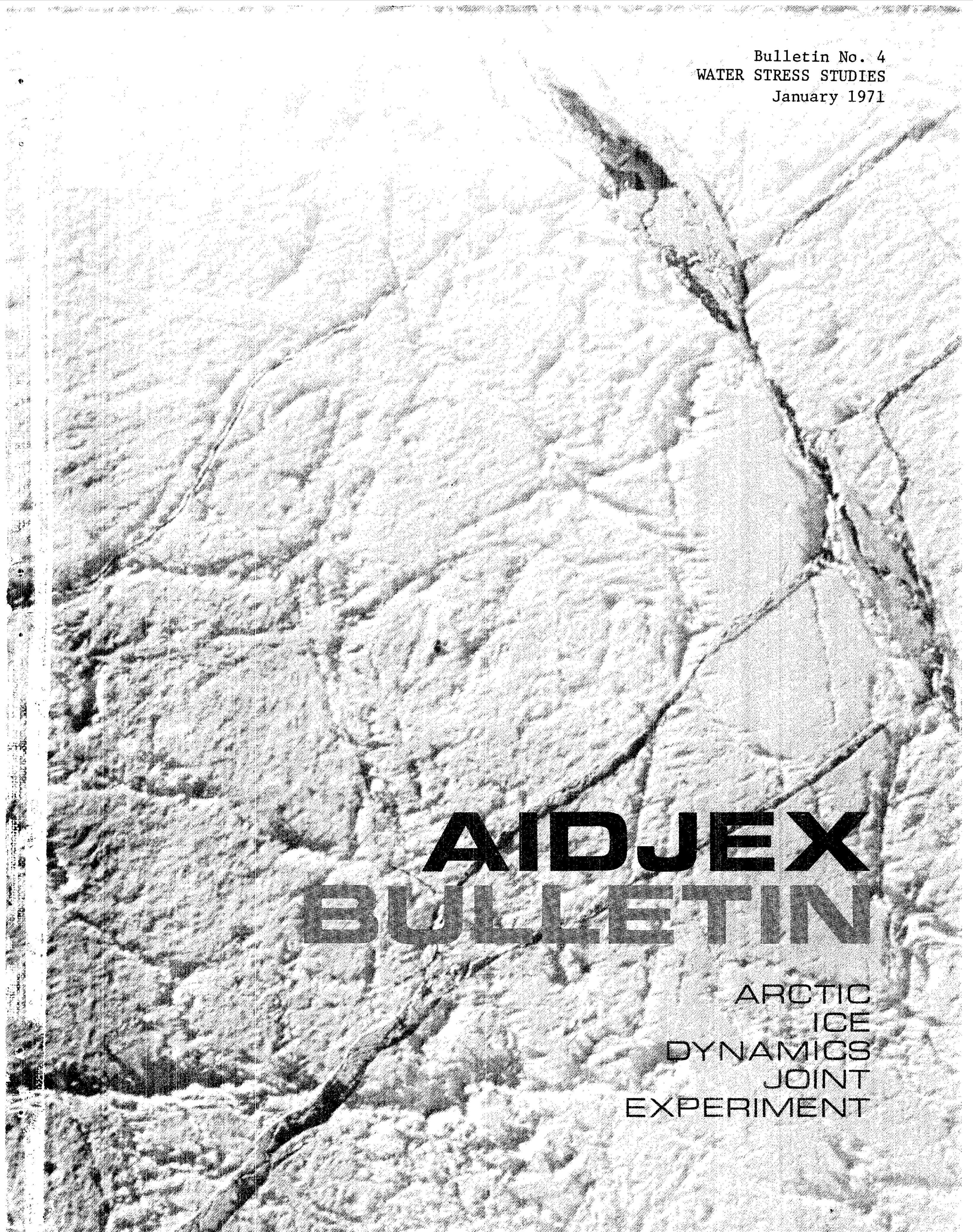
Bulletin No. 4
WATER STRESS STUDIES
January 1971



AIDJEX BULLETIN

ARCTIC
ICE
DYNAMICS
JOINT
EXPERIMENT

AIDJEX BULLETIN No. 4

January 1971

WATER STRESS STUDIES

Arctic Ice Dynamics Joint Experiment
Joseph O. Fletcher, Program Coordinator
Division of Marine Resources
University of Washington
Seattle, Washington 98105

UNIVERSITY OF WASHINGTON

Division of Marine Resources

The AIDJEX Bulletin aims to provide both a forum for discussing AIDJEX issues and a source of information pertinent to all AIDJEX participants.

The Bulletin series will be numbered and dated for easy reference and subtitled according to the contents of each issue.

A status report will appear periodically as an issue. Other issues will contain technical material closely related to AIDJEX, informal reports on theoretical and field work, translations of relevant scientific reports, and discussion of interim AIDJEX results or problems.

You are encouraged to send your comments and contributions to

Mrs. Alma Johnson
AIDJEX Bulletin
3710 Brooklyn Avenue N.E.
Seattle, Washington 98105

AIDJEX BULLETIN No. 4
January 1971
Water Stress Studies

TABLE OF CONTENTS

1971 AIDJEX WATER STRESS PILOT STUDIES

AIDJEX OCEANOGRAPHIC INVESTIGATIONS

by

J. Dungan Smith
Departments of Oceanography and Geophysics
University of Washington
Seattle, Washington

I. INTRODUCTION

During the main phase of AIDJEX, scheduled for 1973, the air stress on the ice surface and the motion of the ice will be monitored. The oceanographic measurements will seek to determine the stress on the underside of the ice from the roughness of the underside and the relative currents. The ice roughness has a variety of scales ranging from a few meters under old floes to several tens of meters under pressure ridges, and slopes of 1:20 or steeper are common even under old floes. (For example, see Figure 3 in the 1970 Pilot Study Report in this Bulletin.) The motion of both ice and water involves the solution of complicated, time-dependent problems.

The flow between the bottom of the sea ice and the quasi-geostrophic currents in the upper Arctic Ocean can be divided into two layers: a frictional boundary layer extending from the base of the ice to a distance of a few meters below the ice sheet, and an Ekman boundary layer extending from a few meters below the ice sheet to several tens of meters below the ice. In the frictional boundary layer, the turbulence is generated locally by the shear in the velocity field (which in turn is due to the presence of the boundary), and the Coriolis effect is negligible. The turbulent mixing in this region is proportional to the local shear velocity and the distance from the boundary. In the Ekman layer, the Coriolis effect is of prime importance, and the turbulent mixing is more or less independent of distance from the boundary as shown by Hunkins (1966). Preliminary analysis of Smith's measurements described in the 1970 AIDJEX Pilot Study Report (this Bulletin) also indicates a constant turbulent mixing coefficient or eddy viscosity in the Ekman layer.

In the atmosphere, the separation of the planetary boundary layer into two regions is also possible. The frictional boundary layer of the atmosphere is several tens of meters thick, and the Ekman layer is several hundred meters thick. The topography over much of the ice surface is several tens of centimeters in height, and even most pressure ridges are small relative to the thickness of the frictional boundary layer. This means that the Ekman layer is generally isolated from the surface topography, which, except near pressure ridges, can be considered as a surface roughness in an otherwise uniform flow. Moreover, during most periods of interest to the ice deformation problem, the wind speed at the top of the frictional boundary layer is high relative to the drift speed of the ice, permitting the ice to be considered quasi-steady for stress calculations.

The situation is quite different in the oceanic boundary layer. The under-ice topography, as mentioned previously, is usually comparable in height to the frictional boundary layer and the pressure ridges are often comparable to the thickness of the Ekman layer. This results in a nonuniform Ekman layer as well as a nonuniform frictional boundary layer under much of the ice. In addition to this complication, the drift speed of the ice is often comparable to the flow speed in the Ekman layer. This tends to make the oceanic boundary layer unsteady as well as nonuniform.

These complications may necessitate an approach to under-ice boundary layer studies somewhat different from that used in atmospheric boundary layer studies--for example, a greater dependence on theoretical calculations. In any case, they require a careful examination of the nature of the oceanic boundary layer and its relationship to both the ice drift and the flow in the upper Arctic Ocean.

For this reason, a fairly extensive oceanographic program was planned for the 1970 AIDJEX Pilot Study, which was carried out by the University of Washington in conjunction with the Canadian Polar Contintental Shelf Project at their ice floe camp in March (Camp 200). An even more extensive oceanographic program is planned for March 1971 at Camp 200. These studies are described in this Bulletin.

II. THEORETICAL CONSIDERATIONS

If the frictional boundary layer is steady and uniform in x and y, then a simple similarity argument in which the variables u, z, and $\partial u/\partial z$ are assumed to define the problem leads to the expression

$$u = \frac{u_*}{k} \ln \frac{z}{z_0} \tag{1}$$

Here u is the velocity a distance z from the boundary; $u_* = \sqrt{\tau_b/\rho}$ is the square root of the boundary shear stress (τ_b) divided by the square root of the fluid density (ρ) and is called the shear velocity or friction velocity; k is a constant of proportionality called von Karman's constant and found experimentally to be about 0.40; and z_0 is a constant of integration related to the roughness of the boundary. If k_s is an appropriate measure of the local roughness of the boundary and if the "roughness Reynolds number" $R_* = u_* k_s/\nu$ (where ν is the kinematic viscosity of the fluid) is less than 3, then the boundary is called "hydraulically smooth" and $z_0 = \nu/9u_*$ (see Schlichting, 1960, p. 519ff). On the other hand, if R_* is large enough, $z_0 \propto k_s$ and the boundary is called "hydraulically rough." For randomly distributed sand grains, "hydraulically rough flow" occurs at $R_* > 100$; in this case, $z_0 = k_s/30$ (see Schlichting, 1960, p. 519ff.). For wave-type roughness, hydraulically rough flow occurs at considerably higher roughness Reynolds numbers. What is considered roughness by some writers is considered to be nonuniformity in the flow by other writers; but if the boundary is uneven with wavelengths on the order of the thickness of the frictional boundary layer or larger, it is best to consider the flow nonuniform rather than to try to treat the topography as roughness elements. By this criterion the flow in much of the frictional boundary layer under the polar ice is nonuniform.

Nonuniform two-dimensional frictional boundary layers have been considered by several writers concerned with the dynamics of deformable boundaries. Much of the recent work on air-sea interaction has been of this type (e.g., Miles, 1967); however, in this case the problem is complicated by the motion of the boundary and by the fact that the boundary is considered to be thick relative to the wavelengths of the surface waves.

On the other hand, Smith (1970), in studying the stability of a sand bed subjected to a shear flow, has considered the boundary to be quasi-steady and has therefore provided a solution to flow over a fixed boundary of small-amplitude topography. Unfortunately, this theory uses a constant eddy viscosity which is somewhat unrealistic for natural frictional boundary layers. Although it is presently being expanded to include the case of a linearly varying eddy viscosity, results of these calculations are not yet available. Smith's theory, like that of Miles, is a first-order theory and therefore applies only to small-amplitude topography; nevertheless, it has been used with some success in predicting the boundary shear-stress distribution over finite-amplitude Columbia River sand waves with wavelengths of about 60 meters and heights of about 3 meters (Smith, 1969). The theory is compared to Preston tube measurements of boundary shear stress in the abovementioned report and is shown to reproduce the major features of the measurements with approximately the correct amplitudes.

Further unpublished work in this area indicates that while the first-order, constant eddy viscosity theory reproduces the major structure of the boundary shear-stress profile, it overestimates the accelerative effects and underestimates the decelerative effects. This agrees with flume measurements made under Smith's direction by Reeder (1970), which show that second-order effects are about 25% as important as first-order effects in regard to flow over sinusoidal boundaries with height to wavelength ratios of 1:15, the latter being a rather common harmonic in natural topography including the Columbia River sand waves and the underside of the arctic ice. No second-order theory is now available, and no three-dimensional theory has yet been attempted.

The boundary shear stress calculated from this theory, called "skin friction" by aerodynamicists, does not include the "form drag" or "pressure drag" due to the boundary geometry. For a given geometry the form drag can also be evaluated; it is typically several times the magnitude of the skin friction. In addition, it is worth noting that the skin friction is typically 30% higher than its flat-bed value for slopes of only a few degrees and may vary by as much as a factor of two for steeper slopes.

