

Mapping Clutter In Situ: Broadband Results from T-MAST 02 and Boundary 2004

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Abstract—This paper presents experimental results of applying two methods to help mitigate the seabed clutter problem by spatially isolating significant reverberant features in situ: 1) a “clutter mapping” technique applied to broadband (400 to 2500 Hz) acoustic data collected in the vicinity of the Stanton Banks off of Scotland during the T-MAST 02 experiment; and 2) the use of a cardioid receiver array on the Malta Plateau off of Sicily during the Boundary 2004 experiment. It is shown that while there are a number of correspondences between strong clutter events and the leading edges of known bathymetric features, there are also a number of clutter returns with no obvious corresponding bathymetric relief. The implications are that relying on archival bathymetric (and wreck) databases will in general be insufficient, and that in-situ reverberation assessments need to be conducted that yield not just the mean (intensity) characteristics, but also the statistics.

I. INTRODUCTION

Clutter often drives the performance of active sonars operating in littoral environments. Compounding this problem, in a given shallow-water environment sufficiently accurate information on the local environmental and man-made features that generate the acoustic clutter are rarely available. However, measurement techniques and tools can help remedy this situation by identifying and spatially-isolating discrete acoustic echoes in situ (e.g., [1]). To evaluate these acoustic methodologies in strongly range-dependent waveguides, the Naval Research Laboratory (NRL) designed broadband “clutter mapping” measurements that were conducted in two geologically complex, shallow-water environments with coherent sources and towed horizontal receiver arrays.

The first experiment was in July 2002 on the Outer Hebrides Platform (just west of the Stanton Banks) off of Scotland (Fig. 1) during The Technical Cooperation Program’s (TTCP’s) Multistatic Active Sonar Technology 2002 experiment (T-MAST 02), a collaboration between the United States, Canada and the United Kingdom (UK). In this experiment, a symmetry-breaking technique was used—first applied to reverberation data by Preston et al. [2]—where backscatter data are collected from multiple towed-array receiver orientations about a common point, and then averaged to both attenuate the ambiguous returns and improve scatterer resolution. A pair of measurements was made about a common centerpoint, one measurement covering 380–420 Hz, and the other simultaneously covering 950–1150 and 2300–2500 Hz.

The second experiment was in May 2004 on the Malta Plateau south of Sicily (Fig. 1) during the Boundary 2004 (B2004) experiment, the last in a series of acoustic boundary characterization experiments [3] made possible by a NATO joint research project, a collaboration between the Applied Research Laboratory of the Pennsylvania State University (ARL-PSU), Defense Research and Development Canada, Atlantic (DRDC-A), NRL, and the NATO Undersea Research Centre (NURC). In this experiment, a measurement tool was used in the geo-referencing process, a NURC cardioid receiver array that helps to resolve left-right ambiguity [4]. A set of measurements was performed using wideband (700–1700 Hz) signals, one on a linear track in a basin area and three on linear tracks along and over the nearby Ragusa Ridge.

In both experiments, the predominant clutter source was the seabed, with neither the sea surface nor fish generating any clutter of note. In B2004, additional sources of occasional clutter were of anthropogenic origin (such as wrecks) [4].

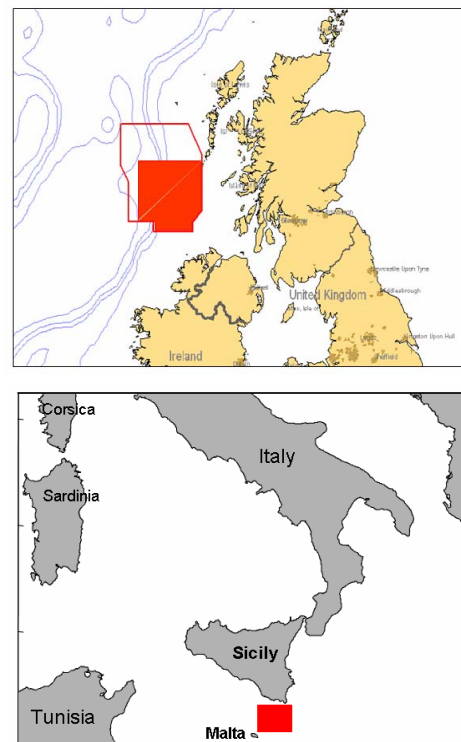


Fig. 1. T-MAST 02 (top) and B2004 (bottom) experimental sites (solid red)

