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Underwater source localization using a hydrophone-equipped glider

Jiang, Y.M., Osler, J.

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The Centre for Maritime Research and Experimentation (CMRE) is a world-class NATO scientific research and experimentation facility located in La Spezia, Italy.

The CMRE was established by the North Atlantic Council on 1 July 2012 as part of the NATO Science & Technology Organization. The CMRE and its predecessors have served NATO for over 50 years as the SACLANT Anti-Submarine Warfare Centre, SACLANT Undersea Research Centre, NATO Undersea Research Centre (NURC) and now as part of the Science & Technology Organization.

CMRE conducts state-of-the-art scientific research and experimentation ranging from concept development to prototype demonstration in an operational environment and has produced leaders in ocean science, modelling and simulation, acoustics and other disciplines, as well as producing critical results and understanding that have been built into the operational concepts of NATO and the nations.

CMRE conducts hands-on scientific and engineering research for the direct benefit of its NATO Customers. It operates two research vessels that enable science and technology solutions to be explored and exploited at sea. The largest of these vessels, the NRV Alliance, is a global class vessel that is acoustically extremely quiet.

CMRE is a leading example of enabling nations to work more effectively and efficiently together by prioritizing national needs, focusing on research and technology challenges, both in and out of the maritime environment, through the collective Power of its world-class scientists, engineers, and specialized laboratories in collaboration with the many partners in and out of the scientific domain.

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Session 4aUWa: Detection and Localization

4aUWa5. Underwater source localization using a hydrophone-equipped glider

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Buoyancy-driven underwater gliders are autonomous underwater vehicles that were originally developed to collect oceanographic data. CMRE is studying the use of this technology for the characterization of denied areas, including alternate sensor payloads and applications. During the Rapid Environmental Assessment phase of the Noble Mariner 2012 NATO Exercise, conducted in Gulf of Lions in September 2012, an omnidirectional hydrophone was mounted on a shallow water glider to sample the spatial distribution of the acoustic and oceanographic fields at different ranges and depths. This paper presents a study of the potential to localize acoustic sources by using the acoustic and environmental data collected by the glider. During the experiment, a bottom moored acoustic source was deployed in an area with benign bathymetry. Continuous wave and frequency modulated pulses were broadcast for approximately 6 hours. The glider was flying along predefined tracks and the distances from the source were typically from 5 to 9 km. A ray tracing model is used to evaluate the arrival structures of the acoustic signal, and to estimate the source location.

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INTRODUCTION

Underwater gliders are a relatively new technology that is undergoing rapid development. The NATO STO-CMRE (Science and Technology Organization – Centre for Maritime Research and Experimentation, formerly known as NURC) has been employing these autonomous underwater vehicles for oceanographic research for the past few years. In addition, the scientists and engineers at CMRE have been integrating novel types of sensors to extend the capabilities and potential applications of gliders.

In a recent sea trial, an omnidirectional hydrophone was mounted on a Teledyne Webb Research Slocum shallow-water glider to sample the spatial distribution of the acoustic and oceanographic fields at different ranges and depths. This paper studies the potential for acoustic source localization using the acoustic and environmental data collected by the glider, with a vision that the requisite signal processing capabilities might eventually be embedded within a glider.