The previously described theory applies to finite depth fluids or to fluids in which the top of the boundary layer remains at a constant level with no shear stress. If a small constant stress is imposed at the top of the boundary layer, the results do not change much. This theory has been described in the present report not as a solution to the problem at hand but as a solution to an analogous problem which should provide a basis from which the effects of topography on the frictional boundary layer under the ice can be anticipated.

A second approach has also been taken by Smith (1969 and later unpublished work). This theory traces the development of a turbulent boundary layer with linearly varying eddy viscosity, over nonuniform topography downstream from a point of separation. In this case, any type of interior flow can be used to calculate the velocity at the top of the boundary layer. Considering only first-order terms, the boundary shear stress (skin friction) is given as

$$\frac{\tau_b}{\rho u_b^2} = C_D \left[(1 + f_4) + \frac{\delta}{k^2 u_b} \frac{\partial U_b}{\partial x} f_3 \right] \qquad (2)$$

where τ_b is the boundary shear stress, C_D is the drag coefficient for a flat bed of known roughness, δ is the boundary layer thickness, and f_3 and f_4 are weak functions of the flat bed drag coefficient. For thick boundary layers, $f_4 << 1$ and can be neglected and f_3 is within a few percent of unity. It is important to note that δ depends upon u_b and $\partial u_b/\partial x$. Thus, the spatially averaged boundary shear stress depends upon the exact shape of the boundary, and a constant drag coefficient cannot be found. This expression also demonstrates that the accelerative effects decrease with increasing flow speed in agreement with measurements such as those of Sternberg (1968). Unfortunately, the flow speeds are low in the oceanic boundary layer under the arctic ice, and this term is important. As was the case in the constant eddy viscosity theory, the form drag can be evaluated: although it is very sensitive to the exact boundary shape, it is typically several times the skin friction value. This theory is presently being extended to include second-order effects, and the first-order theory is also being extended to three-dimensional boundary layers.

As presented above, zero shear was assumed at the top of the boundary layer. This restriction must be relaxed before the theory can be used in the frictional boundary layer problem at hand. Nevertheless, these results show what to expect in the measurements and suggest how to treat the data. They also indicate that the spatially averaged boundary shear stress will depend upon the actual geometry of the boundary rather than on its statistics. The spatially averaged boundary shear stress ($\underset{\sim}{\tau}_{av}$) is given by

$$\underset{\sim}{\tau}_{av} = \left[(\underset{\sim}{\tau}_b)_{av} \, A_b + \underset{\sim}{F}_D \right] / \, A \tag{3}$$

where

$$F_D = - \left[\iint_{A_b} p_b (\underset{\sim}{n} \cdot I \cdot \underset{\sim}{e}_x) \, ds \right] \underset{\sim}{e}_x$$

is the form drag on the boundary, A_b is the area of the actual boundary, A is the projected area of A_b on the xy plane which is defined to be parallel to the mean surface over the area of interest, and p_b is the pressure distribution on the actual boundary. Note that if the topography is periodic, then $A = \lambda_x \lambda_y$ where λ_i is the wavelength of the topography in the ith direction and $\tau_{av}/(eu_b^2)$ is unique. However, if the topography is not periodic--as is the case under the ice--A must be estimated from the minimum in its two-dimensional spectrum, and a unique value of $\tau_{av}/(eu_b^2)$ may not exist even it a statistical sense. The question then arises as to magnitude of the variation in $\tau_{av}/(eu_b^2)$ under the arctic ice. If over large regions this value is reasonably stable, it still can be used to provide an approximate general relationship between stress and current speed. However, it is very important to evaluate the variability of this parameter if it is to be used in the numerical ice deformation studies, for it can easily introduce a systematic error in excess of ±20% into the numerical calculations.

For small-amplitude temporal accelerations, an analogous expression can be derived for a developing boundary layer. For a thick frictional layer

$$\frac{\tau_b}{\rho u_b^2} \cong C_D \left\{ 1 + \frac{\delta}{k^2 u_b^2} \, \frac{\partial u_b}{\partial t} \right\} . \tag{4}$$

This expression is interesting because it shows that the boundary shear stress depends upon the intensity of the temporal accelerations as well as on the square of the velocity at the top of the boundary layer. As in (2), the second term on the right side of the equation is a nonlinear one and does not average out when a time average is taken even for a harmonic acceleration. In addition, this expression demonstrates the lessening importance of the accelerative effect with increasing flow speeds--an often observed fact in atmospheric drag coefficient measurements.

Steady, uniform, constant eddy viscosity Ekman layers are discussed in most elementary dynamical meteorology and oceanography texts (e.g., Haltiner and Martin, 1957, p. 214-215; Neuman and Pierson, 1966, p. 191ff). Some work has been done on unsteady Ekman layers (e.g., Fallor and Kaylor, 1969). A few studies have been made of nonuniform Ekman layers (e.g., Hsueh, 1968). However, considerably greater effort will have to be made in this area as part of the AIDJEX theoretical studies if accurate regional average boundary shear stresses are to be calculated from the field measurements.

A REPORT ON THE 1970 AIDJEX PILOT STUDY

by

L. K. Coachman and J. Dungan Smith
Department of Oceanography
University of Washington
Seattle, Washington

(with contributions by W. J. Campbell, W. Deutsch, and E. Flourié)

I. INTRODUCTION

Arctic ice moves and deforms under the influence of the air stress above and water stress below, while stresses within the ice field modify the motion. Although many methods have been employed to measure these stresses and deformation, we do not yet know the most suitable method for the purposes of AIDJEX. This pilot study, a collaboration between the Polar Continental Shelf Project(Department of Energy, Mines and Resources, Canada) and the Department of Oceanography (University of Washington), explored possible techniques for measuring water stress on the ice and ice deformation.

Water-stress measurements require complicated equipment and personnel; thus, it is not feasible to directly define the water-stress field over a large region. The direct stress measurements must be related to the interior oceanic velocity field, so that over the AIDJEX region the stress field can be inferred from the velocity field.

The portion of the interior velocity field which is geostrophic may, if sufficiently large, be readily inferred from its characteristic association with the internal distribution of mass. The required measurements are those of temperature and salinity in a number of vertical profiles; of all oceanographic measurements, these are probably the easiest to obtain, the

---

This study was supported by Office of Navy Research Contract N-00014-67-A-0103-0014.

most reliable, the most readily reducible, and the least expensive. The degree to which flow in the Arctic Ocean is in geostrophic balance is not known.

Direct measurement of the interior flow field depends on reliable current meters. A number of choices are available, but the meter best suited to AIDJEX must be selected only after extensive testing under arctic conditions. Furthermore, proper horizontal and vertical spacing of the current meters must be thoroughly explored so that the interior flow field can be mapped adequately for translating the direct stress measurements into a stress field under the ice.

II. SCIENTIFIC PROJECTS

The following specific projects were outlined for the pilot study.

A. Boundary Layer Studies

Measurement of the time-dependent velocity and Reynolds stress fields in the nonuniform turbulent boundary layer under the ice was planned utilizing the mechanical current meters developed by E. J. Klink and J. Dungan Smith for boundary layer studies in rivers and estuaries. This method employs meters mounted in orthogonal triplets along the normal to the boundary. Deployment of the instrumentation by divers was to be tested, as were various methods of mounting the current meters. Mean flow at selected depths within and below the boundary layer was to be measured with conventional current meters and with a triplet of the Klink and Smith current meters held by a movable frame. Under-ice topography was to be mapped in the vicinity of the instrument mast by divers, as the boundary geometry is of critical importance in boundary-layer studies.

B. Current Measurements

A vertical array of current meters for the duration of the experiment was planned at the following depths:

10 m, within Ekman layer
40 m, below Ekman layer/above pycnocline
150 m, in pycnocline
500 m, in Atlantic layer

Frequent fixes using the Decca-Lambda system of PCSP would eliminate ice motion from the current meter records. Readings at the main camp were to be recorded frequently, while those at the satellite stations were to be taken during helicopter overflights. Spatial coherence of the horizontal currents at 1-mile, 10-mile, and 20-mile separations was to be investigated by paired current meters at a depth of 40 meters, set out at appropriate satellite stations from the main camp.

C. Gradient Current Measurement

To measure the approach to geostrophy of the flow, synoptic hydrographic casts were planned to 500 m at three stations spaced in a triangle with legs of approximately 10, 20, and 30 km. The casts were to be made at 4-hour intervals for about one week while the current meters were operating.

D. Ice Deformation Measurement

The Decca-Lambda navigation system was to be used for frequent positioning of the two satellite stations as well as of the main station, so that the deformation of the triangle could be followed. For more precise measurement of distances between points, it was planned to test 10-cm wave-length microwave tellurometers.

III. LOGISTICS

The Polar Continental Shelf Project provided the primary logistical support from their base camp at Tuktoyaktuk, Northwest Territories. The pilot study party established its main camp on an ice floe approximately 240 miles north of Tuktoyaktuk, within the Canadian hydrographic survey camp (Camp 200), where two helicopters were stationed. Routine communication with Tuktoyaktuk was maintained by radio and Otter aircraft. All food, fuel, housing, and generators came from the PCSP stores.

Fuel requirements included the following: diesel for one generator and for space heaters in the living quarters; automotive gas for Herman-Nelson heaters, hydrographic winches, and two generators; white gas (naptha) for Coleman stoves, lanterns, and blow torches; gas-oil mix for snow vehicles and chain saws; and turbo fuel for helicopters.

Parcolls* served to house the party: two 4-section Parcolls for five men each; and one old, much smaller Parcoll for two men. One of the larger Parcolls also served the divers as a dressing station and as housing for the compressor which filled their tanks.

To house the research equipment and work, PCSP stores provided the following: one old, small Parcoll, with space heater, for electronic instrumentation; one longhouse tent, with space heater, for current meter assembly and other mechanical work (on winches, corer, chain saws, cable splicing); two "igloo" tents for storing equipment; and three pyramid 10 x 10 tents for hydrographic stations.

Except for the evening meal, which was shared with the Canadian party in their mess Parcoll, all meals were prepared on Coleman stoves in the living units.

(*) A Parcoll is a modern version of a Jamesway hut. The boxes, section by section (each section 4 feet wide), are opened to make a floor. Semi-circular sections of aluminum pipe clamp on the edges to form a half-round structure, over which insulated blanket strips are tied. Separate end walls contain a stove pipe outlet and a door with vestibule.

The generators described below supplied power:

1. one 5-kw diesel generator, for the workshop Parcoll and longhouse tent, and for lights in one living Parcoll. This generator was housed in a longhouse tent(about 300 yards from the electronics Parcoll) with a 3-kw diesel generator which supplied the Canadian party with power for lights and radio gear.

2. one 4-kw gasoline generator, used exclusively for running the diving air compressor.

3. one 1-kw portable gasoline generator for the SIPRE corer, which was driven by a 1" electric drill motor.

IV. EQUIPMENT AND PROCEDURES

A. Interior Flow Field Measurements

1. Hydrographic Stations. At each of three hydrographic stations, ten Nansen bottles equipped with two protected reversing thermomenters each, plus three unprotected thermometers, were installed, as were such ancillary equipment as log sheets, messengers, thermometer reader, tool kit, and sample bottles. Nansen bottles were held in two 5-bottle collapsible aluminum racks designed to hold the bottles in the warmth of the upper part of the hydrographic tent. The racks were lowered by small winches powered by 3-hp Briggs and Stratton engines and holding 750 m of 3/32" hydrographic cable. (These were Hydro Products winches, with metal removed from frame to reduce total weight to about 120 pounds.) Six feet of flexible exhaust pipe allowed the winches to be placed in tents. A meter wheel was hung from a tripod, two legs of which were mounted on the winch frame, the third leg straddling the hydro hole.

2. Current Meters. Three types of current meters were deployed:

Braincon model 316 Histogram
Braincon model 381 Histogram
Braincon model 573 digital.

