An aerial photograph of a vast, cracked ice field, likely in the Arctic. The ice is broken into large, irregular floes separated by deep, dark cracks. The overall texture is rough and uneven. The lighting is bright, creating high contrast between the white ice and the dark cracks.

Bulletin No. 5
1971 PILOT STUDIES
REMOTE SENSING AND ICE MORPHOLOGY
February 1971

AIDJEX BULLETIN

ARCTIC
ICE
DYNAMICS
JOINT
EXPERIMENT

AIDJEX BULLETIN No. 5

February 1971

1971 PILOT STUDIES--
REMOTE SENSING AND ICE MORPHOLOGY

Arctic Ice Dynamics Joint Experiment
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FOREWORD

Bulletin No. 4 discussed in some detail the oceanographic pilot studies planned for the 1971 AIDJEX expedition in the Beaufort Sea. This Bulletin, No. 5, describes in detail the remote-sensing and ice morphology pilot studies, follows with a summary of study plans, and concludes with an account of the Numerical Modeling Working Group session held in November.

In general, these pilot studies aim to define more adequately the appropriate time and space scales of measurements for the main AIDJEX experiment in 1973. They also aim to reveal information on representativeness of stress measurements and the best methods for obtaining them. These pilot studies should thus provide essential information for refining and simplifying the design of the main experiment. Some, such as Jim Smith's boundary layer measurements under the ice, are detailed studies which will not be included in the the main AIDJEX array. They seek to answer specific basic questions which influence the design of the experiment. If successful, they will probably not be repeated.

Following the field program there will be a general convocation of AIDJEX participants to review the results, assess where we stand, and plan next year's pilot studies. This meeting is tentatively scheduled for June 1971.

J. O. Fletcher
AIDJEX Coordinator

AIDJEX BULLETIN No. 5
February 1971
1971 Pilot Studies--
Remote Sensing and Ice Morphology

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REMOTE SENSING, ICE MECHANICS AND MORPHOLOGY

AN OUTLINE OF THE PROBLEM

by M.P. Langleben and E.R. Pounder

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Any consideration of ice movement must start with the morphology of the two surfaces of an ice cover, since it is the roughness of these surfaces which couples the air-ice-water media and permits momentum transfers. The major driving force causing ice movement is the shear force applied to the upper surface by the wind. The lower surface interacts with the water, transferring momentum to it, so that the water stress on the ice is a drag.

Air stress can be divided somewhat artificially into skin friction and form drag, where the former is the result of small-scale roughness of the ice or snow surface and the latter of major obstacles such as pressure ridges. In treating skin friction it is usually assumed that the air flow is turbulent. This is almost certainly true in general, but it is possible that for very light winds over a relatively smooth surface, the flow in the boundary layer may be laminar. The transition from laminar to turbulent flow is usually considered to occur for a Reynolds number Re in the range from 2000 to 3000.

$$Re = \frac{\bar{U} \ell \rho}{\mu} \quad (1)$$

where \bar{U} is a characteristic speed of flow, ℓ a characteristic length, and ρ and μ the density and viscosity of the moving fluid. It is difficult to know what characteristic \bar{U} and ℓ to use. Somewhat arbitrarily let us take $\bar{U} = \bar{u}_{10}$, the mean wind speed at 10 metres

height and $l = 30 z_0$ where z_0 is the roughness parameter. Taking $\bar{u}_{10} = 3$ m/sec (≈ 7 miles per hour) and $l = 1$ cm (a very smooth surface), then $Re = 2250$ since $\rho = 1.29$ and $\mu = 1.71 \times 10^{-5}$ (in MKS units) for air at $0^\circ C$.

Skin Friction

For the turbulent case the wind stress

$$\tau_a = \rho C_{10} \bar{u}_{10}^2 \quad (2)$$

where C_{10} is the drag coefficient at 10 m. Within the boundary layer (at least tens of metres in thickness) τ_a is a constant, but since $\bar{u} = f(z)$, $C = f(z)$ also and the height z must be specified. For neutral stability

$$u(z) = \frac{u^*}{k_0} \ln \frac{z + z_0}{z_0} \quad (3)$$

where u^* is the friction velocity $= \sqrt{\frac{\tau_a}{\rho}}$ and k_0 is von Karman's constant (≈ 0.4). Equation (3) leads readily to

$$\tau_a = \rho \left[k_0 \frac{\Delta u}{\Delta (\ln z)} \right]^2 \quad (4)$$

For a stable or unstable atmosphere, (4) needs modification but only empirical corrections are available (see Businger (1966) for example).

Another useful expression in the turbulent case gives the Reynolds stress or horizontal shear stress as

$$\tau_a = \rho \overline{u'w'} \quad (5)$$

where $u = \bar{u} + u'$ is the instantaneous downwind horizontal velocity and w' is the instantaneous vertical component.

Two methods of measuring the drag coefficient C_{10} have been used. In the profile method, wind speed and temperature are measured at various heights, τ_a is calculated from (4) and the stability of the atmosphere from the temperature profile. The drag coefficient C_{10}

can then be found from (3) (modified if necessary for other than neutral stability) and (2). Equation (5) can be used on data from a three-component sonic anemometer (Smith et al, 1970) to give τ_a .

Form Drag (D)

The wind stress on a macroscopic object can be expressed in a form similar to (2)

$$D = \rho (f A) \bar{U}^2 \quad (6)$$

where A is the projected area of the obstacle normal to the flow, f is a form factor dependent on the shape and on the Reynolds number, and \bar{U} is the average wind speed incident on the obstacle. The averaging must be done not only in time but also in height because of the logarithmic nature of the wind profile. The form factor can be predicted theoretically for simple geometries but in the case of pressure ridges some measurements are needed. In principle careful wind speed profiles on the windward and leeward sides of the ridge would suffice to calculate f but few if any experiments have been done.

Relative Sizes of τ_a and D

To get a feel for the sizes of these drags, let us solve a simple model. Assume a level, rough floe, with $z_o = 1.07$ cm ($C_{10} = 3.5 \times 10^{-3}$), broken at intervals of 500 m by a pressure ridge of width 16 m and height 2m. Take a transverse wind $\bar{u}_{10} = 7$ m/sec and assume a logarithmic profile. As a rough approximation we take $\bar{u}_{1.0}$ to represent the average wind \bar{U} on the ridge. From (3) $\bar{u}_{1.0} = 4.7$ m/sec. For an elliptical cylinder of axial ratio 4:1 Streeter (1958, p. 172) gives $f = 0.16$ (at $Re = 2.5 \times 10^4$), and we assume this is reasonably close to the

proper value for the pressure ridge. Then, from (6), for a 1-meter long stretch of ridge,

$$D = 1.29 \times 0.16 \times (1 \times 2) \times (4.7)^2 = 9.1 \text{ nt}$$

From (2), the skin friction on a strip $500 \times 1 \text{ m}^2$ is

$$1.29 \times 3.5 \times 10^{-3} \times (7)^2 \times 500 \times 1 = 110 \text{ nt}$$

From this calculation, it appears that skin friction is the dominant factor unless ridges are very high or very numerous, or the floe is extremely smooth.

Water Stress

Again in principle all of the equations above can be applied to the lower surface with modifications of the parameters. A calculation of the value of Re shows that the water flow will be turbulent for any reasonable values of roughness and current. e.g. if $\bar{U} = 10 \text{ cm/sec}$ and $l = 5 \text{ cm}$, $\rho = 1025 \text{ kg m}^{-3}$, $\mu = 1.91 \times 10^{-4}$ and $Re = 27,000$.

In fact, water stress measurements are considerably more difficult than air stress ones. The boundary layer thickness is only of the order of a meter or less (Hunkins, 1966; Johannessen, 1970). Current meters tend to be large (several cm in diameter for propellor types). This makes accurate measurement of current profiles difficult. Smaller current sensors, such as hot-film meters, are not as well developed as similar ones for wind speed. Eddy or Reynolds stress measurements have not yet been made in the boundary layer below the ice, although they are planned by several groups. Finally, the relative inaccessibility of the lower surface makes judgement of the representativeness of a site very difficult. On the upper surface 'eyeballing' permits a qualitative classification of the morphology as smooth, ridged, hummocked, etc.

Representativeness

Either profile or eddy stress techniques for upper or lower ice surface morphology are point measurements, representative at best of areas of diameters of a few km. For AIDJEX, or for any predictive methods which may come from it, it will be necessary to characterize ice roughness or morphology over areas of hundreds of km in width, and the only practical way is by remote sensing techniques. Some discussion of airborne techniques follows later in this paper. For underice mapping the most promising technique is the sonically controlled torpedo developed by the Applied Physics Laboratory of University of Washington. This was described at the Hanover meeting of the Working Group on Ice Mechanics and Morphology in August 1970 and is referred to in AIDJEX Bulletin No. 1 (p. 31). The only comment to be made here is to once again stress the obvious - the APL torpedo will remain a research tool, to be deployed rarely and at high cost in any particular ice covered area. It is therefore very important to try to develop quantitative relations between top and bottom surfaces, so that bottom roughness can be deduced from airborne surface observations which could hopefully become quasi-routine in areas of significance.

Ice Mechanics

The topic of this AIDJEX Bulletin includes ice mechanics but Bulletin No. 2 dealt so well with the existing lack of knowledge in this important field that we have nothing to add.

Remote sensing of morphology

The need to obtain good quantitative data on the morphology of the ice cover on a routine basis has been mentioned already. The most

rapid changes in morphology result from preferential ice movement, occurring in areas where, or at times when, the flow is cyclonic or anticyclonic. Under such circumstances, internal stresses in the ice build up to values which cause local failure and lead to the formation of pressure ridges and leads of open water.

The cover is made up of ice of various ages, from thin ice newly frozen in a lead to heavy multi-year pack ice. Each type has a more-or-less distinct morphology, induced not only by the mechanical processes which have been described but also by its thermal history. Annual melting cycles tend to smooth the sharp angular projections of pressure ridges and to produce the characteristic undulations of the upper surface of ice more than two years old. The surface topography, in turn, interacts with the mechanism driving the ice cover, since the tangential stress exerted by the wind against the upper face and the drag between the lower face and the ocean are sensitive functions of surface roughness. (The relative importance of skin friction and of form drag has been discussed earlier.) It is necessary therefore that the distribution in space of the various ice types be obtained during the AIDJEX experiment at regular and frequent intervals.

Although local measurements of surface relief will probably be made at the manned stations, these will be limited in scale by the heavy manpower requirements for such observations. Moreover because of the extreme variability of the ice cover, on-site observations will not in general be representative of conditions on the very much larger scale of distance involved in the array of stations. The solution inevitably lies in the direction of rapid remote sensing of the ice

cover from airborne and submarine platforms. (To the best of our knowledge, satellite coverage (ERTS, ESSA and others) will provide very little information except photographs of the surface during daylight cloud-free periods. A second generation ERTS may have an IR scanner but is expected to be of limited value because of its low resolution and inability to penetrate cloud.) This is not meant to downgrade the importance of local measurements. It is essential that experiments of the type pioneered by CRREL, NAVOCEANO and others in which good ground truth data are obtained simultaneously with the remote sensor imagery be continued and intensified, if the full potential of remote sensors to distinguish characteristic features of the ice cover is to be realized.