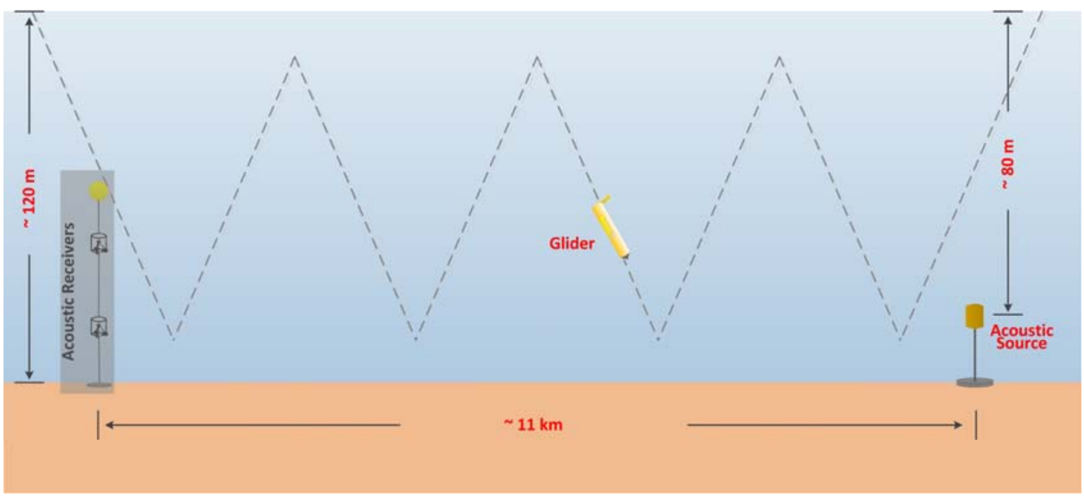

FIGURE 1. Side view of the glider track with respect to the acoustic source.

THE EXPERIMENT

The Rapid Environmental Assessment (REA) phase of the Noble Mariner 12 (NOMR12) NATO Exercise took place from 01 September to 26 September 2012 in the Gulf of Lions.

The acoustic measurements were conducted from 10 September to 20 September 2012, in a 15km by 15km area on a shelf break. Glider GRETA was deployed from 16 September to 18 September, to measure the acoustic field and oceanographic data along pre-defined tracks. An acoustic source and acoustic receivers were deployed along a track with a constant water depth of 120 m. The source depth was 80 m and the receivers were at a range of approximately 11 km.

During one of the acoustic experimental periods, the source was transmitting a combination of continuous wave (CW), linear frequency modulation (LFM) and hyperbolic frequency modulation (HFM) pulses at a duty cyrcle of 20 seconds.

The oceanographic data

Fig. 2. portrays six hours of sound speed data as measured by GRETA on 18 September 2012. The sound speed and depth were derived from the CTD (conductivity-temperature-depth) measurements on the glider. The dead position reckoning coordinates of the glider have been corrected using the GPS data received at the sea surface. The spatial offsets between segments in the glider track arise because the glider was drifts away from the pre-defined track due to the current when it is surfaced to telemeter real-time data. It is seen from the data that there was a spatial variation in sound speed during the six-hour time period used in this example.

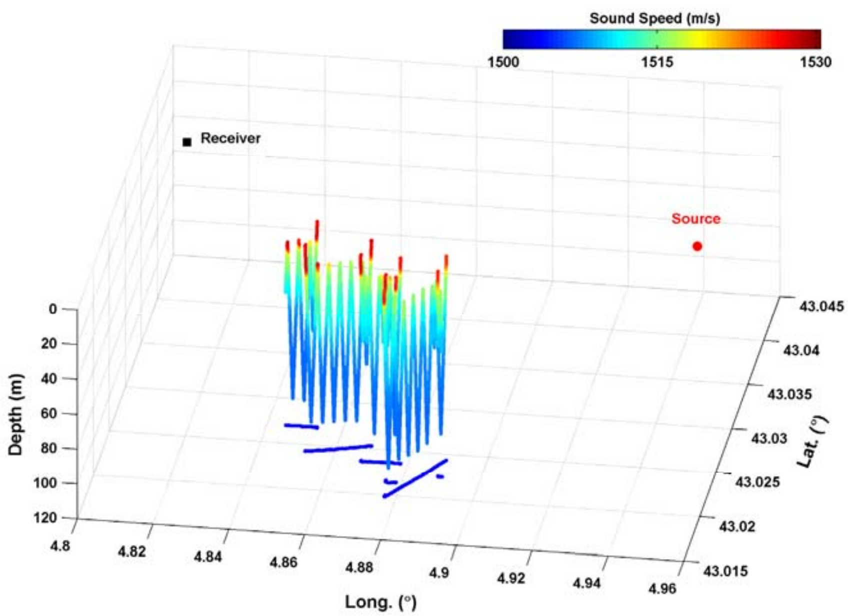

FIGURE 2. The sound speed measured at the positions (coordinates and depths) of glider Greta on Sep. 18, 2012

