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DOPPLER ACOUSTIC VELOCITY PROFILING IN THE ARCTIC

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Abstract

During Spring 1985 two RD Instruments 150 kHz sonars were operated for 37 days in the Beaufort Sea, approximately 450 km northeast of Prudhoe Bay, Alaska. The sonars successfully profiled to a depth of approximately 350 m, with rms velocity precision of 1 cm/sec (for hourly averages). A preliminary analysis indicates that sonar accuracy levels also appear to be of order 1 cm/sec. While rather small, these levels result in significant errors in the Arctic measurements as the naturally occurring signal levels in the Arctic are also quite small. Neverless, at low frequency (< .2 cph), an excellent picture of the internal wavefield is obtained.

Introduction

During March, April and May 1985 two RD Instruments (model RD-DR0150) Doppler sonars were operated in the ice-covered Beaufort Sea, northeast of Prudhoe Bay, Alaska (Fig. 1). The measurements were made in conjunction with many other oceanographic and meteorological experiments, as part of the Arctic Internal Wave Experiment (AIWEX). It had been suspected that the Arctic internal wavefield was much less energetic than its oceanic counterpart. The purpose of AIWEX was to quantify this low energy level and to identify the effects of low wave energy on the related flows at larger and smaller scales. The specific goal of the acoustic experiment was to quantify the wavenumber-frequency spectrum of the wavefield and to identify the interactions between the waves, the moving ice at the ocean surface, and the shear layers in the upper ocean.

An additional objective was to quantify the performance of the acoustic systems. The combination of calm internal seas and ease of obtaining a stable mount makes the Arctic an ideal place to evaluate sonar performance. This paper presents preliminary data from the AIWEX sonars, as well as a preliminary assessment of data quality. Detailed scientific analysis of these data will be presented in future works.

Doppler sonars are attractive for use in the Arctic for several reasons. Continuous depth profiles can be obtained without deploying a mooring. In AIWEX, all of the equipment needed to be hand carried from transport aircraft to the deployment site. The winches and power sources necessary to deploy a heavily instrumented mooring would prove logistically cumbersome. In the high Arctic, magnetic compasses function poorly. The orientation of discrete current meters on conventional moorings is difficult to determine. In the low energy environment of the Arctic, the currents are frequently below the stall speed of mechanical current meters. This isn't a problem for Doppler acoustic (or electromagnetic) sensors. Finally, since the sonar can be deployed just below the base of the sea ice, it is easily accessible. Real time identification and repair of problems and display of data are possibilities.

Fig. 1. Bathymetry of the Arctic Ocean and its seas (depths in fathoms). The AIWEX site is indicated.

Along with these advantages, there are corresponding problems to be overcome. The commercial sonars which offer real time displays require a constant 110 V power source. In Arctic ice camps, power is often interrupted. Also, the sonar electronics and transducers must undergo cooling down to -40°C during shipment and set-up. Changes in response or tuning of the system electronics resulting from the extreme temperature cycling must be determined and corrected in the field. Care must be taken in immersing the transducer in the sea, through the ice. The transition from air to water temperature is approximately 35°C. As the effect of shock warming the transducers is unknown, the

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temperature transition has to be moderated as the transducers are lowered into the sea.

System description

The AIWEX ice camp was established between 12 - 20 March on second year sea ice at 74°N - 143°W in the Beaufort Sea. Access to the camp was by air from Prudhoe Bay, approximately 450 km to the southwest. Approximately fifteen huts were established in the main camp, covering a 1 square km area, with various experiments or accommodations in each (Fig. 2). The two sonars were deployed along the south edge of the main camp, separated in the east-west directions by approximately 1/2 km (Fig. 3).

