Sensitivity Analysis for QPE Pilot Study – Draft 1

Kevin Heaney
OASIS Inc.
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Abstract

In preparation for the QPE pilot study, a set of PE model simulations were computed examining the sensitivity of TL to bathymetry, geo-acoustics, source/receiver location, and (not in DRAFT 1) sound speed. Four sediment types were used: sand, sandy-mud, silty-clay and a hybrid. The sound speed field was taken from the Climatological mean at the shelf break. Bathymetry was taken for 5 tracks (along-shelf, cross-shelf, canyon) provided by UNH. The conclusions so far are that TL is dominated first by bathymetry, then by geo-acoustics (sound speed not being done yet). For the along-shelf runs, source/receiver geometries do not affect TL. For the cross-shelf and canyon runs, significant mode-stripping and downslope propagation leads to strong sensitivities to direction of propagation.

Introduction

In early September the QPE program will be conducting a Pilot Cruise on the continental slope just north-east of Taiwan. The goal of this work is to determine initial (*a-priori*) sensitivities to environmental parameters to facilitate the determination of measurement geometries that help flush out the environmental uncertainty in the area. The PE was run for 300, 600, 900 Hz with a 65 m source for each of 7 bathymetric slices (candidate OMAS tracks). Each track was run forward and in the reverse direction to examine affect of source/receiver orientation. Each track was run over all of the sediments involved.

Geo-acoustics and sound speed

For the initial analysis, three sediment types were considered. Charles Holland (PSU) provided these. The three sediment types, including the half-space basement below are:

	Cp	Rho	Attn
Sand	1650	1.9	0.8
Sandy-mud	1575	1.7	1.0
Silty-clay	1460*	1.4	0.03
Basement	1800	2.0	0.5

The Silty-clay was modeled with a interface sound speed ratio of 0.98, meaning the compressional speed in the sediment was computed to be 0.98 times the water speed at the interface (for the source position). The sediments were modeled in two ways: iso-speed and homongenous unconsolidated sediment using Hamilton-Bachman parameterization. The sediment thickness was 12m. For the cases including deep water (cross-slope and canyon) a hybrid sediment model was computed in addition to the 3 geo-acoustic classes. The hybrid was a range-dependent geo-acoustic model with the following parameterization:

Shallow water	Z<200m	Sand
Shelf break	200m<Z<350m	Sandy-mud
Continental Slope	Z>350m	Silty-clay

For this first pass, a single downward refracting sound speed field was used. It was provided by Glen Gawarkiewicz (WHOI) and is taken from the Climatological mean in the East China Sea (in 400m of water). Further work will include spatial dependence from model results produced by Pierre Lermusiaux (MIT). The sound speed profile, sediment properties and reflection coefficients for Sand are shown in Fig. 1:

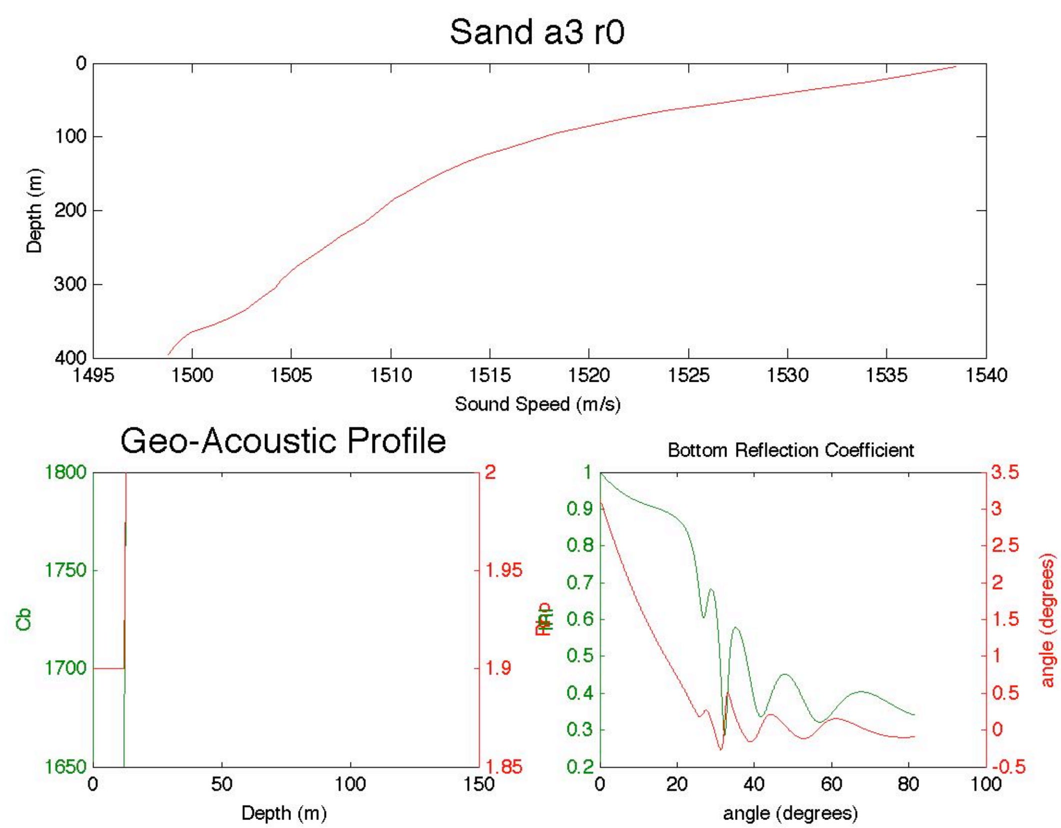

Figure 1. Sound speed profile (range independent), geo-acoustic profile (Cp, density) and reflection coefficient for Sand.

With a sound speed in the sediment of 1650 m/s, and a bottom water sound speed of 1498 m/s, the empirical critical angle is 24 degrees, which is consistent with the reflection coefficient.

The sediment properties and reflection coefficients for Sandy-mud and Silty clay are shown in Fig. 2-3.

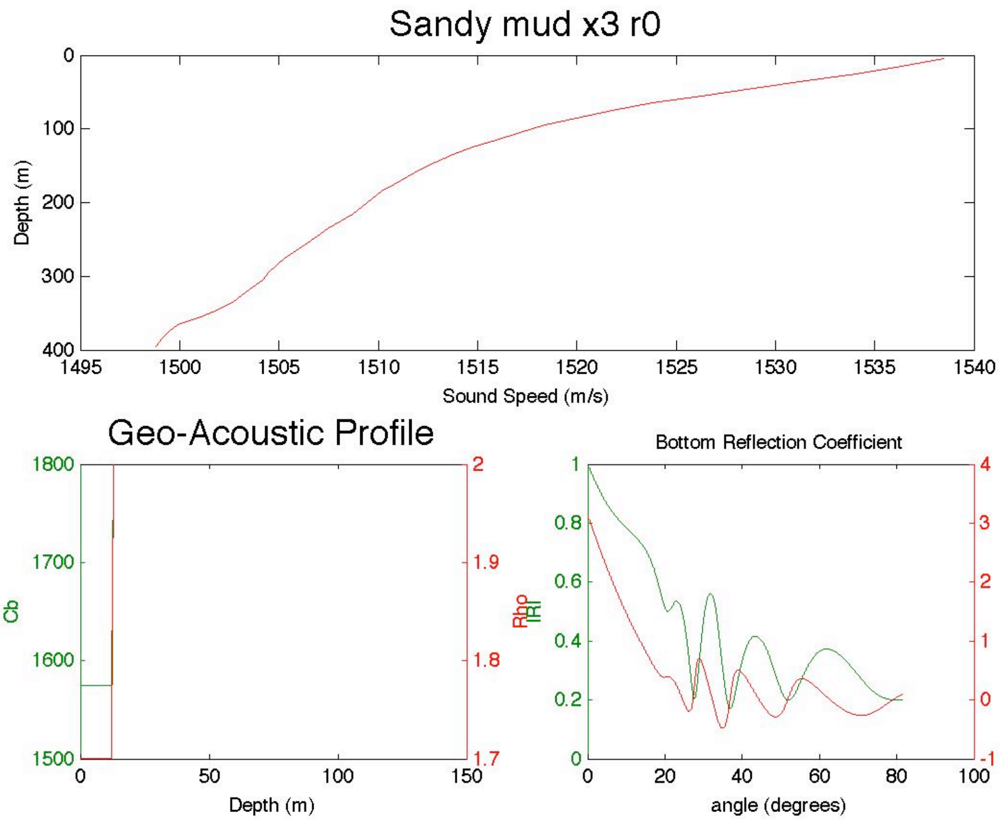

Figure 2. Sound speed profile (range independent), geo-acoustic profile (Cp, density) and reflection coefficient for Sandy-mud.

With a 1575 m/s compressional sound speed, the critical angle is on the order of 18 degrees.

