

Bulletin No. 9  
AIDJEX PLANNING CONFERENCE  
August 1971



# AIDJEX BULLETIN

ARCTIC  
ICE  
DYNAMICS  
JOINT  
EXPERIMENT

AIDJEX BULLETIN No. 9  
August 1971  
AIDJEX Planning Conference

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*Cover: Photograph of Camp 200, site of the 1971 AIDJEX pilot study, taken during a remote-sensing flight at 3,500 ft. by the NASA 990 research aircraft Galileo. The camera used is a Wild-Heerbrugg RC-8 metric mapping camera installed in the NASA aircraft.*

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AIDJEX PLANNING CONFERENCE

Arctic Ice Dynamics Joint Experiment  
Division of Marine Resources  
University of Washington  
Seattle, Washington 98105

*Division of Marine Resources*  
*UNIVERSITY OF WASHINGTON*

*The AIDJEX Bulletin aims to provide both a forum for discussing AIDJEX problems and a source of information pertinent to all AIDJEX participants. Issues--numbered, dated, and subtitled--contain technical material closely related to AIDJEX, informal reports on theoretical and field work, translations of relevant scientific reports, and discussions of interim AIDJEX results.*

*Bulletin No. 9 contains the proceedings of the AIDJEX planning conference, an explanation of the AIDJEX organization, and a paper by S. I. Pai and Huon Li on pack-ice dynamics.*

*You are encouraged to send your comments and contributions to*

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## PREFACE

A meeting was convened at the University of Washington Lake Wilderness Conference Center on June 21-22, 1971, to review recent progress toward the scientific goals of AIDJEX and to discuss plans for the 1972 Pilot Experiment. Over eighty representatives from universities, government laboratories, private concerns, and funding agencies attended.

We have accumulated considerable field experience and theoretical understanding of AIDJEX problems since the Scientific Plan was issued in May 1970. Progress reports and discussions during the conference confirmed our feeling that we have advanced sufficiently to warrant the preparation of a revised version of the Scientific Plan. Similar conclusions have been reached by the NAS AIDJEX Review Board.

As the AIDJEX experiments become more complex, and the logistic burdens more severe, an increase in the intensity of coordination and management seems inevitable. To this end, changes in the administrative structure have been introduced and are described toward the end of this report. It is evident from the minutes of this meeting that AIDJEX continues to be a joint enterprise, deriving its strength from the motivations of many individuals and agencies. The manner in which the participants of this meeting have contributed time and expertise promotes confidence in our ability to conduct the cohesive field experiments necessary for the success of AIDJEX.

The conference was coordinated by R. Trowbridge of the AIDJEX Office. Minutes of the meeting were recorded by S. Hodge.

N. Untersteiner and J. O. Fletcher

## INTRODUCTION

This report contains a condensed and somewhat edited account of the Lake Wilderness Conference. We have taken the opportunity of this introduction to summarize the still rather tentative plans for the 1972 Pilot Experiment, and to emphasize those particular aspects of the program in which notable progress has been made or in which special effort is required.

Plans for the 1972 Pilot Experiment call for three manned stations, designated Main, Satellite East, and Satellite North, and arranged in a 100 km triangle located several hundred kilometers northeast of Point Barrow. Observations at the satellite stations will be limited to Transit Satellite fixes and deep oceanographic measurements. In addition to these observations, determinations of wind stress, water stress, and mesoscale strain will be made at the Main Station. The 1972 Pilot Experiment will also enable us to assess the operation of several recently developed systems, including the unmanned submersible, the automatic data buoy, and certain airborne sensors.

A problem fundamental to the design of AIDJEX is how to obtain regional wind stress values. The most promising approach seems to be to deduce the wind stress from the synoptic scale surface pressure field. Pressure readings from a network of automatic data buoys would be interpreted using the geostrophic approximation; an empirical relationship would then relate the geostrophic wind to the surface stress. Although this scheme has been generally agreed upon, several questions remain open: what are the preferred formulations for relating geostrophic wind to surface stress? what precisely are the specifications the buoys must meet? what is the optimum geometry of the buoy array? how well will stresses obtained in this manner agree with

boundary layer stress estimates? Further field work and analysis will be required before these questions can be answered.

Agreement on the appropriate grid size for taking pressure observations cannot be reached without new field data. Therefore, it is of the utmost importance that during the next pilot study the atmospheric pressure field be observed on at least two scales, 100 km and 300-400 km.

A similar problem exists in the choice of scale for the strain measurements. The appropriate scale must be large enough so that the effect of the fluctuating velocity of any particular station does not obscure the mean deformation of the array. Intuitive arguments, originally advanced in the Scientific Plan, suggested 100 km as an appropriate linear scale. Analyses of the paths of previous drifting stations indicate that a larger grid size is not needed, but the data contain no information on scales of less than 100 km. The argument that the grid size must be large compared to the largest expected ice feature still seems valid, and places a lower limit of about 100 km on the scale length.

Results from 1971 mesoscale measurements suggest that typical daily strain rates on that scale are of the same order as typical daily strain rates on the macroscale. Simultaneous measurements of strain rate on meso- and macroscales will be made for the first time in 1972. Comparison of the 1972 macroscale (100 km) and mesoscale (10 km) strain measurements is expected to confirm this choice of scale length.

Automatic data buoys are an integral part of AIDJEX, both as a tool in evaluating the basic relationship between atmospheric pressure and wind stress and as a future source of data for routine model calculations. Although the buoys may be designed to meet other requirements as well, the minimum AIDJEX requirements are observations of pressure and position, and the ability to store and transmit this information. Numerous problems exist in the design of such buoys for use in the arctic environment. The

encouraging reports of B. Buck (Delco) and R. Francois (APL-UW) in the following minutes offer hope that suitable buoys may be available for testing in the 1972 Pilot Experiment.

The unmanned submersible under development at the Applied Physics Laboratory of the University of Washington is scheduled for an arctic field test in 1972. This vehicle may be used to map the underside of the ice during AIDJEX.

Additional, and particularly promising, technological progress has been made with certain remote-sensing techniques tested on the NASA flights during the 1971 Pilot Study. For instance, there are indications that passive microwave sensors (50-100 cm) can be used to determine ice thickness. Results from these flights will be reported elsewhere. It is hoped that similar flights can be made during the 1972 Pilot Experiment.

## I. MINUTES (CONDENSED)

Introductory remarks were given by Fletcher and Untersteiner. The purpose of the conference was outlined: to review general problems and current and past activities, and, on this basis, discuss plans for the 1972 Pilot Experiment.