The acoustic data

Fig. 3. shows a sample of the acoustic signal measured by GRETA. Although the signal to noise ratio seems to be low in the raw data (top panel of Fig. 3), the pulses are clearly seen in the spectrogram – a combination of two CW and one FM (frequency modulation) pulses, 500 ms later, followed by a second set of two CW and one FM pulses combination, and repeated every 20 s. The signal (from 52 to 78 seconds) was due to the noise from the buoyancy pump, battery shift and air bladder (with all three occur during this time interval when the glider is surfaced). The data used in this study are the second set of FM pulses, which are HFM pulses.

SOURCE LOCALIZATION BY USING A HYDROPHONE ON A GLIDER

The method

Given a sound propagation environment and source-receiver geometry, the impulse response between the source and receiver is defined. If we consider the acoustic channel between the source and receiver as a linear system, then the impulse response can be expressed in terms of a transversal filter. The time delay of the transversal filter is mainly determined the sound speed profile (SSP) in the water and the experimental geometry (i.e., the source depth, the receiver depth, the water depth and the range between the source and receiver).

Experimentally, the impulse response of the acoustic channel can be estimated by transmitting broadband pulses. The channel impulse response is then extracted by matched filter processing of the broadband signal. The quality of the acoustic channel impulse response estimate depends in part on the bandwidth of the signal being transmitted, the larger the bandwidth, the better the resolution of individual arrivals in time domain.

The time delays of the arrivals with respect to the first arrival are easily extracted from the matched filtered received signal. Then a ray tracing acoustic model may be used to estimate the time delays by varying relevant parameters (e.g., the geometry and the SSP). The set of arguments that generates the best match to the measured time delay is the final estimates of unknowns. In this study, we assume the receiver depth and the sound speed profile are known, as they are directly measured by the glider. We further assume that the water depth and source depth are known as an initial approach to applying this time delay based method.

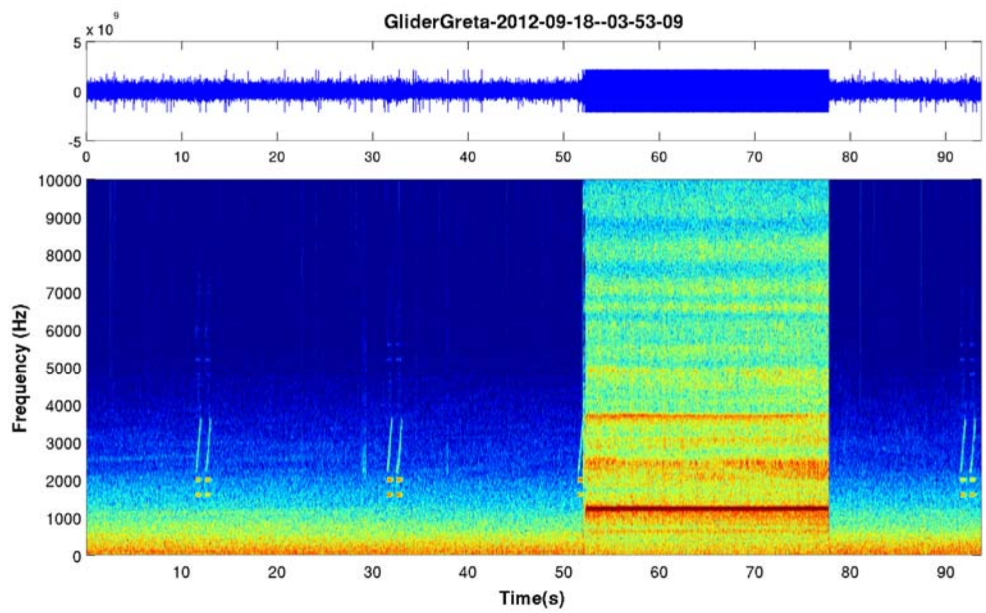

FIGURE 3. Top: a time series of raw signal recorded by glider Greta, and Bottom: spectrogram of the time series.