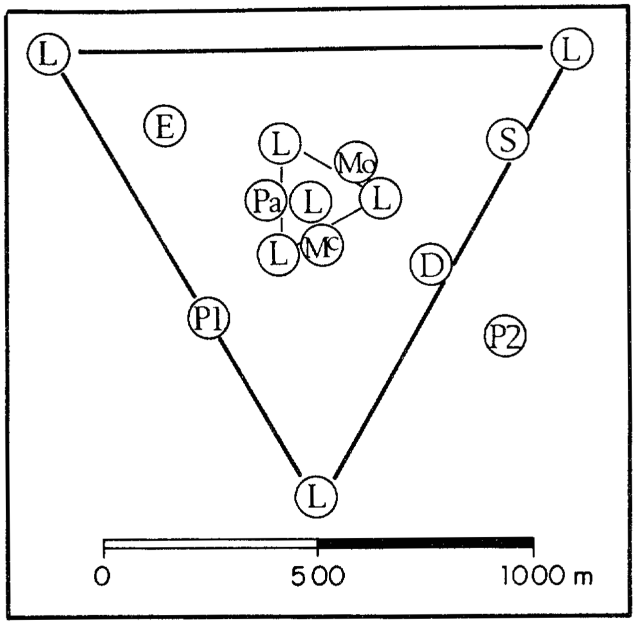


Fig. 2. An approximate schematic of the central part of the AIWEX camp. The acoustic profilers are located on the south side of the camp, to the west and east of camp center(P1, P2). The Arctic Profiling System is operated in a hut on the northeast edge of the central camp (Mo).

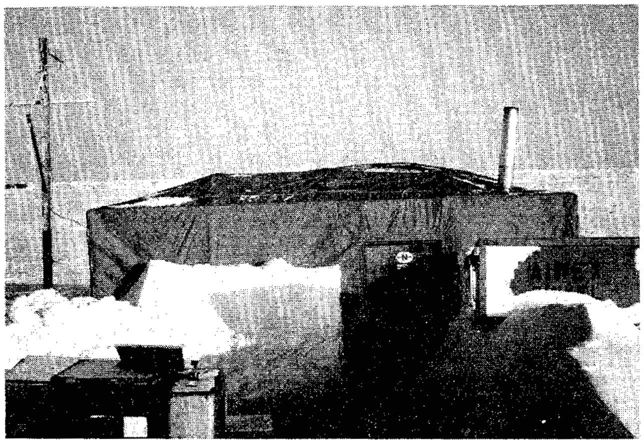
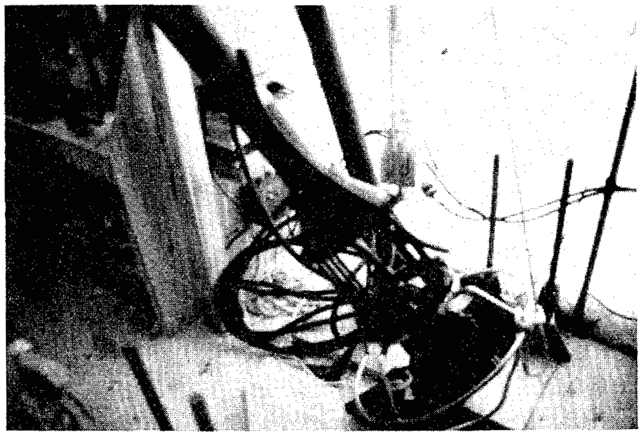


Fig. 3. The west sonar hut. Note the antenna for the radio modem.

The transducer assemblies were mounted on pipe strings and suspended through holes in the floor of each sonar hut (Fig. 4). Each pipe string consisted of 1.75 m sections of aluminum pipe. Assembly flanges on the ends of each pipe were registered so that the orientation of the sonar transducers on the wet end could be determined by inspection of the dry end. Holes approximately 1 m diameter were melted through the ice using a device developed at the Applied Physics Laboratory, University of Washington. The ice thickness at AIWEX was about 2m. Three lengths of pipe were used for each deployment, allowing the transducer assembly to be positioned approximately 2m below the bottom of the ice. To prevent tilting during periods of high ice motion, the pipe was fixed at the level of the floor of each hut and again at ceiling level.