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II. T-MAST 02 MULTIPLE-ORIENTATION RESULTS

A. Test Operations and Data Processing

The T-MAST 02 measurements consisted of short (8–14 min) sequences of temporally-shaded CW and hyperbolic frequency-modulated (HFM) signals transmitted about the cross points of four linear tracks with distinct towed-array receiver orientations. In this paper we only discuss the HFM results.

The first set of four measurements was conducted using the R/V *Oceanus* and the R/V *Knorr*. The R/V *Oceanus* acted as a stationary source ship, deploying a seven-element source array of uniformly spaced XF-4 transducers. The R/V *Knorr* executed the linear tracks towing at ~3.5 m/s ONR’s Five-Octave Research Array (FORA) receiver operated and deployed by ARL/PSU (with the FORA typically ~8 km ENE of the source). Both source and receiver were deployed at roughly mid-water depths. The source transmitted 4-s 380–420 Hz HFMs every 2 min for 8 min, so 4 pings per leg. A total of 12 pings were deemed suitable for averaging.

The second set of four measurements was conducted by the UK with the S/V *Bligh* executing linear tracks towing at ~2.5 m/s their ‘Woofer-Tweeter’ (WT) source and HF Large Aperture Receive Array (LARA) (cut for ~1.8 kHz) at ~70 m in a pseudo-monostatic geometry. The source simultaneously transmitted 4-s HFMs spanning 950–1150 and 2300–2500 Hz every 2 min for 14 min, so 7 pings in each band per leg. A total of 25 pings in each band were deemed suitable for averaging. The HF LARA array also includes a cardioid section. This paper only presents results from the linear section of the array; future papers will present the results from the cardioid section.

For both sets of data, the calibrated reverberation data were beamformed, match filtered, and energy normalized. The data displayed in this paper represent peak values over 0.25-s time windows that were then georeferenced. Finally, in each case the georeferenced results from the four tracks (with distinct array orientations) were averaged (to suppress the ambiguous beam contributions of each track).

B. Environmental Description

The T-MAST 02 area on the continental shelf west of Scotland is a complex area, with sediment types including mud, sand, gravel and bedrock, and strewn throughout with stones, pebbles, and rocks [5-6]. The main bathymetric features [6] are the Stanton Banks to the east of our centerpoints. As determined by echosounder surveys conducted during T-MAST 02, these features included a set of isolated, small-footprint pinnacle structures with steep slopes (~40 deg), rising well into the water column.

The oceanographic conditions were very well surveyed using CTDs, XBTs, thermistor chains, ADCPs, and directional waverider buoys. During these measurements, the surface conditions were relatively benign with low sea states. The sound-speed structure was downward refracting, with a

thermocline from the surface (~1504 m/s) down to 60-80 m (~1494 m/s), and isospeed below to the bottom.

C. Clutter Maps of the Area

Figs. 2-3 compare both calibrated (Fig. 2) and normalized (Fig. 3) georeferenced reverberation averages for each of the three frequency bands. The white ovals in each plot are the ‘blank out’ (receiver overload) regions of each track. It can be seen that the four tracks in each case did not actually pass through a common centerpoint, but were in general offset from one another. While the data from each ping are georeferenced, this common-point mismatch will lead to spatial smearing of individual features.

There are several ways one can average the data from different orientations. As discussed in Ref. [2], dB averaging is generally preferred as it both emphasizes persistent features and helps resolve left-right ambiguities. The other extreme is to pick the peak over all the orientations and do linear averaging. An example of the latter approach is shown in top images of Figs. 2 and 3—they should be contrasted with the corresponding dB-average images below. The most dramatic differences are seen in the calibrated images, illustrating that ping-to-ping SNR fluctuation of false-target returns should be expected, but that these fluctuations seem to be less of an issue with normalized data (important for threshold setting). In general, while dB averaging may underplay or miss an occasional feature, it is the more robust ‘stacking’ method.