### A. SCIENCE SECTION

#### 1. Numerical Modeling

Rothrock reviewed the current status of efforts to model components of the ocean-ice-atmosphere system. He emphasized that a primary goal of AIDJEX is to improve our understanding of many physical processes involving sea ice so that theoretical models of this system can be improved. He mentioned the following points:

- a. The formulation of a model will depend on the immediate goal. Separate models may be required to simulate long-term statistical properties and to make short-term predictions. This dichotomy currently exists with oceanic and atmospheric models and will also exist with modeling sea ice.
- b. The principal problems associated with the oceanic boundary layer are: (1) the stress resulting from interaction of the boundary layer with the topography of the bottom surface of the sea ice, and (2) the convection in the upper layers which takes place before and during freezing. J. D. Smith is working on the first problem, Lewis and Foster on the second.
- c. Problems in modeling the atmospheric boundary layer include (1) a theoretical description of the large-scale structure of the planetary boundary layer, (2) estimation of the surface traction

exerted on the ice by the wind, and (3) thermodynamic modifications of the boundary layer due to the presence of open water.

d. Treatments of the mechanics of sea ice suffer from a lack of (1) a large-scale constitutive equation for sea ice, (2) an understanding of the mechanics of fracturing and ridging, and (3) a suitable method for incorporating thermodynamic processes into the continuity equation.

e. The thermodynamic model of Maykut needs to be extended to predict the production of new ice in leads. More information from the field is needed on the rate of production of ice in new leads.

#### Discussion:

Campbell reemphasized the need to consider the scales of motion involved and suggested that different rheologies might be needed for different scales. Li mentioned that continuum mechanics may not be the only method to describe the motion and that perhaps a statistical mechanics point of view should be tried. He also suggested use of a Lagrangian approach instead of Eulerian. Bryan pointed out that, for the purposes of numerical models, where the mathematics is of necessity discrete, the question of whether one can assume ice to be a continuum is irrelevant provided that the basic conservation laws are respected.

Untersteiner concluded the discussion by emphasizing once again that there are several scales of interest in the ocean, the atmosphere, and the ice. For ice, he proposed the following definitions:

- a. *Macroscale* -- On this scale, the ice behavior approximates that of a continuum. Contributions from individual features to the deformation are obscured. Length scales are at least 30 km and are perhaps as much as 200-300 km.
- b. *Mesoscale* -- Motions which arise from the interaction of a small number of adjacent ice floes are defined as mesoscale motions.

Motions occurring over distances of 0.1 to 30 km may, somewhat arbitrarily, be described as mesoscale.

c. *Microscale* -- Phenomena which occur in a single unbroken piece of ice or which involve a single fracture system are defined as microscale.

## 2. Macroscale Strain

Thorndike reviewed his work using all available position data from previous drifting stations to get velocity gradients and other flow field properties. He then showed his computer-generated movie depicting the motions of the drifting stations. Thorndike observed a peak in the divergence spectra at about three weeks, but reported no significant peaks in the velocity spectra. Furthermore, the motions become less and less coherent as the frequency increases. Buck noted that his acoustic ice noise data showed strong peaks at periods of about three weeks, and Aagaard mentioned similar results for ice drift and ocean current data.

Hunkins gave a brief account of the celestial and Transit Satellite navigation systems used on T-3. Transit Satellite seems accurate to a few tenths of a nautical mile, and Hunkins recommended its use in AIDJEX. The largest errors are due to uncertainties in the orbital parameters. Transit Satellite is, however, not currently capable of providing a reference azimuth, and so occasional celestial fixes will be needed. Orientation poses a serious problem for unmanned stations.

## 3. Mesoscale Strain

Weeks reviewed his 1971 pilot studies. MRA-3 tellurometers were used to observe strains in first-year (2 m) ice to an accuracy of about 10 cm over distances of 10 km. Ridges and buildings were needed to gain height for the instruments. A lead was observed to open up at a rate which agrees with the values for strain rate given by Thorndike.

A multi-year ridge was also studied; it was found to be a massive block of ice about 70 m wide, with a 16 m keel. No cavities were encountered. The correlation between top and bottom topography was poor. Some work is also being done by NAVOCEANO on surface roughness using stereo aerial photographs.

Weeks identified several topics for investigation during the 1972 pilot studies: (a) the correlations, if any, between strains measured over 100 km and 10 km; (b) simultaneous top and bottom roughness, perhaps using the APL unmanned submersible and aerial photography; (c) remote thickness measurements; (d) lateral variation in electrical properties; and (e) internal structure of the sea ice.

Roots mentioned that acoustic transponders placed on the ocean floor appear to work quite well for small-scale motion measurements. Their use should be seriously considered in future AIDJEX studies.

Tooma concluded this section by describing the data collected by the 1971 NAVOCEANO overflights, including stereo photograph pairs, continuous strip photographs, and thermal maps. Semicontrolled mosaics are being prepared. Tooma suggested testing lasers for measuring distances up to 20 miles.

#### 4. Microscale Strain

Untersteiner reported that there has been a tentative offer from Tabata at Hokkaido University to do deformation studies on single pieces of ice using standard engineering techniques.

#### 5. Air Stress

Goddard emphasized the importance of studying form drag in the field and suggested that the problem with air stress is not *what* to measure, but *where* to measure. He then noted dramatic horizontal variations in roughness over large areas and the release of convective

energy over leads. He urged the 1972 experimenters to maintain a high degree of mobility in order to perform measurements over a variety of surfaces. Both the eddy correlation method and the aerodynamic method should be employed during these experiments.

Aagaard raised the problem of determining the surface stress field from maps of atmospheric pressure. He said that considerable differences occur in the calculated stress field when the pressure is measured over different scales.

Swinbank questioned the need for measuring the surface roughness very accurately, as it only appears to the 1/8 power, whereas the geostrophic wind appears to the 7/8 power, in the equation for friction velocity

$$u_* = 0.2 u_g^{7/8} f^{1/8} z_0^{1/8} .$$

J. Brown said that, on the contrary, one of the aims of AIDJEX is to examine in detail the physical processes in the boundary layer.

## 6. High Frequency Acceleration

Rusche described the accelerometer system tested at Camp 200 during the 1971 Pilot Study. Four accelerometers were used, three horizontal and one vertical. Although the sensors were potentially accurate to  $\pm 1/2 \mu g$ , there were several sources of error. Temperature fluctuations affected the response of the instrument. Furthermore, each accelerometer was about 2% sensitive to motions in a direction perpendicular to its axis. Field calibration was difficult, and it was not possible to obtain accurate reference values. In some cases the instruments were knocked off scale, but it was not clear whether this represented a sudden large acceleration or instrument malfunction.