The two sonars were controlled and the data were recorded using equipment in the west hut, which was kept manned throughout the experiment (Fig. 5). The east hut contained only a transducer assembly, deck unit, radio modem and the deployment rig (Fig. 6). Communication between huts was performed by a VECTRAN model VR-30 radio modem, operating at 1200 baud. The radio modem connected directly with the RS-422 port on the sonar deck unit and the data logging system. The modem avoided the need for stringing cables the half kilometer between huts. The radio link performed flawlessly for the duration of the experiment.

There are many operating parameters in a Doppler sonar which can be specified by the user and tuned for specific application. For AIWEX the sonars transmitted 18.6 ms pings at 150 kHz. This pulse length results in a basic depth resolution of 12 meters, given the 60° down slope of the sonar beams. The pulse repetition rate was set at .90 seconds. Velocity estimates were calculated every 8 m in depth and averaged internally for approximately 2 minutes prior to being written on magnetic tape.

Velocity Data

The sonars were installed and operating by the 24th of March 1985. A data collection run was initiated on the 25th, which lasted continuously until 2 May. The only interrup-

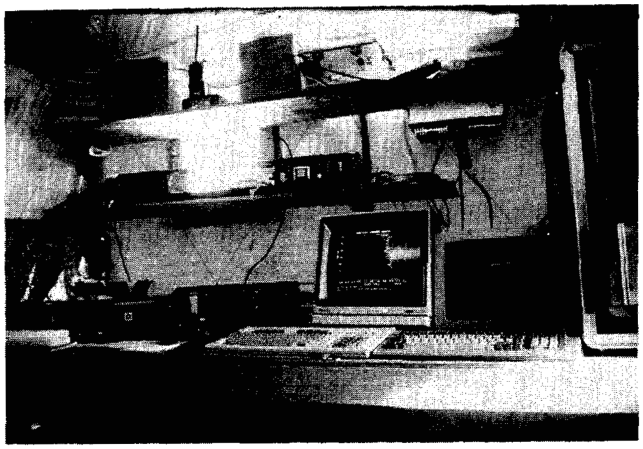


Fig. 5. The interior of the west sonar hut, showing sonar electronics package, data recording package, and data display computer.

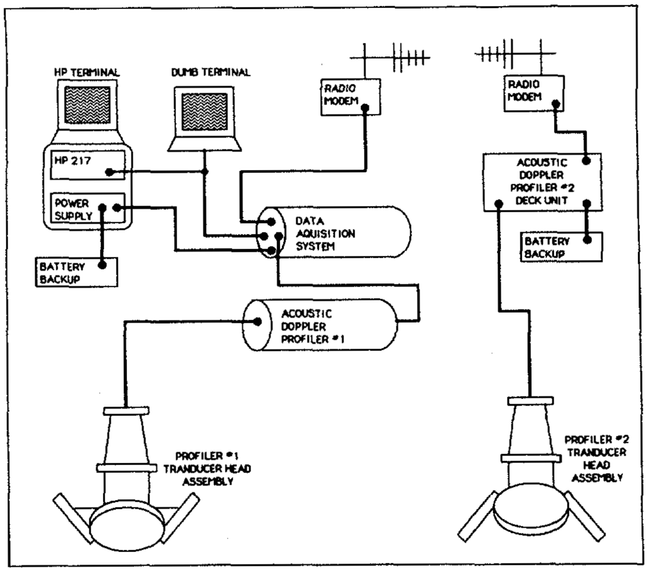


Fig. 6. Block diagram of the two sonar system as operated in AIWEX.

tions occurred on a daily basis, when power was briefly shut off so that the diesel generators could be inspected.

During this period, real time displays of velocity and echo intensity were available from the sonars via the HP 217 computer (Fig. 7). These plots were posted in the camp mess hall (which also functioned as a scientific center) on a daily basis. The profiles were recorded approximately every two minutes, for the duration. Seventy megabytes of information were written on two high density cassettes.