In terms of reverberation decay (left plots), a spatial dependence can be seen only in the 380–420 Hz band, with stronger reverberation to the west and east, consistent both with the seabed being sandy gravel and the mild bathymetric drop-offs to the north and south of this extended gravel region that descends from the Stanton Banks to the east [6].

In all plots, there are a number of correspondences between strong clutter returns and the leading edges of known bathymetric features [6], with most of the significant features coming from rock outcrops of the Stanton Banks between 7.6–8.3W. While the strong returns seen east of 8.0 deg do not always map into specific features on bathymetric maps [6], they are not unexpected as they correspond to the vicinity of the Stanton Banks. There are still other clutter returns observed with no obvious corresponding bathymetric relief.

Interestingly, while in the calibrated reverberation maps (left), the presence of discrete environmentally-based echoes from the Stanton Banks sharply decreases with increasing acoustic frequency; in the normalized data (right) their presence often remained relatively steady. Future work will investigate this phenomenon using a high-fidelity reverberation model that accounts for differences in source characteristics (level, beam pattern), transmission loss, etc.

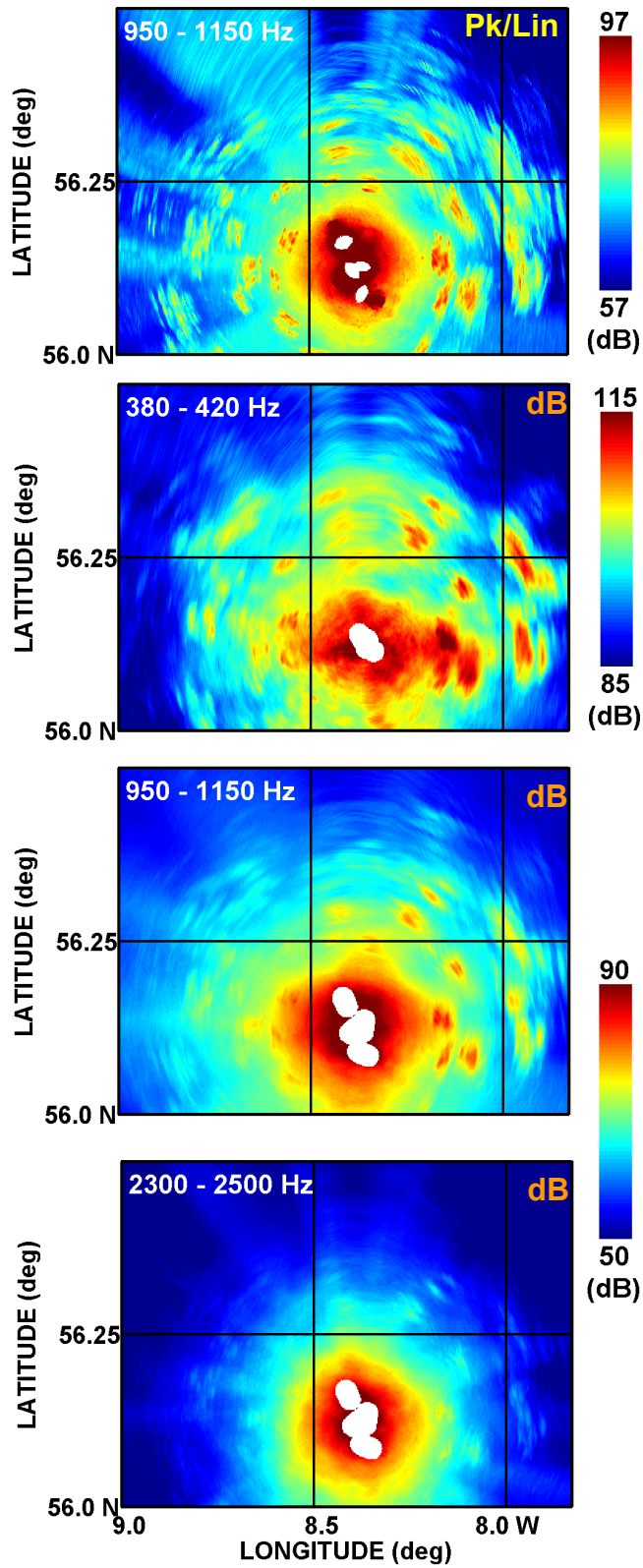


Fig. 2. T-MAST 02 calibrated reverberation mapping results: (top) peak and linear average over tracks; (bottom 3) dB averages over tracks

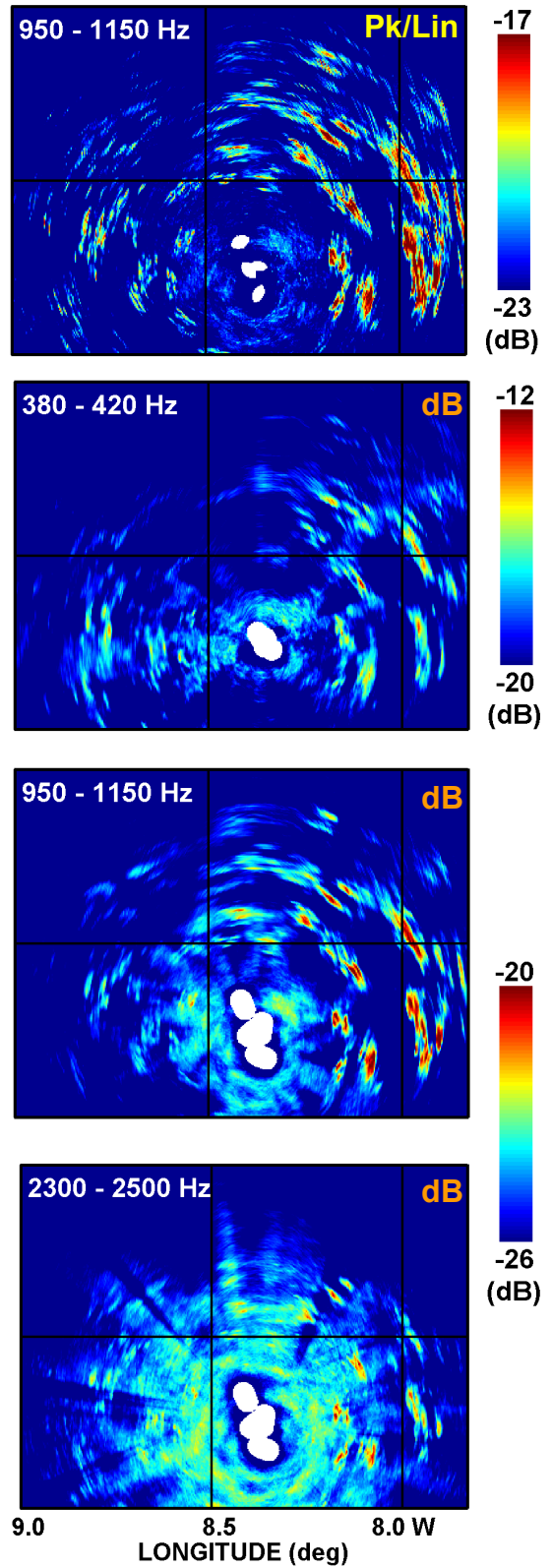


Fig. 3. T-MAST 02 normalized reverberation (clutter) mapping results: (top) peak and linear average over tracks; (bottom 3) dB averages over tracks

III. BOUNDARY 2004 CARDIOID-ARRAY RESULTS

D. Test Operations and Data Processing

The B2004 measurements were conducted with the NRV *Alliance* executing linear tracks, one in the basin, two on the western edge of the Ragusa Ridge, and one across the Ridge (Fig. 4). The NURC ship towed its LF Atlas source at 1.7 m/s at a depth of 30 m (Basin track) and at 2.2–2.6 m/s at depths of 60–65 m (Ridge tracks), and its cardioid receiver at depths of 60–65 m (all tracks). Transmissions consisted of temporally-shaded, 1.5-s, 700–1700 Hz linear-frequency-modulated (LFM) signals, with rep rates of 5 min (Basin track), 7 min (north-to-south Ridge-edge track), and 2 min (south-to-north Ridge-edge and cross-Ridge tracks).