Interpretation of the imagery obtained from scanning remote sensors (IR, SLAR and passive microwave) is, in some instances, subject to ambiguity. Interpretive techniques of the signatures characteristic of ice of different roughness using radar profilers or laser altimeters is still under investigation. The applicability of some remote sensors looks more promising than of others but, at this early stage of our experience, it would be undesirable to discard any sensor which may contribute to our knowledge of the ice cover. While it is anticipated that the pilot projects being planned or underway may clear the air with regard to the potential and limitations of the various remote sensing systems, and while we are aware of considerable overlap of information provided by sensors of different type, nevertheless we make a plea for redundancy to avoid the possibility of ending up with a deficiency of data. For example, development of a system for remote sensing of ice thickness is unlikely in the near future and since there is almost

certain to be insufficient detailed ground measurements, ice thickness will have to be inferred from such information on the ice as its type, roughness, height above water level, etc. as obtained from a number of remote sensing devices. The few paragraphs which follow discuss, in brief, the remote sensors with regard to their potential to provide information on the morphology of the ice cover, the systems being arbitrarily divided into two groups, depending on whether or not they produce an image of the ice cover.

Imaging systems. The output of all remote sensing systems in this category is an image, superficially similar to a photographic image, in which various features of the ice cover are identifiable by their shape, texture and tone.

a) The scanning SLAR (side looking airborne radar) promises to be the most useful remote sensor because of its ability to penetrate cloud, fog, precipitation and darkness. An image of the surface along the flight path and to its sides is obtained. It is possible to detect pressure ridges, leads and various ice types and therefore to determine the distribution patterns from the imagery. A more sophisticated system, the synthetic aperture SLAR, has a higher resolution but is much more expensive and requires elaborate ground facilities to process the data.

b) Given conditions of good illumination and visibility, aerial photography in black and white or colour is well proven in its ability to produce images of the ice cover which are amenable to quantitative measurement. A low-light-level television camera could extend photographic techniques into periods when the ambient light level is too low for standard photography.

c) The IR (infrared) scanner produces an image in which variations from point to point are related to differences in peak Boltzmann radiation from the surface of the ice cover. The system is capable of delineating areas of open water and leads in the ice cover. It is possible to distinguish such features and the early stages of growth of young sea ice from thick first year ice in terms of tone quality, and to detect heavy pack-ice and pressure ridges. The system is not limited to daylight hours but is ineffective when cloud or precipitation intervenes.

d) There has been insufficient experience with emission by the ice cover in the microwave band to assess the full potential of the passive microwave scanner. It has been demonstrated that the imagery reveals areas of open water and melt ponds on the ice. There is also some evidence that undulations on the surface of pack ice are detectable and there is reason to expect that, on further investigation, the passive microwave scanner may be a useful tool for studies of ice morphology.

Profilers. These devices, the laser altimeter and radar profiler, provide detailed information on the surface roughness along the line of the flight path. The laser altimeter, because of its very much shorter operating wavelength, has higher discrimination in range and finer resolution than the radar profiler but the latter has the advantage of all weather capability. Signatures characteristic of the various ice types and of open water have been identified from the roughness profiles and also from the intensity of the returned signals. The ice thickness adjacent to leads or open water can be estimated from the

height of the ice above the sea level. The profilers can provide data in a form amenable to computer analysis to obtain the surface roughness of the different ice types, the frequency and height of ridging, the frequency and width of leads, etc. This information may be combined with that obtained from the imagery discussed earlier on distribution patterns of various ice types, and on the orientation of leads and pressure ridges to calculate a drag coefficient representative of a given area.

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REMOTE SENSING AND GROUND TRUTH INVESTIGATIONS

by

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INTRODUCTION

During the AIDJEX pilot experiment in 1971, we plan to carry out a comprehensive remote sensing experiment over sea ice. Not only will a large ground truth party be on the ice during all of the remote sensing flights, but aircraft from three federal agencies will perform remote sensing missions in the Beaufort Sea during March, 1971. The NASA Convair 990, which may fairly be said to be the most advanced remote sensing airplane in the world, will overfly the AIDJEX experiment in the vicinity of 74° N latitude, 130° W longitude, on March 8, 9, 11, 12, and 15. The Coast Guard Hercules will overfly the AIDJEX test site on March 8 and 11, and the Navy "Birdseye" Constellation will overfly the site between March 22 and 26. To have three such aircraft overflying the same area in one month is a highly unprecedented occurrence, and we of the polar scientific community are immensely pleased with this kind and quality of support.

A wide-ranging remote sensing capability is imperative to the AIDJEX program because a great many of the parameters which we wish to measure during AIDJEX--e.g., albedo and ice deformation--undergo very large spatial variations in very short times. As the reader covers the various topics in this Bulletin, he will be aware that the design of the remote sensing experiments for AIDJEX 1971 involves two phases: (1) detailed measurements at low altitudes of a small area of ice; and (2) large-scale measurements at great altitudes of a large part of the ice canopy. In the remote sensing arena the micro- and macroscale proponents are constantly battling, but since it is hardly the purpose of this Bulletin to enter into the fray, let it suffice to say that we chose to obtain

both kinds of data because the systems were capable of obtaining both on each mission and because a real need for both kinds of data exists.

On January 7 and 8, 1971, a small remote sensing meeting was convened at the Applied Physics Laboratory, University of Washington, to plan and coordinate the AIDJEX 1971 missions. A list of those who attended the meeting appears at the end of this section, on page 22. This group quickly decided what should be done and outlined a plan for each phase of the operation. The Coast Guard, Navy, and NOAA parts of this plan are covered later in this Bulletin. I shall confine myself now to discussions of the CRREL-USGS ground truth investigations and the NASA-Ames Convair 990 plan which I prepared as the Principal Investigator for Sea Ice for SPOC (Spacecraft Oceanography Center) of NASA.

GROUND TRUTH PLAN

During the 1970 AIDJEX pilot study in the Beaufort Sea, I performed tellurometer measurements over the sea ice at several ranges. The longest range attempted was approximately 17 km; and although the signal strength was great enough to give a strong image with the model MRA-2 tellurometer, the dielectric properties of sea ice caused too many reflections to allow proper focusing of the instrument. Measurements at shorter ranges proved very successful. At a range of 5 km, the tellurometer performed at its highest accuracy, measuring distances of several kilometers to around an accuracy of a few centimeters. At a range of several kilometers in which the instruments were located on different ice floes separated by two small leads, changes in length in the order of a meter occurred at intervals of 10-15 minutes. Although these measurements were only along a line and not over an area and were quite fragmentary, they demonstrated that the tellurometer can be used to measure mesoscale strains of sea ice. Therefore, when the CRREL-USGS field program was designed, the task of performing such strain measurements over an area figured significantly in the deliberations. Four model MRA-3 tellurometers will be used during AIDJEX 1971. This instrument has a carrier wavelength of 3 cm versus the carrier wavelength of 10 cm of the MRA-2 tellurometer used in AIDJEX 1970; for field programs carried

out in the Antarctic, it had a range in the order of 50 percent greater than the earlier model.

The main camp will be used as a tellurometer station. Last year a tower approximately 5 meters high was erected of empty fuel-oil drums. This platform proved to be stable and high enough for the measurements for the short-range observations. Two additional tellurometer sites will be established at a range of approximately 9 km from the main camp, forming an equilateral triangle. One of the auxiliary tellurometer stations will be placed along a line joining the main camp with the closer of the two auxiliary oceanographic stations. It is hoped that this arrangement will make for an efficient use of helicopter support. Along each leg of the equilateral triangle of the tellurometer strain network, the CRREL-USGS party will traverse by Ski-doo vehicles and measure snow thickness, ice thickness (as many measurements as possible), size and distribution of hummocks and leads, surface temperatures, and temperature and salinity profiles of selected ice types.

Recent microwave data obtained by the NASA-Ames Convair 990 during the June, 1970, flights over the Beaufort Sea have shown that microwave sensing promises to be an important remote-sensing frequency for sea ice. However, to properly utilize the immense microwave sensing capability of the Convair 990, it is necessary to perform some ground truth measurements in that spectral region. Mr. Al Edgerton of the Aerojet Corporation will be a member of the CRREL-USGS party and will bring to the ice a portable microwave ellipsometer which will be sled-mounted and towed behind one of the Ski-doo's. This instrument is a microwave reflectometer; that is, it is a microwave transmitter and receiver which can vary the angle of incidence and reflection of a microwave beam. This beam can be used to study the dielectrical properties of various snow and ice types. Mr. Edgerton has had a great deal of experience using this ellipsometer on glacier snow and ice, but this is the first time it will be used on sea ice. It is planned to take microwave measurements along each leg of the tellurometer strain network.

Another remote-sensing tool which looks promising for sea ice studies is the side-looking radar (SLAR). Both the NASA Convair 990 and the Coast

Guard Hercules will be flying side-scanning radar. In an effort to get some quantitative relationship between a SLAR image and the actual size of the object being measured, a set of finely calibrated corner reflectors will be installed on the ice in the vicinity of the main camp. This part of the program is being carried out by Dr. Pat Welsh of the U.S. Coast Guard, who is joining the CRREL-USGS ground truth party as its seventh member.

REMOTE SENSING PLAN FOR THE NASA CONVAIR 990

The Convair 990 is an extraordinarily sophisticated remote-sensing platform, probably the most sophisticated in existence. Each of the five missions that it will fly over the AIDJEX test site will last approximately 7 hours and will fly a route from Eielson Air Force Base, south of Fairbanks, over Fort Yukon, then to the AIDJEX site at approximately 74° N latitude, 130° W longitude, and return along the same route.

To operate the large array of sensors and to fly the aircraft, a total crew of 40 people is required. This leaves 4 seats on each flight to be used for scientific observers. During the June, 1970, Convair 990 flight over the Beaufort Sea, it proved useful to have someone knowledgeable about sea ice aboard the aircraft to describe various phenomena to the remote-sensing specialists. Professor Joseph Fletcher, AIDJEX Coordinator, has agreed to participate in all five Convair 990 flights as the chief ice observer. Miss Ann D. Moen, Hydrologist with the Ice Dynamics Project of USGS, will participate in all five flights as the USGS representative. Ten other scientists have been invited to accompany a flight group to get a unique look at the Arctic sea ice and learn at first hand the immense capability of the Convair 990 remote-sensing platform. A list of those invited is included at the end of this section, on page 23.

A schematic of the layout of the Convair 990 is shown in Figure 1. During each of the flights the following sensors will be flown:

- 19.3 GHz scanning microwave radiometer
- 1.42 GHz microwave radiometer, nadir viewing
- 4.99 GHz microwave radiometer, nadir viewing
- 37.0 GHz microwave radiometer, 45° from nadir to rear of aircraft along flight path

