Determining the Causes of Geological Clutter in Continental Shelf Waters

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LONG-TERM GOALS

Geological clutter (geoclutter) is the primary problem encountered by active sonar systems operating in shallow water, because geoclutter is typically confused with returns from an intended submerged target, such as a submarine. To develop operational techniques that reduce the level of physical constraints on signal processing algorithms that minimize the impact of clutter on active target detection and localization, it is first necessary to understand the physical mechanisms that cause geological clutter, which is the primary objective of ONR's Geoclutter Program. Long-term goals are:

- To understand, characterize, and predict lateral and vertical, naturally-occurring heterogeneities that may produce discrete acoustic returns at low grazing angles (i.e., "geologic clutter") in the STRATAFORM site on the New Jersey continental shelf, and then

- To conduct precise acoustic reverberation experiments at this site to understand, characterize, and potentially mitigate the geologic clutter.

OBJECTIVES

A series of joint experimental and theoretical efforts are necessary to investigate the causes of geological clutter. Theoretical efforts aid and direct the experimental design, as well as help in analyzing and interpreting acquired data results. A set of geological experiments and the Geoclutter Acoustic Experiment 2001 (GAE 2001) were conducted under the Geoclutter Program. The plan and design of another major experiment, GAE 2003, is under way. The scientific objectives are:

- Determine the physical mechanisms that lead to geoclutter in continental shelf environments;

- Explain why clutter should be expected from certain classes of sub-bottom geomorphology and not from others;

- Explain how bistatic aspect will influence the prominence of clutter from various classes of sub-bottom geomorphology;

- Determine methods to more accurately chart reverberation and clutter in a dispersive waveguide.

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14. ABSTRACT
Geological clutter (geoclutter) is the primary problem encountered by active sonar systems operating in shallow water, because geoclutter is typically confused with returns from an intended submerged target, such as a submarine.

15. SUBJECT TERMS

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APPROACH

The approach is to have data analysis progress in conjunction with full field modeling of clutter, reverberation, and calibrated target returns, using both acoustic data and geophysical data collected in the Geoclutter Program with participants from the University of Texas Institute of Geophysics (UTIG), Penn State University, Florida Atlantic University (FAU), the Naval Undersea Warfare Center (NUWC), and the Naval Research Laboratory (NRL) and SACLANT.

GAE 2003 and other supporting geophysical experiments are designed with the aid of insights gained from GAE 2001, acoustic modeling and supporting geological data and analysis. The GAE 2003 experimental assets include the ONR 5-Octave Basic Research Array built for this program, a source array used for bistatic experiments, several calibrated BBN prism targets, and a series of moorings for the source ship. The preparations and initial planning of GAE 2003 include the following:

- Design the experiment to measure and quantify the bistatic scattering properties of selected buried river channel networks, and correlate these with channel morphology.

- Develop techniques to estimate the shape, size and orientation of river channel networks from their scattered fields in order to predict clutter level.

- Design tracks to separate returns from various features at a variety of ranges and azimuths and minimize the ambiguity inherent in line-array measurements.

- Plan the deployment of a number of calibrated targets in the water column and receivers on the seafloor to provide ground truth for waveguide scattering models and minimize charting errors.

- Compare and contrast mechanisms for prominent scattering from coherent sources (e.g., river channels, iceberg scours, surface erosional features, sub-surface strata called “R-reflectors”), and incoherent aggregates of compact scatterers (e.g., grave deposits, fish schools, gas pockets).

- Quantify and analyze the dispersive effect of the waveguide on charting of sub-bottom features. Data for this analysis is provided by receivers deployed close to or within the bottom sediment.

- Develop data acquisition, processing, and analysis software that produces results in near real-time for use with a newly-developed and recently field-tested ONR 5-Octave Research Array. Directing the course of the experiment “on the fly” is vital, since clutter from GAE 2001 was extremely dependent on bistatic geometry and location.