The receiver data were beamformed, match filtered, energy normalized, and georeferenced. The data displayed in this paper represent peak correlation values in non-overlapping 100-by-100-m lat-long grid cells. The data from the ~25-km-long Basin track were processed in 9 overlapping 7-ping segments, with composite clutter maps then generated from these 9 segments. The composite Ridge maps were generated from the south-to-north-Ridge-edge and cross-Ridge tracks.

E. Environmental Description

Overviews of the B2004 area that include bathymetry, geology, and man-made scatterers are given in Refs. [3-4].

During the measurements described here, the oceanographic conditions were very well surveyed with XBTs, CTDs, and directional wave buoys. In addition to towing a source and receiver, the NRV *Alliance* also towed a thermistor chain during the Basin track and a 120-kHz Simrad EY-500 fish sonar on the Ridge tracks (where occasional demersal fish schools were seen). Separate runs to characterize the local seabed were made along each track by the NRV *Alliance* towing its chirp and sidescan sonars.

During these measurements, the surface conditions were relatively benign with low sea states. The sound-speed structure was downward refracting. On the Basin track, it was isospeed from the surface (1515–1516 m/s) down to ~35 m, a thermocline to 50–55 m (1511 m/s), and then roughly isospeed (1511–1512 m/s) below to the bottom (1512 m/s). On the Ridge tracks, it had one thermocline from the surface (~1520 m/s) down to ~20 m (~1516 m/s), isospeed to 35–40 m, a second thermocline to ~50 m (1511 m/s), and then roughly isospeed (1511–1512 m/s) below to the bottom (1512 m/s).

F. Clutter Maps of the Area

Fig. 4 presents normalized correlator output for the Basin track and Ridge, along with a map of the corresponding bathymetry (courtesy of NURC), with a few man-made features (crosses) and ship tracks (lines) in gray. The concentric circles apparent in both data images, but especially on the Ridge where there are a number of strong scatterers on all sides of the array, are due to acoustic energy coming in through the sidelobes (grating lobes) of the cardioid array.

In the upper left of both data images, echoes from the Campo Vega oil platform and buffer ship can be seen. In the

Basin image, the outline of the western edge of the Ragusa Ridge can be clearly seen. As reported in Ref. [4] and suggested as due to a change in sediment type, an area of distinctive returns bounded by ~36.3–36.5N and ~14.7–14.85E on the western rise to the Ridge is apparent in the Basin image. The corresponding region in the Ridge plot is not as apparent, presumably due to upslope (Basin track)/downslope (Ridge-edge track) propagation differences. As expected, the Ridge plot displays many returns from the rocky outcrops atop the Ridge, as well as returns from a BBN air-hose reflector (not deployed during the Basin track) near 14.73N, 35.51E.