Analysis of the reliable data shows one accelerometer undergoing a 1 mg fluctuation, with an estimated period of about 45 minutes, and

the other two accelerometers fluctuating with different amplitudes but a similar period.

Rusche suggested using two accelerometer stations to get relative accelerations. Thorndike proceeded to justify accelerometers by the following reasoning. If direct measurements of acceleration are not made, one would have to use finite differences of position measurements, which necessarily span some finite time interval. Furthermore, the mechanical interaction of adjacent ice floes can be examined by relative accelerations, but not by finite differences of position data. He had calculated that accelerations of the order of 100  $\mu\text{g}$  might exist, and these were, in fact, detected by Rusche.

Hunkins said that it is essential to separate tilts from accelerations; that is, one must determine what is the measurement and what is the error. All agreed that this ambiguity should be resolved. It was noted that Weber corrects his tiltmeter readings by removing accelerations measured relative to an acoustic transponder on the ocean floor.

## 7. Water Stress

J. D. Smith reviewed the problem of measuring water stress on the bottom of the ice, and he emphasized the difficulties in deriving estimates of stress from measurements of currents. The straightforward application of the Ekman or Prandtl theories to this problem is hampered by the unknown effects of density stratification, the extremely large roughness elements (pressure ridges) that occasionally penetrate the Ekman layer, and the unsteady nature of the flow.

In his review of the 1971 Pilot Study results, Smith reported that good correlation between the top and the bottom topography was found at Camp 200 in 1971, whereas this was not the case at Camp 200 in 1970. The data strongly suggested that the boundary layer was stratified: a frictional boundary layer down to a 4 m or 5 m pycnocline, then an Ekman layer down to 45 m or so. Smith noted that the response of the ice and water increases rapidly for winds greater than 6 m/sec. Consequently,

large amounts of kinetic energy are transferred to the ocean only during the occasional periods of high winds. Hunkins reported a stress value of  $0.5 \text{ dyne/cm}^2$  during one such period, using the log profile method. For the same period, Smith obtained stress values ranging from 0.42 to  $0.60 \text{ dyne/cm}^2$ . To summarize the state of the art, Hunkins noted that the values for the drag coefficient under ice obtained by various researchers are in relatively good agreement, ranging from  $5 \times 10^{-3}$  to  $24 \times 10^{-3}$ .

In the 1972 Pilot Study, Hunkins will investigate temporal accelerations and the velocity field in the Ekman layer. At the same time, Smith will examine the effects of temporal acceleration and density stratification on the Reynolds stress profiles. Smith will also investigate the form drag on a large pressure ridge. Swinbank suggested testing the results at an air-water interface, where there must be a balance between air and water stresses. Hunkins noted the need for better control on the density profiles, and Untersteiner pointed out the added complication of a summer fresh-water layer.

## 8. Geostrophic Flow and Tilt

The aim of this experiment is to determine the temporal and spatial limits of the geostrophic balance. Coachman's 1970 Camp 200 data showed the following features:

- a. Small peaks in the velocity spectra were found at 23.6 hours and 12.2 hours, although most of the motions were of longer periods.
- b. The 150 m current was more highly correlated to the ice motion than was the 40 m current; however, the deeper current appeared to lead the ice motion.

Whether these motions were in geostrophic balance still remains to be solved. The measurements were repeated in 1971 as part of a more comprehensive experiment in which the sampling error was reduced. Roots pointed out that the character of the ice movement was very

different between 1970 and 1971, and so it may be difficult to compare these results. In 1972, Coachman proposes a 100 km spacing with closer points on each profile, possibly going deeper.

Roots described some tests made by Weber at the mouth of the Moose River using a hydrostatic level with an automatic recording system and compared its results with those of a previously developed manually operated level. The system worked properly and will be tested next on sea ice under winter conditions. The expected accuracy is about 0.01 arc seconds on sea ice, about 10 times better than on the river ice.

## 9. Radiation and Thermodynamics

Weller gave a brief account of the radiation work at the University of Alaska. Currently, the principal effort is to obtain more information on the physical and radiational properties of the summer stratus and of the ice crystal aerosols which occur during the winter; eventually, they hope to develop a model of radiation transmission and absorption in arctic clouds. During the main AIDJEX experiment, Weller and his group plan to monitor the surface radiation balance at all manned stations and record the thermal and optical signatures of various types of arctic surfaces (ice, snow, ponds, etc.).

Maykut summarized other thermodynamic work that will be applicable to AIDJEX. He elaborated on the apparent inconsistencies between large-scale and small-scale values of summer ice albedo, and the role of melt ponds in this problem. Development of the one-dimensional model of sea ice growth will be continued to allow it to approximate growth rates of very thin ice (less than 25 cm). This would permit predictions of the amount of ice growth in leads as a function of season. What the model cannot do is predict the *onset* of ice growth in a lead. Plans are being made to modify the model of Foster to predict freeze-up, and possibly to describe oceanic convection under the growing ice. Because the amount of open water has such a large effect on the energy exchange between the atmosphere

and the ocean, Paulson at Oregon State University plans to investigate modification of the atmospheric boundary layer as air flows from the surrounding ice onto an open lead. Campbell mentioned that the NASA remote-sensing flights will try to provide some accurate values on the percentage of open water in the Arctic.

## B. TECHNOLOGY SECTION

### 1. Unmanned Stations and Positioning

Martin discussed the positioning requirements for AIDJEX. For macro-scale strain, an accuracy of one part in  $10^4$  (10 meters per 100 km) is desired. This will be difficult to achieve. The Transit Satellite System offers a potential accuracy of about 50 m in the absolute mode, but promises improved accuracies in the relative (translocation) mode. Translocation experiments should be made in the Arctic to confirm this. Transit fixes involve errors which result from uncertainties in the velocity of the platform. Hunkins observed that velocity corrections could be calculated from successive position fixes by an iterative process.

For mesoscale strain, an accuracy of one part in  $10^4$  (1 m per 10 km) is also needed. Both tellurometers and laser ranging systems should be considered. Tellurometers are all-weather instruments, but they require personnel at both ends of the path; laser systems require visual contact, but require personnel at only one end of the path. Consideration should also be given to the Motorola Range Positioning System, which is now being used by the Polar Continental Shelf Project; it has an electronic error of 2 m and a propagation error of one part in  $10^5$ . Curvature of the Earth's surface limits its range to about 50 miles with 100-ft. towers. Buck suggested the use of acoustic systems for mesoscale strain measurements.

