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IMPACT OF SEAFLOOR AND WATER COLUMN PARAMETER VARIATIONS ON SIGNAL-TO-BACKGROUND RATIO ESTIMATES - A SENSITIVITY ANALYSIS BASED ON SONAR PERFORMANCE MODELING.

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Abstract: *Regardless of how accurate modeling can be, if the set of assumptions made with regard to the propagation conditions are not precise, sonar performance predictions diverge from the corresponding measured values. Here a model-based sensitivity study of key environmental parameters is performed to generate an input parameter "priority list" and eventually provide feedback on the required accuracy of each parameter to maintain detection performance predictions within certain confidence limits. Using sonar performance simulations, we investigate the sensitivity of Signal-to-Background Ratio to compressional-wave speed in the seafloor, bottom attenuation, seafloor density and sound velocity in the water column. Additional temporal and spatial variability results regarding continuous sound velocity estimates obtained during sea experiments are presented.*

1. INTRODUCTION

A key feature of the Broadband Environmentally Adaptive Concept introduced at the NATO Undersea Research Centre (NURC) is the incorporation of sonar performance modeling in a feedback mechanism for sonar parameter optimization in a given environment. The sonar performance model developed for this task is called SUPREMO [1]. Our goal is to use this simulation tool to examine how key environmental parameters, such as compressional-wave speed in the sediment, bottom attenuation, sediment density and sound velocity profile, affect the signal-to-background ratio (SBR) in active detection scenarios. Ultimately, this could provide feedback on the required accuracy of each parameter to maintain detection performance predictions within certain confidence limits.

In SUPREMO, signal-to-background ratio (SBR) estimates are obtained for each point in space by assuming a grid of uniformly distributed targets in time-bearing space. By defining omnidirectional target strength equal to zero, the SBR coincides to signal excel (SE) with detection threshold equal to zero [2].

For this study, the Gamaray ray tracing model [3] is selected for propagation loss estimates due to its computational efficiency. The simulated range-independent environment is a simplified representation of the Malta Plateau, an area between Sicily and Malta, visited many times during NURC experiments. The acoustic channel boundaries are modelled as pressure release sea surface and infinite half-space seafloor, allowing transmission across the water-bottom interface and thereby introducing an additional loss mechanism to the waveguide propagation. The seafloor is modeled as a fluid, i.e., it supports only compressional wave types and is defined in terms of compressional speed c_p [m/s], density ρ [gr/cm^3] and compressional wave attenuation α [dB/λ]. The monostatic scenario modelled here assumes source, line array receiver and target depth of 70m. The used pulses have bandwidth of 1 kHz. The sensitivity analysis is concerned with the effect the above-mentioned bottom parameters, i.e., c_p, ρ, and α, in conjunction with variations of sound velocity profiles (SVP), have on SBR. Additional SBR sensitivity results based on real SVP's acquired using the Instrumented Tow Cable (ITC) [4] during the BASE'04 experiment are presented.

2. SBR AS A FUNCTION OF COMPRESSIONAL WAVE SPEED AND BOTTOM DENSITY AT A FIXED TARGET RANGE

It is shown that compressional wave speed c_p [m/s] and density ρ [gr/cm^3] are not independent parameters. An analytical relationship between density and sound speed was obtained from a large number of seabed samples by means of a regression curve fitted to a scatter plot of the density/sound-speed pairs [5]:

$$c_p = 2104.2 - 1029\rho + 455\rho^2 \tag{1}$$

We use this formula to avoid unrealistic combinations of these two parameters which vary as follows: compressional sound speed from 1422m/s to 2890m/ (±100m/s around the baseline c_p values) and bottom density from 1 to 2.8gr/cm^3 with 0.05gr/cm^3 steps.