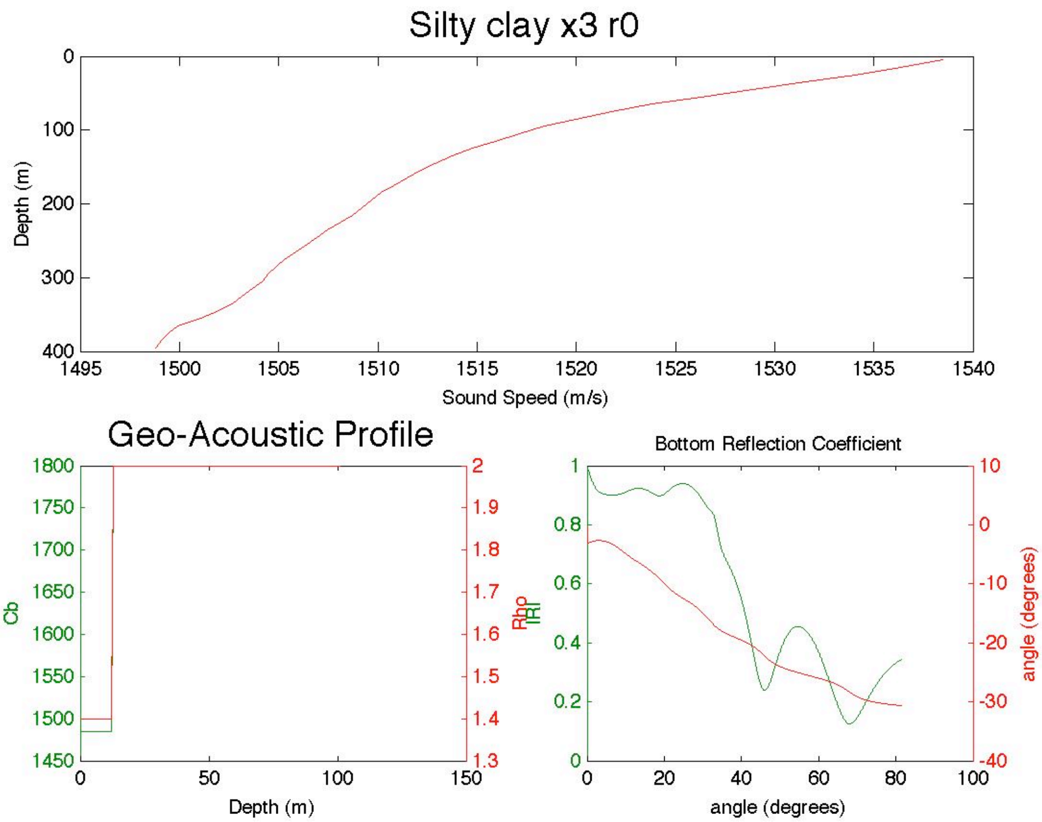

Figure 3. Sound speed profile (range independent), geo-acoustic profile (Cp, density) and reflection coefficient for Silty-clay

The propagation for silty-clay is sub-critical, so the effective critical angle is driven by the basement, which is 1800 m/s. The effective critical angle is on the order of 34 degrees. Although the critical angle is high, the attenuation for low-angle energy is high so this sediment will be lossy.

For comparison, the Hamilton parameterization for Silty-clay is shown in Fig. 4.