On return from the experiment the cassettes were read into the Marine Physical Laboratories HP-1000 minicomputer system via the cassette reader on the HP 7912R Winchester disk drive. Unpacking the data, written in an in-house RD Instruments format, proved to be a time consuming task.

For initial data display and analysis, the two-minute profiles were converted to hourly averages. A set of time series approximately 900 hours (points) long at each of 64 depths, separated by 8m., was formed for each beam of each sonar. A sample record is presented in Fig. 8. Successive profiles are offset by 4 cm/sec and are set to a constant value when the equivalent horizontal speed exceeds 8 cm/sec. This suppresses the very large currents which appeared toward the end of the experiment, associated with mesoscale activity, and enables a clear view of the wavefield.

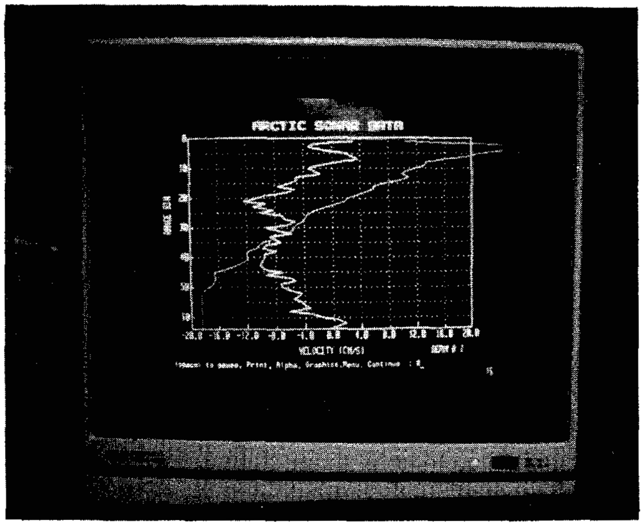


Fig. 7. An example of the real time display of velocity and intensity. Hard copies of this information were available in AIWEX.

In addition to the wavefield, changes in the motion of the ice can be easily seen. These appear as changes in velocity which are nearly uniform with depth. It is apparent that irregular changes in ice motion are of the same magnitude as the underlying waves. With conventional discrete current meters, accurate navigation must be used to correct for the motion of the ice. This is particularly difficult in the Arctic. Satellite passes are available only every several hours and Loran is unavailable. With profiling measurements of current, inadequate navigation measurements can be supplemented, using the measured average velocity over the observed depth range. Subtracting this depth-averaged velocity from the original data set results in time series which are less influenced by the motion of the ice. Unfortunately, motions of vertical wavelength comparable to the vertical measurement range, or longer, are distorted and reduced in amplitude by this procedure. Nevertheless, it is a valuable technique for visualizing the short vertical wavelength field, when unknown motion of the sonar is an issue.

An alternative way to remove the effects of ice motion is to estimate the vertical shear, by taking the difference between velocity estimates at successive ranges (Fig. 9). Here one can see the shorter vertical wavelength motions very clearly, particularly in the upper 250m. A sense of vertical propagation can occasionally be obtained by aligning successive wave crests. Note that there is no "clipping" of the shear signal, as was done in the previous figure. The mesoscale features, which have maximum velocities of order five times the characteristic wave velocity, have comparable shear.

