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The Hydrographic Doppler Sonar System on the Roger Revelle

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Abstract-Turbulent mixing rates in the sea have been found to vary as the fourth power of the fine scale (~10 m) vertical shear. The global distribution of shear is poorly known, associated with phenomena which are potentially quite localized in space and time. With the construction of the R/V Roger Revelle it was deemed appropriate to develop an exploration-mounted Doppler sonar system for the global scale mapping of the fine-scale shear and velocity fields. Termed the Hydrographic Doppler Sonar System (HDSS), it consists of nested quartets of 50 and 140 kHz transducers, installed in two 4"x12' wells, one on either side of the Revelle's keel.

Transmitting repeat sequence coded pulses through a 1" polyethylene window, the 50 kHz system profiles to depths of order 600-1000 m, with 18 m depth resolution. The 140 kHz system attains depths of 200-350 m with 4 m depth resolution.

The HDSS has played a central role in experiments such as ASIAEX, EPIC and HOME, and has provided background information in a variety of other programs. The routine "steaming data" is enabling us to accumulate a growing picture of the global distribution of shear and associated underlying phenomena.

INTRODUCTION

For the past 50 years, the oceanographic research fleet has been mapping the sea floor acoustically. More recently, simple monostatic sounders have given way to complex multi-beam systems that have required significant modification to the ships. The results of this effort have been extremely rewarding scientifically.

A comparable effort to map ocean currents has not developed. Given that deep ocean mean currents are typically 1-2 cm/s, less than the best (short-term) shipboard navigational accuracy, the motivation to attempt measurements to great depths has been limited. The resulting acoustic current measurement systems have been designed to accommodate shipboard constraints (eg. a 3 foot diameter well), rather than visa versa.

However, it is becoming apparent that fine-scale shear plays a significant role in the dissipative dynamics of the ocean. "Climatological" maps of the large-scale variability of fine-scale shear (and related quantities) are needed. In spite of real world navigation (and other) problems, a renewed effort to obtain precise, high-resolution measurements of ocean velocity and shear in the coastal and deep ocean is called for.

During the design phase of the R.V. Roger Revelle, AGOR24, it was decided to develop a long-range high resolution Doppler sonar, to map the global field of fine-scale shear. For acoustic systems with non-vertical beams, depth resolution is established by both the duration of the transmit pulse and the vertical spread of the beams. Typically, vertical spread is the more significant factor at great range. To minimize this effect on the Revelle, it was decided to use relatively large aperture transducers and to modify the ship accordingly.

SYSTEM DESCRIPTION

The resulting Hydrographic Doppler Sonar System (HDSS) consists of nested sets of 140 kHz (Hi Res.) and 50 kHz (long-range) transducers. Oriented in the traditional Janus configuration, Fig 1, the 50 kHz sonar profiles to depths of 700-1000 m, with the140 kHz sonar achieving depths of 200-300 m.

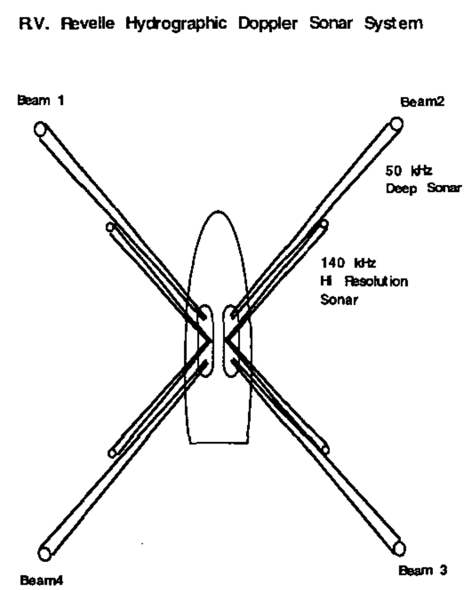

Fig. 1. A plan view schematic of the Hydrographic Doppler Sonar System on the RV Revelle. All sonar beams are oriented downward, thirty degrees off vertical.

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For the 50 kHz system, the expense of constructing four 55 cm x 100 cm transducers using traditional technology would be prohibitive. In an attempt to develop a new, low-cost design, the transducers were assembled from 11" square sections of 1-3 composite ceramic material developed by Materials Science Inc., Fig 2. The 1-3 composite was sandwiched between an aluminum front mass and a steel back mass and subsequently bonded and potted. Transducer design and assembly occurred at the Applied Research Laboratory of Penn State University.