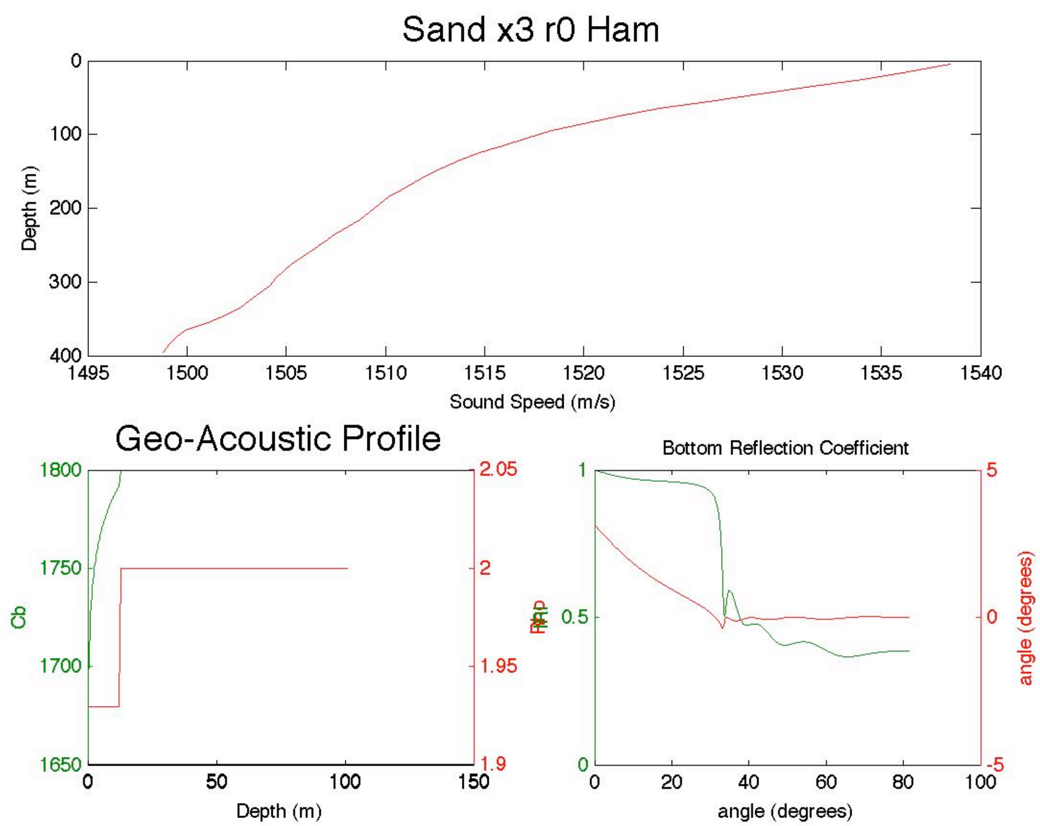

Figure 4. Sound speed profile (range independent), geo-acoustic profile (Cp, density) and reflection coefficient for Sand using the Hamilton parameterization

The strong gradient of the compressional speed with depth leads to an effectively very strong sediment.

Along Shelf Results

Results for 2 along-shelf runs will be presented (a2 and a3). The first result shown is along the 120m isobath (run a3 from Art's bathy profiles). The path is shown, overlaid on the UNH Bathy in Fig. 5 and the TL is shown in Fig. 6.

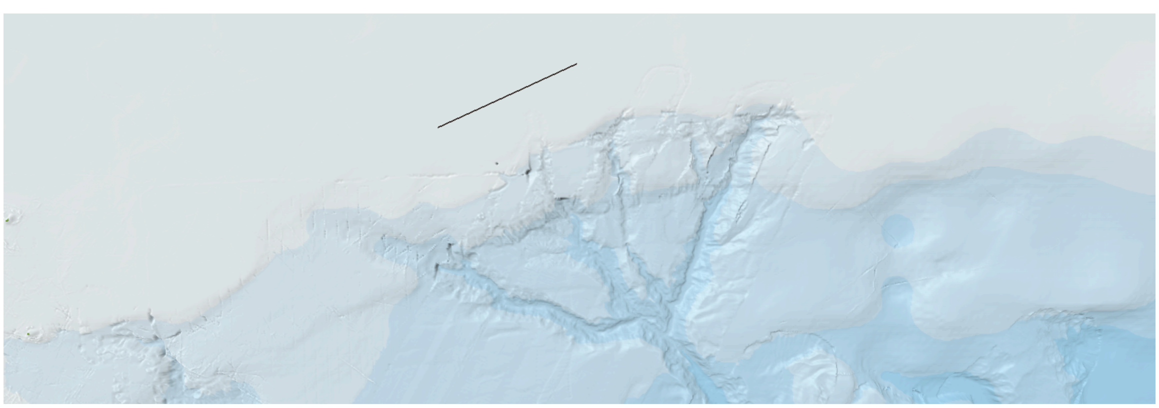

Figure 5. Along shelf run along the 120m isobath.

The Transmission Loss as a function of range and depth for 300, 600 and 900 Hz is shown in Fig. 6.

