FUTURE OF EXPENDABLE INSTRUMENTS IN ARCTIC OCEANOGRAPHY

Ben Cagle
Kenneth Hunkins

Office of Naval Research, Pasadena, CA
Lamont-Doherty Geological Observatory, Palisades, NY

ABSTRACT

Results of a workshop are given. Scientists with interests in the oceanography of Arctic regions, primarily ice margins in the Greenland Sea and Bering Sea, were convened with engineers familiar with the technology of oceanographic measurements in temperate ocean regions. Near-future capabilities in expendable instruments were surveyed, and the potential for new instruments were discussed. Logistics and effectiveness in field programs were considered along with the access to space and time scales in data made efficient by new expendable technology. (The workshop was held in December, 1981 and this is the first public report of its findings.)

INTRODUCTION

In the ice-covered Arctic Ocean, and in the marginal ice zones, the temperatures are low and frequently close to freezing. The density, a most important physical parameter for ocean dynamics, is mainly determined by salinity as a function of depth.

In cases where a strong temperature-salinity correlation exists, a qualitative conception of the salinity structure (and thereby the density structure) may be based on temperature measurements. However, the usefulness of this approach in the marginal ice zones (where temperature-salinity relationships are poorly determined) is open to question.

Unfortunately, the technology for conductivity measurements by expendable instruments is poorly developed. Sound velocity measurements are made by expendable instruments, but the determination of density (by backward calculation from temperature and sound velocity) is poor because of loss of accuracy. The development of a satisfactory expendable conductivity instrument is anticipated.

It appears that horizontal space scales of turbulent structures may be smaller in ice marginal regions than in the major frontal areas of more temperate or tropical oceans. In particular, the Rossby radius of deformation along the ice edge east of Greenland is about five kilometers. Numerous eddies and frontal features fill the region and tend to be smaller in horizontal dimension than eddies and fronts commonly associated with the Gulf Stream or the Subtropical Front in the Pacific Ocean. Smaller horizontal scales, coupled with the existence of strong salinity structures and small-scale processes (including double diffusion), further increase the complexity for designing adequate scientific field experiments to obtain necessary data sets.

Aircraft delivery systems are primitive and need to be improved to be cost-effective and adaptable to the scientific requirements. Poor visibility and lack of accurate navigation further limit present aircraft delivery systems. Most instrumentation must still be placed on the ice or in the water by persons on the ice or on ships. This leads to the primary reason for expendability in the Arctic; it may be hazardous to reach the optimum location or there may be a high risk of not being able to retrieve instrumentation planted there - prudence will often cause a scientist to place his instruments elsewhere. The most common expendable instrument is the bathythermograph probe (XBT). It has been launched from almost every conceivable platform, including ships, submarines, heliocopters, and fixed-wing aircraft. It has been used in ice camps, both by launching directly through holes in the ice and/or through special plastic tubes. The unique aspect of the XBT is the wire system. Sippican's very elaborate production facilities for the small, coated wire are not duplicated elsewhere, and its wire-related products are often incorporated in other instrumentation.

The air-launched expendable bathythermograph (AXBT), was designed for launch from Navy patrol aircraft. It has been supplied in large quantities by several companies including Magnavox, Motorola, and more recently, Hermes. In these instruments, the configuration which falls away from the aircraft includes an aerodynamic drag device, usually a parachute or rotorvane, and a buoy. When the buoy is stabilized in the water, a falling probe containing a thermistor is deployed. As in the XBT, the speed of fall is equated to depth. The buoy contains a radio to transmit the temperature signal back to the aircraft. A new version of the AXBT is designed so that the falling probe resembles the probe in the shipboard XBT. In principle, this design will permit modifications to incorporate various probes which are launched from ships.

Some expendable instruments are relatively new in the community and some are expected to be available in the near future which measure more than temperature alone. One currently available is the expendable sound velocimeter. Another is an expendable velocity shear probe which may be obtained on an experimental basis.

NORDA has an instrumentation program with an objective of developing general classes of instrumentation. These include expendable shipboard instruments and moored instruments, but an emphasis in the last few years has been on expendable instruments.

ACCURACY LIMITATIONS ON EXPENDABLE XBT AND AXBT

In general, the expendable instrument is used where relative values, spatially or temporally, are of significance in understanding the ocean structure. The usual expendable instrument does not have an accurate pressure sensor because of the high cost of such a sensor. Depth is obtained by a time of flight technique which is usually inadequate for accurate determination of microstructure.

A common feature in Arctic regions is the formation of tiny crystals of ice on or near the sensor in any expendable probe. A small amount of ice on the water may not be noticed; yet it will cause spikes in the data from the expendable instruments. This is a problem in launching from shipboard as well as from aircraft. In one lot of 150 XBTs dropped from an icebreaker, almost half produced erratic data, some of which was thought to be due to tiny crystals of frazzle ice.