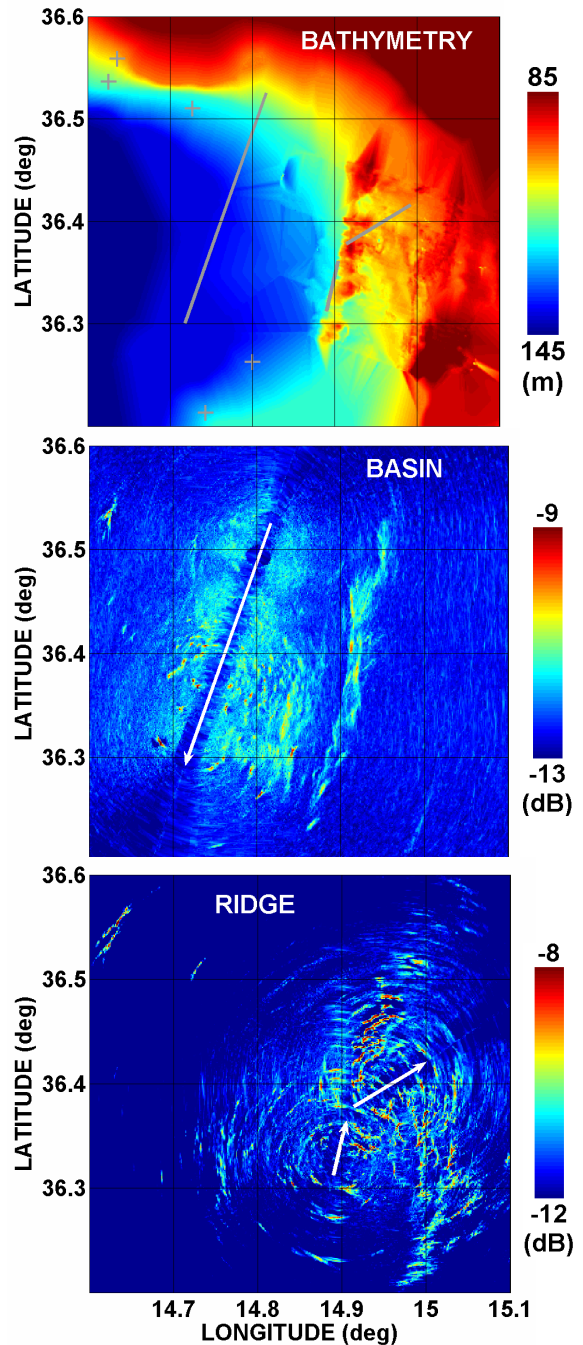


Fig. 4. Bathymetry (top) and B2004 normalized reverberation (clutter) mapping results from the Basin (middle) and Ridge (bottom) tracks

For any active sonar, the number of threshold exceedances determines the number of false alarms. There are a number of methods one can use to identify the more significant returns. In Figs. 5-6, clutter persistence over multiple pings is used. For these plots, for each ping mean values (μ) were first calculated by linear averaging all georeferenced samples (in beam + time/range) and then the peak correlation value in each 100-by-100-m grid cell was compared to the mean plus 5, 6 or 7 dB. If a peak value exceeded the given threshold it was assigned a one, otherwise a zero. This was done for each group of 7 pings, so that a lat-long cell would then have a value ranging between 0 and 7. Finally, the peak over all groups was calculated for each cell, again a value between 0 and 7. Figs. 5-6 have a 2-color scale: each lat-long cell has a blue dot if 43% or more pings exceed the given threshold, and a red dot if 86% or more pings exceed the given threshold.

As Figs. 5-6 show, clutter in this region can be quite sensitive to the threshold value. For the Basin track especially, much of the diffuse clutter disappears as the threshold is increased by 1 dB. In all cases, tracking clutter persistence may provide an avenue for reducing the number of false alarms as the number of red dots is quite small compared to the number of blue dots. That the persistence is often not strong could be due to anisotropy of the scatterers. This is to be expected with bathymetric features and man-made structures such as wrecks. Another factor not studied in this paper is the effect of sound propagation. This could be especially important up on the Ridge where, e.g., one rock outcrop could either partially or completely shield returns from another depending on source-receiver position. (There is also a possibility of occasional discrete returns from demersal fish schools observed on the Ridge.)