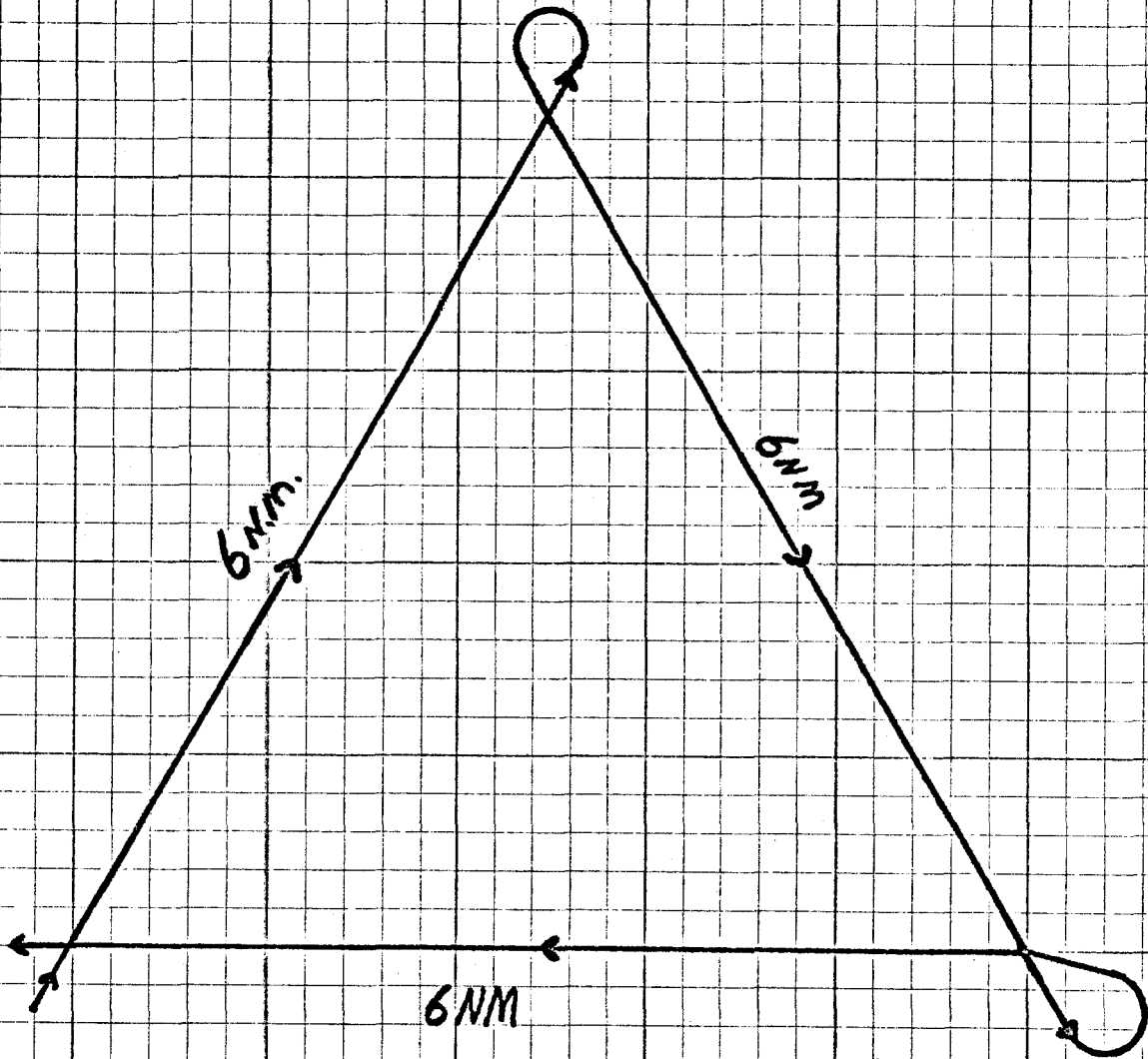
- 2.69 GHz microwave radiometer, nadir viewing
- 31.4 GHz microwave radiometer, zenith viewing
- 9.3 GHz microwave radiometer, zenith viewing
- 10.66 GHz microwave radiometer, nadir viewing
- 0.38-2.4 micron Filter Wedge Spectrometer, nadir viewing
- Multichannel infrared spectrometer
- Laser nephelometer
- Geodolite, laser profiler
- 25 cm side-looking mapping radar
- 70 mm color camera
- 25 cm geodetic color camera
- 35 mm bore-sighted cameras for select microwave radiometers.

The output of these sensors is recorded on magnetic tape with a common time-reference system. Furthermore, the aircraft is equipped with an inertial navigation system which gives a continuous record of positions on magnetic tape, on the same time-reference system as the sensors. A host of airplane parameters such as speed, altitude, pitch, and yaw, are also continuously recorded on magnetic tape on the common time system.

During each of the five Convair 990 missions, the aircraft will arrive over the AIDJEX site at approximately local noon. It will then proceed with the low-level experiment. Figure 2 shows the low-level flight path that the aircraft will take over the CRREL-USGS strain network. The side-scanning radar scans from the right-hand side of the aircraft; therefore, the flight path proceeds in a clockwise direction.

Much of the discussion during the planning meetings for these flights centered around the means by which the aircraft will locate the three tellurometer stations so that it will be able to fly directly along the tellurometer strain triangle. The main station will be relatively easy to locate because it will have a continuously operating beacon (269 kc, call sign India Yankee) and will be composed of so many parcolls and prefabricated huts that it will probably look like a small town. However, locating the other two stations will be far more difficult. At these auxiliary stations, a large X of international orange bunting having dimensions of about 30 meters will be laid on the sea ice. At the time of the low-level overflights, each of the tellurometer points will set off a flare, a smoke bomb, and a smudge pot. The aircraft will fly beneath the cloud deck wherever possible and visually orient itself over the strain network. If

2000' ALTITUDE



TIME REQUIRED - :12

Figure 2. Diagram of low-level flight plan.

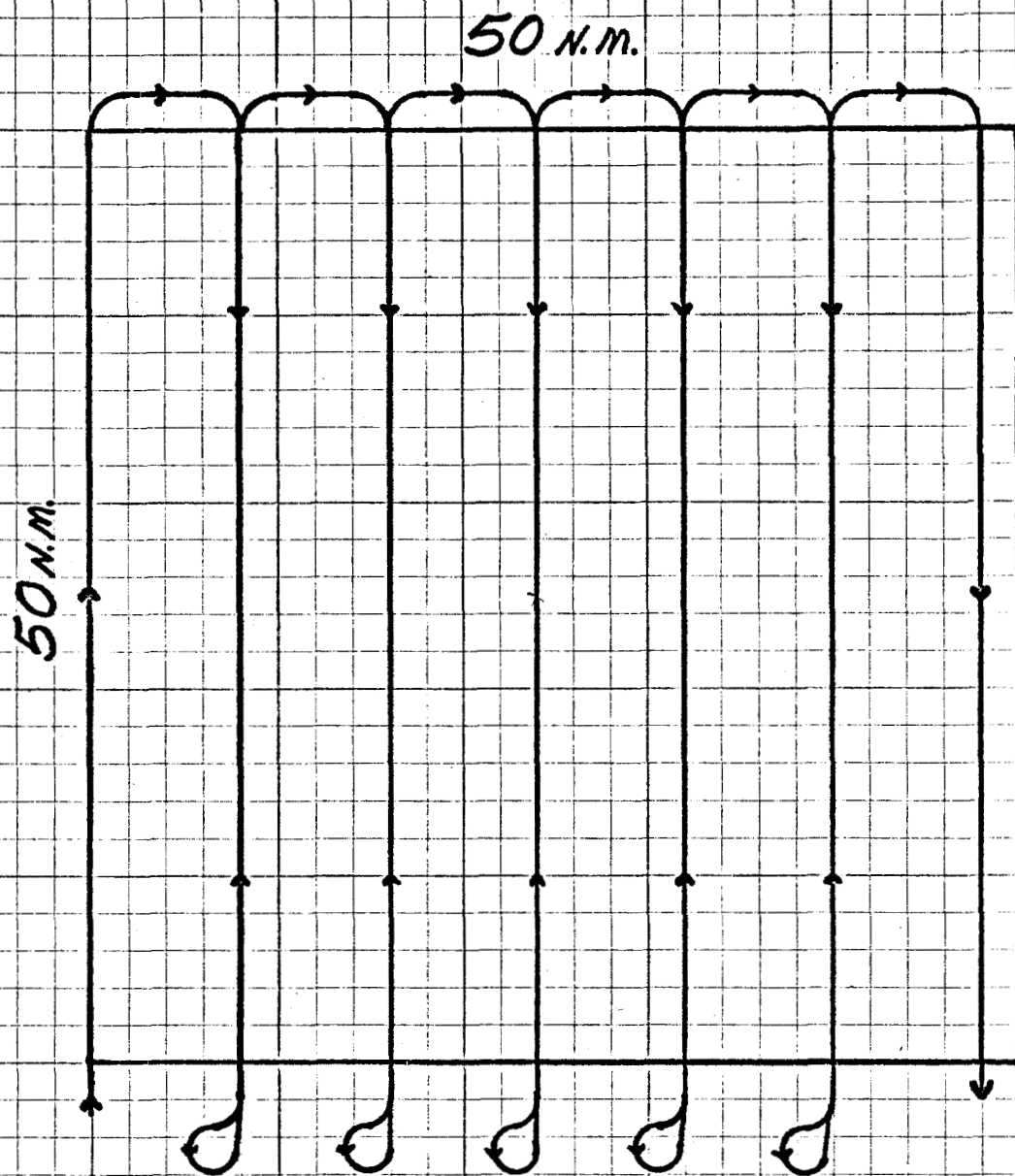
on a given flight the cloud base is lower than 100 m, the low-level part of the mission will be cancelled. Before, during, and after each low-level mission, strain measurements and microwave ellipsometer readings will be made along each leg of the tellurometer network. The low-level mission should take approximately 12 minutes.

The sensors of prime importance on the low-level mission are the SLAR, the 19.3 GHz scanning microwave radiometer, the geodolite laser profilometer, and the cameras. They will allow observable surface changes along the lines of the network to be interpreted in light of the observed strains. The aircraft must be at an altitude of 700 meters (2000 feet) or less for the laser profilometer to work. The Convair 990 will certainly satisfy this requirement, having flown over a considerable part of the Beaufort Sea at an altitude of 100 meters.

Immediately upon completion of the low-level mission, the aircraft will fly to an altitude of 11-13 km to perform the high-altitude measurements. Although SLAR and microwave images of sea ice have been obtained in the past, they have been of limited use in understanding sea-ice dynamics because they were flown along a line and were not repeated. We must attempt to acquire for the first time sequential synoptic imagery of the sea ice on a scale that will be useful in understanding the gross dynamical features of the ice, such as polynya migration.

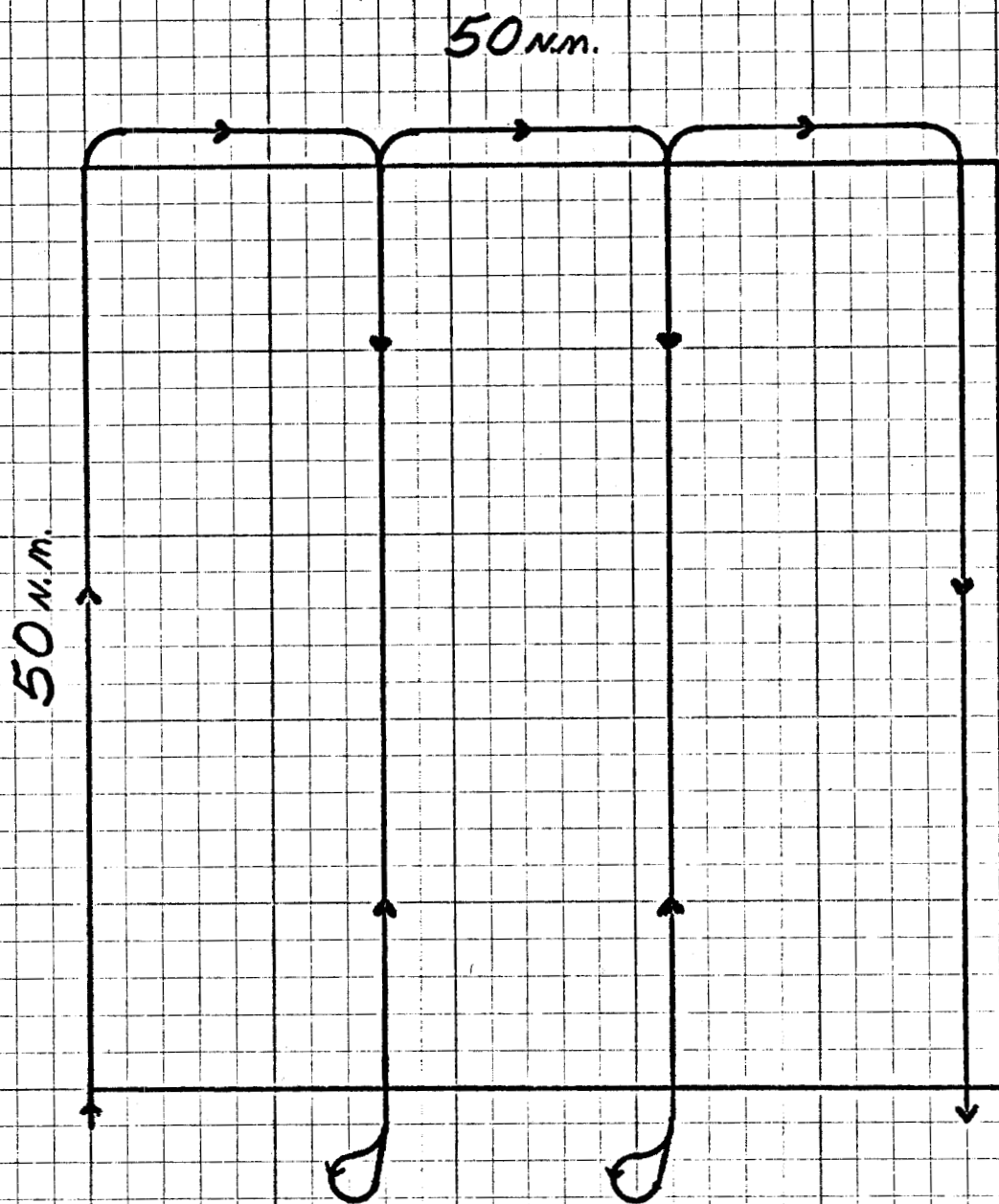
Given the range of the aircraft and the time over target, it was concluded at the planning meetings that a square area roughly 80 km (50 nautical miles) on an edge could be imaged around the AIDJEX location. If the area is cloudfree, the flight path will be as shown in Figure 3 and will require one hour, 52 minutes to fly. Such a path would provide microwave and SLAR images as well as high-quality, false-color photographs of the area around the AIDJEX site. If the area is cloud-covered, the aircraft will fly a flight path as shown in Figure 4. Because the cameras would not be used in this flight plan, fewer passes are required and that part of the mission would take only one hour.