The AXBT is probably more accurate than the Navy specifications require for operational use. In the early days, it was necessary to calibrate every instrument to achieve 0.1°C accuracy. However, manufacturers have improved the product. Now it may be sufficient to simply follow lot numbers and manufacturing practices and calibrate samples from a given production group. Samples calibrated for temperature vs. output frequency may determine an accuracy of about 0.15°C for the group. Thousands of AXBTs have been used in research. None are known to have been dropped in winter further north than 50 deg latitude. Since the AXBT is usually carried externally at high altitudes, it may be at a temperature of -20°C to -30°C when dropped. The probe may be cold enough to ice up before or when released from the buoy, but these effects have not been seen in the Pacific.

It is possible that Arctic applications require a much faster response in a sensor. This may be necessary because of the extreme temperature change that often occurs at the water surface or in the first few meters. The instrument may be much colder than the water when it enters the water. Instruments dropped from warm huts are often warmed before dropping so that the sensor is much warmer than the water when it enters.

LESS-COMMON EXPENDABLE INSTRUMENTS

The expendable sound velocimeter represents a class of expendable instruments which may have increasing use. This sensor is a sing-around type and the probe contains hybrid chip electronics and battery power. The sonar is pulsed at about 6 MHz and it sings around at approximately 120 kHz. The signal is counted down for a frequency measurement so that only frequency is measured in the deck recording equipment. Probes are available for 750 and 2,000 meter depths, and the instrument has been on the market for about three years.

There may be an expendable penetrometer soon for applications in polar regions where it is necessary to determine the ice thickness before landing an aircraft. The need for this application is for a probe which would enable the pilot to determine the thickness of the ice.

It is likely that the third most measured parameter in the world's oceans is the value of dissolved oxygen. The need for an expendable instrument to measure dissolved oxygen has been discussed for many years. None has been developed for quantity production, but there has been some laboratory testing.

EXPENDABLE BUOYS

There are instruments which are expensive but are expendable because it is not practical to retrieve them. Some are designed to produce a long time series of data, essentially to the end of the life of the instrument, and the salvage value is low. This category includes drifting buoys. In general, buoys must be installed in their initial location. Due to the hazards and limitations of remote and severe environments, much thought has been put into aircraft or ship delivery systems which do not require personnel on the ice.

In ice-covered oceans a large variety of expendable instruments are positioned or implanted by landing an aircraft or establishing a camp on the ice. Some systems have been sophisticated and expensive. Data systems have been quite versatile. Such instruments have been used to measure atmospheric parameters as well as ice and oceanographic parameters. Chains of sensors have been lowered in the water beneath the ice, and data have been retrieved by telemetry. There is a large battery pack for a long time series of data. Data sets have mixed spatial and temporal measurements due to drifting of the instrument with ice or water movement.

Drifting buoys have been developed, both for ice-covered oceans and for ice-free oceans. They are usually installed in the ice or dropped into polynyas or leads. During the melt season they must float like a buoy, and during freeze-up they must remain upright. The data transmission system must remain above the ice. Buoys deployed in the ice are usually long vertical cylinders, like spar buoys, while those deployed in the open ocean have followed the Richardson design of a cone shape for static stability. The open ocean variety has been used in ice marginal regions, but is sometimes lost in the ice. Some have been known to free themselves and continue drifting in the open water. Similar buoys are moored to icebergs to determine iceberg drift.

EXPENDABLE VELOCITY SHEAR PROBE

The expendable velocity shear probe is deserving of more detailed description because of its potential for use in marginal ice zones where a strong velocity signature sometimes accompanies the strong temperature and salinity signatures; all three are necessary in determining the structure of mesoscale and smaller scale circulations. This probe measures shear by measuring relative current profiles. The mechanism employed is that of measuring electric fields generated by the motion of sea water in the earth's magnetic field. The probe is locked into this motion. A pair of embedded electrodes simulate the measurement of voltage at the skin of the probe. The probe rotates as it falls producing a modulation of the frequency at seven Hz. This converts the basic dc measurement in the environment into a seven Hz signal in the electronics, easily modulated for transmission to the recorder. In addition, a compass measuring coil is wrapped around the electrode sensor. The probe rotates, measuring a frequency-modulated sinusoidal signal of seven Hz, which is used as a phase sensitive demodulating reference frequency. The result is a compass heading with respect to the vector of the electric field; components are resolved into east and north.

This sensor cannot be tethered. The probe itself must be locked to the motion of the water in which it is immersed, because the motion of the water in the earth's magnetic field is being sensed. It is utilizing electric currents that exist in the water due to the motion of the water itself. The frame of reference is the earth's magnetic field, which raises the possibility that an embedded probe can be a means for measuring the velocity of the ice itself.