The measurement of acceleration with a mass accelerometer was considered primarily for the purpose of interpolating velocities and strains between the times of satellite fixes. Since a mass accelerometer responds both to accelerations and to body forces (here, the Coriolis force and the gravitational force due to sea surface tilt), an independent determination of either

accelerations or body forces would permit the computation of the other. Weber overcomes the same difficulty in hydrostatic leveling by incorporating an acoustic bottom reference system to measure accelerations directly.

Some reference for station azimuth is required. Hunkins mentioned that celestial fixes are accurate to about 0.1 degree. Some means of interpolating between celestial fixes might be required, since weather occasionally prevents observations and most floe rotation occurs during relatively short intervals. Martin mentioned gyros for this purpose, or possibly Transit or acoustic bottom reference for more accurate, although more elaborate, all-weather azimuth reference.

Martin outlined data buoy requirements for the 1972 Pilot Study. A grid of approximately twelve buoys is planned, each buoy capable of measuring and recording surface pressure and perhaps wind velocity hourly. Tentative specifications call for measuring pressure to  $\pm 0.1-0.2$  mb, wind speeds of 1-2 m/sec to  $\pm 10$  percent, and wind direction to  $\pm 5-10$  degrees. Positioning requirements for the buoys will not be stringent in 1972.

Although accurate positioning and data telemetry are not required in 1972, it seems advisable to test promising positioning and telemetry techniques over sea ice paths of a few hundred kilometers in preparation for the main experiment. It is expected that buoys used in the 1972 study will simply store the data for retrieval at a later time and will have an expected lifetime of two to four months.

## 2. Remote Sensing

The ultimate success of AIDJEX requires remote sensing to provide input data for the numerical model of sea ice. Campbell reviewed preliminary results from the 1971 NASA flights over Camp 200. It appears that microwave sensors can distinguish multi-year ice from first-year ice at altitudes of up to at least 10,000 feet. W. Brown believes that it will be possible to determine ice thickness from certain microwave bands. Campbell reported that the ERTS satellites should be operational in time for the main AIDJEX experiment. Edgerton remarked that infrared satellite imagery of 5-nautical-mile resolution was obtained this year, but by next spring the resolution will be improved to 1/2 nautical mile.

For the 1972 pilot study, Petersen suggested a three-part experiment, contingent upon availability of the NASA plane:

- a. Day 1--35,000 ft.; 50 x 50 mile area.
- b. Day 2--10,000 ft. (elevation of maximum resolution); smaller area.
- c. Day 3-- 3,500 ft.; obtain ice thickness and surface roughness.

### 3. Unmanned Submersibles

Francois described the unmanned submersible being developed at the Applied Physics Laboratory (APL) at the University of Washington. It will profile the bottom surface of the ice, traveling about 50 feet under the ice. The position will be measured relative to acoustic beacons fixed at the corners of a one-mile square. The position accuracy should be about  $\pm 1$  foot. The submersible will travel at 3 knots and will be able to operate at depths of 1500 feet for a maximum of 10 hours. About half the available power will be used for propulsion, the rest for instruments. Approximately 200 pounds of instrument weight can be accommodated. APL hopes to have the submersible ready for the 1972 pilot study.

Lewis suggested mapping the same area from a helicopter to get the surface topography relative to the bottom topography.

### 4. Data Management

Lahore described a central data acquisition system for AIDJEX. He suggested that selected information from analog, digital, and teletype inputs be recorded at the central station on a common data tape. A choice of sampling rates (1 Hz to  $10^{-5}$  Hz) should be available for each sensor. With approximately 60-100 sensors (channels), this would amount to about one reel of tape per day. This tape would be transported to a permanent data processing facility, where the data would be converted into physical units. This would allow rapid distribution of raw data to all investigators. Seven-track tape will be used, with 11-bit words. The teletype input would allow for paper tape input. Each researcher would, of course, be free to record data in other ways or at a different sampling rate, but some effort should be made to sample all the data and record this common data for general AIDJEX use by all participants.

Lewis emphasized the need to check the data recording system in the field. Lahore replied that two tape drives are envisioned, one for recording and the other for backup and simple data analysis.

Untersteiner stressed that the feasibility of a central acquisition system depends on the cooperation of individual researchers. A reasonable degree of conformity in the data acquisition and recording is imperative. The AIDJEX Office is in the process of hiring a data engineer.

### C. PLANS FOR THE 1972 PILOT STUDY

The 1972 Pilot Study is expected to have three manned stations about 100-150 km apart, roughly the same spacing as the main AIDJEX array. The main station will have 30-40 men to perform the following experiments: (1) macroscale strain or station positioning, (2) air stress, (3) water stress, (4) geostrophic flow, (5) mesoscale strain and ice morphology, (6) buoy testing, (7) remote sensing. At the two satellite stations, 5-7 men will conduct the following experiments: (1) Transit Satellite navigation, (2) geostrophic flow, and (3) buoy testing.

The following outline summarizes the discussions of these experiments.

#### 1. Positioning (Hunkins)

There was general agreement to use the Transit Satellite positioning system. Martin claimed that a good receiver (#702) could be leased

for about \$5,000 per month. Roots cautioned that, from his experience, there seems to be a long waiting period for delivery.

## 2. Air Stress (Goddard)

Goddard's portable profiling system will be used to obtain heat and momentum fluxes. Witting mentioned the problem of obtaining wind stress from a geostrophic interpretation of surface pressure gradients. Untersteiner replied that some pressure data would be available from nearby land-based stations and remote data buoys.

## 3. Water Stress (Smith and Hunkins)

Smith described an experiment designed to separate skin friction from form drag on a large pressure ridge, using current meters and possibly differential pressure transducers. He will also investigate the influence of stratification and flow unsteadiness on Reynolds stress and mean velocity profiles, using the equipment and procedures described in AIDJEX Bulletin No. 4.

Hunkins's work will continue the previous years' work. He has proposed using an STD to obtain more information on the density structure. Current profiles will be taken along a rigid inverted mast, using a digital data recording system. A continuous profiling current meter is being developed and may also be deployed in 1972.

## 4. Geostrophic Flow (Coachman)

Coachman suggested use of the STD system developed by Lewis. After Lewis showed his movie, there was general agreement to follow this suggestion. Lewis stressed the need for an electronics engineer to run the instruments in the field. One man could operate the system during AIDJEX.