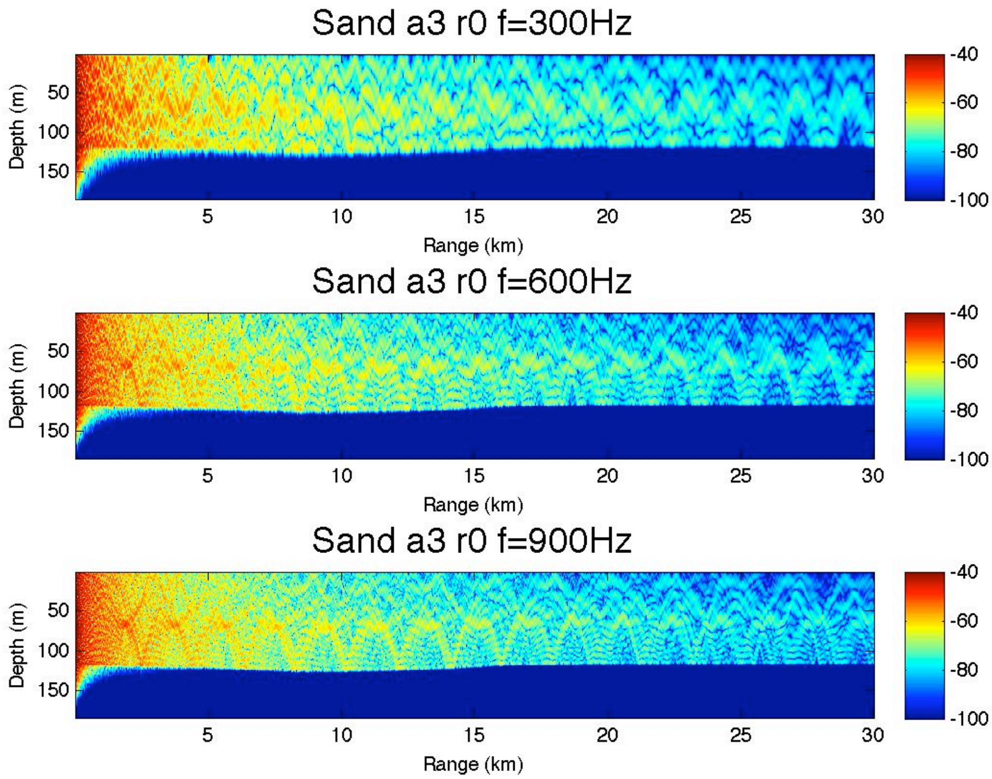

Figure 6. TL for 300 Hz, 600 Hz and 900 Hz for the Sand Bottom along the 120m isobath.

The bathymetry for this path is so smooth (it is NOT flat) on this scale that the reverse orientation results will not be shown. They are effectively identical. Apart from the change in spatial scales of peaks and valleys in the TL, there is little frequency dependence. It is not expected with this sound speed profile that there will be very much source depth dependence. The TL for the Sandy-mud sediment is shown in Fig. 7.

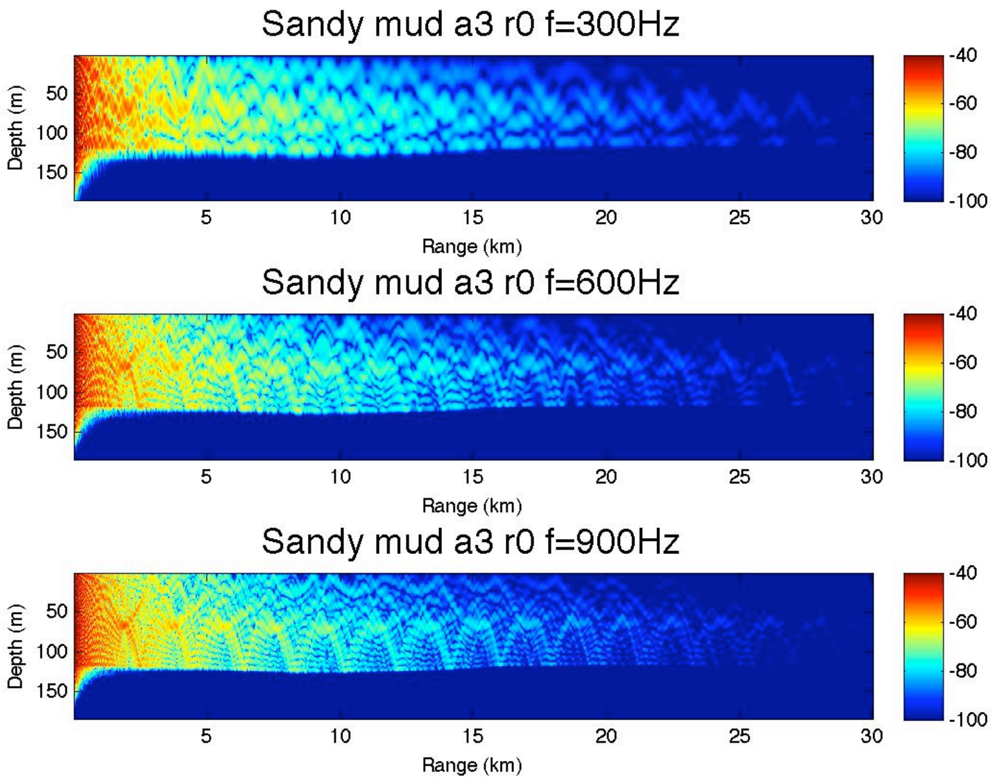

Figure 7. Sound speed profile (range independent), geo-acoustic profile (Cp, density) and reflection coefficient for Sand.