After completing each high-altitude mission, the aircraft will return to low level and again fly the path shown in Figure 2 over the CRREL-USGS strain network. It is highly likely that in the 2-3 hours between the first and second low-level missions, measurable deformations



30° OVERLAP, 40,000' ALTITUDE
 TIME REQUIRED - 1:52

Figure 3. Diagram of high-altitude flight plan.



50° OVERLAP, 40,000' ALTITUDE
TIME REQUIRED - 1:00

Figure 4. Diagram of alternate high-altitude flight plan.

will take place within the area of the strain triangle. Thus we hope to have high-quality in situ strain measurements coupled with high-quality photographs and images of the strain network and of the surrounding area to a distance of 40 km. It is our feeling that this kind of data will be very useful in determining the rheological properties of sea ice on a mesoscale basis.

The reader can see at this point that the CRREL-USGS experiment and the Convair 990 remote sensing experiment are closely coupled systems in which the design criteria are mutually compatible. We hope that the plans made in the last four months have foreseen all contingencies. But I should point out that because we will have excellent communication with the aircraft and because scientists directly involved with AIDJEX will be on board the aircraft, it is possible to alter the flight plan during each mission to best serve our scientific needs. We feel that if our plan succeeds we will obtain excellent data which will be highly beneficial in designing the full AIDJEX study to take place in 1973.

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January 7-8, 1971, Seattle, Washington

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March 8

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Dr. R. J. Evans
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March 12

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Dr. D. C. Archibald
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Dr. Paul Bock
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Dr. Kirk Bryan
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March 15

Dr. Lawrence Larson
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Dr. William Criminale
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March 11

Dr. Norbert Untersteiner
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Dr. Gary Maykut
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THE CRREL-USGS ICE MECHANICS AND MORPHOLOGY PROGRAM

by

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Pack ice is essentially in continuous motion. This motion produces the more striking features of the pack: ridges, hummocks, and open leads. However, neither the detailed mechanisms of formation of these features nor their role in determining the state of the ice cover is clearly understood.

This lack of understanding stems from two main causes: a lack of good observational data and the inherent complexity of the overall problem. The forces acting on the pack at a given location are the pressure gradient force (\vec{G}), the coriolis force (\vec{C}), the wind and water stresses ($\vec{\tau}_a$ and $\vec{\tau}_w$) and the internal ice stress (\vec{I}). \vec{I} is related to the transmission of stress through the pack, which in turn is associated with the development of morphological features such as ridges and leads. The detailed response of the pack is also certainly strongly affected by the geometry of the floes, leads and ridges, and the distribution of ice thicknesses in the area of interest--in short, by the deformation and thermodynamic history of the ice. As the ice types in a region change and new deformation features form and are modified by snow drifting and ablation, the roughness of both the upper and lower ice surfaces changes. This changes the wind and water stresses exerted on the ice, which, in turn, affects \vec{I} . To understand the motion of the ice pack we must, therefore, understand the behavior of a complex, partially internally regulated, feedback system. The CRREL-USGS program is designed to provide preliminary data on several aspects of this problem.

A triangular strain net will be laid out near the main AIDJEX sea ice camp; one station will be at the main camp while the other two stations will be at distances of 3 to 6 miles. The distances will be measured with

MRA-3 tellurometers. The strain sites will be occupied during the remote sensing overflights and for 4- to 8-hour periods at two-day intervals during the intervening times. The exact timing of the strain measurements will, in large part, be determined by preliminary on-site data analysis.

The sequential remote sensing coverage will serve as a valuable complement to the surface strain measurements, since they will give some information on the mesoscale deformation in the area surrounding the strain network. In particular, the photography will provide a base for the identification of specific deformation features that can be correlated with observed strains. When possible, low-level aerial photography will be taken from the station aircraft to document features of particular interest.

Detailed ground observations will be made of the local ice deformation leading to the formation of ridges and hummocks. The surface geometry and distribution of elevations within and between ridges and hummock fields will be studied. An attempt will be made to document block size distributions, the degree of bonding both above and below the water line, variations in the void volumes, and physical property profiles of the ice in both newly formed and old pressure ridges and hummocks. The geometry of the lower surface of selected ridges will also be examined by sonar and by drilling. The sail-height/keel-depth ratios will be studied as a function of both ridge and hummock types and the specific location on a ridge pattern. The variations in ice thickness along the strain lines will be established by drilling. Also, a number of temperature and salinity profiles will be obtained on representative ice types in the general test area. The ratios of the anions in the salinity samples will be studied for possible strong departures from the ratios found in normal sea water.

The laser data from the non-colinear patterns will be used to estimate the two-dimensional autocorrelation function. From this function one can calculate the two-dimensional power spectrum which will provide information on the directionality of ridging. It is also planned to use differences in the observed power spectra along a known track to estimate the two-dimensional strain tensor for the ice.

NASA FLIGHT PROGRAM

The following is a memorandum from Earl V. Petersen, Expedition Manager, NASA AMES, at Moffett Field, California, concerning the 1971 Convair 990 Meteorology-AIDJEX expedition.

This memorandum presents scheduling and planning information for the 1971 Meteorology-AIDJEX Expedition to be conducted with the NASA-ARC Convair 990 (N711NA) aircraft in February and March 1971.

The 1971 Meteorology-AIDJEX Expedition has two major objectives (1) to study the use of microwave radiation to measure the characteristic of sea ice, moisture content of snow and soils, and sea state, and (2) to support the Arctic Ice Dynamics Joint Experiment (AIDJEX), which is a cooperative U.S. and Canadian effort to understand quantitatively the interaction of the motions of the atmosphere, the pack ice, and the liquid ocean. The CV-990 will obtain the remote sensing data required by the AIDJEX scientists. This requires 990 overflights of the AIDJEX ice-based stations in the Beaufort Sea. To support the 990 experimenters, the AIDJEX scientists will provide ground truth data.

The following personnel will coordinate the NASA-ARC and NASA-GSFC support of this expedition.

- (1) Earl V. Petersen (ext. 2084) is the NASA-ARC Expedition Manager. Herbert V. Cross (ext. 2084) is the NASA-ARC Assistant Expedition Manager.

Both E. Petersen and H. Cross will coordinate the activities at ARC to prepare the CV-990 for the expedition.

- (2) John W. Weyers (ext. 3013) is the NASA-ARC Technical Services Engineer responsible for aircraft and logistic support arrangements for the CV-990.
- (3) R.H. Davidson (ext. 2472, 2226) is the NASA-ARC Engineer responsible for final equipment stress certification and scheduling of equipment installation aboard the CV-990.
- (4) Harold Z. Reed is the NASA-GSFC Experiment Coordinator (GSFC ext. 4576, ARC ext. 2084). Mr. Reed will be at ARC by January 27 to assist in preparing the equipment for installation.

The equipment installation and flight schedule is as follows: (Note: The installation date, as stated in a previous memorandum by Dr. Nordberg, is advanced from February 3 to February 1)

February

- 1-18 Installation of equipment. Mr. Hjalmar Schacht, the Airborne Science Office laboratory technician, will coordinate support of equipment preparation as required by visiting experimenters between 8 a.m. and 4:30 p.m. Please schedule your work between these hours if you require his assistance. On weekdays the hangar will be closed at 11:30 p.m. All equipment must be installed on the aircraft (ready for flight) and final checks completed by the evening of February 18.
- 19 (Fri) Aircraft weighing. After this date, any equipment installed on or removed from the 990 must be recorded on the weight and balance sheet posted at the 990 main entrance.
- 20 (Sat) Optional workday for equipment check-out. At the end of this day the 990 is off limits to all experimenters until after the pilot proficiency flight of February 22.
- 22 (Mon) (1) Aircraft safety and arctic survival indoctrination.
This indoctrination is compulsory for all flight participants.
TIME: 9 a.m. LOCATION: Flight Operations
Conference Room.
- (2) Experimenters' meeting
TIME: 1 p.m. LOCATION: Airborne Science Office
Conference Room
- (3) Pilot proficiency flight
- 23 (Tue) Data flight, Moffett/Moffett
- 24 (Wed) No flight - Experimenters' instrumentation repairs, calibration, and check-out.
- 25 (Thu) Data flight, Moffett/Moffett
- 26 (Fri) Load aircraft in preparation for trip to Texas and Colorado. Supplies are to be ready for loading aboard the 990 by 2 p.m.

March

- 1 (Mon) Data and transit flight, Moffett/Ellington AFB, Texas. To allow adequate time for loading the aircraft, the expedition members must have their baggage at the aircraft 1.5 hours before boarding time.
- 2 (Tue) Data and transit flight, Ellington/Buckley ANGS, Denver, Colorado.

March

- 3 (Wed) Data and transit flight, Buckley/Moffett
- 4 (Thu) Load aircraft in preparation for trip to Alaska. Supplies are to be ready for loading aboard the 990 by 2 p.m.
- 5 (Fri) Data and transit flight, Moffett/Eielson AFB, Fairbanks, Alaska. Personal baggage must be at the aircraft 1.5 hours before boarding time.
- 6 (Sat) Coordination meeting with AIDJEX group
- 8 (Mon) Data flight, Eielson/Eielson
- 9 (Tue) Data flight, Eielson/Eielson
- 11 (Thu) Data flight, Eielson/Eielson
- 12 (Fri) Data flight, Eielson/Eielson
- 15 (Mon) Data flight, Eielson/Eielson
- 16 (Tue) Load aircraft for return trip to Moffett.
- 17 (Wed) Data and transit flight, Eielson/Moffett. Baggage to be at aircraft 1 hour before loading time.
- 18 (Thu) & Unload aircraft and pack equipment for shipment to home station.
- 19 (Fri)

Flights are not scheduled for weekends; however, weekend flights may be scheduled to make up for canceled or aborted weekday flights. The support of AIDJEX requires that five data flights be completed from Eielson, thus the return date from Alaska could slip if aircraft or weather problems delay our flights.

