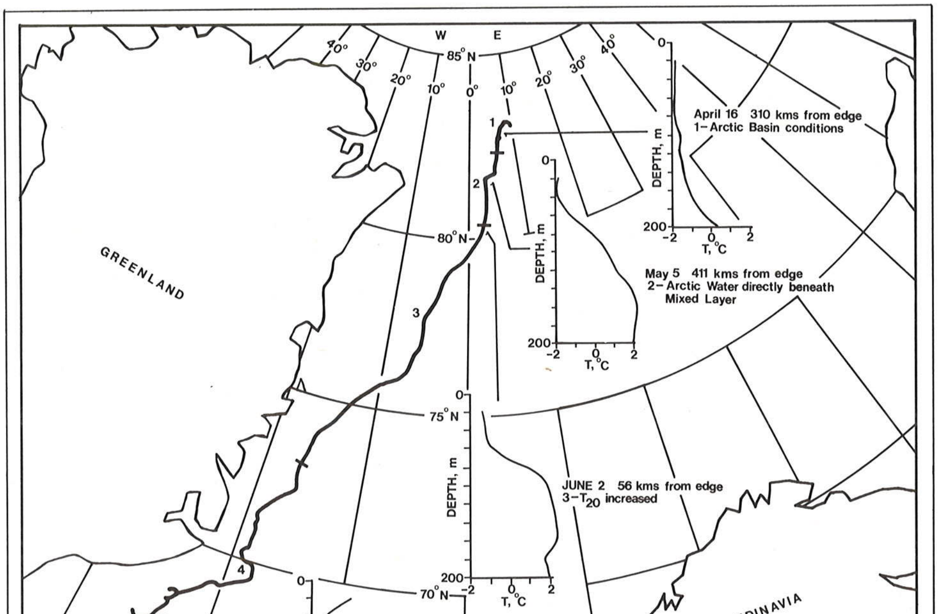


Fig. 4. The drift of the thermistor chain buoy. The device measures temperature to 200 m and transmits through the ARGOS system. During segments (2) and (3) of the drift, the buoy was over warm Atlantic water. During segments (1) and (4) it was over cold polar water.

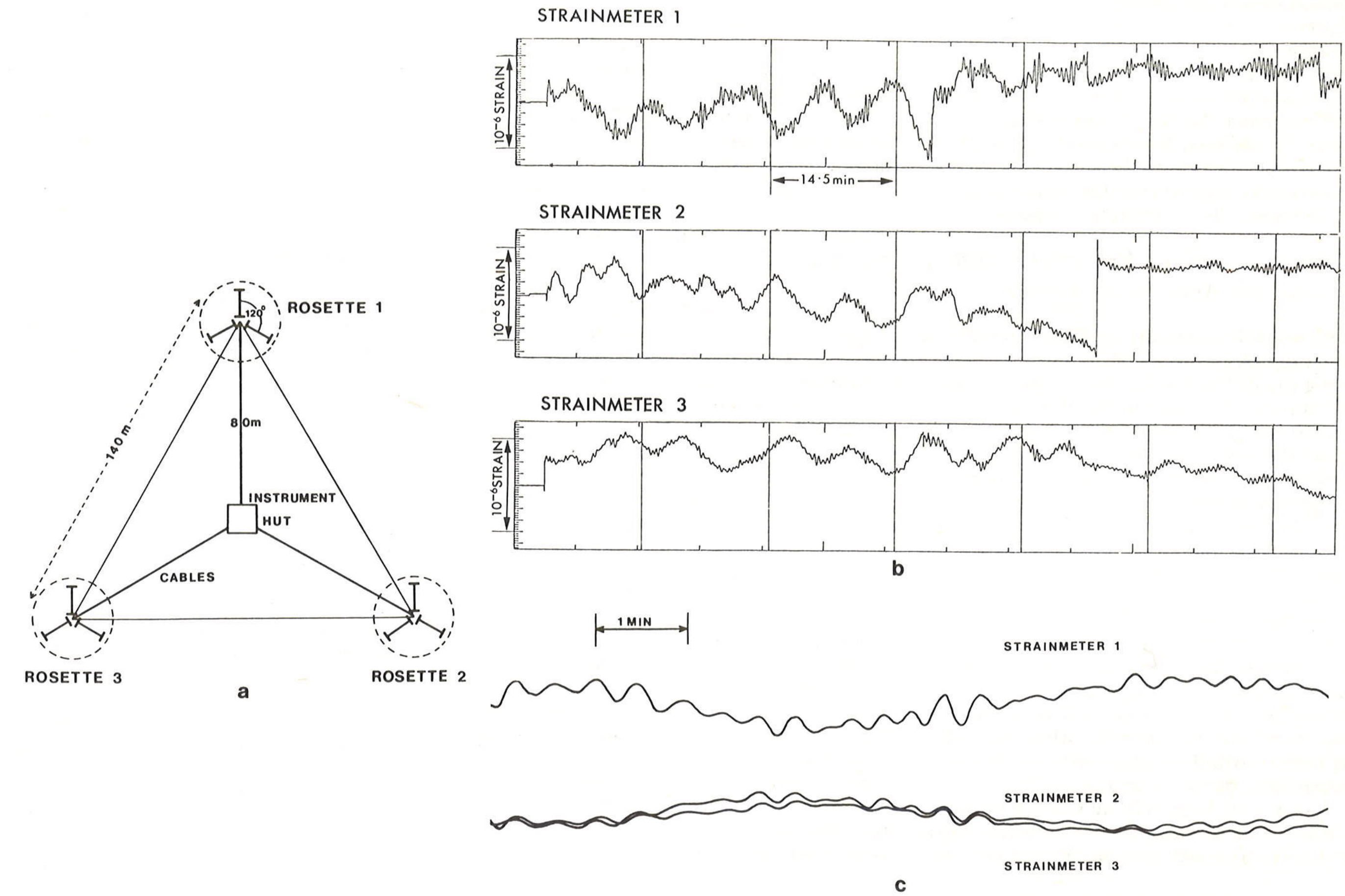


Fig. 5 (*a*) Configuration of the strain rosettes in relation to the instrument hut at *Fram 3;* (*b*) Portion of time series data obtained from one of the strain meter rosettes at *Fram 3;* (*c*) Expanded section of *b.*

