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14. ABSTRACT

The approach of the instrument upgrade included improving the SHRU clocks by utilizing chip-scale atomic clocks (CSAC), enlarging battery packs to extend the operation duration, and adding data storage capacity for long-duration missions. The advantage of CSAC on clock precision can improve synthetic aperture processing and ocean acoustic tomography and achieve excellent long-term timing precision. A one-year deployment with continuous recording can be accomplished in the Arctic Ocean acoustics experiment, to capture both summer and winter conditions. Besides the hardware upgrade, we also improved the software controlling the SHRU data acquisition systems. After the hardware and software upgrades, the SHRU units were placed in a cooler at 0˚C for comprehensive system testing.

15. SUBJECT TERMS

acoustics, shallow water, Arctic Ocean, 3-D acoustic propagation, shelfbreak

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DURIP Final Report

Array Receivers and Sound Sources for Three-Dimensional Shallow-Water Acoustic Field Experiments

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LONG-TERM GOALS

Over the last few decades the effects of ocean dynamics (both on the sea surface and in the water column) and bathymetric and seabed properties on underwater sound propagation have been examined with great success. Our acoustics research groups, the Ocean Acoustics and Signals Laboratory and the Acoustic Communications Group, in the Applied Ocean Physics and Engineering Department of the Woods Hole Oceanographic Institution (WHOI) regularly participate in the Office of Naval Research (ONR) field efforts in shallow-water acoustics and underwater acoustic communications. We have plans to upgrade our existing hydrophone arrays and sound sources. These instruments will improve our research capabilities and enhance the quality of our research currently funded by the ONR in the following research directions.

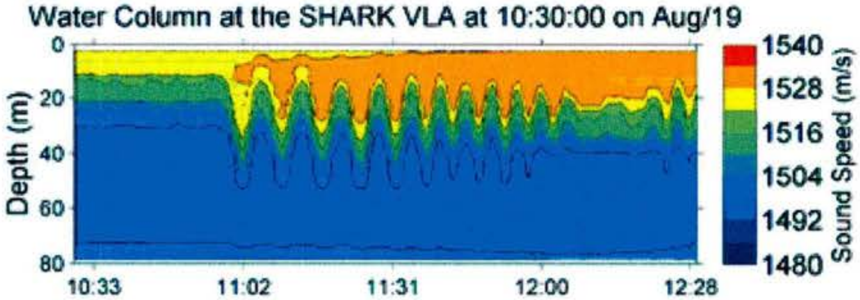
a. 3-D propagation, scattering and reverberation in an Arctic slope/canyon region.
b. Ambient noise in the Arctic Ocean
c. 3-D effects in standard and ambient noise based geoacoustic inversion.
d. Temporal variability of geoacoustic inversion uncertainties on the New England Shelf.

OBJECTIVES

Specifically in this project, the DURIP funds we received were utilized to upgrade seven of the WHOI-designed "SHRU" (Several Hydrophone Receiver Unit) arrays. The immedate objective was to improve our fieldwork capibility and to enhance the quality of our underwater acoustic research currently funded by the ONR Ocean Acoustic Program in the Arctic ocean. These instruments can also be utilized to support future ONR acoustics experiments, specifically the experiment planned in the New England Shelf in March, 2017. Other applicable studies are explained in the following.

Figure 1 presents the types of oceanic environments in the study areas where we will use the upgraded equipment. On the continental shelf and shelfbreak, it is known that both physical oceanographic processes and marine geological features can cause the medium properties to have horizontal heterogeneity. Therefore, horizontal refraction of sound can occur and produce significant three-dimensional (3-D) acoustic propagation conditions. The main oceanographic process that can yield 3-D acoustic effects in shallow-water oceans is nonlinear internal gravity waves. For sound propagating across the waves, mode coupling, scattering and resonant types of effects are most important (Zhou et al., 1991). Nonlinear internal waves can also act as reflective fronts, so that a horizontal interference pattern can occur (Lloyd's mirror pattern is an example) (Badiey et al., 2011;

McMahon et al., 2012). When two nonlinear internal waves align, a 3-D acoustic duct will be formed, which can potentially trap sound over a long distance and radiate it from the end of the duct (Lin et al., 2009). Nonlinear internal waves can have curved fronts, and the curvature will make the propagation pattern even more complicated.



(a) Water-column sound speed perturbations by internal gravity waves

(b) Surface water waves
Artwork by Kerem Gogus

(c) Ice floes float in the Arctic Ocean
Baffin Bay in July 2008
THE CANADIAN PRESS/Jonathan Hayward

(d) Submarine Canyons
Monterey Canyon
© Monterey Bay Aquarium Research Institute

(e) Continental shelf and slope
Arctic Ocean area
Image courtesy of NOAA NGDC

Figure 1: The types of environments considered in our research.

Many studies have shown that seafloor topography can also cause acoustic scattering and focusing. At the edge of continental shelves, i.e. shelfbreak areas, strong features like submarine canyons (Lin et al., 2014) and seafloor scours (Ballard et al., 2012) can cause focusing of sound. These seabed effects, when considered alone, have no temporal variability, but they will be modulated by physical oceanographic processes and become varying in time. The ultimate scientific objective of our recent studies is to understand the underlying physics of the 3-D sound propagation effects caused jointly by physical oceanographic processes and geological features.