A scientific point can be made for measuring velocity profiles. Mesoscale structures usually have a velocity signature. For example, eddies were first detected in the ice-covered ocean by current meters rather than by CTD profile. Variations in water currents can be greater than variations in salinity or temperature. A single velocity profile from this probe contains a lot of information. For example, inertial waves tend to be polarized with depth which leads to some perception of the internal wave field from a profile. Some of the inferences about time-averaged currents can be drawn from this profile. Some inferences are possible about high and low frequency currents. A separation between internal waves and low frequency currents can be inferred. Geostrophic currents tend to have shears that extend over the whole thermocline, and the energetic higher modes of variability can be perceived. This kind of information is important when one is trying to determine vertical heat and mass transfer.

AIR-DEPLOYABLE OCEAN MOORING

Possibly the most expensive and complex expendable instrument under development is the Air-Deployable Ocean Mooring (ADOM). There are two versions: one for the open ocean and one for the ice-covered ocean. Major components have been developed and tested at sea. ADOM will contain a complete data system, from a long string of sensors extending to great depths to sophisticated data compression and sampling techniques. Both real time and delayed data transmissions are planned through a satellite system to laboratories in the United States. It is designed to be carried by patrol aircraft (P-3 type) but can be launched from almost any aircraft having cargo doors or cargo bays. It has been launched from the Lockheed Hercules C-130.

One of the intriguing aspects of the ice-covered-ocean version is the ice penetration system. This drilling system has the ability to seek vertical from any landing attitude, even among the rubble of a large pressure ridge. The energy source is a battery pack, and the drill is a water scrubbing and recirculating system. Only sufficient ice is melted to fill the boundary layer of the 8-in. diameter bullet-shaped drill. The hole it makes is not permitted to fill with water, and the melted water is recirculated past the heating element for the continuation of drilling. It is a most energy-efficient system that could be reliably manufactured to operate totally unmanned and unpositioned by man.

SCIENTIFIC AND TECHNICAL ISSUES

When one considers the broad transitional regime from the completely ice-covered ocean to the completely ice-free ocean, it is difficult to conceive how far into the ice-covered ocean are the subtle influences of the ice margin and correspondingly how far out in the completely ice-free ocean are the subtle effects of the ice margins. However, in the ice marginal region itself the signatures of oceanographic parameters are sufficiently sharp to enable planning of experiments which will obtain significant data sets. Although the significant forcing functions in the atmosphere and ocean in the marginal ice zone may be sufficiently understood, it is not intuitively obvious what the resulting mesoscale structure in the ocean will be.

Field experiments are planned for the next several years, beginning in the spring of 1983. Some of the questions being addressed are: What determines the location of the edge of the ice pack, and what processes modify that location? What are the relative importances of forcing functions which influence the marginal ice zone? There is a large seasonal migration; what are the spatial and temporal scales of this migration? There are many feedback processes in the coupled atmosphere, ice, and ocean environment of the marginal ice zone; one needs to know the interrelationship of parameters to be measured. Although expendable instrumentation is applied primarily to the ocean structure, a scientific question in the background of those who are planning large field experiments is: What is the effect of the marginal ice zone on global climate?

An estimate of the Rossby radius of deformation in the ice marginal zone is about 5 km. Thus, mesoscale-type processes can be anticipated down to this spatial scale. Eddies have been detected in the marginal ice zone having diameters of approximately 30 km (within the magnitude of 2 pi times the Rossby radius). This implies the horizontal scales that must be sampled. Smaller scale processes are known to exist, both vertically and horizontally including internal waves, upwelling, double diffusion, and convergences and divergences leading to strong shears. In such strong frontal features there can be strong inertial waves with relatively high wave numbers, and shears which change across the front. A sampling scale must not miss the scales of these important features.

A reconnaissance survey of an area by means of a network of expendable conductivity probes might be useful in planning the deployment of more classical oceanographic instrumentation. Expendable instruments are candidates for use in research strategy where it is desirable to do scouting or reconnaissance in order to determine the optimum location of a ship or an ice camp. The corollary of this potential application of expendable instruments is that they may be used to fill in, on smaller space and time scales, data between major hydrographic stations, where such stations cannot be closely spaced for cost and logistics reasons.

DETERMINATION OF DENSITY STRUCTURE

Since there is no expendable density probe, methods for calculating density must be considered in selection from available instruments or in encouragement of new development. It is best to have an expendable instrument which measures both conductivity and temperature with appropriate sensitivities and time constants for performing a straightforward and accurate calculation of density. However, because such an instrument is not available in quantity, other approaches have been attempted. For example, the expendable sound velocimeter was fitted with a thermistor to obtain data useful in calculating density. This is generally referred to as the backward method of calculating density. Tests were conducted at sea comparing such expendable instruments with CTD stations. Although a sound velocity profile may be relatively smooth, any small noise or inaccuracy in the temperature signal is magnified in the calculation of density.