The effect of the softer sediment is clear, as is the change in frequency dependence. In order to qualitatively compare the frequency dependence and the effect of geo-acoustics, we plot the TL depth averaged from 50-100m in depth. These are expected to be the depths of the sonobuoy receivers. Range averaging is usually done, but in this case the depth average is deemed equivalent. The depth averaged TL as a function of range (for the 3 frequencies) is shown in Fig 8-10 for the 3 sediments.

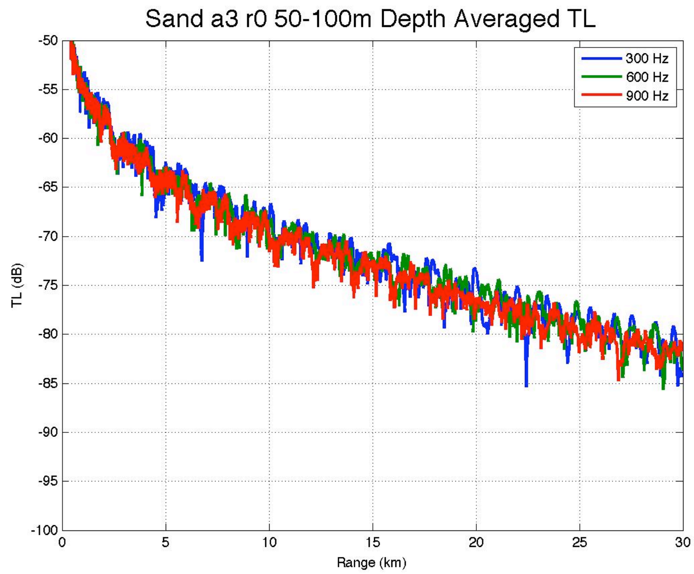

Figure 8. Depth (50-100m) averaged TL for the 120m isobath, Sand bottom.

Note the lack of frequency dependence in Fig. 8 for the Sand bottom. This bottom also leads to very good propagation (TL~82 dB at 30 km).

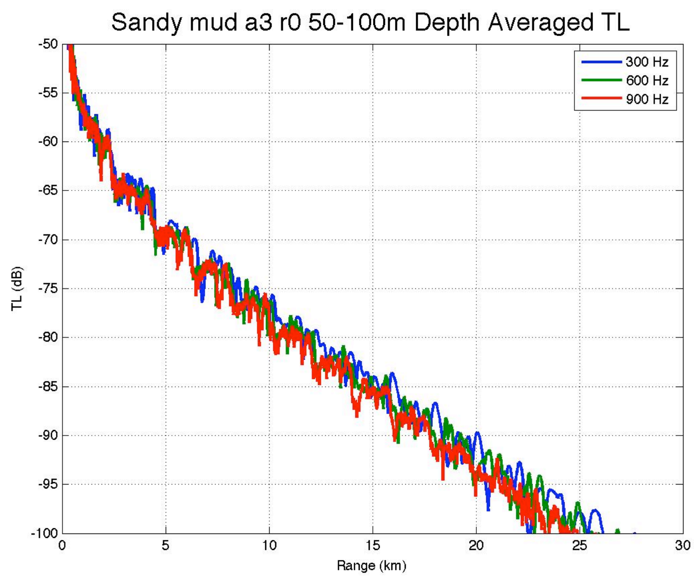

Figure 9. Depth (50-100m) averaged TL for the 120m isobath, Sandy-mud bottom.

Again there is little frequency dependence for the sandy-mud sediment, but TL is significantly higher, on the order of 25-30 dB higher TL than the sand sediment at 30 km.