3. Hole Cutting. One hole approximately 8 x 8 feet through 11 feet of ice was cut adjacent to the main camp. Chain saws and ice chisels were used to cut blocks from the upper 10 feet. A Herman-Nelson heater provided ventilation of chain-saw fumes, a necessity when the hole became deeper than about five feet. The bottom one foot of ice was blown with CIL 60% Geogel, and the pieces mucked out by shovel. The hole was reopened frequently by ice chisel or chain saw.

Numerous holes were drilled through the main floe (ranging from 10 to 22 feet) with a 4" SIPRE corer, powered by a 1" electric drill motor and 1-kw portable generator.

At the two hydrographic satellite stations and one current meter station, holes through approximately six feet of ice were opened as follows. After ice thickness was tested with a 1" hand auger, the 2 x 2 foot holes were outlined with SIPRE corer holes bored to within 6 to 8 inches of the bottom of the ice, indicated by the increased salt content of the borings. A central hole was bored through and blown with a charge of Geogel placed just below the ice bottom. Mucking was by shovel and ice tongs.

B. Boundary Layer Studies

A single downward-facing mast was employed as an instrument frame. The mast was attached to the ice by a bracket fitted into a SIPRE core hole and serviced by divers working through the large hole 20 m distant. This instrument mast consisted of eight 10-foot sections of 3/4" O.D. thick-wall stainless steel tubing. At the end of each section, a 6-inch half-cylindrical piece of the tubing had been removed and a stainless steel plate 1/4" thick, 1 1/2" wide, and about 12" long welded in its place. The overhanging sections of these pieces of 1/4" flat stock were drilled so that they could be attached together with three 5/16" stainless steel bolts to hold the frame together rigidly. Each joint was numbered, and a shallow slot was milled continuously across all sections of the frame parallel to its axis; this provided a means for orienting any piece of equipment attached to the frame.

The mast was located in an area with less than 25 cm relief within a radius of 10 m. The topography in a 40 m square centered on the mast was mapped by the divers. An appropriate grid of lines was fixed to the underside of the ice, and a pressure transducer mounted on a buoyant underwater sled was pushed steadily around the grid. A strip-chart recorder recorded pressures.

The current meters were designed to measure velocity component fluctuations from d.c. to 10 Hz with 1% accuracy. Moreover, the sensors were designed to be small but rugged, to have a low threshold velocity, and to be sufficiently inexpensive to permit simultaneous use of many of them. These criteria were satisfied by a neutrally buoyant impellor with a horizontal axis of 3.5 cm, encaged in a wire frame (Figure 1). The impellor is moulded around a stainless steel shaft which is attached to the wire frame by water-lubricated jeweled bearings mounted on stainless steel rods. Each of these rods passes through a hole in a fared support on the end of the wire frame. These fared supports grip the bearing mounts tightly with little wire fingers and hold them in place. The wire cage is supported by a 3/8" stainless steel tube which contains all the underwater components of the electronics system. This tube, in turn, is gripped by a p.v.c. mounting block that also attaches to the 3/4" stainless steel mast.

Rotations of the impellor are picked up by a photoelectric system mounted at the base of the 3/8" diameter support rod. As the rotor turns, light from a lamp mounted at the center of the support rod base is reflected back from a mirror on the rotor first to one of two photodiodes mounted lateral to the lamp on the base and then to the other. These photodiodes are wired in series with opposite polarity so that a dipulse is produced; the direction of rotation is given by determining whether the negative or the positive half of the dipulse comes first. The current speed is proportional to the dipulse frequency. As the photodiodes are high-impedence devices, an emitter follower is mounted in the support rod to match the impedence of the transmission cable. The power leads, +12 volts and -12 volts, are common to all meters and are used to power the photodiodes, emitter followers, and lamps. A signal lead and two power leads are required for each probe. A junction box is situated about 4 m from the probes; from this point to the surface there is one signal and two power leads for each current meter. The signal leads are shielded, and the shields are grounded at the surface. To avoid ground loops, these shields are not connected to sea water ground at the meter end of the wire.

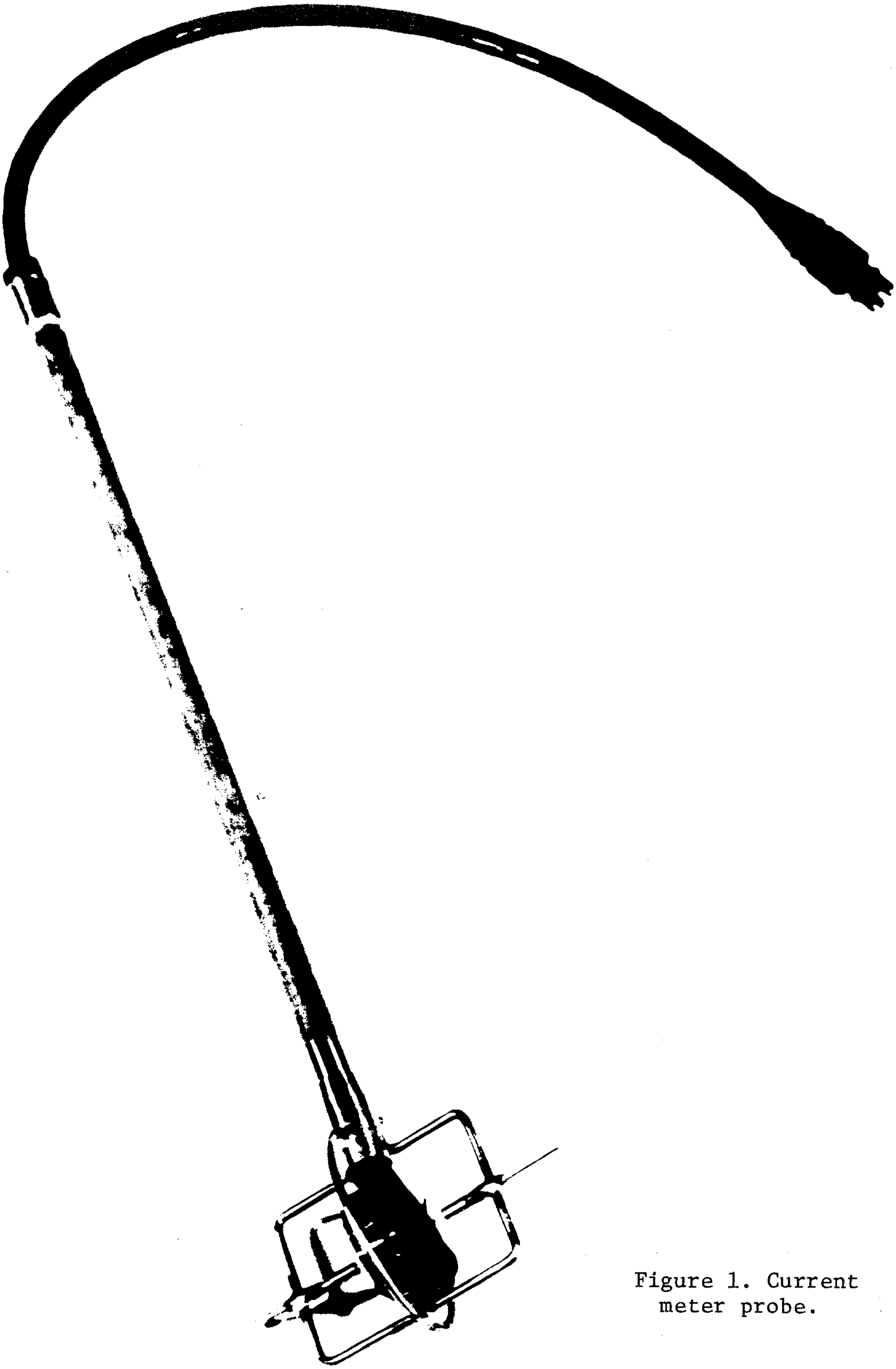


Figure 1. Current meter probe.

Two types of mirror configurations on the impellors are generally used. The first kind employs a circumferential band around the impellor on which 20 mirrors are mounted parallel to the axis of rotation. The second kind employs a fixed band mounted on the wire cage, with the mirror attached to the ends of the rotor blades. The first configuration permits better frequency resolution in turbulence studies, but the impellor has a lower effective Reynolds number and therefore a higher threshold velocity (about 2.5 cm/sec). The second configuration sacrifices frequency response for a lower threshold velocity (somewhat less than 0.9 cm/sec) and a more nearly cosine response with angle of attack. Removal of the circumferential band mounted on the frame leads to an unacceptable response at low angles of attack. It should be noted here that a rotor in a circular duct, even a short duct, has a multivalued response with angle of attack in a given quadrant which makes calculation of the actual velocity components impossible if only three current meters are used at each point. On the other hand, an unducted rotor gives values which are too low at high angles of attack.

In river and estuary studies, the banded rotors are used to obtain maximum information on the turbulence. In these situations, mean velocities range from 50 to 100 cm/sec, and the higher threshold speed associated with the banded rotors is not a problem. On the other hand, unbanded rotors are better suited for the kind of experiments described in this report because of the lower threshold speed. However, because there were neither enough unbanded rotors available nor enough funds to construct new ones, this study used banded rotors. They were satisfactory for measurements made during storms, but they were only marginal at best at other times. Any future studies should use unbanded rotors.

Fifteen banded current meters were attached orthogonally to the main frame in five groups of three. The groups were placed 1.26, 2.33, 9.08, 14.0, and 17.7 m below the base of the ice. Electrical signals were transmitted to the instruments through a special 1000' cable made by IT&T for arctic conditions. The main frame was serviced by two such cables. Each had nine signal leads and two power leads and ran from the instrument chassis to a junction box. On the other side of each of these two junction boxes were three 4m cables; to the end of each of these were spliced three 18" Marsh Marine connectors. Eighteen current meters could have been attached to the two cables; however, three current meters did not work, so a 4m cable was removed from one of the junction boxes and the hole was plugged with a standard pipe plug. A third IT&T cable was attached to a third junction box from which two of the three 4m cables had been removed. This cable was used in conjunction with three current meters mounted orthogonally on a wire lowered frame.

At the surface, the cable connects to a 15-channel instrument chassis. The first part of this unit is essentially a power-supply chassis; the second part processes the current meter data in the field. The system accepts the input dipulse signals from any 15 of the 18 current meters, then processes the signal by amplifying and clipping until a high-quality square wave dipulse results. This dipulse enters the decoding section, which gives positive or negative pulse of constant width on one of two lines depending upon the polarity of the signal. The logic is designed to reject any degraded signal. Fifteen pairs of lights on the front panel of the chassis denote the polarity of the signal on each channel; the lack of a polarity light on any channel denotes below-threshold currents, an improperly functioning rotor, or some electrical problem in that channel. Also, a horn can be made to sound when a channel shuts down, and a pen on a 20-channel event recorder is triggered and runs for the time that the channel is out of order.

Because a very exacting criterion for operation is set, these systems ensure that the data being processed and recorded on an f.m. tape recorder are valid and represent actual measurements of currents to better than 1% accuracy. The entire system uses pulse circuitry, thereby circumventing d.c. drift problems. The pulses from the decoder and logic sections are fed to (1) an analog rate meter with a 40 db/decade roll off-set at an f_o of 0.25 sec and (2) one of two analog integrators which effectively count pulses for 1000 sec ±10 msec, giving a 1000-second incremental average. The two integrators per channel are used alternately so that no data are lost during the time it takes to read the averages on the 15 channels.

Although the cards for the system had all been checked prior to the Arctic trip, the main chassis into which these cards fit was not finished until the day we left Seattle and could not be checked until arrival at Camp-200. When it was turned on, a poorly designed 24-volt power supply overheated, blew out its regulation section, and then put more than 40 volts on all the circuits originally designed for 24 volts. When the power supply went out, it took with it the digital clock which controlled the integrator and logic sections, as well as three integrator cards. Because so many of the clock components were burned out that it could not be fixed at Camp-200, a scheme was devised to replace the clock with a laboratory timer. Before this plan could be realized, the electronics engineer became ill and had to be flown to a hospital at Inuvik. At this point our only hope was to record the raw data on the Pemco f.m. tape recorder and process it after returning to Seattle.