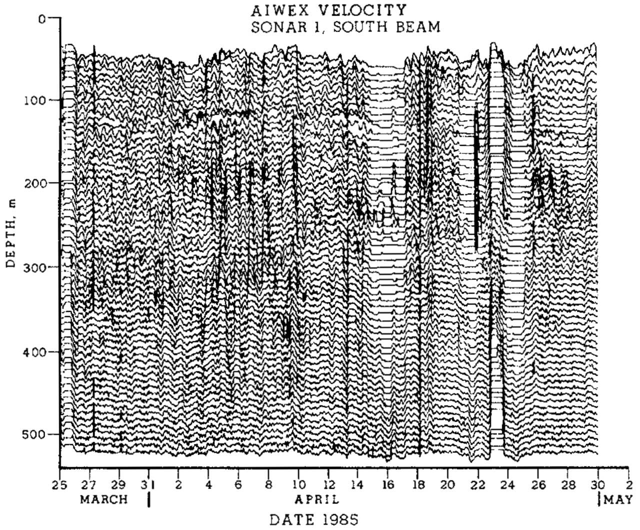


Fig. 8. Time series of velocity vs. range and depth from the south beam of the west sonar. Successive range bins are offset by 4 cm/sec in horizontal velocity and 8 m in depth. Velocity values greater than ± 8 cm/sec are truncated to enable a clear view of the weakly energetic internal wavefield. The low velocity levels at great depth result both from refraction of the wavefield and from a bias in the sonar system. Velocity estimates at low signal to noise ratio are biased toward zero.

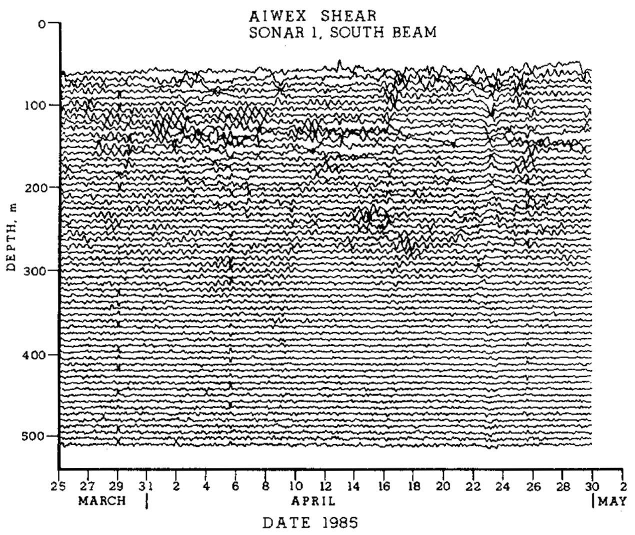


Fig. 9. Time series of shear vs. range and depth from the same sonar beam as in Fig. 8. The highly coherent (in depth) features in the velocity field associated with variations in ice drift velocity , do not appear in the shear. Low frequency high vertical wavenumber waves dominate the signal.

Spectral Analysis

Velocity data from the north and east beams of the west sonar are Fourier transformed, combined, squared and averaged to form the rotary spectra presented in Fig. 10. Averaging is done both in frequency and in depth, such that each spectral estimate corresponds to a 64 m. depth interval. Estimates are prepared both with the raw velocity data and with the vertical mean velocity over 24 to 344 m removed, to partially correct for ice drift. The "ice drift correction" reduces not only the low frequency signal but also the diurnal barotropic tidal signal as well. The resultant spectral slopes are approximately minus one on a log-log plot. A pronounced near inertial peak is present at all depths (.08-.1 cph). Note the excess of clockwise (viewed from above) over counter clockwise variance in the near inertial band.

At high frequency, the near-range spectra become noise dominated at a level of approximately 2 cm^2/sec^2/cph. This corresponds to an effective horizontal velocity noise variance of 1 cm ^{2}/sec ^{2} for the hourly averaged profiles, assuming a white noise spectrum.