Full acoustic models are developed to optimize the design of and analyze data from experiments. They

- Predict the range, bearing, and level of prominent geoclutter,

- Determine seabed/water column sound speed/density profiles that make clutter more pronounced,

- Investigate the relationship between waveguide-induced dispersion of acoustic arrivals and the coherent-processing-gain of an active towed-array sonar system operating in shallow water.

WORK COMPLETED

The long range imaging of submerged objects, seafloor and sub-seafloor geomorphology in continental shelf waters using an active sonar system was explored experimentally and theoretically. The tasks completed and technical accomplishments include the following:

- A long-range bistatic sonar system, consisting of a horizontally towed receiving array and two low-frequency vertical source arrays, was deployed in GAE 2001 and used to image extensive networks of buried river channels and inclined sub-seafloor strata over tens of kilometers in near real time. This capability to rapidly map extended geomorphology over large spatial areas is of great advantage in geophysical applications.

- Wide area images acquired remotely during GAE 2001 identified the location and extent of previously unknown sub-bottom geomorphology, i.e., an organized network of strong, highly aspect-dependent returns appeared in a region where the sub-bottom had not yet been profiled. Subsequent geophysical surveys specifically designed to explore the sub-bottom in this area revealed a dense network of buried river channels at the location of these prominent features. These findings show that a low-frequency sonar system can be used to remotely image previously unknown sub-bottom features over wide areas in continental shelf waters in near real-time.

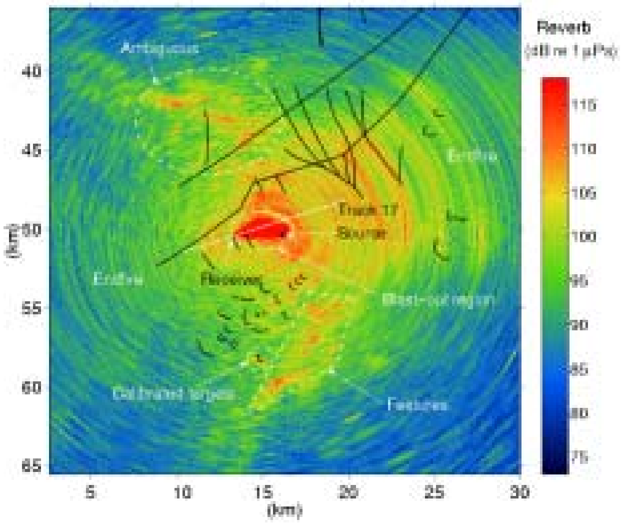
- During GAE 2001, roughly 3000 waveforms were transmitted, and roughly 10 to 100 discrete clutter events per ping were received on average. This gives a total of at least 30,000 clutter events that could be confused with a discrete target over the period of the experiment. All broadband signals have since been processed and analyzed to create "hotspot" consistency charts, which are derived from images of individual transmissions along each track and show the location of strong and persistent echo returns.

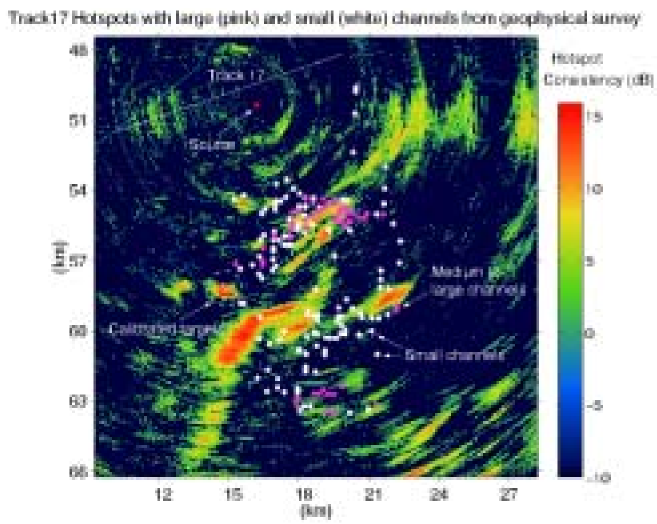
- Taking into account the coupling between propagation and scattering in a stratified medium, a unified model was developed for 3-D object scattering and reverberation. Simulations with the unified model indicate that the detection of submerged target echoes above diffuse seafloor reverberation is highly dependent upon waveguide properties, bandwidth, array aperture, measurement geometry, and the scattering properties of the target. This unified model was used extensively to guide the experimental design of GAE 2001. The effect of the sound speed profile is being investigated with simulation using the unified model. Similar models will be used to optimize the design of GAE 2003.