Finally, the power supply section of the chassis was disconnected from the rest of the system and rewired so that the input signals could be recorded directly on tape. A storm came up a few hours before this rewiring job was finished, so direct recording of the storm-induced velocities in the boundary layer began as soon as the system was ready to use. All 15 current meters were operating, and 45 tapes of raw data were recorded at 7 1/2 ips. These tapes included the rest of the storm and several quiescent hours of data after the storm. Recording was stopped when the currents dropped below the threshold of all but the bottom two current meters. Because of the problems with the data analysis chassis (which have only recently been rectified), only a crude picture of the flow in the boundary layer under the ice can be reconstructed at the present time.

V. PRELIMINARY RESULTS

A. Gradient Currents

One 3-station and nine 2-station synoptic casts were obtained. The following is a summary of hydrographic station cast times.

	Hydrographic Stations		
	C-200	Leo	Aquarius
March 24	1330	1430	1330
	1630		
March 26	1030	1030	
	1330		
	1630	1630	
March 27	1030	1030	
	1330	1330	
	1630	1630	
March 29	1030	1030	
	1330	1330	
	1630	1630	
March 30	1030	1030	
	1335		

B. Current Measurements

Poor results are available from the current-meter records, largely because of equipment malfunction.

The old Braincon mod. 316 histogram meters are still the most reliable, but they have seen heavy use for over five years and are not so absolutely dependable as they were when new. Nevertheless, with proper maintenance these meters should continue to produce reliable results.

The smaller Braincon mod. 381 histogram meters do not operate dependably in water colder than 0°C. They did operate satisfactorily when extensively tested in cold rooms to -20°C, but apparently this does not completely test the clock-drive mechanism (where all the failures occurred) for use under field conditions.

The Braincon mod. 573 digital meters are of a new design. They recorded speeds well, but they did not record direction when placed in the water, although they worked properly both before and after immersion. The external--and much of the internal--design appears good, so further work by Braincon and further field testing seem indicated.

Following is a summary of meters (identified by Braincon model number) used to measure currents at the specified hydrographic stations. An asterisk indicates meters which recorded speed only. DNR means the meter did not run.

	Hydrographic Stations			
Depth	C-200	Pisces	Leo	Aquarius
10 m	#381 (14 days)			
40 m	#316 (2 days)	#381 (7 days)	#573* (8 days)	#381 (3 days)
	#573* (14 days)	#381 DNR	#381 DNR	#381 DNR
150 m	#316 (14 days)			
500 m	#381 DNR			

C. Diving Operations

1. General. The problems encountered during diving operations on arctic sea ice were similar to those encountered elsewhere. However, the solution to a problem can be more involved in the Arctic because of the scarcity or unavailability of replacement parts and materials. Even simple tasks, such as measuring or assembling equipment, can easily take two or three times as long because of weather conditions and the novelty of the situation.

The diving operation was set up so that it could be curtailed if weather conditions became unbearable or if the standard diving equipment proved inadequate. Fortunately, neither was the case. The air temperature rarely went below -25°F on the day of a dive, and even with a 10-knot wind the divers could easily get to the diving hole. The factors which we believe contributed to our success were: (a) being in a warm diving hut while suiting up, and (b) having a short, 15-meter, distance to go from the diving hut to the diving hole. In fact, so much body heat was built up in getting into the wetsuits and the other diving gear that it was a relief to enter the water. The temperature of the water was approximately 28°F. With standard diving gear this temperature was not too low for diving operations. The divers at first tried additional rubber face protectors which left no part of the face in direct contact with the water; however, conditions proved good enough that these accessories were discarded.

Because it is so easy to imagine the worst occurring beneath the ice, the possibility of claustrophobia and panic concerned us before the diving began. Fortunately, this concern was not realized; the divers were not afraid under the ice. There might have been greater cause for worry had the water been less clear or the currents stronger. Possibly the fear was subconscious and was reflected in increased air consumption. Our air supply was consumed much faster than is normal--twice as fast as in Puget Sound, for example. However, this might be attributed to two other factors. First, the divers did more than a normal amount of manual labor (carrying instruments, securing current meters, etc.); second, the respiration rate had to increase to replace the heat energy being lost to the colder water.

After the initial chill upon entering the water, the diver's body adjusted rapidly and he could carry out his work. It was relatively easy in the first 15-20 minutes to handle screws and bolt or make measurements; however, after 20 minutes a diver's hand really started feeling the cold as he lost heat to the water, and manual dexterity decreased drastically. Dives were limited to 25 minutes because of this, and also because of the rapidly depleting air supply. Generally, after a 25-minute dive, 800 psi remained in twin 53-cubic-foot tanks that had been filled to 2250 psi.

Getting out of the hole was probably the most awkward part of the entire operation. Once the diving hole was cut, the water rose into the hole to within about one-third of a meter from the ice surface. However, the slipperiness of the ice and the weight of the diving gear made it difficult to climb out that last foot. To overcome this difficulty, we simply cut good-sized steps into the ice as the hole was being made and the divers used them to climb out.

The retreat from the diving hole to the heated diving hut caused little difficulty. The divers noted a good deal of pain in their fingers as they warmed up after the first few dives; however, this was the only part of the body which appeared to get exceptionally cold. After the initial dives, even this pain noticeably lessened. It is doubtful that they were becoming adjusted to the water after so few dives; rather, it is believed that some of the nerves in the fingers had become deadened. The divers' hands recovered completely shortly after the return to Seattle.

The necessity for competent diving tenders on the surface deserves special attention. A minimum of two tenders is recommended. Ideally there would be two teams of two divers each, with one team acting as tenders for the other couple. This is not often possible; but whatever the arrangement, the tenders should know--in detail and in advance--what assistance they should provide and what procedures to follow in an emergency. It is very disheartening to have to surface and wait for an item to be fetched that could have been ready beforehand. To give an example, we had a problem with regulators freezing. When they froze on the surface, it was a great help to the divers to have ready a pail of hot water in which to immerse the second stage to free the mechanism. (Fortunately, when they froze in the water, they froze in an open position and the divers could make a safe exit.) The regulator problem is discussed more fully in the Diving Equipment section.

2. Light Conditions. We had little foreknowledge of light conditions beneath the ice. To prepare for any eventuality, we brought three underwater lighting systems to Camp-200: (a) battery-powered underwater searchlights; (b) surface-powered 100-watt sealed-beam lamps; and (c) small battery-powered strobe lights which could be attached to any item of interest and could be seen approximately 70 meters away. In the area of study, the ice reached a maximum thickness of approximately 5 meters and its snow cover averaged around 30 cm. The snow, however, did form dunes 40 to 60 cm high during major storms. Sufficient light penetrated the ice and snow cover so that diving operations were in no way hampered by darkness. If the snow covered was removed from local areas of interest, the lighting was even better. In general, the ambient light was sufficient to allow

efficient operation without the underwater search lights and sealed-beam lamps mentioned above.

The clarity of the water was another major factor which freed the divers from the need for lights. It was possible to see 50 to 70 meters in the horizontal and approximately 40 meters in the vertical. The clarity of the water and the light which passed through the cover made visibility excellent, and the divers were not limited by light conditions.

3. Diving Equipment. The diving equipment used in this study is quite similar to that employed in other cold-water areas, such as Puget Sound. Only that gear found to be particularly useful will be described here.

Standard, custom-fitted 1/4" wetsuits with an inner vest and "Farmer John" pants proved to be adequate for most of the divers' needs. The divers tried a surgical-type glove worn beneath the standard 5-finger model, but this did not help much to keep their hands warm. If a mitten instead of a glove had been used, the problem of cold hands might have been solved, but the type of work required 5-finger gloves. On future trips a glove-mitten combination may be used. This would require a 5-finger inner glove with a removable outer mitten. Most of the time the diver would wear both coverings, but for a job requiring the use of his fingers the mitten could be removed by means of a zipper or other arrangement. This combination has not yet been developed, but it appears feasible.

The amount of weight required to overcome the buoyancy of the wetsuit did not differ appreciably from the 18 pounds normally used in Puget Sound.

The problem of regulator freeze-up was mentioned earlier. It happened at least six times while under water and was disconcerting both because of the potential danger and because it curtailed the dive. We finally decided that this malfunction was caused by waiting too long out in the cold air before entering the water; the first diver to enter the water never had a freeze-up, but apparently the extra time the second diver had to wait before his turn was long enough to cause a problem. Once this was understood, only one diver came out of the diving hut and into the water at a time. This system was used for the last three dives and no trouble occurred. As a safety measure in case of a freeze-up or other underwater air problem, a float was attached to a spare tank and regulator and the divers dragged this combination with them wherever they worked for any length of time. Although it was never needed in an amergency, the divers found it very reassuring.

Probably the first safety measure that a diver would think of for work under the ice is a strong safeline. A reel-type model was purchased which permitted the line to be reeled in by the divers as they went back to the hole, thereby keeping it from tangling with the instruments. It was used as a safeline only on the first dive. Because of the extremely good visibility and the absence of strong currents, a safeline as such was deemed unnecessary. However, it was useful for measuring distances. One diver held the end of the line while the second diver swam the distance to be measured and tied a knot in the line at that point. It was then reeled back in and measured later on the surface.

One good safety item was the small battery-powered blinking strobe lights ([c], above) which each diver strapped to his arm. This was an excellent signaling device and would have been very helpful if a diver had become lost.

Because of its proven usefulness in other areas, an underwater writing pad was included in the diving gear. It might have been useful in the Arctic if the diving schedule had been freer. However, because of the limited time in the water, it was necessary to plan each dive in minute detail in advance, making sure each diver knew what he had to do and how long he had to do it. When this procedure was followed, the diving went smoothly and there was little need for the pad.

The divers learned a good deal about underwater tool handling. It is a mistake to use slotted roundhead bolts for underwater work; the divers found it almost impossible to screw in this kind of bolt in a reasonable amount of time. A speed wrench used with allenhead bolts worked quite well, but even this operation was time consuming and required dexterity. More efficient joining methods should be developed.

Socket wrenches and vise grips were found to be helpful in several instances. Equally important was a good sharp knife.

To keep from weighting down the diver with tools, they were put into a bucket suspended by a 7-pound fishing float and the whole unit moved to the work area. It worked well, but it did tend to float away. If the currents were strong they could drag the unit out of the area. One solution to this problem was to screw an ice screw into the ice and secure the bucket to it. This worked where there was a thick layer of newly formed soft ice (often found in the domes), but in most places the divers had trouble getting the screw to hold. No satisfactory method was found whereby equipment could be secured by anchoring it to the ice.

In this kind of diving it should be expected that tools will be dropped, and in 3000 meters of water they are not recoverable. The attrition rate can be decreased by tying the tools around one's wrist, but sometimes this is neither possible nor foolproof. A good supply of spares, therefore, is absolutely essential.

The last, and very important, item to be mentioned is the air compressor. The 2 CFM electrically powered model which was purchased required some special care in arctic conditions. It would not run properly when cold, so it had to be placed in the living hut, off the floor and next to the space heater. This meant that for about two hours a day, while the tanks were being filled, the hut was too noisy to stay in. Aside from keeping it warm, the compressor required little more than normal maintenance.

4. Assembly of an Instrument Frame. The first major job for the divers was to complete the assembly of an instrument frame by installing sets of current meters on it. The positions for the current meters were first measured along the frame using a meter stick. Then a junction box with its attached current meters and electrical cable was brought to the frame through the diving hole. To keep the cable from sagging and interfering with the operation, floats were tied to it at regular intervals and kept it up against the ice.

Each current meter set was held together by a PVC block which also provided a means means for attaching the set to the frame. Through the center of each block had been drilled a hole the size of the stainless steel rod. By removing a section of the block held to the main block by screws, the hole could be lined up on the rod. This section could then be replaced and screwed down solidly against the rod, securing the current meters in place. This operation was time consuming even with allenhead bolts and speed wrenches. Simple snap-in blocks would have been preferable.

After the first junction box (with its meters) was installed, the second one was added and all loose cable was secured to the frame. This was done by tying short lengths of line around the cables and frame.

We devised a satisfactory way to increase the rigidity of the three-quarter inch O.D. frame. A diver swam to the bottom of the frame with a shackle attached to a hydrowire extending back to the surface. Once he had attached the shackle to the frame, a second line lowered a 50-pound weight through the hole. The weight hung vertically below the frame until the operation was over; it was then pulled to the surface by the still-attached second line.