Data preprocessing

The sound speeds measured during a complete 'dive' (half of a cycle, depth from 102.9m to 2.8m, from 04:18:1.2 to 04:25:42.98, 18 September 2012 UTC) are used to generate a full SSP. The measured SSP (blue curve in the left panel of Fig. 4) is extrapolated to the sea surface and sea bottom, and finally sub – sampled (red curve in the left panel of Fig. 4.).

The acoustic signals within the aforementioned time frame of the glider dive are matched filtered. The acoustic data available within the time frame of interest are shown in the right panel of Fig. 4. The depths at which the acoustic signals were recorded are extracted by cross - referencing the time stamps of both CTD and acoustic data.

Preliminary result

Due to the fact that the acoustic source was moored beneath the thermocline, the acoustic arrival structure presents some challenges, such as a very week direct arrival that is hard to identify from the background. Accordingly, only the signals received at depths well below the thermocline (102.9, 100.9, 92.1, 87.2, 82.4, and 77.6 m) were used in the study. In searching for the arguments, in this case is the range between the bottom-moored acoustic source and the glider, the bounds of the search-space are set to 3.5 to 5.5 km. The geoacoustic inputs for the acoustic model assume a half space with: p-wave sound speed of 1580 m/s, density of 1.8g/cm^3 and p-wave attenuation of 0.4 dB/λ.

The range estimates from those six time series are 4.56 ± 0.26 km, in comparison to glider – source ranges (calculated using the post-processed glider coordinates) of 4.71 to 4.68 km. Explaining the bias in this solution and the magnitude of the error in the localization are topics for further investigation.

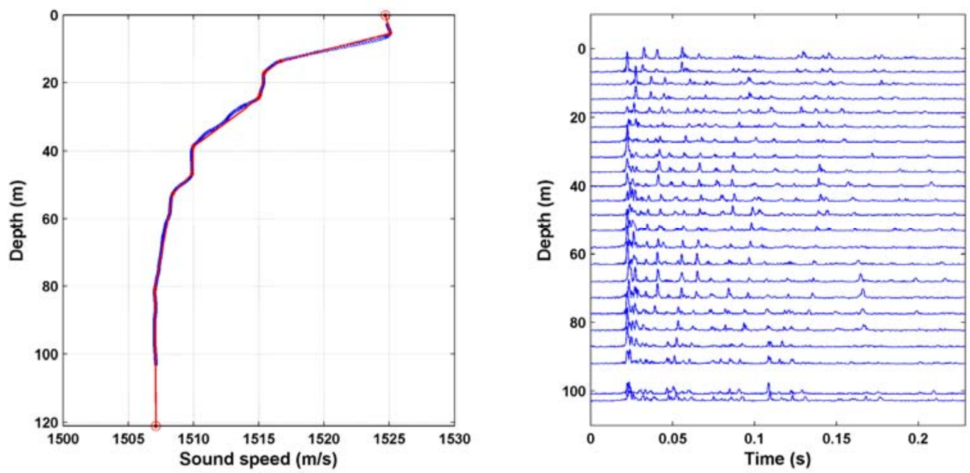

FIGURE 4. Left) sound speed profile collected by glider Greta, and Right) time series of acoustic pulses collected by glider Greta at the same time.

FURTHER INVESTIGATION

The preliminary result indicates that there are several issues to be investigated to continue this study:

- Cost functions other than the time delay based approach;
- Use of multiple signals from all depths to better constrain the solution;
- The effect of a spatially varying SSP (the SSP used in this study was measured by the glider at a range of 4.7 km away from the acoustic source);
- The transfer of uncertainty in the glider positions to the uncertainty in the source localization, and
- The impact of uncertainty in the sea bottom geoacoustic parameters.

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Keywords

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