An airlift between Moffett Field and Eielson AFB, Alaska, has been arranged for experimenters and aircraft support items. Any item which is not required for the 990 transit flight should be sent by the airlift. The schedule for the airlift will be announced at a later date.

GENERAL INFORMATION

Flight lunches can be purchased for all flights originating from Moffett Field from Miss Ann Teshima, Airborne Science Office Secretary. Lunch requests must be made the working day before a flight; cost \$1.15. A quarter will be collected from everyone for the coffee fund.

Hotel reservations will be made for all flight personnel by the Airborne Science Office. At Eielson AFB we will use the BOQ accommodations (two persons to a room).

For the Alaska trip, all flight personnel will be furnished arctic clothing. This clothing will be for your general use in Alaska and it will also be part of your aircraft arctic survival equipment. Thus, on

all flights in Alaska, this clothing must be aboard the 990. The clothing to be furnished is as follows:

- (1) Parka (outerjacket)
- (2) Cold weather flight suit, coverall type
- (3) Boots, vapor barrier type
- (4) Kit bag
- (5) Thermal insulated gloves
- (6) Combination mitten set
- (7) Insulated cap

In addition, it is recommended that each individual supplement the above list of arctic clothing with the following:

- (1) Three pair of thermal undergarments, waffle-weave type
- (2) Four pair of heavy wool socks
- (3) Six pair of light-weight cotton or silk socks
- (4) Warm working shirts and pants (wool preferable)
- (5) Flashlight

To facilitate the issue of aircraft arctic survival clothing, please complete the enclosed form and return it to me by not later than January 28, 1971.

U. S. COAST GUARD RESEARCH RELEVANT TO AIDJEX

by

J. Johnson, J. McIntosh, and L. Breslau
Department of Transportation
U. S. Coast Guard
Washington, D. C.

Remote sensing of sea ice has consisted, for the most part, of periodic photographic coverage. Recently, however, an increasing amount of work has used side-looking radar, infrared, and laser systems. Almost all this work is research oriented and is directed toward establishing methods of observing sea-ice characteristics.

Of the sensors mentioned above, the Coast Guard is conducting research in ice reconnaissance utilizing a side-looking airborne radar (SLAR) system. The first experiment of this nature, by the Coast Guard, was performed during the MANHATTAN tanker test in the fall of 1969. The results of this experiment were promising and indicated that SLAR was indeed a useful tool for mapping sea ice.

The radar system used was an AN/DPD2 SLAR manufactured by Philco-Ford. It mapped an area 10 miles on the left side of the aircraft. Ice characteristics easily observed from SLAR imagery were concentration, floe size, and water openings. Categorical ice age, topographic features, and fracture patterns were more difficult to identify. Future research will seek to improve the identification of these latter parameters.

The SLAR has been modified by an additional antenna to image a swath 20 miles wide on both sides of the aircraft. The Coast Guard plans to conduct SLAR flights over the AIDJEX pilot study area in March, 1971.

In addition to the SLAR, a T-11 aerial camera will be installed on the aircraft (C-130) so that photographs can be obtained to correlate with the SLAR imagery. It is hoped that multisensor data can be obtained from NASA aircraft, also flying over the AIDJEX area at approximately the same time, to correlate with the Coast Guard imagery and with the ground truth data collected on the ice.

It was found during the MANHATTAN test that, largely due to the season and the geographical location, the SLAR did not satisfactorily distinguish first-year sea ice from older forms. Therefore, to develop a basis for this distinction, the Coast Guard plans to conduct SLAR flights over predominately first-year ice in Baffin Bay sometime during February and March. As part of its program to extend the Great Lakes shipping season, it will also conduct SLAR experiments over the Great Lakes to establish interpretational techniques for use in operational reconnaissance.

Another major ongoing research effort by the Coast Guard is the classification of pressure ridges. While it has been known for many years that pressure ridges are a severe impediment to arctic sea transportation, the inaccessibility of these ridges and the difficulty of working in the Arctic have served as formidable obstacles to scientists. The work of the Russians and Japanese has been either too sparse or on thin ice.

In 1968, the Coast Guard, as part of its polar marine transportation mission, began an investigation of sea-ice pressure ridges that might impede ships. Coast Guard and CRREL scientists performed pressure ridge studies during 1969 and 1970, and although the subject is far from exhausted, two authoritative papers have resulted from this effort. These studies seek to learn about the methods of formation, distribution patterns, and mechanical and physical properties of pressure ridges, and ultimately to categorize them into distinct groups so that their keel depths can be correlated with their surface heights. Most of the work so far has been limited to rather small ridges formed in first-year ice. This winter, the Coast Guard plans to conduct pressure ridge studies in multi-year ice conditions in the vicinity of the proposed Canadian site near Banks Island.

NAVOCEANO PARTICIPATION IN AIDJEX

by

Robert D. Ketchum
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To participate in the AIDJEX pilot study during March, 1971, the NAVOCEANO Birdseye aircraft has been scheduled to make flights over the study area on March 22 and 24, with a possible third visit on March 26. The aircraft, an NC-121K (Super Constellation), will carry a laser profilometer, an infrared scanner, and a CA-14 aerial camera.

The mission will obtain data for (1) cross correlation studies to aid in further development of data interpretation techniques, (2) studies of ice roughness with regard to topographical and morphological conditions, and (3) assessment of distribution of ice types and features and their relative motions.

During each of the visits to the AIDJEX study area, the following flight procedures are planned:

(1) At an altitude of 5000 feet (weather permitting), fly a rectangular grid pattern to map the study area with stereo photography and infrared imagery, and to obtain a grid of laser terrain profiles.

(2) At an altitude of 1000-2000 feet, fly several flights over each leg of the trinagular study area (defined by three auxiliary stations outlying the main central station). Again, data will be obtained with all three sensors.

The infrared imagery, photography, and laser profiles will be cross correlated to aid further development of interpretation techniques. Mosaics of the study area will be constructed from the photographic and infrared imagery. Strip mosaics will be constructed from the photography taken along the legs of the triangle. The mosaicked data will enable a comprehensive assessment of ice conditions in the study area and determination of changes that occurred between the flight periods. In addition, the ice conditions represented on these mosaics can be compared to other photographic

or side-looking radar representations of ice conditions obtained by NASA and the U. S. Coast Guard one to two weeks prior to the Birdseye flights. The strip mosaics will show changing ice conditions along the legs between the outlying stations, where strain measurements and other ground truth data are obtained. The several laser terrain profiles taken over essentially the same terrain (between the stations) will be compared to see if similar ice statistics (ice types distribution, ridges by height) are obtained. Laser and photographic data will be used for topographic studies in the area.

NOAA SATELLITE RESOURCES AVAILABLE TO AIDJEX

by

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Weather satellite imagery of the Arctic has been available since 1967. The resolution, approximately 2 n.mi. diameter/pixel (picture element) is quite adequate to delineate the pack edge but too coarse to resolve anything but the largest pack features, and hence too coarse to resolve any features of primary interest to AIDJEX. Satellite data are very difficult to relate to aircraft and surface observations because of the great difference in resolution. This imagery, however, can be most important in forecasting meteorological conditions for aircraft missions and as a meteorological record during the test periods.

The National Environmental Satellite Service (NESS) operates the National Oceanic and Atmospheric Administration (NOAA) satellite systems. Two basic forms of data are available. The data from one series of satellite instruments are recorded on the satellite, and then transmitted to a NESS receiving station. These data are then telemetered to NESS in Suitland, Maryland, for processing. From these global data several computer products are produced on a daily basis. The second data form is direct readout. As the satellite instrument is operating, data are transmitted in real time. All receivers within receiving range can receive these data. The Automatic Picture Transmission (APT) from the vidicon camera system provides the direct readout of visible cloud imagery.

NESS can produce maps from the recorded vidicon camera data at a resolution of 2 n.mi. (augmented resolution); however, some degradation of the image may occur. The brightness level for each picture element is automatically corrected for system errors and for changes in sun angle. At high latitudes and with the low sun angles there is some loss of

contrast due to this normalization. In compiling daily brightness maps, only the most recent data are retained for processing where there is orbital overlap. This results in only the "right edge" of each high-latitude frame being used. In the spring and fall, the light level in this portion of the photographs is too low, hence no images are retained.

The Improved TIROS Operational Satellites (ITOS) now carry infrared scanning radiometers. A daytime and nighttime image can be produced. This infrared system has a ground resolution of approximately 5 n.mi. diameter/pixel. Programs are available to enhance this imagery to display the thermal patterns in ice and water. Direct readout of this system will also provide the best cloud imagery during March for planning the aircraft mission.

During the AIDJEX period several new satellite remote sensing systems will be launched. In 1972 the NOAA-4 satellite is scheduled to carry a Very High Resolution Radiometer (VHRR). This will provide visible and infrared imagery at a resolution of 1/2 n.mi. diameter/pixel (900 meters). The Fairbanks receiving station will be capable of receiving the data for the entire Arctic Ocean. The VHRR is a direct readout system due to the great volume of data necessary at such high resolution.

The National Aeronautic and Space Administration (NASA) will launch the first Earth Resources Technology Satellite (ERTS) in 1972. The satellite will carry multispectral imaging systems that will have ground resolution of about 100 meters. Later ERTS satellites will carry IR imagers with ground resolution of about 250 meters.

The scheduling for ERTS data may be more difficult due to the complex multi-agency requirements placed on the system. NESS will handle the processing, archiving, and distribution for ERTS data pertaining to meteorology and oceanography. A request for some Arctic data has been placed by NOAA/NESS.

The first passive microwave imager is scheduled to be launched on Nimbus E in 1973. This imagery will provide ice/water information through most clouds, but the resolution will be 30 n.mi. diameter/pixel.

With all these new systems being tested during AIDJEX, great care will have to be taken to assure proper utilization of the satellite time,

retention of the data, proper processing, and the best application of the data to the experiment.

If AIDJEX feels these new satellite data are useful, it is important that they develop contacts with NASA and NOAA to assure that satellite data are obtained for AIDJEX and to assure that AIDJEX feedback is directed to the proper offices.