After sufficient current data had been taken, the divers removed all the current meters from the frame and brought them back out the diving hole. Because the core hole through which the frame had been lowered had frozen in, it was impossible to get the frame out its hole. We finally disconnected the frame from its upper section, which was imbedded in the ice, and pulled it out of the diving hole by the hydrowire attached to its lower end.

5. Topographic Measurements. We made a topographic survey because of the lack of any precise data on the small-scale (less than 20-meter wavelength) topography of the under-ice surface.

The equipment used in this survey consisted of a differential pressure transducer and its associated amplifier mounted in a water-tight PVC housing equipped with wheels and a skid. The ports of the transducer were connected to two externally mounted three-way valves which provided the necessary water contact. The underwater unit was not self-contained but required an umbilical cord from the surface to provide power for the transducer and amplifier. The cable also allowed for transmission of the signal to the surface, where it was recorded on a strip chart recorder. A system for measuring horizontal displacement along the ice was devised; it consisted of a reed switch mounted within the housing which was tripped by a large magnet connected to one of the wheels, each wheel rotation placing a spike on the record. This measuring system failed; the wheels, even equipped with spikes, did not have enough traction to rotate properly, and the weight of the magnet (2-3 pounds) did not help. Probably a carriage of this design would best be moved over the ice by small skis instead of wheels. This would require some other apparatus for measuring distance. Our makeshift solution was to lay out a precisely measured grid system and then move along it at a constant speed.

This grid consisted of a square 40 meters on a side and centered at the instrument frame. It was set up by using premeasured lengths of line which were put in place by wooden pegs. The problem with the ice screws was repeated with the pegs: it proved very difficult to hammer a peg into the hard ice. The system worked, however, because the low current speeds did not put too great a stress on the lines. It took two and one-half dives to set up the entire network. The grid is shown in Figure 2.

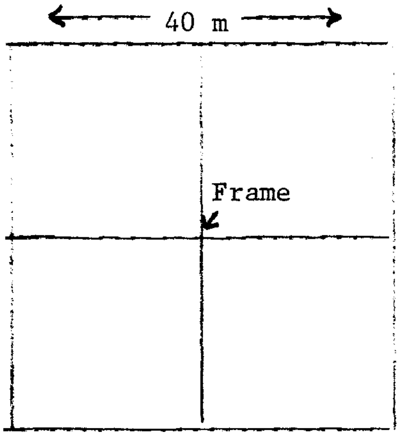


Figure 2. Grid System

Our planned method of running the grid consisted of (a) lowering the transducer into the water, (b) zeroing the unit against the ice surface, (c) closing one port, and (d) running a prearranged pattern through the grid. We not only ran the marked section but also ran the diagonals, because the frame stood out so well that from a corner one could easily head straight for the frame. Each turning point along the grid was marked by lowering the transducer unit down approximately one meter and then quickly bringing it back to its original position. This put a clear spike on the record. We were able to translate the pressure record directly into a depth by marking on the frame a one-meter distance below the ice surface. When the transducer was brought to the frame, it was lowered this distance to give a good calibration value.

The entire operation required two divers; one diver pushed the carriage along while the other handled the cables. Barring equipment failure, it would require two dives to run a complete grid of the same size again.

6. Discussion of the Topography. The topographic map, Figure 3, shows a broad plateau-like region centered near the instrument frame. This plateau is bounded by a long trough in the upper part of the map and by a dome in the lower left corner. The numbers refer to centimeters above a zero point taken as the lowest projection of the ice into the water. Therefore, the top of the dome in the lower left is approximately 2.8 meters above a horizontal plane passing through the zero point.

The region immediately around the current meter frame was chosen for its regularity and lack of appreciable relief. If the frame had been positioned closer to a dome or ridge, the current meters would have recorded wake effects which would have interfered with the Ekman layer study.

In general, the map shows a typical ice profile--typical, at least, of the ice sheet on which we were located. In all directions it was possible to see ridges extending away beyond vision. There were approximately five of these ridges in sight beyond the one portrayed at the top of the map, and they all seemed to be of the same order of magnitude. Domes with diameters of from 5 to 10 meters were also present in the area. Small-scale features were definitely lacking, probably due to the masking effect of the growing ice on small protuberances.

The map is very similar to the divers' previous descriptions of the topography. The map-making technique appears to be a good one.

7. Underwater Photography. We hoped that a series of panoramic views could be taken of the area to complement the map. An amphibious 35 mm camera equipped with a flash was used with Agfa-chrome CT-18 (ASA 50) film. Unfortunately there was not sufficient light, even with a flash, to take a good panoramic shot with film of this speed. A higher speed film may be the answer. The equipment did work well for ranges less than 5 meters, and a good underwater camera is deemed worthwhile.

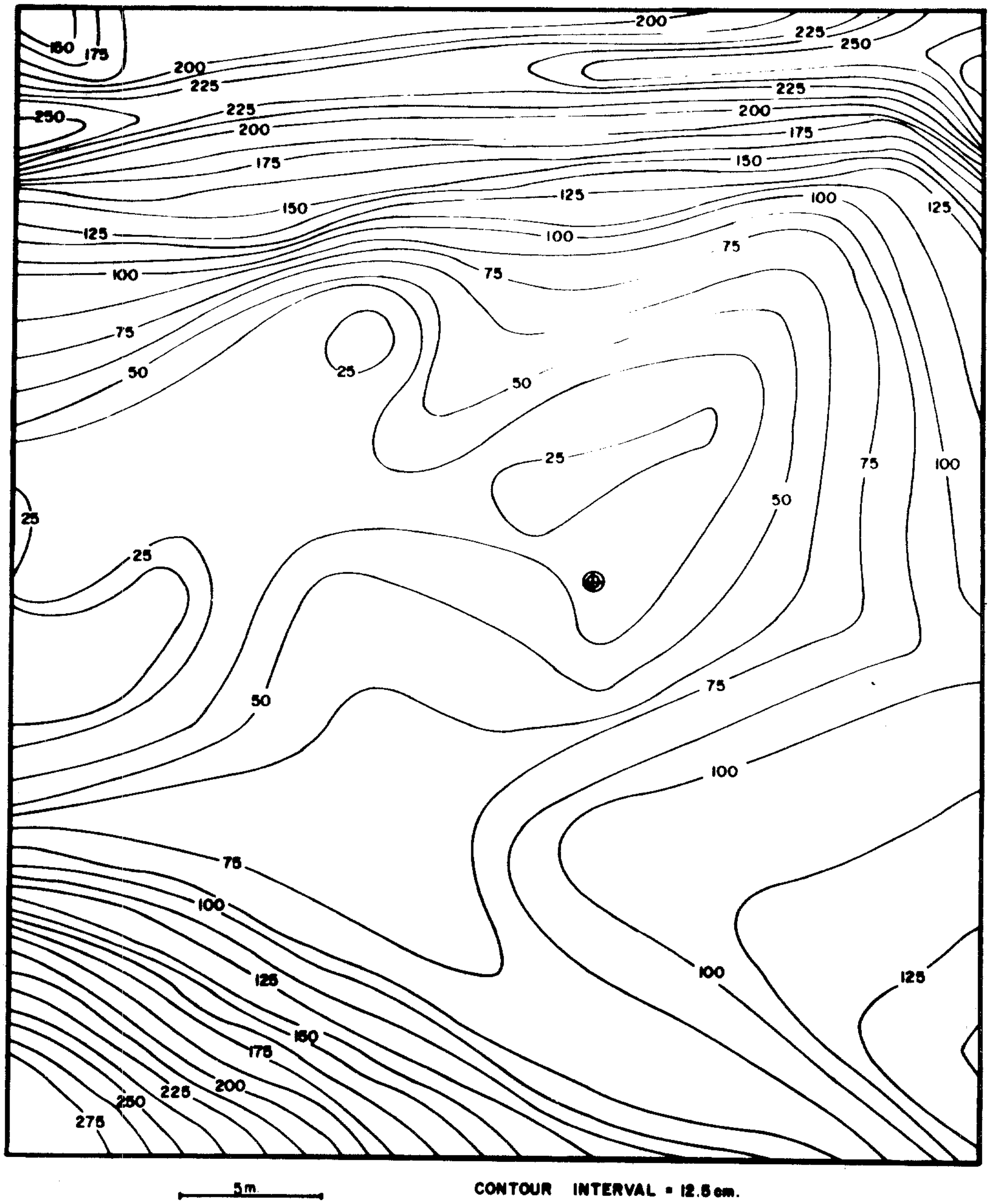


Figure 3. Under-ice topography around instrument frame. Deepest projection of ice is zero reference; contours are cm above zero reference. Cross indicates mast location.

D. Boundary Layer Studies.

Before assembling the main frame, we mounted three current meters orthogonally on a wire frame and the frame was lowered so that the meters were situated 2 m below the bottom of the ice. Raw data from these three meters were recorded on a Sanborn oscillographic recorder and were analyzed in a preliminary way in the field. During meteorologically quiet periods the vertical and cross-flow velocity components were almost always below the current meter threshold, and the during part of the time the velocity component in the direction of flow was below the current meter threshold (about 2.5 cm/sec^{-1}). The meters were no doubt working during this time because they always responded when the support wire was disturbed. Therefore, these measurements provide an upper limit for the currents at the depth during this time. However, part of the time during these meteorologically quiescent periods the horizontal velocity component parallel to the direction of flow showed a distinct wave motion for which the speed ranged from below threshold to more than 10 cm/sec and back to below threshold in about 5.5 seconds. These waves came in packets of from 3 to 30 waves. The velocity components always retained the same sign relative to the support frame, and visual observations of the frame confirmed that it remained more or less steady in direction.

Not much can be said about the main set of boundary layer measurements until they have been properly analyzed. These were made primarily during a storm in which the wind velocity averaged about 10 m/sec. and exceeded 12 m/sec only occasionally. The few sets of data which were crudely analyzed in the field showed that the magnitude of mean velocity at the bottom set of current meters relative to the ice exceeded 25 cm/sec during a good part of the storm, whereas the current speed 1.2 meters from the boundary was only about 10 cm/sec. Moreover, there was less than $\pi/2$ of angular shear between these two points, indicating that the Ekman depth under these conditions exceeded the 20 meters found by Hunkins and expected at the start of the present study. Presumably the difference was due to the time-dependent nature of the flow and the higher mean speeds in the observed situation relative to the cases studied by Hunkins.

Mean speeds during quiescent periods appear to average about 3 or 4 cm/sec at 17.7 m below the ice bottom. These values appear to increase to speeds in excess of 25 cm/sec when the wind speed exceeds 10 m/sec. The phase lag between changes in wind speed and current speed appears to be a few hours or less. Wind speeds of less than 6 m/sec seemed to have little effect on the relative flow between the water and ice even when the storm was subsiding.

E. Ice Deformation

The plans for the pilot study called for the drifting stations to be equipped with Decca Lambda navigational systems. Although the accuracy of fix within the range of operation was only in the order of hundreds of feet (best probable estimate $\simeq$ 500 ft.), strain estimates for large mesoscale strains could have been obtained had the sytems been installed. The systems were not installed because logistical support was not available to continuously man the auxiliary stations. Thus, the only strains measured by the Decca Lambda system were those provided by the occasional landings of helicopters at the auxiliary stations, the positions of which were recorded each time a helicopter landed.

Plans had also included the use of tellurometers to measure strains. Four Model MRA2 tellurometers and two sets of nickel-cadmium batteries were taken to Camp-200. We hoped to measure strains over a triangular station array, but logistical considerations as the study progressed dictated that measurements be made only along a line between Camp 200 and another remote station. Since the key stresses needed to numerically model the ice pack are believed to be those in the mesoscale region, we decided to measure strains between Camp 200 and Station Leo, a distance of about ten miles.