## 5. Mesoscale Strain (Weeks)

The hardware exists to measure strains over distances of about 50 km to an accuracy of about 1 m. Final equipment selection has not been made. Strain nets will be established over various distances to see the interactions between adjacent floes and to observe near-mesoscale strains.

## 6. Remote Sensing (Campbell)

Several remote techniques for measuring ice thickness will be tested. It would be desirable to arrange the aircraft flights on a sliding schedule, so that one could wait for the best weather conditions. A remote-sensing meeting will convene in the fall.

## 7. Unmanned Weather Stations (Buck and Francois)

Both APL and Delco Electronics have projects to develop unmanned buoys, and they have agreed to cooperate with the AIDJEX effort. Buck mentioned some points regarding the Delco project (called RAMS). It will have a capability similar to the Soviet buoys (called DARMS). Delco is aiming for a 1000-mile telemetry range and a one-year lifetime for the buoy. Initially, the development effort will concentrate on the power supply and radio. Delco expects to have a preliminary system in the Arctic this fall. If it works well during these tests, it could be moved to the proposed AIDJEX site and left there, telemetering data back to Barrow. The memory will be digital, and any digital inputs should be compatible. The storage capacity will be about  $2 \times 10^6$  bits over a two-hour cycle, and it will transmit data for five minutes every two hours. Eventually they hope to use the Transit Satellite system for positioning. Buck mentioned that they will have a RAMS transmitter which could be used for two months this winter.

Francois briefly mentioned that Haugen at APL is working on a similar program, which currently uses satellite interrogation. The main effort is directed toward platform design , power supply, and ease of handling. It will be tested at T-3 this winter and might be available for use in AIDJEX.

The consensus after a lively discussion about the requisite accuracy for pressure measurements was that  $\pm 0.1$  or  $\pm 0.2$  mb would suffice.

#### D. CANADIAN PROJECTS

Roots stressed that there is no Canadian agency responsible for coordinating Canadian participation in AIDJEX. Nevertheless, a number of Canadian investigators have already participated or have expressed a wish to participate in the future. Their participation is being coordinated by the AIDJEX Office.

##### 1. Polar Continental Shelf Project (Roots)

The PCSP has provided substantial logistic support for the last two pilot studies. As a result, costs for AIDJEX during these experiments were unrealistically low. In the 1972 Pilot Study, as presently envisioned, the Polar Continental Shelf Project may be able to provide logistic support for the Satellite East Station. Roots pointed out that it will be difficult to locate three suitable sites for the manned stations in the semidarkness of mid-February.

## 2. St. Lawrence Ice Drift Study (Pounder)

This project was presented as a miniature AIDJEX; it has met many of the problems which confront AIDJEX. Until now, much of the work has been done aboard ships, but an automatic buoy system with telemetry is envisioned for the near future.

## 3. Cambridge Bay Study (Lewis)

This fall they plan to observe changes in the water structure throughout the freeze-up period and to delineate seasonal patterns. Eventually, they intend to use this information to discriminate between various theories of water circulation beneath sea ice.

## 4. Robeson Channel Study (Dunbar)

This group is studying the drift of sea ice using radar on Ellesmere Island. They are encountering problems caused by the unexpectedly fast currents (about two knots).

## 5. McClure Straits Study (Milne)

Twenty drifting buoys will be deployed to study ice movement in the McClure Straits region. Each buoy will have a life expectancy of one year and will be positioned by Argos aircraft. They have found that buoys placed in first-year ice have a much higher mortality rate than those placed in multi-year ice.

## E. LOGISTICS AND OPERATIONS IN 1972

Bjornert described the operational plans for the 1972 AIDJEX Pilot Study. According to present plans, Barrow will be the logistics base for the main camp and one satellite station; PCSP in Tuktoyaktuk has been asked to support the other satellite camp. An advance group will set up the camp, and the scientific gear and personnel will be flown out after the buildings are habitable. The R4D aircraft of the Naval Arctic Research Laboratory will probably be available, but other chartered heavy aircraft will also be needed. The twin Otters will probably be used for light aircraft support, and two helicopters could be used. Radio communications will be improved, with a greater number of frequencies being made available. A medical person is being sought. The time schedule will remain approximately the same as it was this year.

All participants have been requested to submit their logistics requirements to the AIDJEX Office. Cost estimates are being prepared.

Hunt remarked on the element of chance in finding suitable floe sites and pointed out that the range of the aircraft must be kept in mind. Schindler reinforced this warning, saying that the distances being talked about are at the operational limits of available aircraft. Untersteiner said there was no reason that the array could not be adjusted to aircraft operating ranges. Fletcher concluded the discussion by noting that the lower limit was determined by requiring that the array lie beyond the active shear zone (150-200 km) and that the upper limit would be determined by logistics requirements.

## F. AIDJEX ORGANIZATION

An explanation of the AIDJEX organization--going into greater detail than was possible at the conference--appears as a separate section on page 27 of this Bulletin.

## G. CLOSING COMMENTS

Swinbank undertook a brief mathematical exercise to show that, for the profile method to work,  $u_*$  must be independent of  $z$ . He emphasized that  $\frac{\partial u}{\partial x}$  must be sufficiently small; thus, horizontal as well as vertical gradients should be measured so that corrections can be made if necessary.

Leith reiterated the point that careful thought should be given to the measurement of pressure gradients in the atmosphere. Swinbank submitted that a precision of 0.1 mb is sufficient.

Leith suggested that ultimately not the wind but the surface stress directly will be used in the models. He also wondered if the elastic properties of the ice could be tested by observing it when it is being driven onshore. Untersteiner, however, claimed that such an observation would probably not reveal anything, because the surface traction is never great enough to make the ice fail. Leith added that ultimately the grid spacing of the buoys should be similar to the grid spacing of the models used. Bryan concluded that the most important information to come from the AIDJEX field measurements will be a spectrum of strain measurements over different scales.

In his final remarks, Untersteiner stated that it had been the purpose of this meeting to raise and resolve any remaining questions

pertaining to the 1972 Pilot Study. In light of the scientific and technical discussions of this meeting, the results of the two previous pilot studies, and the numerous working group discussions, he called for the preparation of a revised and expanded version of the AIDJEX Scientific Plan to be released later in the year.

#### H. LIST OF CONFERENCE PARTICIPANTS

|                                       |  |
|---------------------------------------|--|
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## II. AIDJEX ORGANIZATION

### INTRODUCTION

The Arctic Ice Dynamics Joint Experiment (AIDJEX), as described in the Scientific Plan (1970), is shared by scientists and supporting agencies who seek to provide a more fruitful arctic program through their joint efforts than the participants could undertake separately. In this spirit, AIDJEX aims to provide a framework for cooperative research endeavors, building on the strength of existing programs and supplementing them where necessary.