The determination of depth is an important concern in the calculation of salinity from any instrument. Few expendable instruments use a pressure sensor and when they do the pressure sensor must be calibrated for temperature. All commercially available expendable instruments depend on knowing the time rate of fall of the probe to determine depth. A depth equation must account for the calibrated fall velocity of similar probes through different density stratas of the water column. It must also account for the loss in mass due to paying out of the wire system. There can also be dynamic terms in the equation. The result of the depth equation is a determination of depth vs. time from the first indication that the probe is actually falling in the water. Probes have been dropped in different water masses in order to check and improve on empirical coefficients and power factors in the depth equation. Controlled tests at sea indicate that the depth error is of the order of $\pm$ 5 meters.

PLATFORMS

A consideration of the use of expendable instruments in remote and severe environments is coupled with a consideration of the methods for delivering the instruments. Platforms available for delivery of expendable instruments in the marginal ice zone include ships, aircraft (fixed-wing and helicopters), and ice camps. An aircraft platform is immediately attractive because of speed and versatility and because it places people in less hazardous situations than in operating on the ice surface. However, limitations of this platform must be considered. One of the limitations is that of navigation. The spatial and temporal scales of ocean features being studied may require extremely skillful navigation and timing for the deployment of sensors – a capability presently unavailable on most aircraft.

Spatial and temporal scales of the data set being obtained for scientific purposes may require greater positional accuracy than is normally available by navigational and bush pilot techniques. For example, it is sometimes easier to visually deploy an instrument through a lead or polynya or in open water but very difficult to accurately determine its deployed position with respect to others already deployed.

Equipment has been developed which permit an aircraft to be operated in lieu of an ice camp. When a landing can be effected on the ice, the necessary oceanographic data can be obtained before the aircraft must leave the ice. Hole cutting equipment has been developed which permits lowering of instrumentation and discharge of expendable instruments into the water beneath. One technique involves running helicopter lines radially from a manned station on which the helicopter makes successive landings. Holes are bored and oceanographic data are obtained at each landing site. Expendable instruments are used to avoid the time required to retrieve lowered instruments.

INSTRUMENT REQUIREMENTS

Precision, accuracy, and standard deviation should be distinguished in requirements. Also, in reconnaissance applications of expendable instruments, an emphasis is placed on resolution. To avoid misunderstandings about the precision of an instrument, it is better to state precision and standard deviation separately so that the user may understand the probability of achieving a desired accuracy when running an oceanographic line of many similar instruments. In comparing data from a group of similar expendable instruments, it is necessary to know their accuracy because, although there may be high precision in the instruments, the use may not have the desired accuracy. Definitions are: precision is the ability to get the same measurement with the same instrument, accuracy is the absolute relationship of the instrument against some external standard, and resolution is the smallest difference one can record in the data.

A concensus on the requirements for the expendable, conductivity temperature depth instrument was reached, as follows: for temperature, the resolution should be $0.01^{o}C$, and the precision should be $0.02^{o}C$, while the accuracy should be $0.05^{o}C$; the corresponding resolution in salinity should be 0.02 parts per thousand. If there were a pressure sensor on the instrument, it should produce a resolution of ± 2 meters in vertical position. To be consistent with salinity requirements, the pressure sensor should have a precision of ± 5 meters and an accuracy of ± 10 meters. The depth capability should be at least 500 meters, and it is desirable to have some go to 800 meters.

WORKSHOP FINDINGS

A major finding of the workshop was the need for an expendable instrument which can be used to calculate salinity. The workshop found that no existing expendable instrument meets the requirements related to this need. What is desired in applications such as survey and reconnaissance is a relatively simple expendable instrument.

The stategy for use of expendable instruments in the marginal ice zone is quite different from their use in more moderate oceans. Due to hazards involved in other means of obtaining data, an expendable instrument is a means for obtaining data not otherwise considered and for extending the effort beyond that normally made. Because of the severe environment, placing of non-expendable instruments for necessary data sets must be very prudent. Survey and reconnaissance of general areas can be made with expendable instruments in order to more precisely position a camp or platform which will be used to install non-expendable instruments.

One of the discoveries of the workshop was the versatility and potential application of the expendable velocity shear instrument in the marginal ice zone. With complex data processing and proper scientific interpretation, this vertical profile of velocity shear can be used to infer a substantial amount of information about the processes going on in the ocean.

Note: A much more extensive report will be distributed at the meeting session.