The tellurometer at Leo was mounted atop an ice pinnacle projecting from an old pressure ridge, with the antenna approximately twenty feet above the top of the undisturbed polar ice floes. At Camp 200 the tellurometer was mounted on a tower--or, rather, a hill--constructed of empty gasoline drums; the height of the antenna was 18 feet above the top of the undisturbed floe. The signal strength between these two stations was very strong, leading us initially to be optimistic about measuring strains over ten miles of sea ice. However, as the measurements continued, it was found that clear separation of the phase image was not occurring and that the distances measured between the stations were varying in an impossible way, with apparent strains of 15% in one hour. The scope image, instead of forming a sharp ring with a clear phase break, appeared as a doughnut ring with no discernible phase break. Ten different cavity settings were tried. The best results were obtained with a cavity setting of 4.0 at the master station (Camp 200) and 3.5 at the remote station (Leo).

Since none of these measurements was acceptable, we attempted to improve the reception by tilting the antennae at each end in the vertical plane between each station. These angles went from a few degrees to 50 degrees above horizontal. These tiltings did not result in an improved scope image. We decided that the sea ice was causing either reflections or refractions, or both, and that it was not possible to use the tellurometer MRA2 with its carrier wave of 10 cm for strain measurements at the range of 10 miles over sea ice.

To determine the maximum range over which the MRA2 could be used to measure strains, we made a series of measurements in the vicinity of Camp 200. One tellurometer was mounted on the gasoline drum tower and the other was carried by snowmobile and sled to various points along a line running northeast from Camp 200. A very good reading was obtained at a range of 5840 feet with the remote station on the same floe as Camp 200 (no pressure ridge between stations). At Station Pisces (7910.5 feet), the reading was equally good although several small ridges were between the stations. At a range of 13,730 feet the last clear readings were were obtained. Beyond this range, readings were possible but not up to the accuracy of the tellurometer (± 2 cm). At this range one could actually see changes in the fine scale readings happening at time intervals of a few seconds, and we believe that these resulted from deformations in the ice pack.

We conclude that the tellurometer MRA2 would work fine for strains of small mesoscale size (or large microscale). The tellurometer MRA3, with a carrying wave of 3 cm, has been used on the Antarctic Plateau and has achieved greater ranges than the MRA2. The MRA3, or possibly a laser strain meter, will be tried during the 1971 pilot study.

F. Special Chemistry.

Water samples were collected at various depths (2, 10, 30, 50, 75, 100, 150, 200, 250, 300, 350, 400, 450, 500 m) to be analyzed for soluble Zn and Pb by Anodic stripping method.

Water from 30, 100, 200, and 300 meters was filtered through a Gelman metrical filter of 0.47 pore size to look at various trace elements by emission spectroscopy. The filtering rates observed indicate that this water is at least two to three times cleaner in particulate matter than water from the Sargasso Sea from comparable depths.

VI. PERSONNEL

The following personnel participated in the oceanographic experiments:

Name	Title	Project
Dr. L. K. Coachman	Assoc. Prof.	physical oceanography
Dr. Knut Aagaard	Res. Asst. Prof.	physical oceanography
Dr. J. Dungan Smith	Asst. Prof.	boundary layer studies
Dr. W. J. Campbell	Affil. Assoc. Prof.	ice deformation
R. B. Tripp	Oceanographer	physical oceanography
J. Bronson	Asst. Oceanographer	physical oceanography
M. Welch	Oceanographer	boundary layer, diving
W. Deutsch	Marine Technician	boundary layer, diving
E. J. Klink	Engineer	boundary layer
T. Liffiton	Marine Technician	physical oceanography
J. Rosenberg	Graduate Student	boundary layer
E. Flourie	Graduate Student	physical oceanography, certain chemical measurements
J. O'Shea	Canadian Hydrographic Service	Commander, Camp-200
L. Lundgaard	PCSP	camp assistant
F. Alt	PCSP	camp assistant

VII. NARRATIVE

February 25. -- R. B. Tripp departed for Barrow, with most of the equipment (about 8000 pounds). The Naval Arctic Research Laboratory transported this equipment to Tuktoyaktuk in time to make the staging flights by Bristol Freighter aircraft from Tuktoyaktuk to ice floe Camp-200.

March 10. -- The remainder of the party left from Seattle, arriving at Tuktoyaktuk on the 12th. About 1000 pounds of equipment accompanied the party.

March 14. -- Four Otter flights carried the party (except for Tripp and Campbell, who arrived a day later) and about 3000 pounds of gear to Camp-200.

March 14-18. -- Erected camp and settled in. Began digging the large diving and instrument hole and opened it on the 18th. Air temperatures ranged between -25°F and -40°F; winds were from 7 to 18 knots.

March 19. -- Began cutting the hole for the main camp hydrographic station, on ice about six feet thick approximately one-half mile southwest of the camp, just off the main floe. Discovered several wiring problems in the boundary layer electronics; and a power supply burned out, taking with it the master clock and some other components.

March 20. -- Placed the main current meter string in the large hole, using a hydrographic winch (described earlier) fitted with 5/32" wire. An A-frame of 2x4 was located over the hole, and a meter wheel was suspended from it. Cut the wire and spliced it with a Micropress set. Deployed the meters as follows:

Depth	Meter
10 m	Braincon mod. 381
38 m	Braincon mod. 316
39.5 m	Braincon mod. 573 (digital)
148 m	Braincon mod. 316
301 m	Braincon mod. 381

Finished the hole for the main camp hydro station and established the hydro station.

March 21. -- Established first satellite station (LEO) approximately ten miles north of Camp-200.

March 22. -- Temperature -35°F, but no wind. Deployed two current meters at Leo: one Braincon 381 at a depth of 39 meters, and one Braincon 573 at 40 meters. Lowered a Hydro Products current meter through diving hole. Current speed ranged from 2 to 4 cm/sec during times of low wind speed.

March 23. -- Established second satellite station (AQUARIUS) approximately twenty miles northwest of Camp-200. Placed two Braincon 381 meters, at 39 m and 40 m. Lowered a frame with single orthogonal triplet of current meters through diving hole. Measured waves with approximately 5.5 sec period and 5 cm/sec amplitude.

March 24. -- Accomplished a synoptic hydrographic cast at three stations.

March 25. -- Air temperature -20°F, wind 14 knots with gusts to 18 knots. No flying. Made the first dive.

March 26. -- Located Aquarius after an extensive search. Severe pressure ridging close on all sides dictated that all equipment be removed and the camp abandoned. An overflight in the afternoon showed that the floe had completely vanished. Located a suitable place for the current meter mast.

March 27. -- Established a current meter station (PISCES) by snowmobile about one and one-half miles north of Camp-200. Two current meters from Aquarius placed at Pisces at 39 m and 40 m. Positioned the main current meter mast and one set of meters.

March 28. -- White-out precluded all flying. Made two dives, and mounted most of the current meter sets on the mast.

March 29. -- Began tellurometer measurements between Camp-200 and Leo. Placed all current meters, and secured the electrical cable to the frame. Started the topography grid.

March 30. -- Wind building up to 18-22 knots ESE. Pressure ridging occurred within 5 feet of Leo. Abandoned the camp. Made tellurometer measurements from Camp-200 out various distances to a maximum of approximately three miles.

March 31 - April 2. -- Began packing of equipment and evacuation of some personnel and equipment to Tuktoyaktuk. Ran the topography grid, but a technical failure resulted in no data.

April 1. -- Successfully ran the topography grid.

April 2. -- Made the first dive; took photographs and began to disassemble current meter mast. On the second dive, completed disassembly and removal of mast.

April 3. -- Retrieved the current meter string at main camp in the afternoon. Retrieved the current meters at Pisces and terminated the measurement program.

VIII. SUMMARY

The first AIDJEX Pilot Study, a collaboration between the Polar Continental Shelf Project (PCSP) of the Canadian Department of Energy, Mines and Resources and the University of Washington Department of Oceanography, was conducted from March 12 to April 5, 1970, to explore techniques for measuring water stress on the ice and ice deformation. Specific scientific projects were:

A. Boundary Layer Studies. Measurements of the time-dependent velocity and Reynolds stress fields at one location under a fairly smooth section of ice were made with the mechanical current meters developed by J. Dungan Smith. Fifteen meters in orthogonal triplets were placed at five locations down to 17.7 m beneath the ice. Good records were obtained over a four-day period during which a storm passed by with significant relative ice-water motion. Divers deployed the meters and mapped the under-ice topography.

B. Current Measurements. Mean flow within and beneath the boundary layer was recorded using three different models of Braincon current meters. The Decca-Lambda system of PCSP provided the navigational control. To document coherence in the current field, current records for more than a week were obtained from pairs of meters at 40 m depth (bottom of Ekman layer and above pycnocline) with horizontal separation of 1 1/2 miles and 10 miles. A pair spaced at 20 nautical miles produced only three days of record, because one of the stations, threatened by ice breakup, had to be abandoned.

C. Gradient Current Measurements. To measure the approach to geostrophy of the Arctic Ocean flow, synoptic hydrographic casts to 500 m were attempted at three stations spaced in a triangle with legs of approximately 10, 20, and 30 nautical miles. Only one 3-station cast was obtained, because the 20-mile station was abandoned. Ten paired synoptic casts were recorded over one week, at stations 10 miles apart.

D. Ice Deformation Measurements. Gross deformation of the 10-20-30-mile triangle of stations was measured twice a day by position fixing of the stations with Decca-Lambda.

For precise distance measurement of station separation, tellurometers of 10-cm wavelength were tested. Maximum range over sea ice for these instruments proved to be about 3 nautical miles.

From a scientific point of view, the preliminary results are very exciting. They provide the first fairly comprehensive set of boundary layer data made under the ice. Many new phenomena were found, such as a strong 5.5 sec period wave under the ice and a much thicker Ekman layer than described by Hunkins. In addition, the mean flow and turbulent structure of the Ekman layer have been observed through a typical arctic storm.

Some other conclusions drawn from the study are:

A. The mechanical current meter system, deployed by divers, works well in the Arctic, provides accurate stress measurements, and is a straightforward approach to the ice-water boundary stress measurement problem.

B. Under-ice topography is relatively easily mapped by divers to a distance of about 50 meters.

C. The testing and development of recording current meters for arctic operations need to be continued.

D. The methods for monitoring ice deformation require further conceptual study and equipment development.

E. More pilot studies are required to work out many of the technical details to ensure the scientific success of AIDJEX. A second AIDJEX study is now being planned for spring 1971, and will be addressed to much-improved techniques for executing all these projects. Particular attention will be given to more extensive use of the stress-measuring equipment, better techniques for following ice deformation over different horizontal scales, and finding the best current meters for arctic conditions.

During 1970, two diver-oriented experiments relevant to AIDJEX were carried out in the Arctic. The first of these is described on page 20 of this Bulletin. The second experiment was carried out by the U.S. Naval Oceanographic Office and is included here because of its relevance to future AIDJEX oceanographic investigations.

AN ARCTIC UNDER-ICE DIVING EXPERIMENT

by

Patrick Martin
U. S. Naval Oceanographic Office
Washington, D.C.

The U.S. Naval Oceanographic Office initiated an under-ice arctic diving experiment to determine equipment and techniques suitable for detailed survey of the underwater portion of ridges. Although a few under-ice dives had been made in the Arctic, little summary information was available in print. After discussion and review of previous experience, a field party was deployed in November, 1970, to the Naval Arctic Research Laboratory, Barrow, Alaska.

Two teams of two divers each made daily dives adjacent to the beach at Barrow and, later, at the edge of Fletcher's Ice Island, T-3. Sunlight did penetrate the 12-14 inches of shore-fast ice at Barrow, but the available moonlight at T-3 was not apparent under the ice there, which was 13 to 15 feet thick. The water temperature was about 29°F for all dives, with currents about three-fourths of a knot at Barrow and negligible at T-3.

Twenty team dives were made on ten diving days during a two-week period. Average dive duration was one hour; the minimum was 25 minutes on the first dive. After tailoring suits, a maximum duration of one hour 55 minutes was achieved. Three different diving suits were evaluated, as were several demand regulators and various underwater lights. Air tanks were filled by a gasoline-powered air compressor in temperatures as low as 39°F.

Both a well-tailored wetsuit and a constant-volume drysuit gave thermal protection adequate for the conditions encountered. A poorly tailored noncompressible suit was not adequate. Cold hands often limited the duration of the dive. Neopreme gloves with good fit at the wrist seemed to be the best combination with the materials at hand. Keeping the hands warm longer would significantly increase quality and quantity of diver work.