### AIDJEX MANAGEMENT

The National Science Foundation, as the lead agency for the extension of research in the Arctic, chairs the Interagency Arctic Research Coordinating Committee. This committee coordinates all unclassified research in the Arctic by the United States Government. The NSF, through its Assistant Director for National and International Programs, supports research projects, often by contract, which involve an interdisciplinary or multidisciplinary approach, special logistics support, coordination with other federal agencies, and international cooperation in the pursuit of arctic research. Such projects constitute the Foundation's Arctic Research Program and are managed by the NSF Office of Polar Programs. These projects are in addition to the basic research efforts which are supported by grants awarded by the NSF Assistant Director for Research.

Other federal agencies--notably the Office of Naval Research, with a history of significant arctic research activities, the Naval Oceanographic Office, the Coast Guard, and the National Oceanic and Atmospheric Agency--also provide continuing support of arctic research programs through grants and contracts.

The National Academy of Sciences, at the invitation of NSF, has established a joint panel to advise NSF and the AIDJEX coordinating office on the scientific program of AIDJEX. This NAS panel, under the chairmanship of Dr. Richard Goody, includes representatives from the Ocean Affairs Science Board, the Committee on Polar Research, and the Committee on Atmospheric Science. (A list of the NAS panel members is included here as Appendix A.)

The NSF Office of Polar Programs has also appointed a review panel to make recommendations concerning individual projects under AIDJEX which have been proposed for funding through the Foundation. Similar review mechanisms exist in the other agencies which fund AIDJEX programs.

The National Science Foundation has contracted with the University of Washington, Seattle, for assistance in coordinating the planning and carrying out of the AIDJEX programs. In accordance with the contract, the University has established an AIDJEX coordinating office in a leased building adjacent to the campus at 4059 Roosevelt Way N.E., Seattle. The office has been under the direction of Mr. Joseph O. Fletcher, who will leave on September 1, 1971, to become head of the NSF Office of Polar Programs. At that time he will be replaced in the AIDJEX office by Dr. Norbert Untersteiner, who will be on leave from his academic duties at the University.

In addition to the overall responsibility for developing the AIDJEX scientific plan, the AIDJEX office has the following specific responsibilities under the present NSF contract:

1. Plan and conduct extensive field pilot studies and evaluate their results.
2. Develop and coordinate the main experiment.
3. Develop a data bank.
4. Identify participants and their responsibilities, and monitor their progress with respect to the main experiment.

5. Coordinate and disseminate technical, operational, and logistic information, and perform such tasks as are necessary to enhance the usefulness and ensure the success of AIDJEX.
6. Assist in the coordination of funding activities with respect to AIDJEX.
7. Develop performance specifications for the automatic data buoy stations, the unmanned submersible, and other advanced instrumentation.

To deal effectively with the increasing complexity of the AIDJEX program, a steering committee has been established to advise the AIDJEX Coordinator (see Appendix B). The mandate of the committee is as follows:

The Steering Committee will be responsible for the continuous review of the scientific plan, its focus and continuity, the distribution of effort, and the determination of priorities. The Committee will review proposed programs and make recommendations to the AIDJEX Coordinator as to their relevance and priority. The Committee will also review the operations and logistics plans to ensure that, within the available resources, the scientific missions are adequately supported. If circumstances require, the Committee, through the AIDJEX Coordinator, may seek the advice and assistance of the NAS Joint AIDJEX Review Panel.

Each member of the Steering Committee will represent a major area of AIDJEX activity. Members will be responsible for keeping abreast of all development and for coordinating the planning and execution of projects in their area. Members are encouraged to consult with experts in their field outside the Committee, and individual investigators are encouraged to pursue scientific questions through the appropriate area representative on the Committee. It is understood that some of the individual research projects have, besides their contribution to AIDJEX, additional commitments to their respective funding agencies. It is expected that such commitments will be identified to the cognizant area representative and fulfilled in coordination with the AIDJEX Office.

Initial appointments to the Steering Committee are made by the AIDJEX Coordinator. Subsequent additions and replacements will be made by the Coordinator with the advice and consent of the

Committee. The Coordinator is an *ex officio* member of the Committee and serves as its chairman.

It is expected that, because of the immediate need for intensified scientific coordination, the Steering Committee will have to meet frequently and its members will have to be available for consultation.

Within the AIDJEX coordinating office, the staff functions are divided into three areas of responsibility: logistics and operations coordination, technical development coordination, and administrative services.

The responsibility for preparing overall logistics and operations plans (including cost estimates) based upon the scientific project requirements, coordinating base and field operations, and maintaining inventory and property control rests with the logistics coordinator, Mr. Rolf Bjornert.

Responsibility for coordinating the development of the overall data management system, including hardware and software, the development and acquisition of a data buoy network, and utilization of remote-sensing and arctic submersible technology is vested in the technical development coordination function. Mr. Pat Martin has been coordinating the data buoy programs and providing staff assistance in meeting AIDJEX positioning requirements. The most immediate requirement in this area is a qualified person to coordinate the overall data handling system.

Administrative services include information, library, budget, and secretarial services.