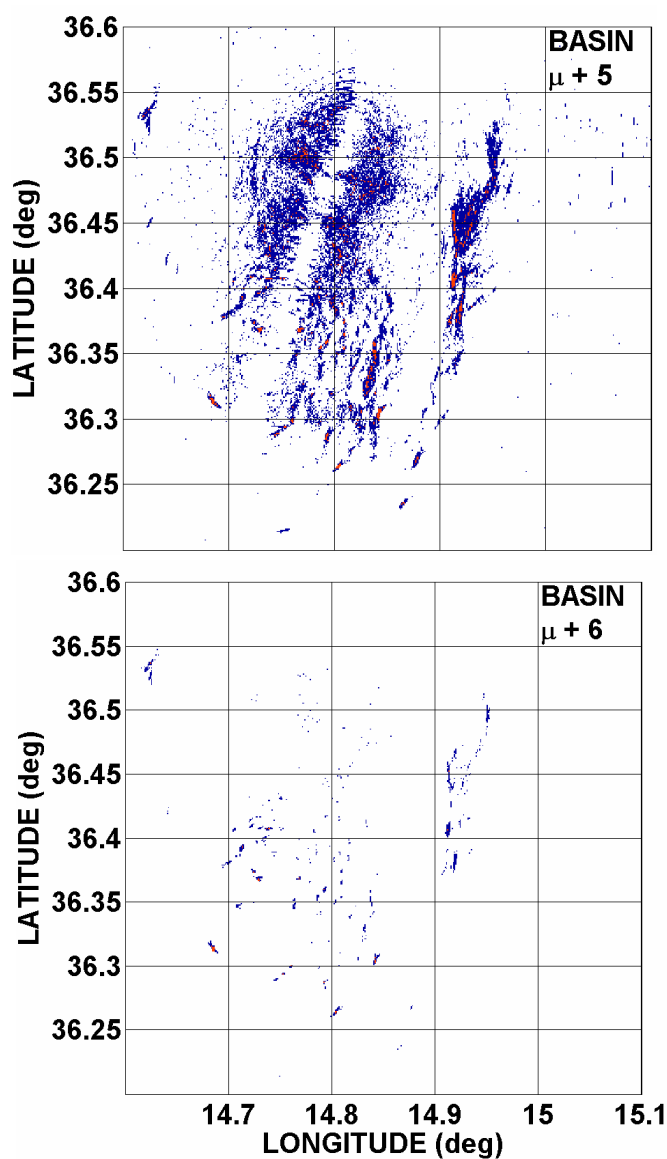


Fig. 5. Composite B2004 threshold exceedances from the Basin track pings

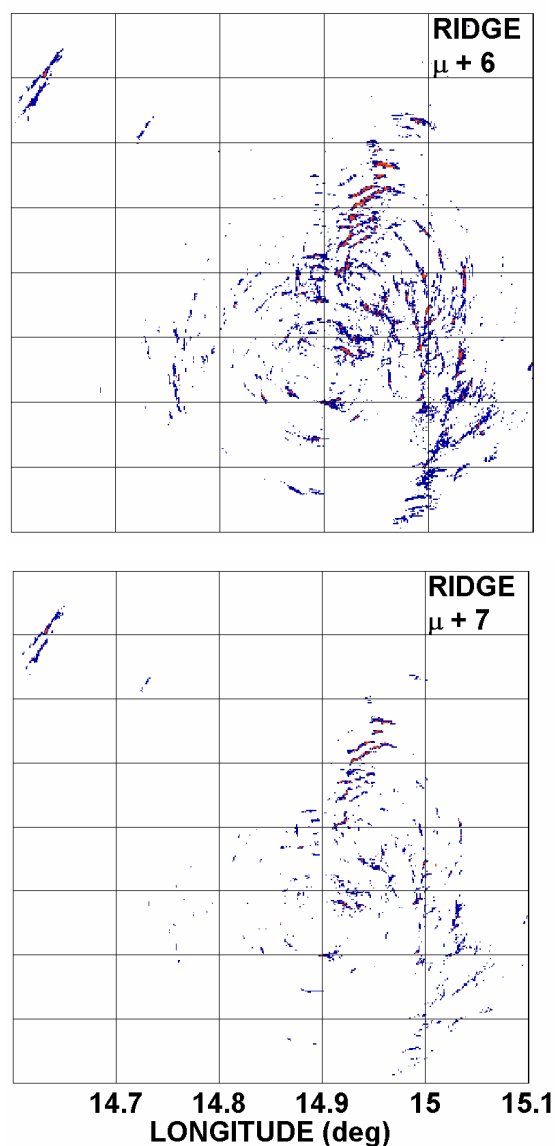


Fig. 6. Composite B2004 threshold exceedances from the south-north Ridge-edge track and cross-Ridge track pings

Fig. 7 presents blow-ups of normalized correlator output from the Ridge as acoustically viewed from the cross-Ridge track (top) and from north-to-south down-Ridge-edge track (bottom), overlain with bathymetric contours (depths 84-90 m, white in 2-m steps; 90-98 m, light gray in 3-m steps; 100-106 m, dark gray in 3-m steps; and 108-114 m, black in 6-m steps).