Each diver carried two tanks, each with a separate regulator so that an entire backup system was immediately available at all times. Several models of single-hose regulators were tested and were found to freeze, usually in a partially open position, after several minutes' use. All such regulators tended to freeze, although occasionally a regulator would function without failure. The double-hose regulator tested never froze through use under water, and only once when tested in very cold open air. Moisture in the air tanks can cause freezing at the coupling to the regulator, so care should be taken that the tanks are clean and dry inside and that they are filled with dry air.

Two 1000-watt underwater lights were used and worked well. At T-3, divers were able to see such a light, when pointed their way, from about 550 feet, so that they provide a good orientation reference. Small battery-powered lights also worked well and were a convenient aid. One model was especially convenient; it was attached to the wrist, thus leaving the hands free.

All dives were made with a 150-foot polypropelene line attached to each diver and tended at the surface by the other team. A simple sequence of pulls on the line provided valuable communication with the divers.

At Barrow, the divers investigated a block of ice grounded in about 15 feet of water. They found horizontal extensions and large irregularities in the underwater mass. Surfaces eroded by current were noted on this block and on the edge of T-3. Biological samples taken at Barrow included kelp, jellyfish, fish, worms, isopods, and several amphipods which lived in the ice-water interface.

At T-3, an unusual fungus was collected. Attempts were made to sample an acoustic scattering layer at 123 feet which was clearly visible as bioluminescence. The contact between T-3 and sea ice was measured and photographed. A large fracture extending into the island was observed. The change in slope from the horizontal sea ice to the near-vertical edge of the island took about three feet; this edge extended down to about 65 feet.

Samples of the skeletal layer at the sea ice-water interface were brought to the surface and preliminary measures of the distribution of thickness of this layer were made around the diving hole. Thicknesses of a few inches were predominant, and the lattice had some strength within itself and its attachment to solid ice.

A team of experienced divers was able to work under arctic sea ice to sufficient depths, distances, and durations to make detailed measurements of the underportions of ridges. Experience with a variety of equipment and techniques should permit improvements in safety and work capacity of divers under sea ice.

Individuals Participating

James P. Welsh	Oceanographer	Naval Oceanographic Office
Patrick C. Martin	Oceanographer	Naval Oceanographic Office
Chester V. Bright	Diving Officer	Naval Oceanographic Office
James E. Turcotte	Oceanographer-Diver	Naval Oceanographic Office
H. Doug Huddell	Oceanographer-Diver	Naval Oceanographic Office
Wallace T. Jenkins	Oceanographer-Diver	Naval Ships Research and Development Laboratory

Acknowledgments

The Naval Arctic Research Laboratory and the U.S. Air Force provided logistical support for this operation. The U.S. Naval Ships Research and Development Laboratory, Panama City, Florida, contributed valuable personnel and equipment. The Department of Oceanography, University of Washington, offered advice and arctic diving and lent their hut and hole at T-3. This assistance is appreciated.

1971 AIDJEX WATER STRESS PILOT STUDIES

INTRODUCTION

by

J. Dungan Smith

A field program similar to the 1970 AIDJEX pilot study is planned for March 1971 at the Polar Continental Shelf Project ice floe camp (Camp 200) in the Beaufort Sea. The oceanographic goals of this program are (1) to provide a comparison of possible methods of measuring stress transmission between the Arctic Ocean and its cover of sea ice and (2) to provide background information on several questions critically important to designing the main phase of AIDJEX.

Within this second goal fall such questions as whether the interior flow in the Arctic Ocean is in geostrophic balance; what level of coherence in the arctic water layer (about 50 meters below the ice cover) can be expected on scales of a few miles to a few tens of miles; whether transient currents in the upper pycnocline region are important to sea-ice deformation; whether local water-stress measurements can be extrapolated to the regional scales of concern to AIDJEX; whether the effects of local topography of the oceanic boundary layer can be adequately accounted for; and whether the effects of unsteadiness in the boundary layer can be handled as it affects the water-stress problem.

Following the same procedure as in 1970, Camp 200 will be split into subcamps, each a more or less self-contained unit handling its own logistics to suit the work it is doing. Present plans call for a Canadian Department of Energy, Mines and Resources camp, an AIDJEX water-stress camp, and possibly an AIDJEX air-stress/ice-morphology camp. Each will house and feed from 12 to 15 people. In connection with the water-stress camp, two small hydrographic stations with two people each will be located on the floe ice about 10 and 20 miles from Camp 200.

Three projects will operate through the water-stress camp:

(1) an Ekman boundary layer study under the direction of Dr. Kenneth Hunkins of the Lamont-Doherty Geological Observatory, Columbia University;

(2) a boundary layer investigation directed by Dr. J. Dungan Smith, Departments of Oceanography and Geophysics, University of Washington;

(3) an interior-flow project under the direction of Dr. L. K. Coachman, Department of Oceanography, University of Washington.

The first two of these studies will be located entirely at the main camp and will require three and seven men, respectively. The interior-flow project will operate with two men at the main camp and two men at each of the outer hydrographic stations.

The abovementioned projects are described on the following pages. Since Smith's and Coachman's projects were combined in a joint proposal, their project descriptions are also combined under a University of Washington heading.

LAMONT MEASUREMENTS OF WATER STRESS AND OCEAN CURRENTS

by

Kenneth Hunkins

Background

The objective of this AIDJEX project is the measurement of the stress on the ice pack and its ensuing deformation. One of the important stresses is that of the water on the underside of the ice. In general this will be a drag, tending to retard the ice which is being driven by the wind.

The drag caused by the bottom of the ice will be a combination of skin friction and form drag. Skin friction will dominate for relatively smooth, level floes. Form or pressure drag will domiante for heavily hummocked areas with many pressure ridges. Rough calculations, based on our meagre knowledge of ice roughness statistics, indicate that the two types of drag will be of about equal importance. It will be necessary ultimately to arrive at effective drag coefficients for various parts of the AIDJEX array which will be used for calculating the stress from the formula

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

where

τ = water stress,

ρ = water density,

C_d = effective drag coefficient, and

V = relative velocity between ice and water at a fixed depth.

The effective drag coefficient will depend on the roughness of ice in the particular area. Profiles of under-ice roughness will assess the statistics of ridge roots and smooth ice. Then, based on a knowledge of the form and friction drag of these features, an effective drag coefficient can be assigned to the area. Emphasis in the pilot study will be on developing techniques for evaluating form and friction drag beneath different types of ice.

Two different techniques have been used with some success for the measurement of friction drag beneath pack ice: the profile method and the eddy flux method. The profile method utilizes a vertical string of current meters to give a profile of velocities. Profiles in both the frictional boundary layer and the Ekman boundary layer have been used in the past to measure water stress. Untersteiner and Badgley (1965) measured current profiles to a depth of four meters. Their results, in the frictional boundary layer, were interpreted in terms of Prandtl theory. Hunkins (1966) measured current velocities to a depth of 32 meters which he interpreted in terms of Ekman layer theory with a thin Prandtl-type layer immediately below the ice. These two investigations yielded roughly equivalent results. When translated into terms of Prandtl theory, the results of Hunkins are equivalent to a roughness length of about 1 cm. Untersteiner and Badgley found the roughness length to vary widely around an average of 2 cm.

Soviet workers have measured Reynolds stresses beneath an ice floe using a hot-wire instrument (Kolesnikov et al., 1965). Their results with the eddy flux method bracket the stress values found by the profile method as determined by Hunkins.

Ocean currents beneath the ice are in part generated by the wind-driven ice. At times these currents may persist after the ice stops moving. In this case the water stress may be a driving force rather than a drag. For this reason it is desirable to better understand the complex system of transient and permanent currents in the upper layers of the Arctic Ocean. Current observations in these upper layers have revealed swift currents in the region between 50 and 100 m (Belyakov, 1968) and between 100 and 200 m (Galt, 1967). Further observations of these currents, as yet unpublished, have been made by Hunkins in 1968 and 1970 at T-3. The relation of these relatively extra-swift currents to ice drift is not clear, and further investigation is necessary.

Research Plan

(1) Water stress will be determined by the Ekman spiral method using a vertical string of Savonius rotor current meters. A profile of currents through the Ekman boundary layer will be obtained continuously as a function of time. This string of meters will also furnish data on the ocean current behavior in the upper layers. Output from the speed and direction sensors will be carried to the surface by a cable. The signals will be converted to analog voltages and recorded with a multipoint servo recorder. The analog charts will be later digitized at Lamont in the interests of economy and field simplicity. The current meter system and data reduction method have been developed over several years of research at Fletcher's Ice Island (T-3). However, there has been no opportunity to make boundary layer measurements at T-3 because of the large draft of the ice island.

It is expected that the Ekman-layer method may be most effective at the lower wind and ice speeds, with the profile approximating a simple Ekman model. At higher speeds, instability will probably produce helical vortices. Under unsteady conditions, inertial oscillations (period approximately 12 hours in the Arctic Ocean) are commonly observed and are to be expected theoretically (Hunkins, 1967). Averaging procedures will be used to arrive at the mean Ekman flow to be used for stress determination.

(2) A hot-semiconductor or hot-wire current meter will be developed for measuring water stress by the eddy flux method. The eddy flux (or Reynolds stress) method provides a desirable supplement and check for the Ekman method of part (1). The aim is to develop an array of hot-wire instruments with directional sensitivity and response time in the neighborhood of 1 sec. Measurements will be made in the frictional boundary layer, within which stress is independent of height. This layer extends about 1 m below the lower ice boundary. The turbulent momentum flux results in a stress,

$$\tau = \rho\, u'\, w'$$

where

ρ = water density,

u' = horizontal current fluctuation in direction of mean horizontal flow,

w' = vertical current fluctuation.

The stresses determined by this method will represent the average stress over a limited area in the vicinity of the instrument. These values may then be compared with the Ekman method which should integrate stress over a much larger area since the Ekman boundary layer is between one and two orders of magnitude thicker than the frictional boundary layer. The comparison should provide some assessment of drag provided by different types of ice, smooth and hummocked.

The hot-wire instrument is still being developed. It is hoped to have a prototype for the 1971 pilot project, but there is a possibility that it will not be ready for field use until 1972.

UNIVERSITY OF WASHINGTON WATER STRESS STUDIES

by

L. K. Coachman and J. Dungan Smith

The 1971 project objectives are the same as those of the 1970 study: (1) measurement of the time- and space-dependent velocity and Reynolds stress fields in the boundary layer under the ice, with typical topography, using the mechanical current-meter systems of Klink and Smith; (2) current measurements to relate the deeper flows to those in the boundary layer and to determine the horizontal coherence of the flows at various scales up to about 30 miles; (3) hydrographic measurements to determine the approach to geostrophy of the Arctic Ocean flow; and (4) accurate positioning of stations by Decca-Lambda to permit strain calculations.

Boundary Layer Measurements

In the 1970 pilot study (in this Bulletin) we employed a single instrument frame under the ice situated in the same position throughout the experiment. We expected to have difficulties due to nonuniform flow, so we made every effort to find a flat-bottomed piece of ice. However, we discovered that the bottom of the ice was not flat; it was composed of depressions and domes, ridges and valleys, with spacings of a few tens of meters. Our sample of the polar ice is small, but we see no reason to believe that smoother ice is more typical than the type of ice in which we worked. Moreover, this opinion is enhanced by the available nuclear submarine echo-sounding profiles of the underside of the ice. If our sample is indeed typical, the magnitude and steepness of the under-ice topography eliminates any possibility of using the standard frictional boundary layer profile methods to determine the under-ice stress and velocity fields. The question then arises as to whether the Ekman layer profile method used by Hunkins (1966) can be substituted for frictional boundary layer profile methods and whether his method can be used in unsteady flow. It is imperative to examine the validity of this procedure before continuing with routine measurement of this type in the main phase of AIDJEX.

As described previously, the natural boundary layer flows are unsteady as well as nonuniform. Moreover, the periods of greatest interest to ice deformation problems occur during storms, during which the flow is unsteady and the stresses are many times stronger than the steady flow stresses. Therefore, a comprehensive set of data must include a long time series of velocity and Reynolds stress measurements at a single location.