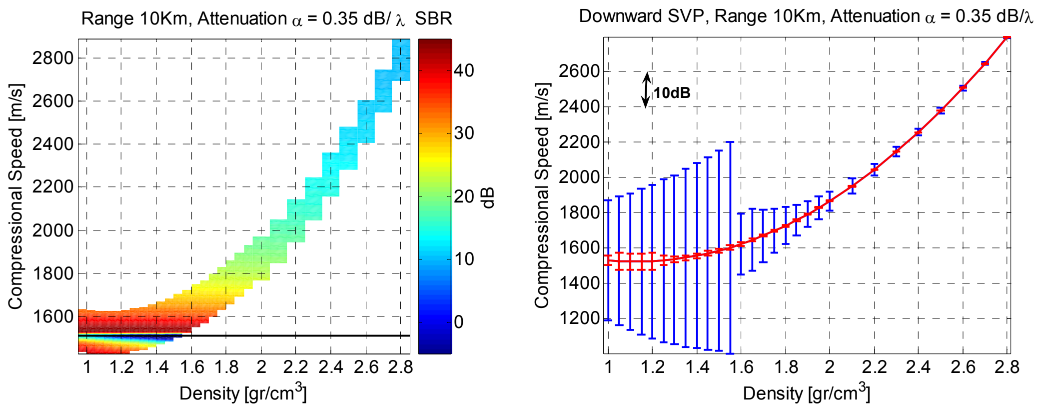

Fig.2: Left: SBR estimates as function of compressional speed and sediment density. Right: SBR variability with respect to compressional speed (blue bars) and density (red bars).

The left plot in figure 2 shows SBR values as a function of c_p and ρ for a fixed attenuation α=0.35 dB/λ. The water speed at the water-seafloor interface is 1514 m/s (indicated by the straight line). The right plot in figure 2 demonstrates the variability of SBR with respect to varying compressional speed (blue bars) and density (red bars). As expected, for hard sediments that favor reverberation through seafloor interaction, SBR magnitude and SBR variability are significantly inferior to "soft", low speed bottom types.

The particularly high SBR variability for "soft" sediments is due to the low acoustic impedance mismatch, which implies similar speed/density combinations at the sea-bottom interface. In this case, most of the incident energy penetrates into the seafloor and therefore reverberation becomes insignificant, leaving ambient noise as the dominant background interference factor. These results are obtained at an arbitrary distance of 10 km from the target. As shown in Figure 3, SBR estimates are range dependent, not only due to propagation effects that manifest themselves as alternating high-low SBR zones due to converging and diverging energy interference patterns, but also due to the ambient noise effect toward "softer" bottom types.

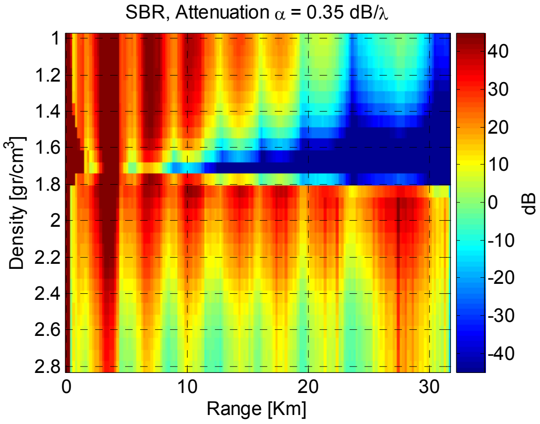

Fig. 3: SBR variability as a function of density versus range (the compressional speed values are calculated from formula (1)).

3. SBR AS A FUNCTION OF ATTENUATION

Contrary to the physical link between compressional wave speed and bottom density, wave attenuation is independent of these two parameters [6]. For indicative values of clay (c_p =1500 *m/s*, ρ=1.5) and silt (c_p=1575 *m/s*, ρ=1.7) the corresponding attenuation is α =0.2 dB/λ and α =1.0 dB/λ, respectively. Wave attenuation is given in dB per wavelength indicating that the attenuation increases linearly with frequency. Figure 4 shows the SBR vs. attenuation for the baseline combinations of compressional wave speed and bottom density (only density values are referenced). With increasing bottom attenuation more energy is absorbed by the seafloor, which results in reduced background interference and therefore increased SBR. The higher the bottom density is with respect to water, the more evident this effect becomes. The only irregularity in this pattern refers to bottom attenuation less than 1.4gr/cm^3 that corresponds to the compressional speed and density regime dominated by ambient noise.