other systems, only while personnel were at the camp. The results indicate it worked well. Instantaneous conductivity values from APS and the T-C buoy generally agree within ±0.001 s/m, and the temperature values agree within less than ±0.02° C. It has been found that the deepening of the mixed layer examined with the APS could also be observed with the T-C buoy. This illustrates the usefulness of the T-C buoy, even in studies of relatively short-term processes.

Finally, a suite of atmospheric measurements were made. They included continuous recordings of temperature, atmospheric pressure, wind direction at 2 m, and wind speeds at 2 m and 10 m. The data will be correlated with changes observed with the oceanographic measurements. They will also be used in conjunction with geostrophic wind estimated from buoys, to determine geostrophic drag laws appropriate for the region.

In addition to their other projects, a thermistor chain was installed for the study of internal waves. Preliminary results suggest the presence of an active internal wave field.

Scott Polar Research Institute

Ice strain and wave propagation. The purpose of this experiment was to measure the directional energy spectrum and velocity of propagation of flexural gravity waves in the ice cover of the Arctic Ocean, using three rosettes of three strain meters, each in a triangular array, and the attenuation rate of the waves by simultaneous recording from three-strain meter rosettes, two being retained at the main camp and the third being taken to a helicopter-established camp some tens of kilometers away.

For the first experiment an existing hut at the main camp was used as an instrument hut, and three rosettes of strain meters were set up as shown in Figure 5. Each rosette consisted of three wire strain meters of high sensitivity (better than 10^{-8} strain) and rugged design evolved at SPRI for this purpose [*Moore and Wadhams,* 1980]. The strain-sensing element was a 1-m long Invar wire. Each instrument was frozen into the ice and protected by a wooden box, which was placed over it. Snow was then shoveled over each box to reduce thermal drift.

Data were recorded on digital and FM analog tapes at times when radio interference was least, i.e., at night or when there was no flying between Nord and *Fram 3.* Recording went on for 4 weeks during April–May 1981, and about 150 hours of data were recorded.

Ice thickness was measured at the strain meter sites. Other data needed for interpretation of the results and recorded by other investigators on *Fram 3* were wind speed and direction (continuously), floe rotation (daily, usually only about 1° per day), and internal wave activity (by J. Morison using thermistor chain).

During the second project, three attenuation experiments were carried out by deploying a fourth strain meter rosette away from the main camp. Positions of these remote sites relative to the main camp were 93 km north, 46 km south, and 139 km north. Each remote rosette was set up with its axes aligned as closely as possible with those at the main camp. At each remote site, at least 1 hour of data was recorded concurrently with recording at the main site.

Part *b* of Figure 5 shows a typical length of record from three strain meters in a single rosette. It is immediately apparent that there are two distinct components of oscillation present. The short-period oscillations have a typical amplitude of 10^{-7} strain and period of 30 s. An expansion of the time scale (Figure 5*c*) shows that oscillations from the three strain meters are in phase. This suggests that they are flexural gravity waves, as recorded on previous occasions in the Arctic Ocean [*Hunkins,* 1962; *LeSchack and Haubrich,* 1964]. The ice thickness at the site was 3.2 m, from which we can infer that the wave amplitude was about 3 mm. Long waves of this kind can be explained as being the envelopes of wave packets found in the open sea [*Larsen,* 1978*a*, *b*]. The Arctic Ocean ice cover, however, acts as a filter, which removes all shorter-period components by scattering or creep mechanisms. Full analysis of the results will reveal whether this is really the case, since it will give the directional spectrum of the waves (to show whether they are coming from the nearest open ocean in Fram Strait), any correlation with local wind (in case direct generation through the ice is occurring), and the attenuation rate.

The long-period oscillations apparent in Figure 5*b* were unexpected. They are of greater amplitude than the short-period oscillations—typically 5×10^{-7} strain—and have periods of about 10 min. This is far too long for any flexural gravity wave, especially since it implies a very large vertical amplitude of ice oscillation. Furthermore, on the expanded scale (Figure 5*c*), and on Figure 5*b*, it can be seen that two strain meters are in phase while the third is in antiphase. This is the result that we would expect from a wave of compression passing through the ice, i.e., a longitudinal wave. Our interpretation is that (1) the ice is responding to the presence of internal waves, concurrently measured by J. Morison and found to have a typical period of 10 min or (2) the ice is responding to the very small variations in sea surface elevation associated with the internal waves.

On April 10 the long-period strain field increased greatly in amplitude some 24 hours after the onset of a 12 m/s wind. If it is true that ice acceleration generates internal waves through interaction with pressure ridge keels, then we would expect increased long-period ice strain to follow a storm. Further analysis of the joint data sets will determine whether this hypothesis is valid.

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