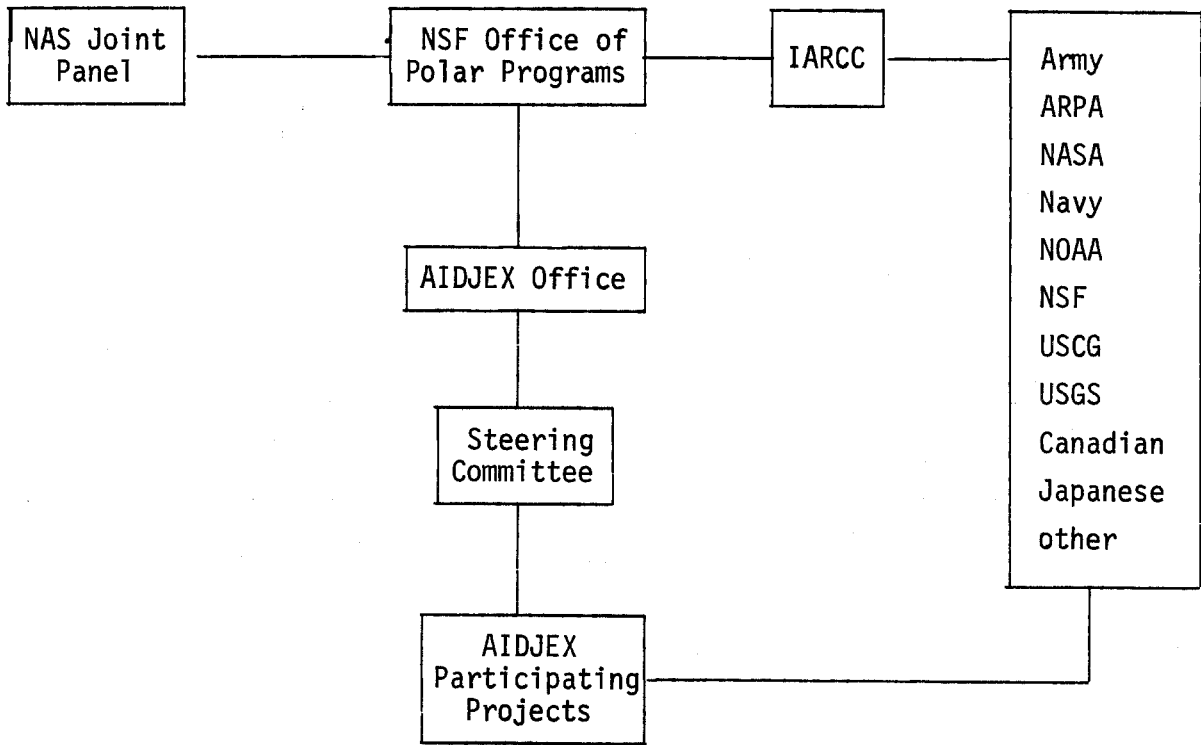


Diagram of relationship of AIDJEX to participants.

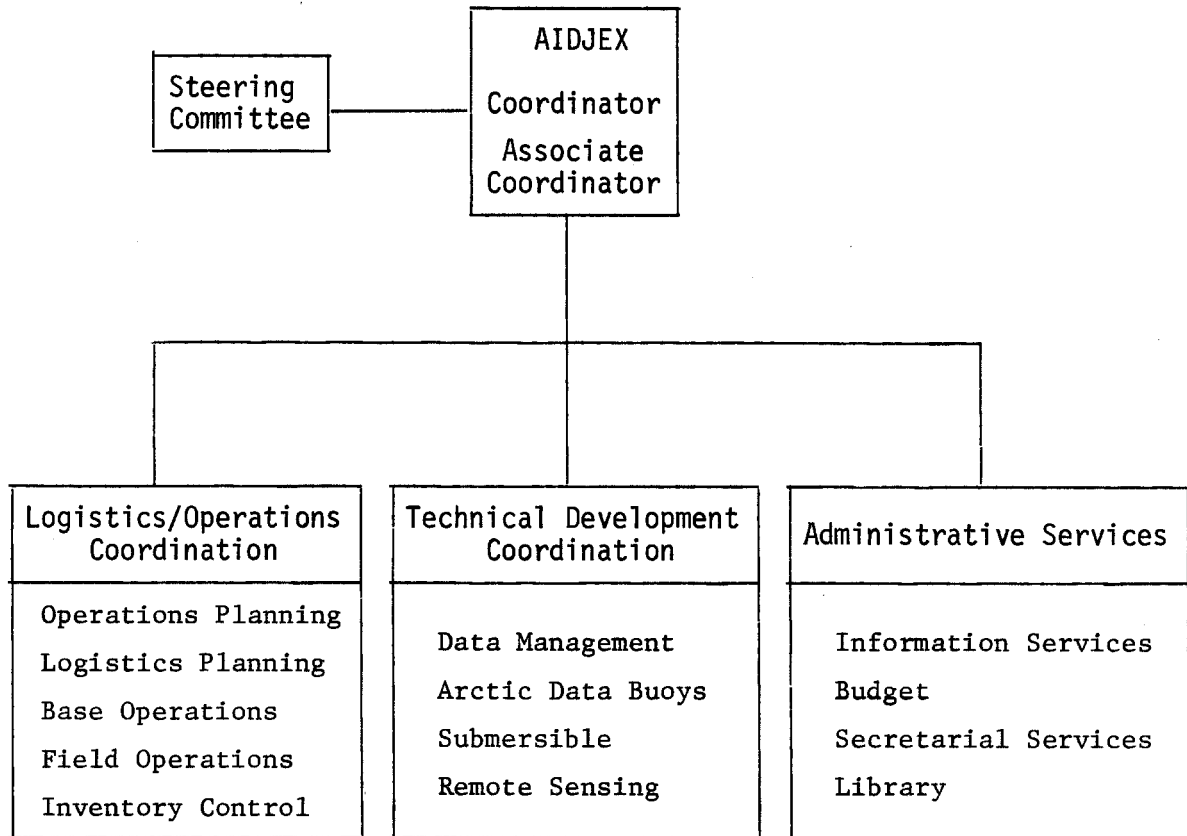


Diagram of AIDJEX office organization.

## APPENDIX A

### NATIONAL ACADEMY OF SCIENCES JOINT REVIEW PANEL FOR AIDJEX

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release or absorption during the formation and melting of ice would affect the general phenomena of pack ice--particularly the source term in the equation of continuity of ice--we should study the equation of energy simultaneously with the equations of motion and equation of continuity.

In studying these fundamental equations, some mathematical model should be assumed and then the fundamental equations may be derived rigorously for such a model. In this note, we present a two-phase flow model for pack ice which would take into account the heat transfer effects, compactness, and salinity so that a more logical analysis will be obtained.

It is well known that large numbers of ice floes of various sizes are floating on the surface of the Arctic Ocean. If we consider the Arctic Ocean as a whole, the two dimensions along the surface of the ocean are much larger than the depth of the ice. Let the depth of the ice be  $h(x,y)$ , which is in general a function of  $x$  and  $y$  where  $x$  and  $y$  are the two coordinates on the surface of the ocean. If we choose a typical length of the ocean  $L$  to represent the dimension on the surface of the ocean such that  $x \sim L$  and  $y \sim L$ , we have  $L \gg h$ . We may divide the ice-packed ocean into two layers. In the upper layer, i.e.,  $z < h$ , where  $z$  is the coordinate perpendicular to the surface of the ocean, measured from the surface of the ice and positive downward, we have a mixture of ice floes and sea water. In the lower layer, i.e.,  $z > h$ , we have sea water only. Since  $L \gg h$ , the ice floes may be considered as small solid particles in a fluid (sea water). In our mathematical model, we use the concept of fluidization of solid particles in a fluid [5]. Hence for  $z < h$ , we have a mixture of two fluids: one is the sea water and the other is the pseudo-fluid of ice floes.