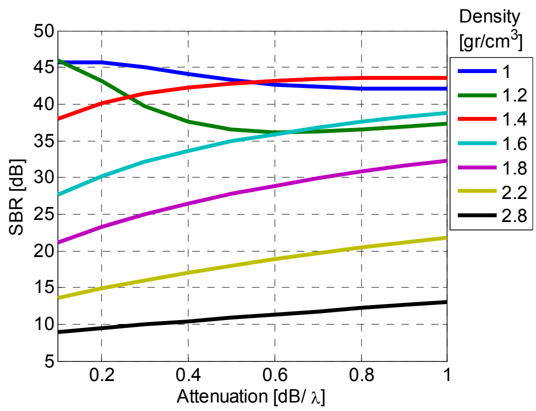

Fig.4: SBR as a function of attenuation for different values of density and sound speed pairs, as calculated from formula (1).

4. SBR AS A FUNCTION OF SOUND VELOCITY PROFILE TYPE (DOWNWARD, ISOVELOCITY, AND UPWARD REFRACTING)

The effect of bottom parameters on SONAR performance depends on the amount of interaction of sound with the seafloor. For fixed source, receiver and target positions, this interaction is mainly controlled by the sound velocity profile (SVP). The results obtained so far were based on a downward refracting profile which favours significant interaction with the seafloor. Here we compare the sensitivity of SBR to bottom parameters for three types of SVP's, i.e. downward, isovelocity and upward refracting.

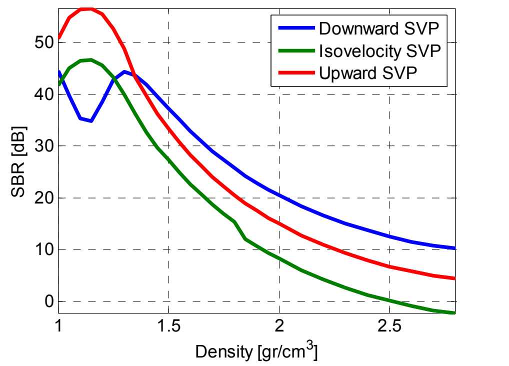

Fig.5: SBR at a fixed range as a function of bottom density and for three types of SVP (upward refracting, isovelocity and downward refracting). Results obtained for 10 km range.

As expected, isovelocity and upward refracting SVP's reduce the lower boundary interaction and therefore reduce energy absorption at the seafloor. This implies higher SBR values (and SBR variability) for "soft" sediments as shown in figure 5. With rare exceptions, this appears to be a general trend for soft sediments. On the contrary, for "hard" sediments there is no such trend. For these bottom types, the effect of SVP on SBR is reduced and SBR values are dominated by the combination of sound propagation patterns with respect to the geometry of the experiment. The example in figure 5 shows a case in which at 10 km, for $\rho > 1.4$, the downward refracting profile offers higher SBR's than the other two.

5. SBR VARIABILITY DUE TO CONTINUOUS SVP MEASUREMENTS OBTAINED USING THE ITC DURING BASE '04.

The ITC-Lite is a towed, distributed fiber optic sensor able to measure the temperature of the upper layer of the water column in real time [4]. Typically, a new measurement can be made every 3 minutes with an error of $\pm 0.5°C$. The ITC cable was used in the BASE '04 sea trial providing continuous temperature profiles for a dynamic environmental characterization. ITC measurements were successfully tested against XBT drop measurements.