APPROACH

The approach of the instrument upgrade included improving the SHRU clocks by utilizing chip-scale atomic clocks (CSAC), enlarging battery packs to extend the operation duration, and adding data storage capacity for long-duration missions. The advantage of CSAC on clock precision can improve synthetic aperture processing and ocean acoustic tomography and achieve excellent long-term timing precision. A one-year deployment with continuous recording can be accomplished in the Arctic Ocean acoustics experiment, to capture both summer and winter conditions. Besides the hardware upgrade, we also improved the software controlling the SHRU data acquisition systems. After the hardware and software upgrades, the SHRU units were placed in a cooler at 0°C for comprehensive system testing.

WORK COMPLETED

Each of the upgraded SHRU data acquisition systems is equipped with four hydrophones. Again, the objectives of the equipment upgrade include increasing the continuous data acquisition time to a full year and improving the stability of the SHRU time base by a factor of 10. The following system upgrades have been successfully accomplished.

1. Replacing the existing Seascan timebase (drift 2 to 3ms/day) with a Microsemi Chip Scale Atomic Clock (CSAC, drift ~10μs/day for a short deployment). This entails the design of a carrier printed circuit board that supports the CSAC and a plug-in replacement for the existing Seascan oscillator (see Figure 2).
2. Upgrading the data storage to 1TB.
3. Changing the deployment configuration to use dual pressure housings to augment the alkaline primary battery payload to achieve the one-year duration.

Figure 2. CSAC-SHRU electronic board. A Microsemi Chip Scale Atomic Clock (CSAC) and a PERSISTOR miniature computer are used on the SHRU system.

RESULTS

Five of the upgraded CSAC-SHRU array moorings have been deployed on the Chukchi Sea shelf as a part of the Canada Basin Acoustic Propagation Experiment (CANAPE) Shallow Water (SW) component. The deployment is for one year, and the objective is to continuously record ambient noise and acoustic signals transmitted from the Canada Basin, up to 500 km away. In addition to the five SHRU arrays, we have also deployed another SHRU array on the fantail of the ship (R/V Sikuliaq) during the mooring deployment cruise (see Figure 3). Both the mooring and array dipping deployments were sucessful, and the received signals (Figure 4) confirms we can hear the signals transmitted from the Canada Basin 500 km away.

Figure 3. A CSAC-SHRU array was to be deployed on the fantail of R/V Sikuliaq during the mooring deployment cruise of the CANAPE SW experiment.

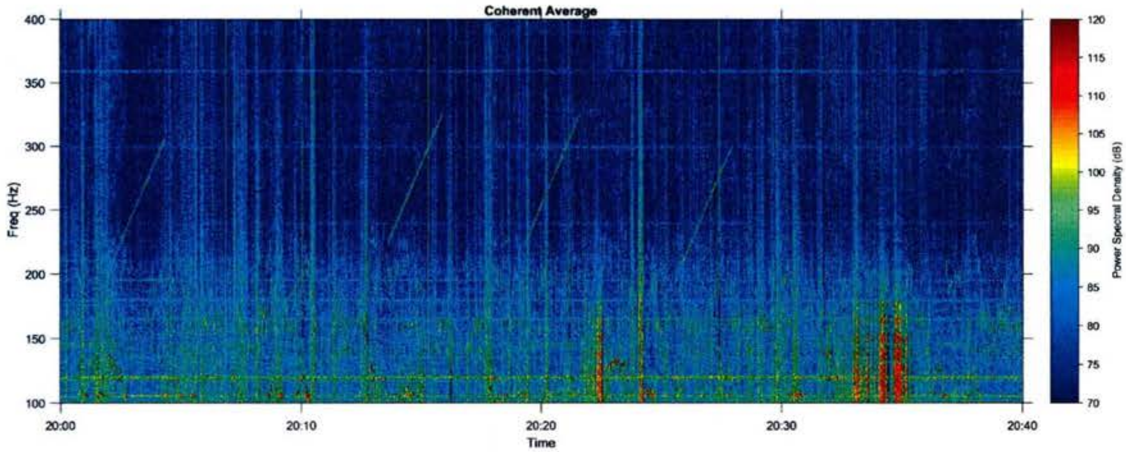


Figure 4. The acoustic signals transmitted from the Canada Basin and received by the CSAC-SHRU deployed on the fantail of R/V Sikuliaq. The coherent average across the four channels is shown.

IMPACT/APPLICATIONS

The upgraded SHRU arrays with chip-scale atomic clocks can be configured as either vertical arrays, horizontal arrays, or hybrid arrays. They can be deployed with smaller vessels and in difficult areas such as slopes and canyons. The potential relevance of this work to the Navy is on increasing the capability of mobile or portable sonar systems using chip scale atomic clocks.

RELATED PROJECTS

The instruments are utilized in an Arcitic acoustic research program funded by the ONR Ocean Acoustic program entitled, "Alaska North Shore Ocean Acoustics Study," Grant # N00014-15-1-2196.

HONOR

A B Wood Medal, the Institute of Acoustics, UK, 2015

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Zhou, J., Zhang, X. and Rogers, P. H., "Resonant interaction of sound wave with internal solutions in the coastal zone," *J. Acoust. Soc. Am.*, vol. 90, pp. 2042-2054, 1991.

PUBLICATIONS

1. Non Peer refereed papers

2016 **Y.-T. Lin**, M. Badiey, T. F. Duda, J. Kemp, J. Eickmeier, M. Dzieciuch and P. Worcester, "Numerical analysis of underwater sound propagation over the Chukchi Sea shelfbreak," *J. Acoust. Soc. Am.*, vol. 139, p. 2198.

EQUIPMENT

Equipment purchased: None.

Supplies purchased were battery packs, connectors, and chip-scale atomic clocks.