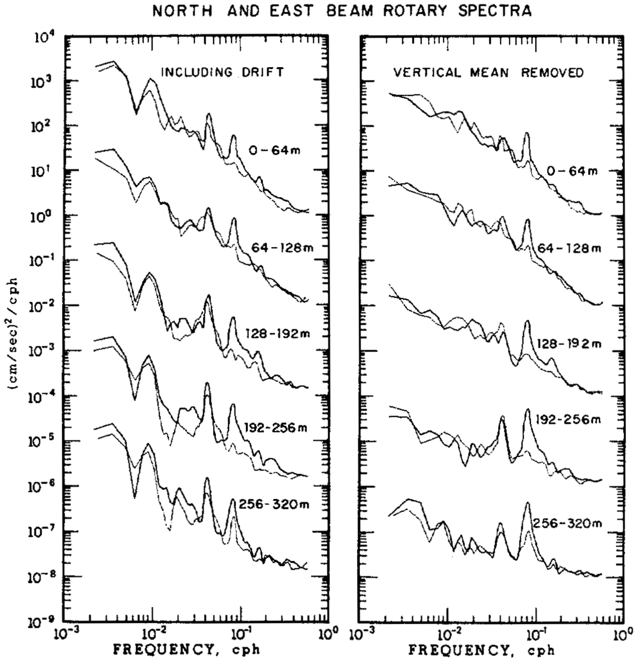


Fig. 10. Rotary spectra of effective horizontal velocity obtained with the north and east beams of the west sonar. The spectra are obtained from averages over 8 range bins (64 m) in depth and are also smoothed in frequency.

The high frequency spectral noise level quantifies spectral precision. The accuracy of the measurement is a different but related issue. In an attempt to determine accuracy, back to back sonar beams can be compared. This is done using power spectral techniques in Fig. 11. The heavy line in each depth range represents the one-component spectrum from the north beam of the west sonar. One of the lighter lines represents the spectrum of the signal from the south beam. The second light line represents the spectrum of the sum of the north and south velocity signals. If the signals were totally accurate (and there were no vertical component of velocity), they would be mirror images. The sum should then be zero, to within twice the random error of

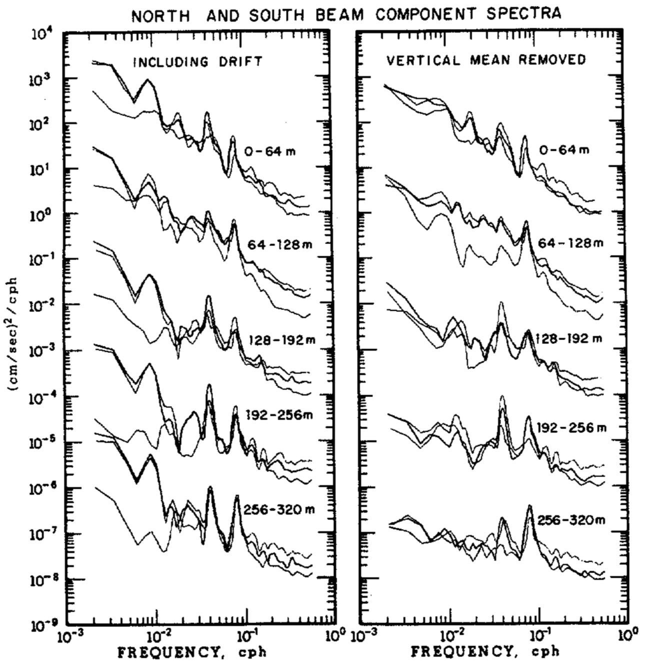


Fig. 11. Component spectra of effective horizontal velocity from the north (heavy line) and south (light line) beams of the west sonar. The spectrum of the sum of north and south beams (second light line). If the velocity profiles from the two beams were mirror images, the sum signal spectrum would be white, with a noise level twice that of the individual beams.

each beam. The second light line in each spectral depth range represents the spectrum of the sum signal. At frequencies higher than inertial, the sum spectrum is typically greater than either of the component spectra. This suggests that the signals are either only marginally coherent or coherent but not out of phase. Only at extremely low frequency, below 10^{-2} cph, is the sum signal consistently lower than either of the component signals (Fig. 11 left). When the depth averaged mean is removed, even this level of agreement is diminished (Fig. 11 right).

In spite of this alarmingly low level of agreement, there is only one clear indication that the sonar is grossly malfunctioning. In the depth band 64-128m the south beam has a factor of 3-10 less variance than the north beam (Fig. 11 right). The east sonar does not replicate this disparity.