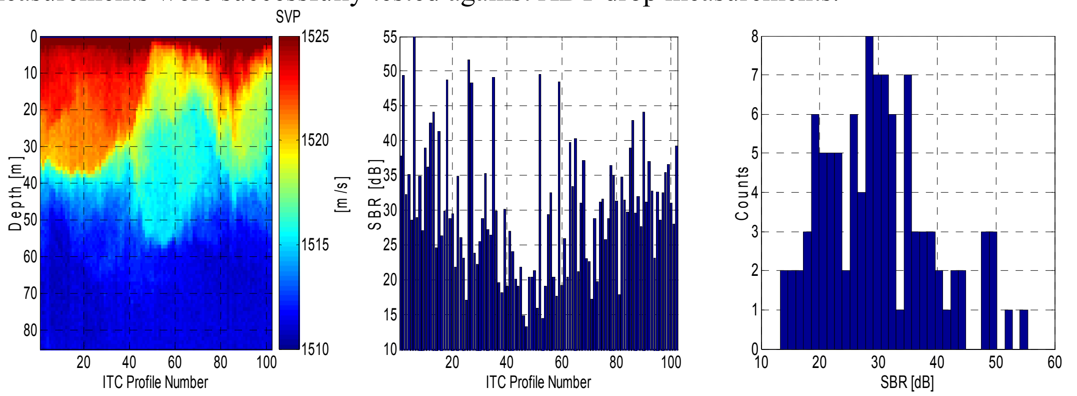

Figure 6: Effects of SVP temporal and spatial variability on SBR. The significant variations in the sound velocity profiles (left) are reflected in SBR fluctuations (middle) having standard deviation of 9 dB (right). Results include part of the track with significant bathymetric changes.

Figure 6 shows ITC measurements obtained during run B18 in BASE '04 and their effect on SBR measurements. The left plot shows 100 SVP's calculated using the Mackenzie formula [7] from ITC temperature measurements and salinity 38.1 ppt. The track was 15 nm long (the duration of the run was approximately 3 hours). The middle plot indicates the SBR calculations for every SVP and the right plot is a histogram of the SBR values with mean 30 dB and standard deviation 9 dB. It is worth mentioning that, in real life scenarios, a track of that length could be characterized only by a limited number of SVP's, e.g. one or two measurements per hour.

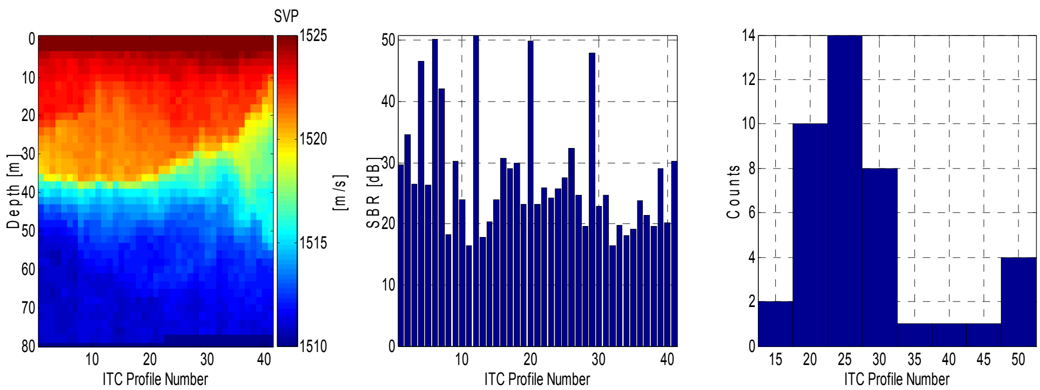

Figure 7: Same as in Fig. 6 only for the range-independent part of the track.

The results shown in figure 6, besides the variability in SVP, include significant bathymetric changes that affect considerably the propagation pattern and therefore SBR calculations. Figure 7 shows a similar analysis concentrating only at the first part of the run that was characterized by very small water depth changes. Here the mean SBR estimate is 27 dB and the standard deviation 9 dB. Although the mean value is reduced, the standard deviation remains the same, something that underlines the importance of this type environmental information both in case of range dependent and range independent environments.

6. CONCLUSIONS

The sensitivity of SBR to compressional-wave speed in the seafloor, bottom attenuation, seafloor density and sound velocity in the water column is examined using the SUPREMO sonar performance model. It was found that the compressional speed, together with the sound velocity profiles, are the two leading factors that influence SBR estimates. The necessity of dense temperature/velocity sampling of the water column has been demonstrated (both in range dependent and range independent environments) using real data obtained from the ITC cable during the BASE '04 experiment. In general, a sonar performance modeling capability, such as the SUPREMO which is used here, is very useful for an initial assessment of the environmental impact on sonar performance and, together with in situ measurement comparisons, may be utilized to provide feedback on where sonar performance is likely to be challenged.

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