1971 PILOT STUDY SUMMARIES

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CRREL-USGS-USCG FIELD PROGRAM

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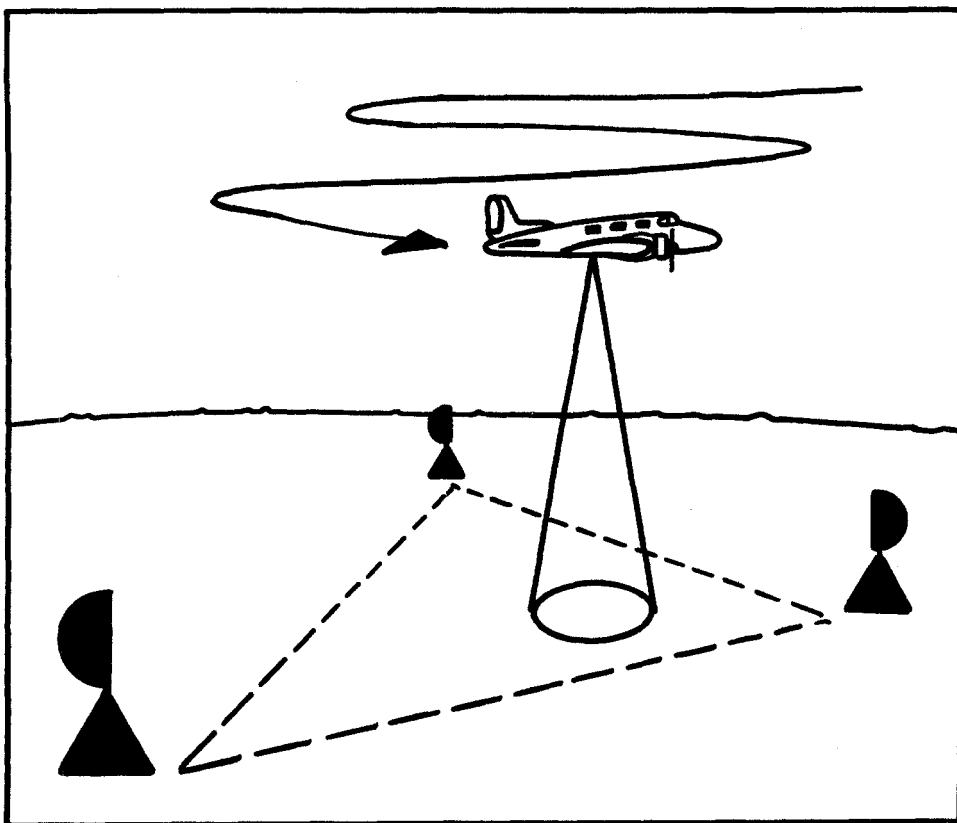
General

Strain measurements during the 1970 AIDJEX pilot study demonstrated that deformation of sea ice over ranges of 5-8 km could be measured by tellurometers. A CRREL-USGS team designed a series of strain experiments to take place during AIDJEX-71 along with morphological studies and remote-sensing overflights of sea ice. A triangular strain network with tellurometer lines of approximately 8 km length will be established on the sea ice using the main AIDJEX camp as one vertex and two small, occasionally occupied, camps as the other vertices. Along each strain line, measurements will be made of snow thickness, ice thickness, size and distribution of hummocks and leads, ice temperature and salinity vs. depth, and microwave dielectric properties.

Three remote-sensing aircraft will overfly the strain array: the NASA-AMES Convair 990 on March 8, 9, 11, 12, and 15; the U.S. Coast Guard C-130 between March 8 and 11; the U.S. Navy Birdseye C-121 between March 22 and 26. The Convair 990 will image and photograph an area of 80 km by 80 km

surrounding the AIDJEX site and will also make two low-level missions over the strain network during each flight. The Coast Guard C-130 will perform SLAR studies, and the Birdseye C-121 will concentrate on laser profilometer studies.

The final design of the total experiment is the evolutionary result of a coupling of the remote sensing with the strain and surface morphology criteria. If the experiment succeeds, we shall have the first mesoscale sequential synoptic images of sea ice and the first mesoscale deformations to interpret in light of observed surface changes.



Remote sensing will be performed by three aircraft overflying the tellurometer network.

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Charles E. Davis, Jr. (Jr. Chemist), ASL

Steven L. Speidel (Physicist General), ASL

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Program

The Arctic Submarine Laboratory plans to measure and interpret the main energy components (sensible, latent, net radiant and conducted flux, and air-ice stress) during the 1971 pilot study. Two 10-meter masts located on the floe will measure temperature, horizontal wind speed, and specific humidity profiles. A tethered aerodynamic wing will be used to extend the profiles to a height of 1000 meters. From these profile measurements, scale effects for the sensible energy, latent energy, and shear stress should be observed.

The conducted heat flux will be determined from temperature profiles and heat flux meters placed in the snow and ice. Measurements of snow and ice density will be made. The salinity of the ice at various depths will be measured. From these measurements the thermal conductivity and dielectric constant of the snow and ice may be computed.

The net radiation will be measured at several locations using different types of radiometers. It is also planned to determine short-wave, long-wave, direct, and diffuse radiation components. Pyrheliometric measurements will be made with various filters to obtain the atmospheric turbidity coefficients.

Water stress measurements will be made with a hot film probe and by three special thermoprobes oriented in the vector directions.

Efforts will be made to measure accelerations of the ice floe using sensitive accelerometers. These will be oriented in the plane of the ice floe and normal to the ice floe.

SYNOPTIC HYDROGRAPHIC MEASUREMENTS (UNIVERSITY OF WASHINGTON)

Participants

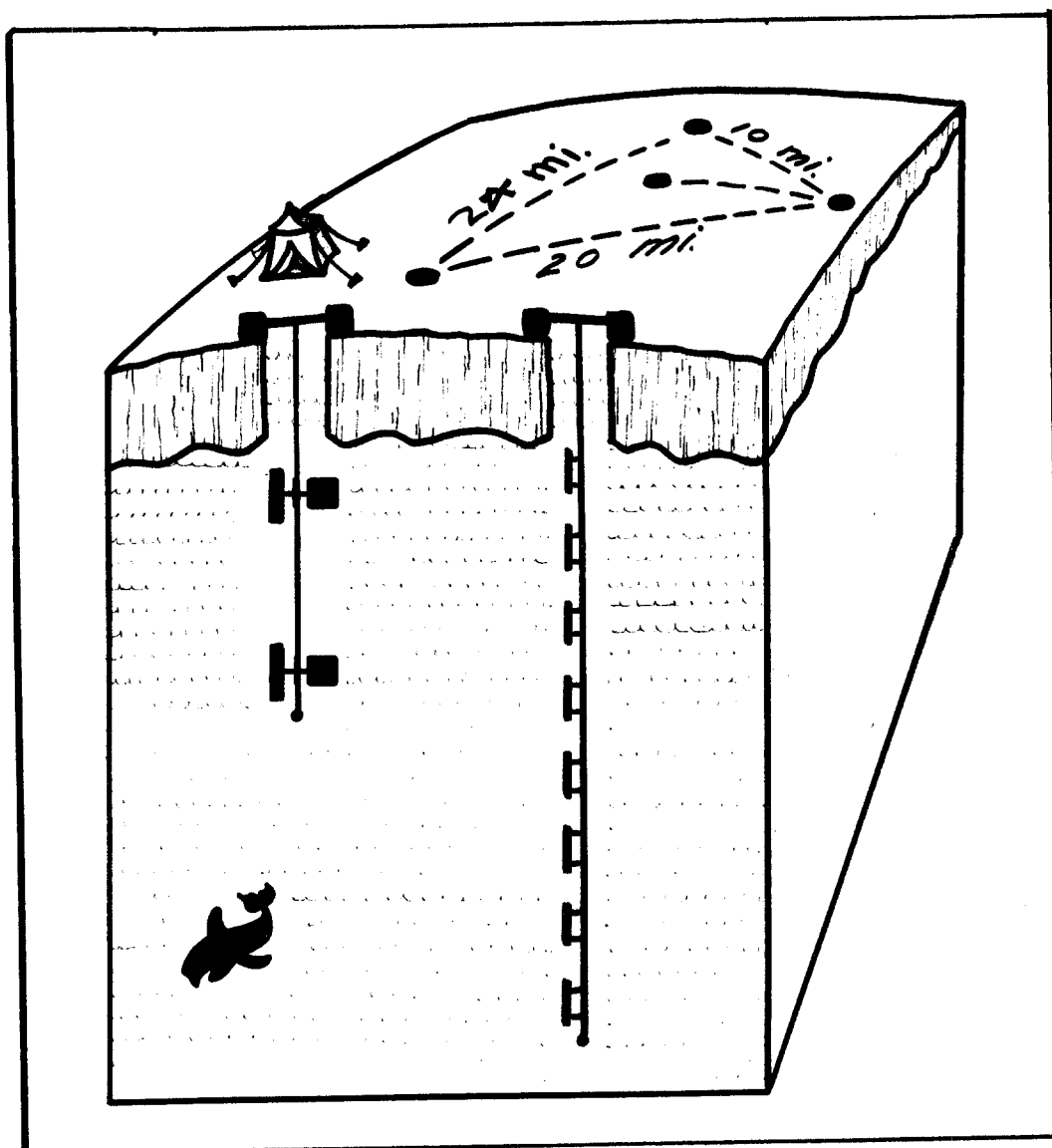
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Program

Measurements will be made locally of the interior flow. The question here is the horizontal and vertical spacing of current meters necessary to translate the direct stress measurements into a stress field under the ice.

Measurements will be made of the interior mass field over a 30 km² area. This will tell us if it is possible to utilize "geostrophic" currents to relate the direct stress measurements to the interior flow. If this is possible, these measurements, though less direct, may provide more reliable results for the main AIDJEX study.

Current meters, both at the main camp and at two satellite camps 10 and 20 miles away, will be placed at depths of 10 m and 50 m. Salinity and temperature will be measured at 30, 60, 100, 140, 180, 220, 260, 300, 350, and 500 m. At an unmanned location, inside the triangle formed by the main camp and the satellite stations, current meters will be placed at depths of 10, 50, 150, 250, and 500 m. Decca/Lambda recorders at the three manned stations will record relative position.



Schematic of camp and current-meter placement.

DETAILED WATER-STRESS MEASUREMENTS (UNIVERSITY OF WASHINGTON)

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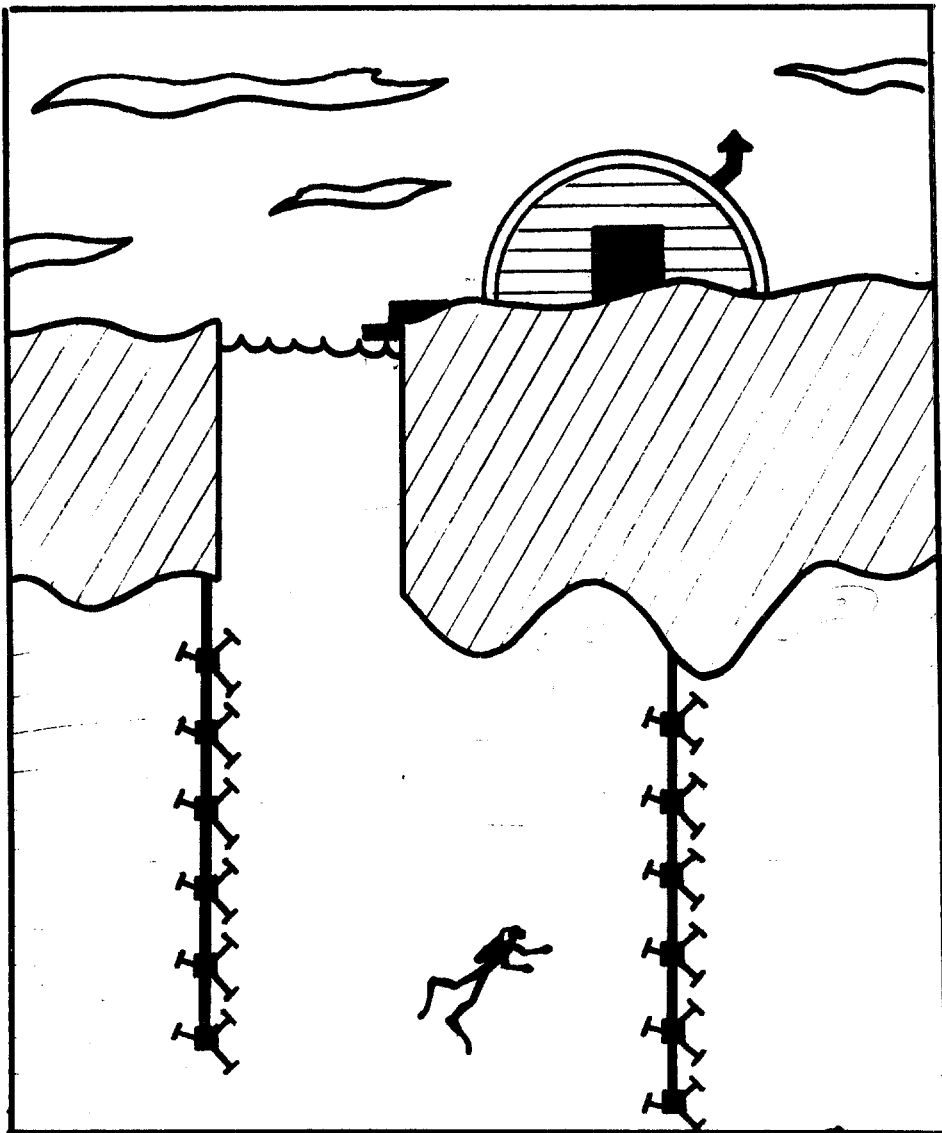
Program

Measurements made under the ice at Camp 200 in March, 1970, indicate that the average boundary shear stress can be at least one order of magnitude greater during storms than under quiescent conditions, thus emphasizing the importance of arctic storms in local stress determination. In addition, measurements of under-ice topography made both in March, 1970, at Camp 200 and in past years by nuclear submarines, when combined with boundary-layer calculations, demonstrate that significant nonuniform flow effects must occur and that proper under-ice stress measurements or calculations must include these effects.