We may extend the well-known theory of two-phase flows of a mixture of small solid particles and a fluid [5] to study the fundamental equations of ice dynamics. We may derive rigorously the fundamental equations of ice dynamics from the two-phase flow theory [5], particularly the equation of energy which should include the melting and freezing of ice and the equation of continuity in which the source terms depend on the freezing and melting of ice which are coupled with the energy equation.

It should be noticed that the fundamental equations just mentioned are not the fundamental equations used by the authors of [2], [3], and [4]. The fundamental equations they use in the literature are essentially the integrated form of those three-dimensional equations, even though no one has pointed out this fact before. Because  $L \gg h$ , we may integrate the three-dimensional fundamental equations with respect to the vertical coordinate  $z$  with the limit  $z = 0$  to  $z = h$ . The resultant equations depend on two spatial coordinates  $x$  and  $y$  only, with the thickness of ice  $h(x,y)$  as an unknown parameter. This procedure is similar to the integral method which has been extensively used in the theory of boundary layer flows [6].

It is interesting to note that the integrated equations of motion are of a form similar to the equations of motion of a single ice floe used by Campbell [4]. In the integrated equations of motion, the shearing stresses on the surfaces  $z = 0$  and  $z = h$  occur such that at  $z = 0$  the shearing stress is equal to the wind stress  $\tau_\alpha$ , while at  $z = h$  the shearing stress is equal to the water stress  $\tau_w$ . Conceptually, the integrated forms of the fundamental equations are consistent with the mathematical fluid model for the ice. It is rather difficult to justify derivation of the equations of motion for a fluid model by using the equations of motion of a single ice floe. Furthermore, we may have a better understanding of various terms in the integrated forms of the fundamental equations, such as the source term in the equation of continuity of ice, than the empirical derivation from a single ice floe. Since the fundamental equations of ice dynamics by the integral method may be derived rigorously from the fundamental equations of the three-dimensional two-phase flow, we expect that some new information about the fundamental equations of ice dynamics may be revealed.

For  $z > h$ , our equations will be reduced to those of ocean water where the compactness is zero. On the other hand, the atmospheric wind may be taken into account as the boundary condition on the surface of the upper layer of the ice for our integrated two-dimensional equations--i.e., the external stress  $\tau_\alpha$  and the pressure term.

Another important fact in the consideration of melting and freezing of ocean ice is salinity  $S$  [7]. In our two-phase model, we may include salinity  $S$  as an additional variable in our problem. An equation of diffusion of salt may be introduced to take the variation of salinity into consideration.

It is useful to show the relations between our two-phase model and the classical model of Campbell [4] so that we may see clearly what kinds of improvements one may obtain. In the two-phase model in general, we should consider 13 variables with 13 fundamental equations. These variables are:

$$\vec{q}_r, T_r, p_r, \rho_r, S \quad (I)$$

where subscript  $r$  may be subscript  $i$  or subscript  $w$ ; subscript  $i$  refers to the values for the pseudo-fluid of ice, and subscript  $w$  refers to the values for the sea water.  $\vec{q}$  is the velocity vector with components  $u, v, w$ . Hence  $\vec{q}_r$  means six variables. There are two temperatures  $T_i$  and  $T_w$ , two pressures  $p_i$  and  $p_w$ , and two densities  $\rho_i$  and  $\rho_w$ . It should be noticed that the density  $\rho_r$  is known as partial density of two-phase flow [6], which may be expressed in terms of the volume fraction of ice in the mixture  $z$  and the species density of the ice. The volume fraction  $z$  is closely related to the compactness. The salinity is denoted by  $S$ . We have 13 equations for these 13 variables: six equations of motion (three for pseudo-fluid of ice and three for sea water), two energy equations, two equations of continuity, two equations for state, and one diffusion equation for salinity.

In his fluid model [4], Campbell considered only four variables:

$$u_i, v_i, u_w, v_w \quad (II)$$

Now we are going to show how to reduce the 13 variables of method (I) to the four variables of method (II) by various approximations.

In the first place, because of the fact  $L \gg h$ , we may apply the concept of boundary layer flow so that the vertical velocity component  $w_r$  is much smaller than the transverse velocity components  $u_r$  and  $v_r$ . As a result, the pressures  $p_r$  may be considered as a known function given by the atmospheric pressure and the inclination of the ocean. Hence we reduce two variables. Then we apply the integral method to the three-dimensional fundamental equations and the vertical velocity component  $w_r$  will be eliminated. Hence we have only nine variables for the dynamics of packed ice, as follows:

$$u_i, v_i, u_w, v_w, T_i, T_w, \rho_i, \rho_w(N), S \quad (III)$$

In our two-phase model of ice dynamics, we have nine variables given in (III). We may replace one of the partial densities,  $\rho_r$ , by the compactness  $N$ . From a logical point of view, we may reduce the nine variables of method (III) to the four variables of method (II) by assuming that the temperatures  $T_r$ , the densities  $\rho_r$ , and the salinity  $S$  are all constant. It is evident that such approximations are not very good and many important phenomena would be missed.

It would be very good if we could study the dynamics of packed ice by method (III) with nine variables. We should first derive the nine fundamental equations. Before we study the complete set of nine equations, it would be useful to consider some simple cases which may improve on the classical approach of Campbell. For example, we may consider the case in which  $S = \text{constant}$ ,  $\rho_w = \text{constant}$ , and  $[T = (T_w - T_i)]$  is small. As a result, we have six variables only:

$$u_i, v_i, u_w, v_w, T, N \quad (IV)$$

Method (IV) may be considered as a first improvement of Campbell's analysis [4]. Our improvements by method (IV) are twofold: (1) we consider the temperature effect  $T$  and the open water effect ( $N$ ); (2) we use more logical equations than those of Campbell.

For a second approximation, we may consider salinity  $S$ , and we have seven variables:

$$u_i, v_i, u_w, v_w, T, N, S \quad (V)$$

Method (V) should give us reasonably good results for the dynamics of packed ice.

The most complete analysis would be the study of all the nine variables of method (III).

For each of the methods (III), (IV) or (V), we may integrate the fundamental equations numerically in a similar manner as that carried out by Campbell.

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CORRECTION

CORRECTION

CORRECTION

In AIDJEX Bulletin 7, "Arctic Data Buoy and Positioning Systems," the authors of the RAMS report (page 37) should have been given as John O. Anderson and Beaumont M. Buck.