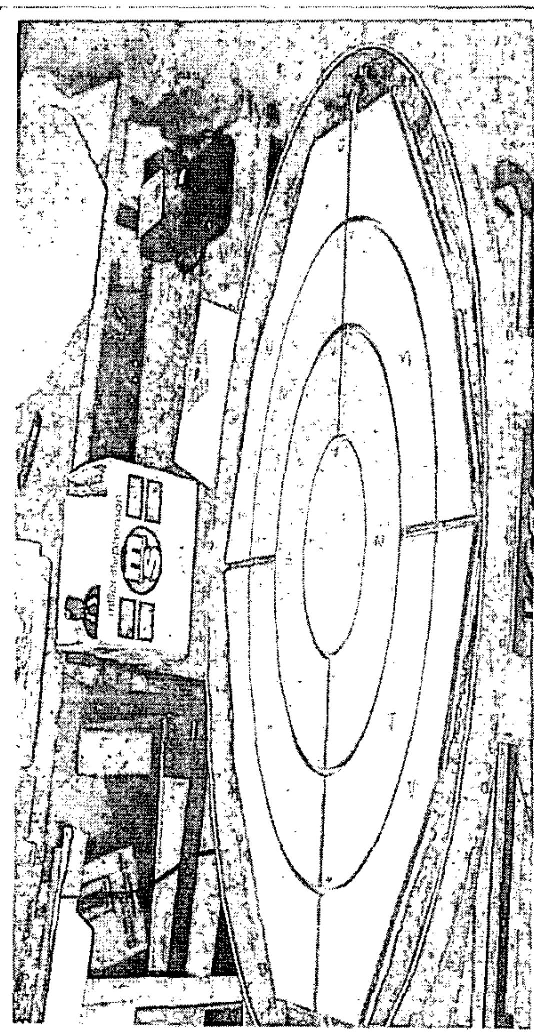

Fig. 2.One of four, 50 kHz transducers, prior to potting. The 1-3 composite material is sandwiched between metal front and back masses and segmented into concentric rings, to enable spatial shading.

Following construction, the transducers were shipped to Sasebo, Japan where, in November-December, 1999, they joined the Scripps-crafted 140 kHz sonar transducers, electronics and ancillary hardware and were installed in the dry-docked Revelle, Fig3. The sonar wells in the Revelle were then covered with 1" polyethylene windows to protect the transducers from impact and to reduce flow noise. The polyethylene attenuates the round-trip acoustic signal by approximately 3 dB at 50 kHz. The reduction is presumably greater for the 140 kHz system.

The Revelle was re-launched in January 2000. Following an initial shakedown in the winter time Sea of Japan, the HDSS has been operational over most of the subsequent three years. The 50kHz sonar transmits (nominally) fifteen repeats of a four-bit repeat-sequence code (Pinkel and Smith 1992), with a bandwidth of 2 kHz. The associated depth resolution is 16m, neglecting the range-dependent effects of transducer beamwidth. The 140 kHz system transmits eleven repeats of a four-bit code, with a 6.25 kHz bandwidth. Nominal depth resolution is 4m. Echo data are averaged into fixed-depth (rather than fixed-range) bins using input from the Revelle's TSS inertial reference. One-minute averages of echo intensity and covariance are routinely recorded. Single-ping statistics are available to advanced users. Real-time displays of absolute ocean current (using the ship's P-Code GPS and Ashteck ADU2 heading sensor), shear and acoustic scattering strength are available to on-board personnel. The sonar is operated by the Scripps Shipboard Computer Group. Data are archived at the SIO Geological Data facility.

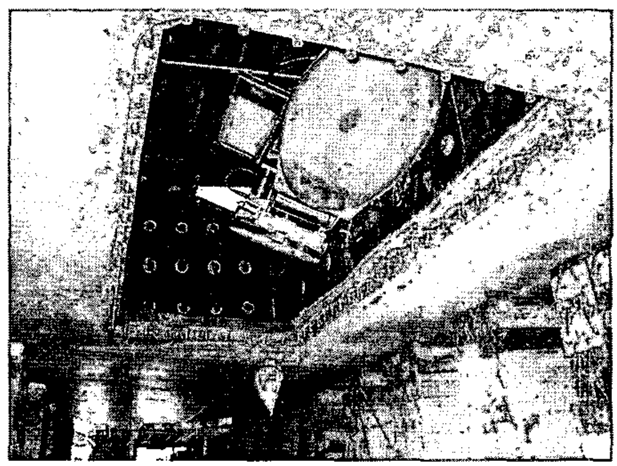

Fig. 3. One of two sonar wells in the RV Revelle, showing two completed 50 kHz transducers (ovals) and two 140 kHz transducers (smaller rectangles).

REPRESENTATIVE DATA

As an example of HDSS data, profiles of velocity and shear are presented (Fig. 4) from a May 2001 cruise when the Revelle crossed the Kuroshio in the East China Sea, south of Japan, as an aspect of the ONR ASIAEX Experiment. A series of very energetic shear layers were found (by graduate student Luc Rainville) to underlie the base of the Kuroshio. These slope downward offshore and have horizontal coherence scales of 30-50 km. The observed slopes slightly exceed the slope of isopycnal surfaces, suggesting that they are waves with a near-inertial intrinsic frequency. The shear associated with these waves is comparable to the geostrophic shear of the Kuroshio.