To investigate these problems during the 1971 study, two masts, each containing six triplets of current meters, will be placed below a typical sheet of arctic ice. One mast will be situated under a thick section of ice, and the other mast will be moved to various nearby locations by

divers. In this way, topographic effects can be monitored to some extent even during storms.

The current meters to be used respond to frequencies up to 10 Hz; thus, Reynolds stress profiles as well as mean flow profiles will be measured. This experiment aims to provide detailed information on the time-dependent stress and velocity fields in the Ekman layer under the ice from which general models can be derived for under-ice flow and stress transmission between the ice and the water.



Masts with triplets of current meters under the ice.

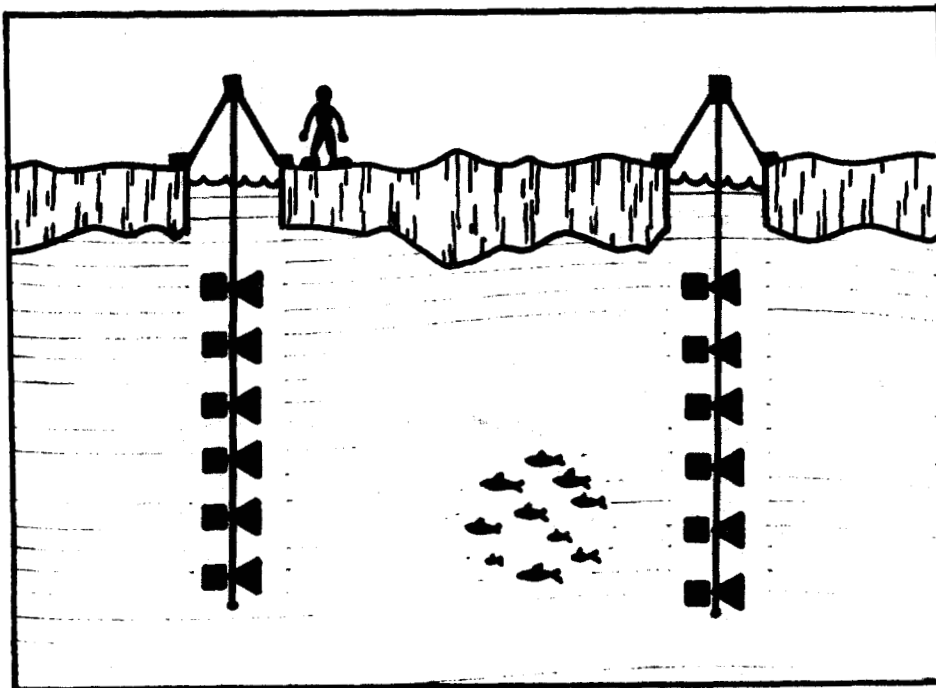
COMPARATIVE HYDROGRAPHIC ACTIVITIES (LAMONT-DOHERTY GEOLOGICAL OBSERVATORY)

Participants

K. L. Hunkins (Senior Research Associate), L-D, *Principal Investigator*
with crew of two men

Program

This activity seeks to determine water stress by measuring the relative mass transport in the Ekman layer. Ocean currents will be continuously monitored at six depths: 2, 4, 8, 16, 32, and 75 m. The current meters will be mounted on two inverted aluminum masts placed through ice holes in the camp area.



Placement of current-meter masts.

AIDJEX SPOKESMEN

Since the AIDJEX activities on the ice will be conducted from Camp 200 of the Polar Continental Shelf Project and will be entirely supported by PCSP operations, final operational authority on all matters affecting the safety and success of the operation will remain with the designated PCSP authorities.

To facilitate operations and avoid misunderstanding, it is important that a single person have the final authority to speak for AIDJEX on the ice. That person will be Dr. J. Dungan Smith.

It is also desirable to have a designated person at Tuktoyaktuk with final authority to speak for AIDJEX. This will be Mr. Rolf Bjornert.

We ask that all participants fully support these AIDJEX representatives.


J. O. Fletcher
AIDJEX Coordinator

LOGISTIC SUPPORT FOR AIDJEX-71 PILOT STUDIES

by

Rolf Bjornert
AIDJEX Operations Coordinator

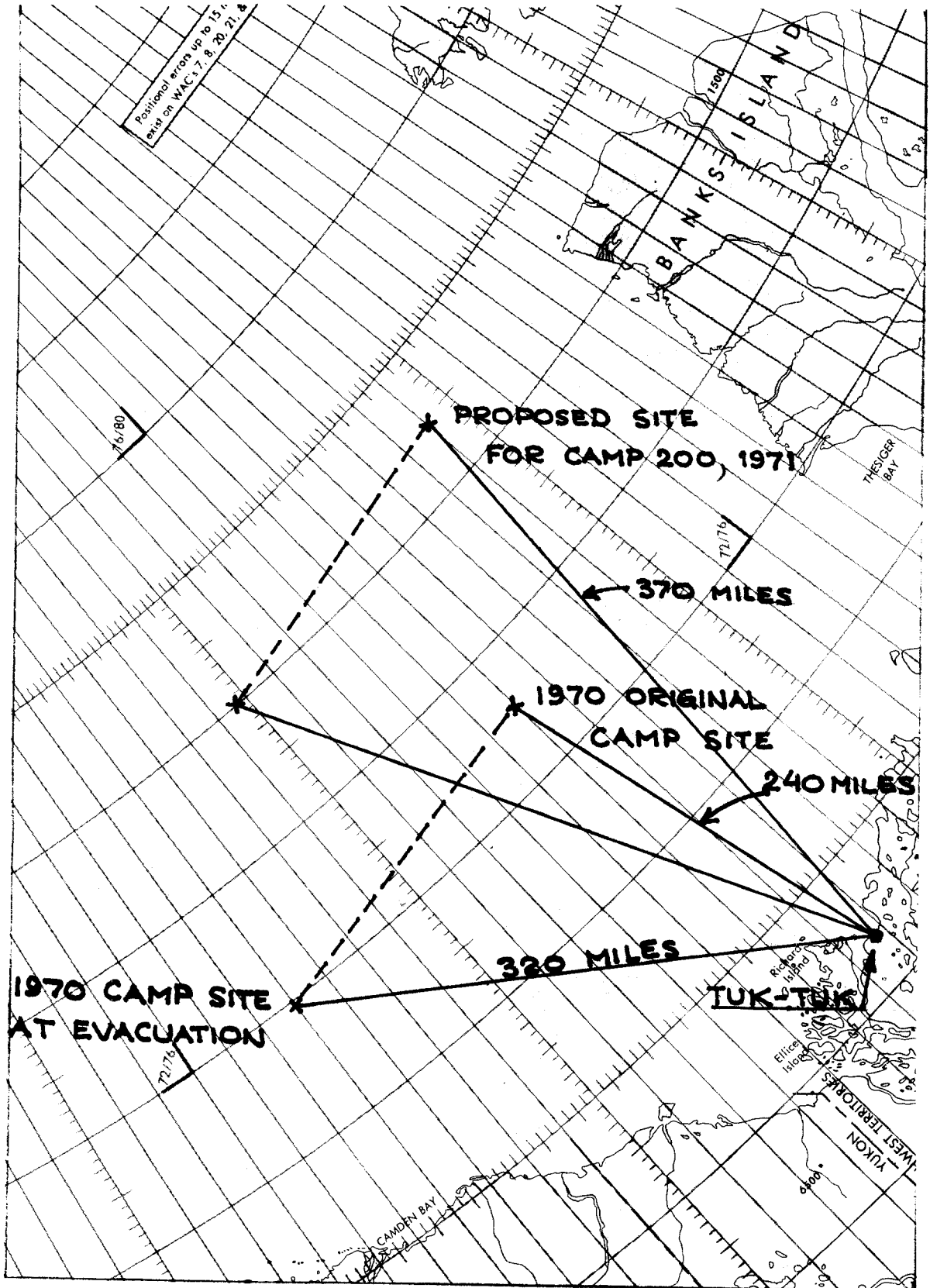
The purpose of this report is to inform you of the planned operational and logistic support for the AIDJEX-71 pilot studies.

The 1970 AIDJEX pilot study was a collaboration between the Polar Continental Shelf Project (PCSP) of the Canadian Department of Energy, Mines and Resources and the Department of Oceanography, University of Washington. PCSP served as host to the U.S. participants by operating the mainland camp in Tuktoyaktuk, Northwest Territories, setting up the ice camp (Camp 200) approximately 240 n.m. north of Tuktoyaktuk, supporting the activities, and evacuating after the completion of the study. This year PCSP is sending out its own Hydrographic-Gravity group, and it was appropriate that the AIDJEX office again request assistance from PCSP in initiating the 1971 field program. In view of their valuable cooperation last year, their willingness to help again is most welcome.

The mainland camp will again be located at Tuktoyaktuk. From there the personnel and equipment will be airlifted to the ice camp (Camp 200) approximately 350 n.m. north of Tuktoyaktuk. Camp 200 will consist of three subcamps, each undertaking a different scientific program.

The first subcamp will consist of 18 men (Dr. L. K. Coachman with 6 men, Dr. J. Dungan Smith with 7 men, and Dr. K. Hunkins with 2 men) housed in 9 prefabricated buildings. They will bring 19,500 pounds of equipment including instrumentation, generators, and camping equipment, and will use 129 drums of heating, generator, and helicopter fuel. The total weight for this group (98,000 pounds) will require 16 flights by a Bristol aircraft from Tuktoyaktuk to Camp 200.

The second subcamp will be divided into two groups. One group (Dr. J. Brown with 9 men) has 26,500 pounds of instrumentation, support equipment, etc. This group will occupy five prefabricated buildings and one Parcoll and will use 48 drums of generator and heating fuel. Their total weight transported to Camp 200 will be 61,500 pounds on 10 Bristol flights.



The other group in this subcamp (Dr. W. F. Weeks and Dr. A. Kovacs with 5 men) is bringing 2,400 pounds of instrumentation and personal gear. They will live and work in one Parcoll and will use 14 drums of heating and helicopter fuel. Their scientific work does not require electrical generators, and they will only connect their lights to Dr. Brown's generators. The total weight transported to Camp 200 for this group (14,000 pounds) will require two Bristol flights.

The third subcamp consists of the 16-man PCSP Hydrographic-Gravity group. Thirty-one Bristol flights will transport their 200,000 pounds of gear and fuel to Camp 200. Fuel for their Bell 204B and Bell 205A helicopters comprises a major portion of this weight, since they have scheduled 300 hours of helicopter time. A helicopter consumes approximately 65 gallons of fuel per hour, so all but 50 drums (for generators and heating) of the 460 shipped will be used for that purpose.