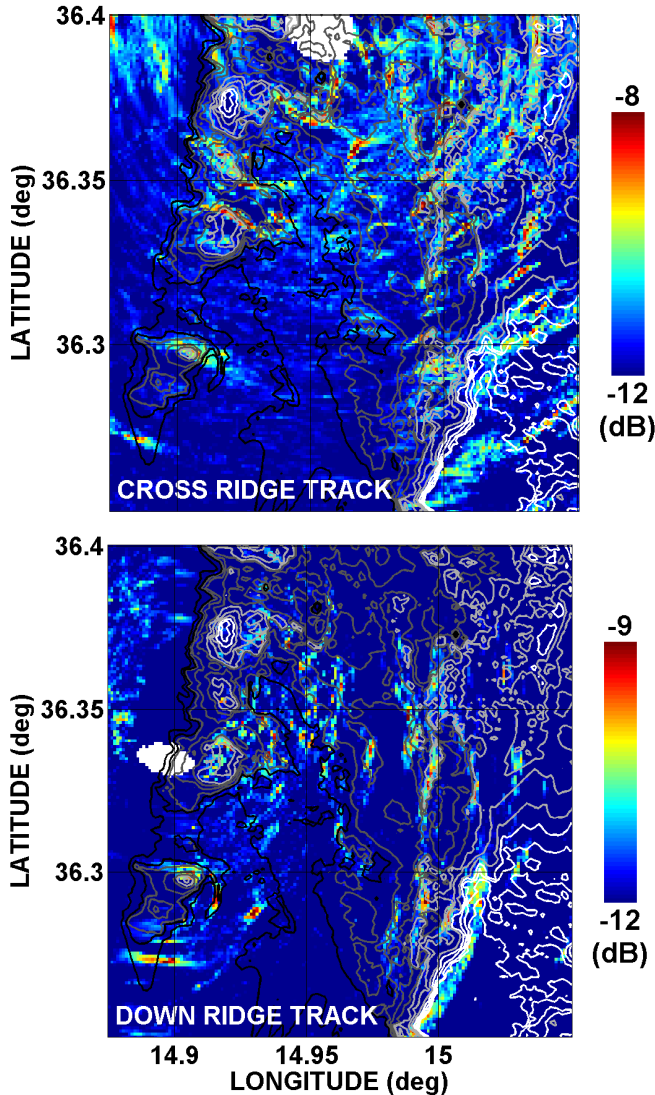


Fig. 7. B2004 high-resolution clutter plots with bathymetric overlays from the cross-Ridge track (top) and from the north-to-south Ridge-edge track (bottom). (White ovals are blank-out regions.)

As expected, a common observation is the strong returns coming from the leading edge of bathymetric features, in each case from the side of the feature facing the source/receiver. Also notable is that some returns do not have obvious corresponding bathymetric relief.

IV. DISCUSSION

We conclude with the recommendations that: 1) in-situ symmetry-breaking reverberation assessments be routinely conducted in shallow waters; and 2) these measurements be broadband to help isolate the physical mechanisms (topography, wrecks, biologics, sediment heterogeneities, bubble clouds) responsible for the observed clutter. Then, through the use of high-fidelity range-dependent reverberation models, this in-situ knowledge can be used to minimize the impact of clutter such as by repositioning assets or selecting alternate waveforms.

Future work will include processing/analyzing the LARA cardioid data from T-MAST 02 which will combine and contrast the two methodologies discussed here: averaging over multiple orientations and using a left-right ambiguity-breaking tool.

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