To properly measure the flow in the boundary layer under an ice sheet of nonuniform thickness, information is needed simultaneously from many suitably located strings of current meters. Unfortunately this is financially and logistically impractical. However, as long as the flow varies only slowly with time, stationary and movable masts can be used to obtain the necessary data. In this study we plan to instrument three masts: one fixed and two movable. We will use two movable masts because, although on most days we can expect to make only two dives, we want to measure currents at seven, rather than four, locations per day. The tape recorders are expensive, so we plan to record data from only two masts at a time, switching between the movable masts every forty minutes or so. The currents may change slightly with time; it is therefore essential to record currents simultaneously at two masts.

The under-ice topography will be measured and analyzed by the same procedures as employed in the 1970 study. Currents will be measured by meters of the type described in the 1970 report. They will be mounted n orthogonal triplets at five positions on each of three masts. Data from these meters will be transmitted from the masts through three special instrument cables designed for use in -50°F temperature. These cables will terminate in a main switching box unit which will also contain the power supplies for the current meter lights. From the switching box the signals will lead to the two Pemco 120 tape recorders, a monitor scope bank, and the preliminary processing chassis. At this point the signals from any cable can be switched to any of four output cables. Ordinarily, the signals from the stationary frame will lead to the first tape recorder, and the signals from the movable frame will be switched to the second tape recorder alternately, with about a 40-minute cycle time. The inputs from all the frames will be monitored periodically with the monitor scope section to make sure the current meters are operating correctly. In addition, the signals on the tapes will be monitored periodically to make sure the tape recorders are working correctly. This type of continuous signal monitoring is absolutely necessary to obtain error-free, high-quality current data.

The processing chassis can be connected to any of the input signals to provide analog outputs or pulse outputs which drive a 14-channel up-down counter unit capable of giving the average currents at any time. This latter unit will be used to get average currents at each of the frames at least once at each location, thus providing the necessary field monitoring of the experiment. For example, if two closely spaced masts show strange mean velocity profiles, we will know that additional data must be taken between these positions; if two stations show very little variation, we will know that we can widen the station spacing. Field monitoring of this type is essential if maximum information about a complicated flow field is to be gained from relatively few sensors. The ability to process some data in the field makes the difference between a well-designed experiment which can be altered to fit the environment when necessary and blind data gathering.

Final processing of the data will be done in Seattle on the University of Washington CDC 6400 computer. The data will be read through the Atmospheric Sciences Department data processing system, which is ideally suited to accept pulse data from our tape recorders and convert it to "instantaneous" velocities stored on digital magnetic tape compatible with CDC 6400. Mean velocity fields and Reynolds stress fields will be calculated. In addition, the frequency composition of the Reynolds stress tensor and several other standard statistical relationships will be analyzed using available fast Fourier transform programs.

The structure of the mean fields will be examined using the measured bottom topography and nonuniform turbulent boundary layer theory. A similar approach has been used by Smith (1969, 1970) to interpret nonuniform flow measurements in rivers and estuaries, although three-dimensional and Coriolis effects must be included in the analysis of the under-ice flow.

Interior Flow Measurements

Figure 1 illustrates schematically the proposed pilot study. The base camp will be on an old polar floe suitable for long-term occupancy. The boundary layer study equipment will be deployed at base camp. Wind will be monitored with a recording anemometer system to correlate with the water stress, and recording associated with the boundary layer studies will be accomplished here. Decca-Lambda gear will be used to monitor the station position.

The two satellite hydrographic stations will be placed on ice sufficiently thick to last the duration of the experiment. One building at each station will serve both as hydrostation and as housing for the two-man team. Decca-Lambda gear will monitor the station positions to follow the deformation of the triangle and provide the information for converting the measured relative water motion to true currents.

The main string of current meters will be located in the middle of the triangle to measure currents at the following depths:

10 m	Ekman layer
50 m	surface (arctic) water beneath Ekman layer
100 m 150 m 250 m	top, middle, bottom of pycnocline
500 m	core of Atlantic water

These depths include the major components of the water mass structure and flow regime (for example, see Coachman, 1968).

At the apices of the station triangle, meters will be used at 10 m and 50 m depth, allowing examination of coherence of horizontal flow over space scales of 5 to 30 nautical miles. These depths are within and just beneath the frictionally influenced layer, the seemingly most logical levels to monitor currents for ultimately relating the flow field to the stress field.

Hydrographic casts will be made simultaneously every few hours for at least ten days. Temperature and salinity will be sampled at depths of 30, 60, 100, 140, 180, 220, 260, 300, 350, and 500 m. (In contrast, the equivalent program in the open sea would require four ships.) By comparing

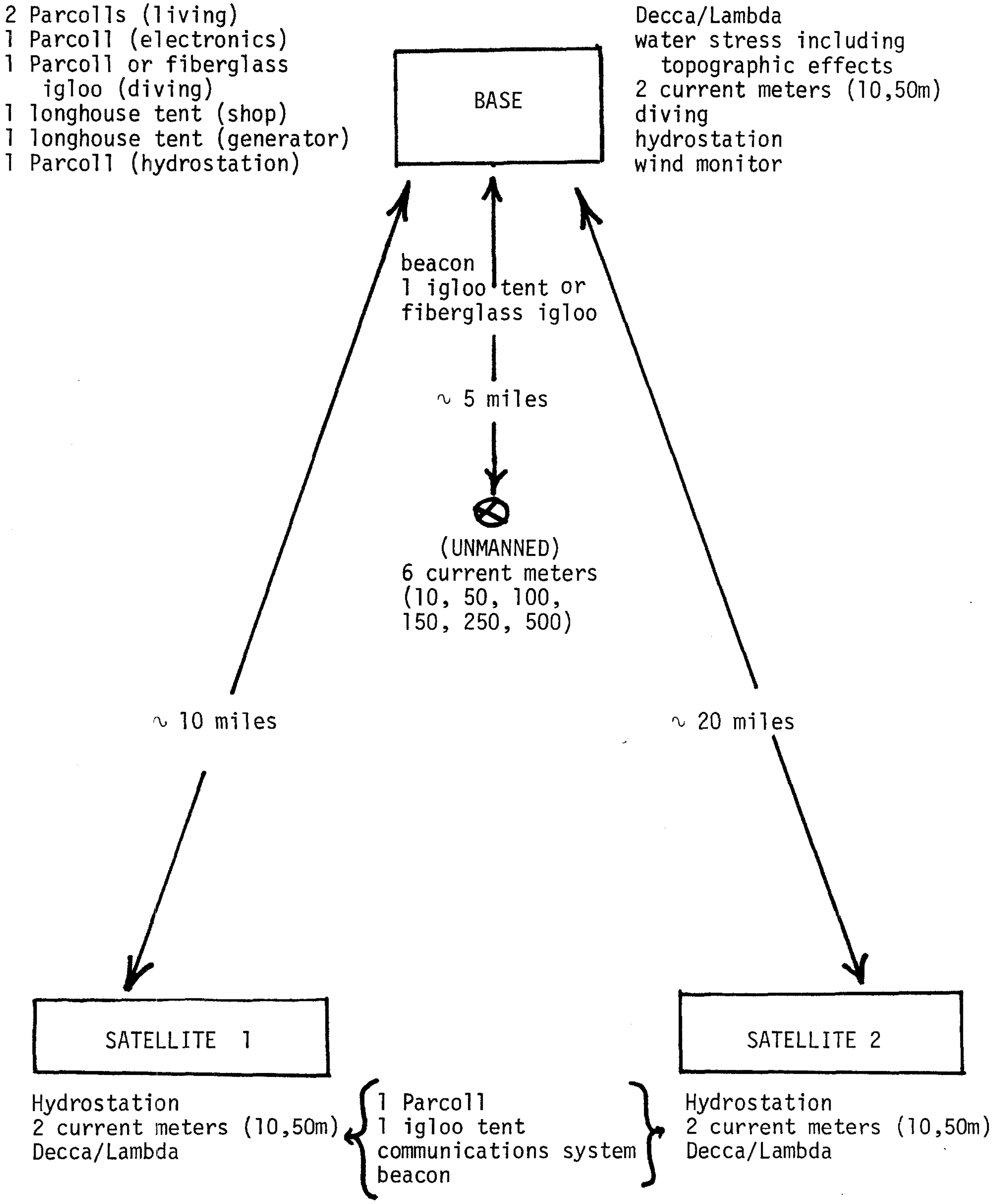


Figure 1. Schematic illustration of 1961 water-stress study.

the observed currents with those computed from temperature and salinity, the experiment will help to resolve two important problems: one, separating the two geostrophic modes, barotropic and baroclinic; and two, determining the degree to which geostrophy is approached. Information about these questions is fundamental to the most efficient and economical design of AIDJEX, and the solutions will be of great general oceanographic interest.

REFERENCES

1. Belyakov, L. M. 1968. The role of currents in the development of the Pacific water layer in the eastern Arctic Basin. Problems of the Arctic and Antarctic, 28, pp. 29-34.

2. Coachman, L. K. 1968. Physical oceanography of the Arctic Ocean: 1965. Pp. 255-280 in Arctic Drifting Stations: A Report on Activities Supported by the Office of Naval Research. J. E. Sater, Coordinator. Arctic Institute of North America.

3. Fallor, A. J. and R. Kaylor. 1969. Oscillatory and transitory Ekman boundary layers. Deep-Sea Research, Supplement to Vol. 16, August, pp. 45-58.

4. Galt, J. A. 1967. Current measurements in the Canadian Basin of the Arctic Ocean, summer, 1965. U. Wash. Dept. Ocean. Tech. Rpt. No. 184, 17 pp.

5. Haltiner, G. and F. L. Martin. 1957. Dynamical and Physical Meteorology. McGraw-Hill, New York.

6. Hsueh, Y. 1968. Viscous fluid flow over a corrugated bottom in a strongly rotating system. Phys. of Fluids, Vol. 11, No. 5, pp. 940-944.

7. Hunkins, K. 1966. Ekman drift currents in the Arctic Ocean. Deep-Sea Research, 13, 697-620.

8. ------------ 1967. Inertial oscillations of Fletcher's Ice Island (T-3). J. Geophys. Research, 72, pp. 1165-1174.

9. Kolesnikov, A. G., N. A. Pantaleev, and V. N. Ivanov. 1965. Experimental studies in the turbulent layer under drift ice. Izv., Atmos. and Ocean Physics Series, 1, 1310-1318.

10. Miles, John W. 1967. On the generation of surface waves by shear flows, Part 5. J. Fluid Mech., Vol. 30, Part 1, pp. 163-175.

11. Neuman, G. and W. J. Pierson. 1966. Principles of Physical Oceanography. Prentice Hall.

12. Reeder, C. M. 1970. An Experimental Study of Nonuniform Flow in a Flume with a Wavy Bed. Master of Science Thesis, University of Washington.

13. Schlichting, H. 1960. Boundary Layer Theory. 2nd ed. McGraw-Hill, New York.

14. Smith, J. Dungan. 1969. Studies of nonuniform boundary-layer flows. Part 2 of Investigations of Turbulent Boundary Layer and Sediment-Transport Phenomena as Related to Shallow Marine Environments. Final Report for the U.S. Atomic Energy Commission on contract AT(45-1)-1752, Ref. A69-7. Dept. of Oceanography. U. of Wash.

15. ------------ 1970. Stability of a sand bed subjected to a shear flow of low Froude number. Journal of Geophysical Research, Vol. 75, No. 30, pp. 5928-5940.

16. Sternberg, R. W. 1968. Friction factors in tidal channels with differing bed roughness. Marine Geology, Vol. 6, pp. 243-260.

17. Untersteiner, N. and F. Badgley. 1965. Roughness parameters of sea ice. Journal of Geophysical Research, 70, 4573-4577.

18. Untersteiner, N. and K. Hunkins. 1969. Arctic Ice Deformation Joint Experiment. Final Report, Naval Contract N00014-67-A-0103-0004 (mimeographed).

19. Untersteiner, N., G. A. Maykut, and A. S. Thorndike. 1970. AIDJEX Arctic Ice Dynamics Joint Experiment Part I: Scientific Plan. Univ. of Wash. Div. of Marine Resources (mimeographed).