Twenty service flights by Twin Otter aircraft have been scheduled between Tuktoyaktuk and Camp 200. They will carry food, spare parts, and other items that might be needed on short notice.

Camp 200 will be in radio contact with Tuktoyaktuk and with the overflying remote-sensing aircraft.

For transportation around the immediate area of Camp 200, 45 hours of helicopter time have been scheduled: 40 hours for Dr. Coachman and 5 hours for Dr. Weeks. The helicopters will assist in erecting the instrumentation, setting up satellite stations for the hydrographic and water-stress groups, and transporting personnel to and from these remote stations. In the camp area itself, Ski-doo's will move equipment from the airstrip to the camp grounds and transport people to the nearby stations.

Each camp will have its own messing facilities with a cook. A Camp Master (provided by PCSP) in each subcamp will look after the support equipment and take care of routine matters.

The experiments are expected to continue for 30 days; if necessary, another two weeks can be added. At the completion of the scientific activities, 13 Bristol flights will take back to Tuktoyaktuk all the personnel, prefabricated buildings, instrumentation, and anything else worth salvaging. A point of interest is that these buildings have been prefabricated in

sections by local workmen for the Naval Arctic Research Laboratory at Point Barrow. They will also erect the Camp 200 buildings.

I would like to mention that space and accommodations are limited and have been provided only for the specified participants; it would therefore be inadvisable for anyone to visit the ice camp. Documentary coverage by 16mm movie camera will be available later in the year. Anyone interested in viewing this is welcome to contact the AIDJEX office.

TIME SCHEDULE FOR THE 1971 AIDJEX
PILOT STUDIES

- February 20 The Decca navigational system will be operating and the search for the ice floe for Camp 200 will begin.
- February 23 PCSP will begin airlifting equipment for their Hydrographic-Gravity group out to Camp 200.
- February 25 The prefabricated buildings made at Point Barrow arrive at Tuk, and will soon thereafter be transported to Camp 200. Local laborers will assemble the buildings. One or two advance men arrive from each U.S. group to prepare their gear to be transported to Camp 200.
- March 1 It is assumed that PCSP is now operating at Camp 200 and that the U.S. prefabricated buildings are erected. Begin to airlift equipment for Dr. Coachman and Dr. Smith.
- March 3 Dr. Brown's data systems are flown out.
- March 4 Dr. Weeks's group and equipment is transported to Camp 200.
- March 5 Dr. Brown's remaining equipment and personnel will be flown out.

From now on, the remainder of the flights will transport fuel and food for the entire stay at Camp 200.

Weather conditions may alter the dates mentioned above, but the sequence in which the various groups go remains the same.

The intent is to fly out electronic equipment, instrumentation, and one or two advance men as early as possible so that rigging and tuning procedures can begin. Furniture, personal equipment and personnel will follow.

The evacuation date has not been decided. This will be discussed with PCSP at the beginning of March.

AIDJEX WORKING GROUP ON
NUMERICAL MODELING AND ANALYSIS

Third Working Session Held on November 13 and 14, 1970,
at the University of Washington

All members of the scientific community interested in the objectives of AIDJEX recognized from the outset that the development of theoretical concepts and procedures for the effective application of AIDJEX data has to be one step ahead of the experimental work. In keeping with this philosophy, the Working Group on Numerical Modeling and Analysis was the first to be established. Their first meeting was held on July 9, 1970, at the University of Washington.

Membership in the Working Group is highly informal: anyone with an active interest and ideas to contribute is welcome to participate. So far, this method has proven to be practical and effective. Other working groups (such as Air and Water Stress, and Remote Sensing) are using the same procedure.

AIDJEX Bulletin No. 2 (October 1970) contains eight articles summarizing current thoughts on some of the fundamental concepts and problems of sea ice dynamics. The Working Group session reported here sought to (1) communicate these thoughts to a larger group of interested scientists, (2) look for faults or inconsistencies in the planning of AIDJEX, (3) shop for new ideas and participants, and (4) sharpen and, if necessary, reassess long-range goals.

Scheduled activities of the session were as follows:

Friday morning, November 13 - Introductory Reviews

- Rothrock - Dynamic behavior of sea ice
- Campbell - Water stress
- Badgley - Air stress
- Thorndike - Ice strain
- Untersteiner - Heat balance and ice dynamics
- General discussion -

Friday afternoon - Progress Reports

Bryan - Ocean models

Campbell - Viscous ice models

- General discussion -

Saturday morning, November 14 - Review of Future Plans

Fletcher - Current status of overall planning and time schedules; committed and prospective participants; review of pilot experiments planned for spring 1971.

Coachman - Horizontal coherence of currents; interpretation of geostrophic flow from temperature and salinity measurements (pilot experiment, spring 1971).

Smith - Water stress, with special reference to ice-bottom topography (pilot experiment, spring 1971).

Hunkins - Water stress and Ekman boundary layer (pilot experiment, spring 1971).

Campbell - Small-scale ice deformation (order of 10 km), and airborne remote sensing (pilot experiment, spring 1971).

- General discussion -

Summary

All presentations were followed by discussions. Rather than recount them in their necessarily somewhat roving sequence, we have attempted to present here a summary that omits points of previous agreement and emphasizes unresolved questions and new viewpoints.

Air stress from pressure maps. According to the report by Badgley, it will be feasible to deduce the air stress field from surface pressure observed at the manned and unmanned stations of the AIDJEX array to an accuracy of 30% in magnitude and 5 degrees in direction. This seems adequate for a first approximation to the model to be developed.

The inadequacies of computing wind stress on the assumption of geostrophic flow were discussed. Smith affirmed that slopes of the ice surface and

gustiness of wind would cause errors in stress calculated from mean wind measurements. Fleagle suggested that Ekman layer instability could significantly affect the actual stress.

Time-dependent Ekman layer. It was the consensus of the group that greater activity will be required in designing suitable models of time-dependent motions in the ocean boundary layer. AIDJEX should seek to add to its staff a fluid dynamicist who specializes in these problems.

Ice acceleration. It was agreed that direct observations of horizontal ice acceleration at the manned stations by means of suitable accelerometers would be desirable to detect motions on a short time scale. No specific recommendations or offers were made as none of the participants had sufficiently detailed information.

Processing of data from remote sensing. It was stressed that remote sensing instruments usually produce unwieldy amounts of data. It was recommended that an experienced specialist in remote sensing and data processing be added to AIDJEX staff. A large portion of the remote sensing work will involve the interpretation of sequences of images. It is not clear at present how they should be analyzed--i.e., how a useful set of parameters should be defined and how one should describe their changes in time.

Interaction of ice strain and heat balance. According to the review by Untersteiner, the question of the large-scale albedo of the Arctic Ocean is still unresolved. Experimental programs, such as extensive airborne albedo measurements between March and October, and observations of the heat balance of leads will be required before the ultimate goal of connecting ice dynamics to its overall mass balance (and hence the response to climatic variations) can be achieved.

Mass balance equation. It was suggested by Bryan that the mass balance equation is more fundamental to a model of pack ice than is the momentum equation with an appropriate constitutive equation. The mass balance equation should, of course, eventually include the dependence of ice generation on dynamics. The consensus was reached that the next step in the development of a numerical model should include both a mass balance equation and a momentum equation.

Numerical models. Campbell and Rasmussen showed results of their recent computations of a model using a constant stress field (of geometrically regular shape) and various combinations of ice viscosities. Both reporters and participants agreed that steady-state viscous models have yielded considerable insight but that their further pursuit should await the initial results expected from AIDJEX.

Continuum, or not. All work and deliberations so far have been based on the assumption that the ice can be treated as a continuum. What should be done if Thorndike's station drift paths, or the initial data from AIDJEX, indicate rigid motion of large plates? Preliminary results from the drifts of NP-10, NP-11, T-3, and Arlis II during June and July of 1962 indicate that divergences and shears of the order of $.01 \text{ day}^{-1}$ can be expected for large portions of the ice (10^5 km^2 in this case). The assumption continues to be that the continuum hypothesis will be used until some evidence against it appears.

Scales. There was discussion about the space scale and time scale on which strain measurements should be made. No definite conclusion was formed; however, the limits of 10 to 100 km for the space scale and 90 minutes to weeks for the time scale were generally accepted. From the discussion, it became apparent that the criteria on which to base the choice of scales are not sufficiently well defined, although, ultimately, the basic criterion is that an ice-covered ocean be modeled on time and space scales on which most of the important phenomena described by Newton's equations are resolved. The remaining phenomena can either be ignored, if this does not mean a complete loss of realism, or included parametrically. At present the only criterion being considered for choosing a space scale is that it be the smallest scale on which the pack ice behaves as a continuum. We do not now know what this scale is, but it is hoped that the 1971 AIDJEX pilot experiments will help to define this scale.

Finding a constitutive law. Following discussion of the scale on which continuum idealization is appropriate, discussion ensued on the manner by which the constitutive law should be deduced. Two approaches suggest themselves.

As was originally proposed, if the divergence of stress is the only quantity in the momentum equation not measured in the field, then it can be computed as the residue in that equation. From this and from field measurements which enable the divergence of strain to be calculated, some information on the constitutive law may be obtained.

An alternative approach (discussed below in greater detail) would be to deduce forms of constitutive laws from theoretical reasoning or with the aid of laboratory models. Then for a given constitutive law and for a given strain field the divergence of stress may be computed and compared with that determined from field measurements.

It was generally felt that the second approach would be more fruitful.

Interpretation of stress and strain data. A most useful point concerning the interpretation of stress and strain data was raised by Raymond.

As derived in Appendix I to the scientific plan of AIDJEX, the equation, A(6), relating the acceleration of the ice to the forces acting on it, contains the stress tensor $\nabla \cdot \vec{\tau}$, which cannot be measured directly. Suppose that stress can be related to strain and strain rate, in the most general way, by an equation of the form

$$\tau_{ij} = F_1 \delta_{ij} + F_2 \dot{e}_{ij} + F_3 e_{ij} + F_4 \dot{e}_{ik} e_{jk} ,$$

where F_α ($\alpha = 1,2,3,4$) depend only on the invariants of strain and strain rate. (See Evans, AIDJEX Bulletin No. 2.) If we are willing to postulate (or can somehow derive) the form of the F_α , except for the values of certain parameters, then we can produce an expression for $\nabla \cdot \vec{\tau}$ in terms of the strain and strain rate, and their derivatives, and the unknown parameters. Thus equation A(6) can be written completely in terms of measurable quantities and some unknown parameters which can then be estimated from data. If the estimates obtained in this way are compatible with independent data (to within experimental error), then the postulated F_α are acceptable.

For the continuum approach, the proposed 100 km array will take on the role of the "infinitesimal element" surrounding a point, say the center of the array. The strain, strain rate, and their spatial derivatives at this point will be computed from relative displacements of points of the array. The array is thus essential for determination of strain and strain rate

but not for determination of acceleration, wind stress, water stress, and slope of sea surface. Values of these quantities are required as an integral over the area of the array. Their measurement at outer stations of the array in addition to the central station will be important to ensure that sensibly average values are obtained.

The original arguments for the size of the AIDJEX station array still stand: the area must be large enough so that individual structural irregularities do not contribute significantly to the overall behavior, yet small enough so that spatial variation of driving forces over the array can be estimated.

Acknowledgments

Thanks are due to the Arctic Institute of North America, who provided travel funds for several participants in the work session. We are especially obliged to Mr. Terry Fox and Mr. Steven Hodge for their excellent performance as note-takers. Mr. Henry Lahore tape-recorded the sessions. We are indebted to the Department of Oceanography for providing facilities for the meeting.

Seattle, Washington
January 8, 1971

N. Untersteiner
D. A. Rothrock

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November 13 and 14, 1970

University of Washington

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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

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