RESULTS

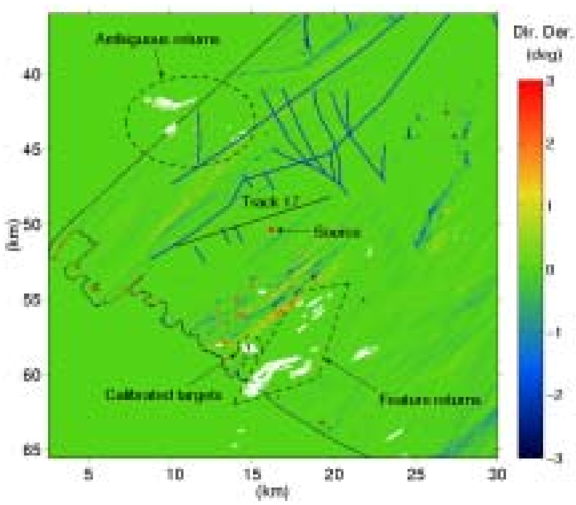
GAE 2001 used a long-range bistatic sonar system that rapidly imaged geomorphology over wide areas of the New Jersey continental shelf south of the Hudson Canyon. The candidate sources of prominent scattering include buried river channels, iceberg scours, surface erosion features, and seismically reflective subsurface strata called "R-reflectors". The vast majority of features imaged correspond to sub-bottom geomorphology that sound waves apparently reach after tunneling as well as propagating through the overlying sediment. Returns from buried river channels were often found to be as discrete and strong as those from calibrated targets placed in the water column. Since buried river channels are expected to be ubiquitous in continental shelf environments, sub-seafloor geomorphology will play a major role in producing ``false alarms" or clutter in long-range sonar systems that search for submerged objects such as underwater vehicles or marine mammals. One of the greatest challenges to active sonar operations in shallow water arises when echo returns from the intended target become indistinguishable from reverberation returned by the waveguide boundaries and volume. To study this problem, a unified model for submerged object scattering and reverberation was developed directly from Green's theorem. Analysis with the model showed that coherent scattering from smooth but finite segments of inclined sub-seafloor strata, corresponding to buried river channels, can produce returns that stand significantly above diffuse or incoherent returns arising from small-scale roughness from the waveguide boundaries.

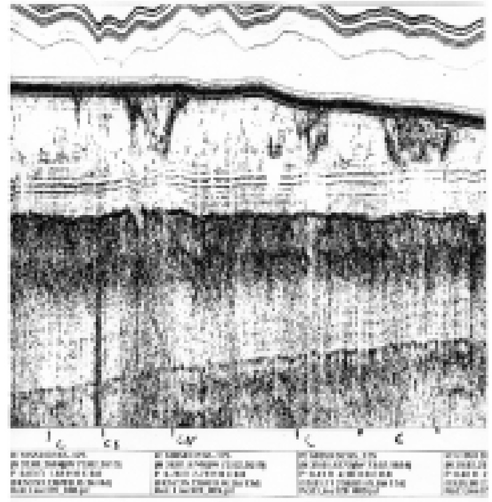
For every transmission, a wide area image of received sound pressure level as a function of horizontal position over tens of kilometers was generated. The bottom left figure shows a single bistatic transmission from site 2, illustrating the diffuse background reverberation level in decibels from the ocean environment, as well as strong scattered returns from geologic features and submerged objects. In order to measure the frequency of occurrence of a strong scattering event from a target or feature along a given track, hotspot consistency charts, like the lower-right figure, were generated for each track. These charts are used for clutter classification to distinguish consistent echoes from fluctuating ones, resolving right-left ambiguity inherent in horizontal line array data, providing significantly improved imaging of sub-bottom features compared to the individual reverberation images, and reducing charting errors due to waveguide dispersion.