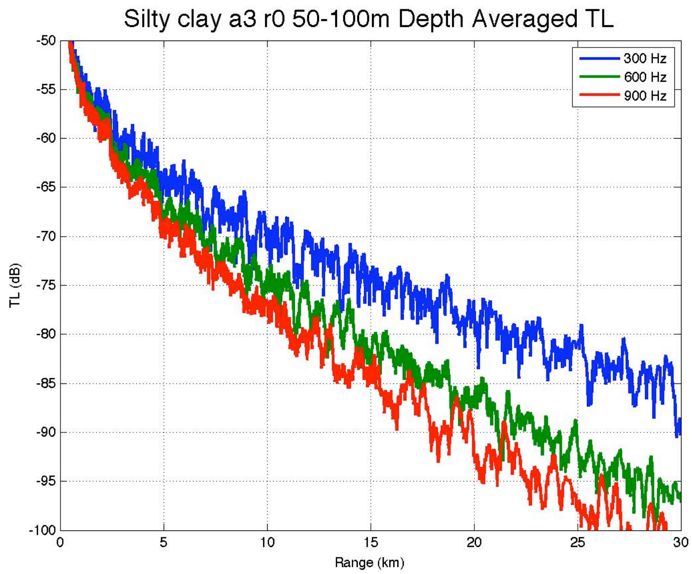

Figure 10. Depth (50-100m) averaged TL for the 120m isobath, Silty-clay bottom.

Now we see significant frequency selection by the sediment. The low frequency sound propagates as well as for the Sand sediment. This is due to the 12m sediment, which is effectively transparent to 300 Hz sound, but definitely an absorbing layer for 900 Hz energy. All 3 sediments (including the Hamilton variants) are shown in Fig. 11 for the 600 Hz case. The sandy-mud case is strongly changed by the Hamilton parameterization. There is as much as 25 dB spread in the TL at 25 km.

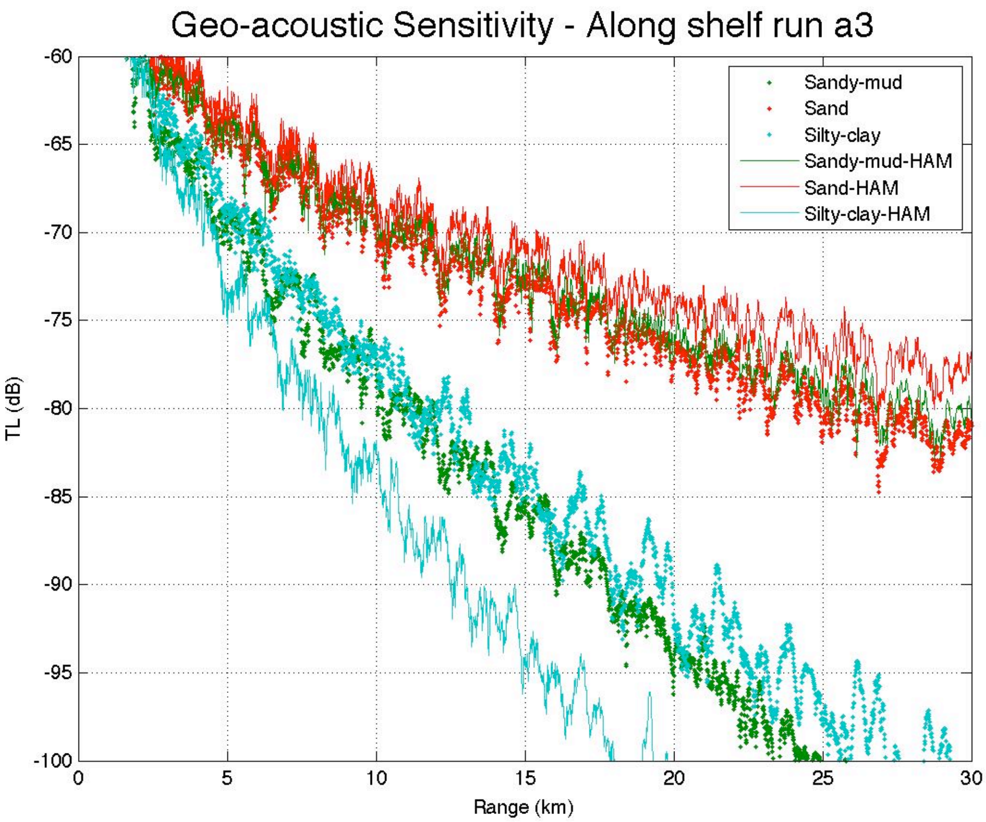

Figure 11. Depth (50-100m) averaged TL for the 120m isobath for 6 sediment profiles (sandy-mud, sand, silty-clay and Hamilton variants of these).

Alongshelf run (a2) 250m Isobath

For the 250m isobath, shown in plan-view in Fig. 12, there is some range dependent bathymetry.