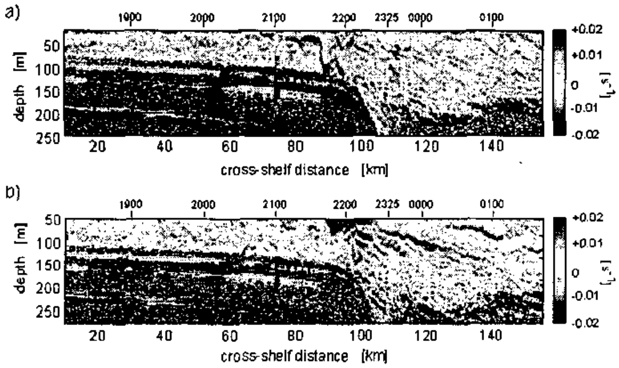

Fig. 4. Shear transects across the Kuroshio in the East China Sea , as seen by the 140 kHz sonar on April 17,2000.

We have been unable to detect a vertical energy flux associated with these waves. In part this is a consequence of the short duration of the transect measurements. It is difficult to sense the time-evolution of flow from a moving platform.

If the shear layers are frontal, in approximate geostrophic balance, one would expect to find large horizontal density gradients, perhaps with T-S variations, through the layers. Such variations are not seen.

At present, the analysis is most consistent with the hypothesis that the shear layers are refractively trapped waves, more or less frozen in space by the vertical and lateral shears of the region. With time-series measurements at the site, the issue could be resolved.

These organized motions must greatly influence dissipative processes at the Kuroshio Front. In turn, they must be strongly influenced by the meandering nature of the Kuroshio and its interaction with the continental shelf.

The highly coherent, anisotropic, step-like features induced in the density field by the straining of these layers will have a profound influence on the propagation of sound. Given the strong acoustic signature that these layers must have, an experiment focused on their study might well make use of acoustic techniques.

OPERATIONAL EXPERIENCE

In parallel with the incoming observations, a wealth of operational experience is being gained. With the continued cooperation of the Revelle's crew, we have succeeded in reducing shipboard noise contamination significantly. Wave slam noise and under-hull bubbles are the predominant noise sources for the 50 kHz sonar. At depth, the strength and constitution of the mid-water (300-800 m) biological scattering community has a great effect on system range. The diel vertical migration is clearly seen in both scattering strength and vertical velocity signals.

Given that the dominant system noise is environmental, to increase overall system range it is necessary to increase transmit power. Each 50 kHz beam presently transmits with 2 kW peak power, a number that can be substantially increased.

We have found the 1-3 composite transducers to be relatively poor transmitters. Variability in the bonding between the 1-3 ceramic and the front and back mass sheets has also lead to degraded beam patterns. The effort to develop a narrow beam, low cost 50 kHz transducer continues. A second-generation prototype transducer is now being developed using conventional tonpilz technology.

It was anticipated that, while the co arriving 50 kHz and 140 kHz echo signals could easily be separated, electronically, the transmit pulse of one sonar would surely contaminate reception on the other. To avoid producing permanent "dead zones" in the 50 kHz record, the transmit interval of the 140 kHz sonar was set to 0.6s., while the 50 kHz transmitted at 2.0s. Data are simply set to zero on each sonar while the other is transmitting. Transmit "holes" are indeed produced in the data at some ranges, but at most on every third ping. Thus, the simultaneous operation of two different systems results in a variation of the statistical stability of the various echo averages with range, rather than a variation in acoustic / electrical noise.

This spatial variation in statistical stability has been found to yield clear bands of increased velocity imprecision in the 50 kHz sonar, which gathers statistics at a slower rate than the 140kHz system. (A one-minute average corresponds to 30/100 data in the "good regions, 20/66 data in the "dead zones', for the 50/140 kHz sonars.). Given the central interest in fine-scale shear, the periodic bands of increased imprecision have proven to be troublesome. Since May 2002, the system has been operated with a 1-second repetition time for the 140 kHz sonar. This produces a single, isolated ~10 m dead "band" in the 50 kHz record, which is easy to identify and deglitch.

The overall experience of developing a relatively complex system that can run continuously, virtually unattended, has been gratifying. While the initial expense has been significant (~$1M, corresponding to ~40 days of ship-time at the 2002 rate), the cost of maintaining a research fleet that cruises the world while NOT measuring ocean current and biological scattering information is much greater, measured in lost decades of potential advancement.

ACKNOWLEDGEMENTS

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