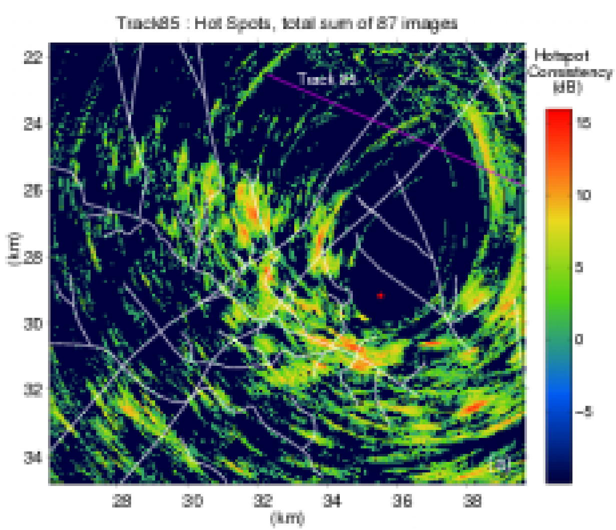
The Site 2 figures above illustrate an organized network of prominent and highly aspect-dependent scattering events in a region of flat bathymetry, where the sub-bottom had not yet been profiled. These scattering events (trapezoidal area above) were often more prominent than and just as discrete as the calibrated targets. Geophysical surveys, using a high-resolution sub-bottom profiler, revealed a dense network of buried river channels that rise up close to the seafloor at the location of the discrete scattering events. The above right figure illustrates the location of the buried river channels mapped by the geophysical survey, overlain onto the hotspot consistency chart from a single track at site 2.