The disagreement in the estimates from the two beams, while as large as the estimates themselves, is not very large in absolute terms. The rms velocity in the 0-64m depth bin is of order 2.6 cm/sec. With the vertical mean velocity removed, the value will further decrease with increasing depth. Biases or slowly varying drifts in the sonar electronics of a few cm/sec will result in errors of the same order as the signals. In mid-latitude oceans, where the internal motions are much more energetic, such problems will not appear as significant as in the Arctic.

Intercomparison With the Arctic Profiling System

The Arctic Profiling System (APS) was developed at the Polar Science Center, University of Washington, as a profiling in situ sensor package for Arctic research (1). The instrument contains temperature, conductivity and pressure sensors. In addition, three ducted fans sense relative current. During AIWEX this instrument was operated by one of us (J. Morison) and approximately 800 profiles were obtained, down to 400 or 600 m.

One of the profiles is reproduced in Fig. 12, along with corresponding hourly averaged profiles from the four beams of the two sonars. Note that while the spread between the various profiles looks encouragingly small, it is more than ample to explain the discouraging results in Fig. 11. For Arctic research, a system is called for which can tolerate 40°C temperature changes and still keep drift and bias problems small compared to 1 cm/sec. It is hoped that future refinements of the present sonars will provide this performance.

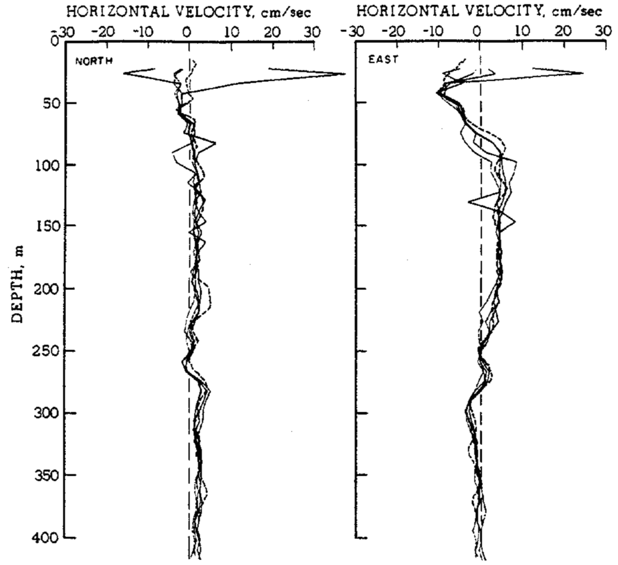


Fig. 12. Hourly average profiles from the two sonars (solid lines), as compared with a single velocity profile from the Arctic Profiling System (dashed line). Profiles from the south and west beams of each sonar have been reversed to be consistent with the velocity sign convention of the APS.

Conclusions

Two 150 kHz Doppler sonars, manufactured by RD Instruments, Inc., were operated for a period of 37 days in the Beaufort Sea, as a component of the Arctic Internal Wave Experiment, AIWEX. In spite of being only a small part of the total effort the sonars contributed greatly to the overall goals of the experiment. In addition to providing velocity and shear information in their own right, they provided valuable "context in formation," which is aiding other investigators in the interpretation of data from the various discrete sensors employed.

The precision of the sonars was found to be approximately 1 cm/sec rms for hourly averages. Accuracy, as determined from comparisons of back to back beams, was of the same order. While these limits are generally adequate for mid-latitude research, natural signal levels are much lower in the Arctic. Typically, the internal waves signal could be seen only at frequencies below .2 cph, wave periods longer than 5 hr. However, the performance characteristics of these devices is certain to improve over the next few years. They will surely play a role in future Arctic research efforts.

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Reference

(1) J. H. Morison, "Forced internal waves in the Arctic Ocean," Ph.D. Thesis. University of Washington, 1980.