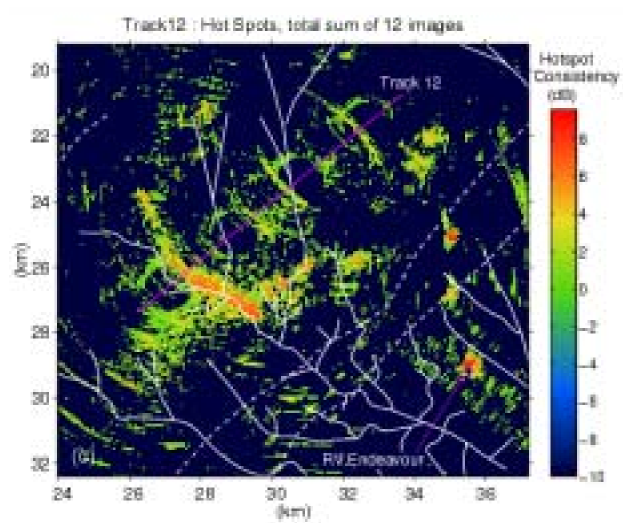




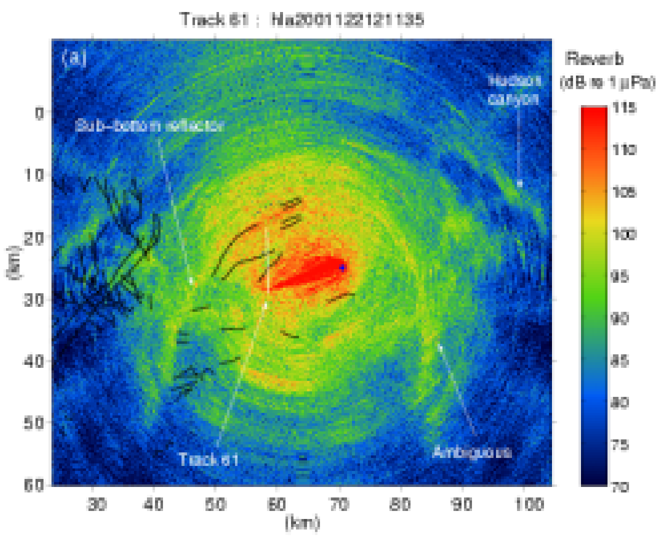
In the upper-left figure, these same prominent events are overlain in white on the directional derivative of the bathymetry. The upper right figure shows a deep-tow chirp profile of several buried river channels found in this area. The extent and distribution of the channels match the distribution observed for the clutter events in the top half of the trapezoid.

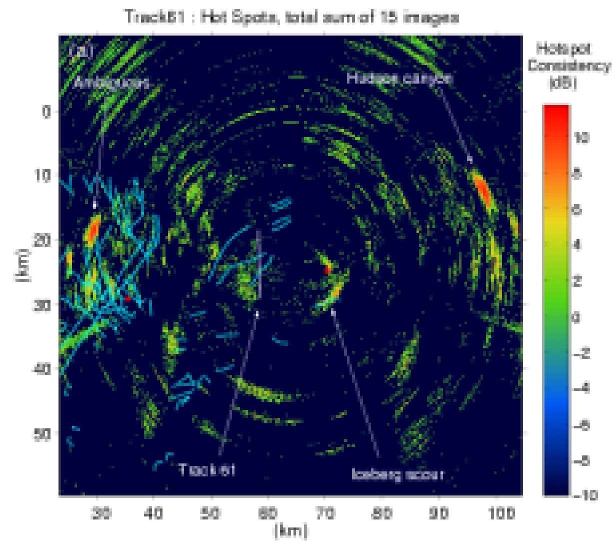
Site 1 had clutter features that scintillate or fade in or out along a track. “Glints” from walls of buried river channels originate from channel sections that are less deeply buried under the water-sediment interface, as shown in the hotspot consistency charts below. The less deeply buried river channels have higher amplitude incident waves, which lead to stronger scattered field as compared to the more deeply buried ones. Registrations with known channels also suggest that the occurrence and level of returns depend on bistatic orientation with the strongest and most frequent target-like returns coinciding with features that project the largest area in the direction of the source and receiver array.





Moderately strong, lineated returns from R-reflectors were imaged at sites 1 and 3 from long range (lower left figure), and consistently observed in regions where the R-reflector approached the water-seabed interface. Wide-area images provided more extensive mapping of the R-reflector surface expression than that available from geophysical surveys. Much stronger discrete features also appeared on those lineations, in regions where buried river channels crossed the near surface expression of the sub-bottom layer. Two prominent seafloor features were also imaged at site3 in the lower right figure, namely an iceberg scour (~2 km away) and the Hudson Canyon (>20 km away).





IMPACT/APPLICATIONS

Results from the Geoclutter Acoustic Experiment 2001 show that sub-bottom morphology is a primary cause of prominent target-like clutter in Continental Shelf Environments.

TRANSITIONS

Transition of Geoclutter Program results to direct Navy programs has already begun with data acquisition by the Hull-Mounted Sonar System of a US Destroyer in the STRATAFORM area. This experiment used the Destroyer's sonar to probe areas where clutter from sub-bottom origins were identified and characterized in the Geoclutter Program. Initial analysis shows that strong clutter returns were also found by the US Destroyer Sonar System from these areas.

RELATED PROJECTS

Some organizations involved with the Geoclutter Program are: UTIG, FAU, ARL-PSU, and NUWC.

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