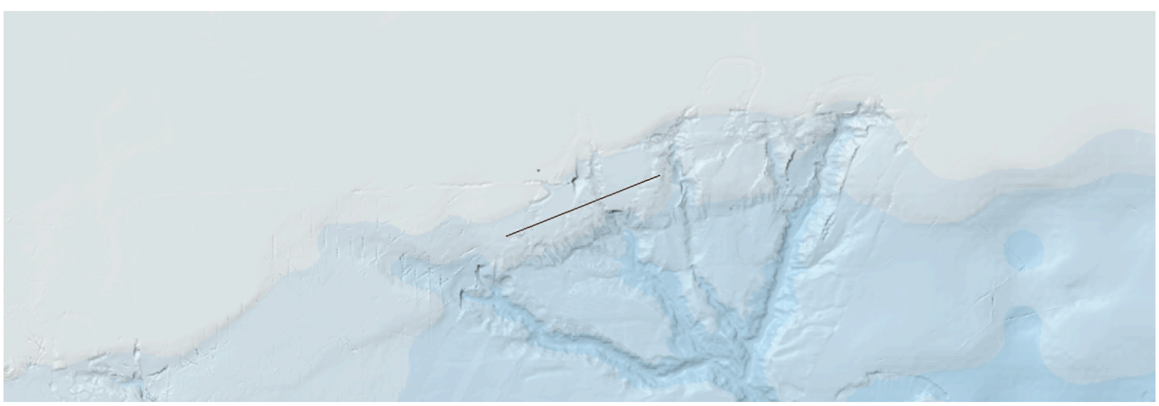

Figure 12. Plan-view of along-shelf path.

In 250 m of water, the sediment is expected to be sandy-mud so we will lead with this TL result.

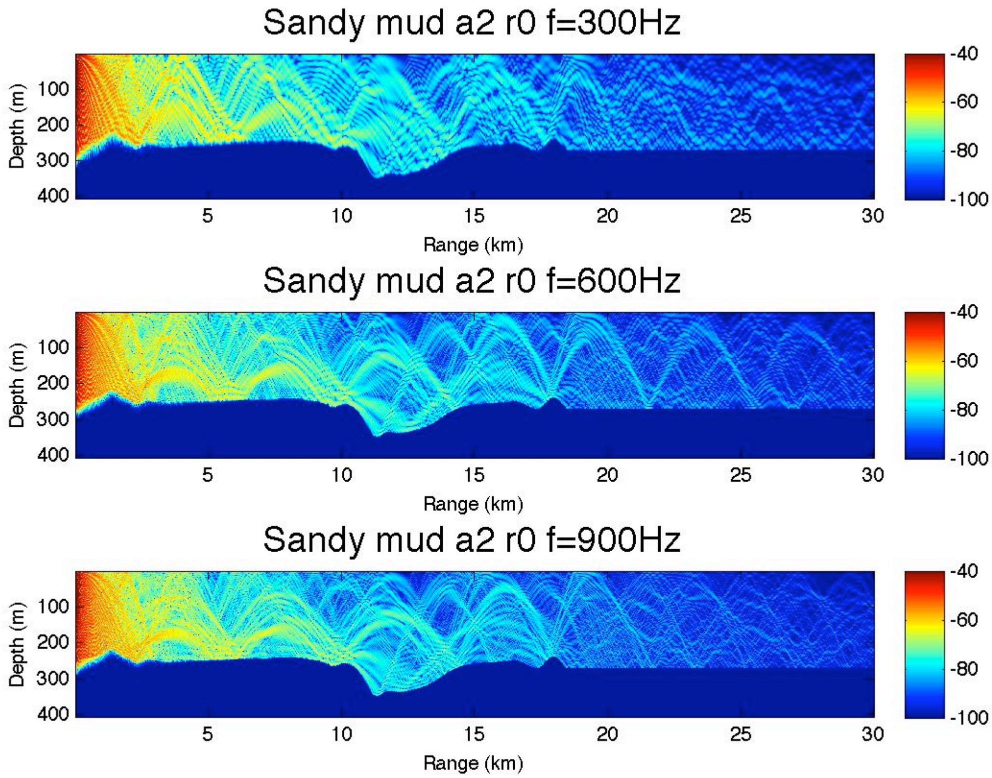

Figure 13. TL vs. range/depth for 250m isobath.

The presence of the ‘canyon’ at 12 km does affect the propagation. There is also a bit more frequency dependence than the 120m isobath case. Plotting the reverse path TL in Fig. 14 demonstrates the mild sensitivity to orientation (in locations of peaks and valleys), but not in overall levels of TL.

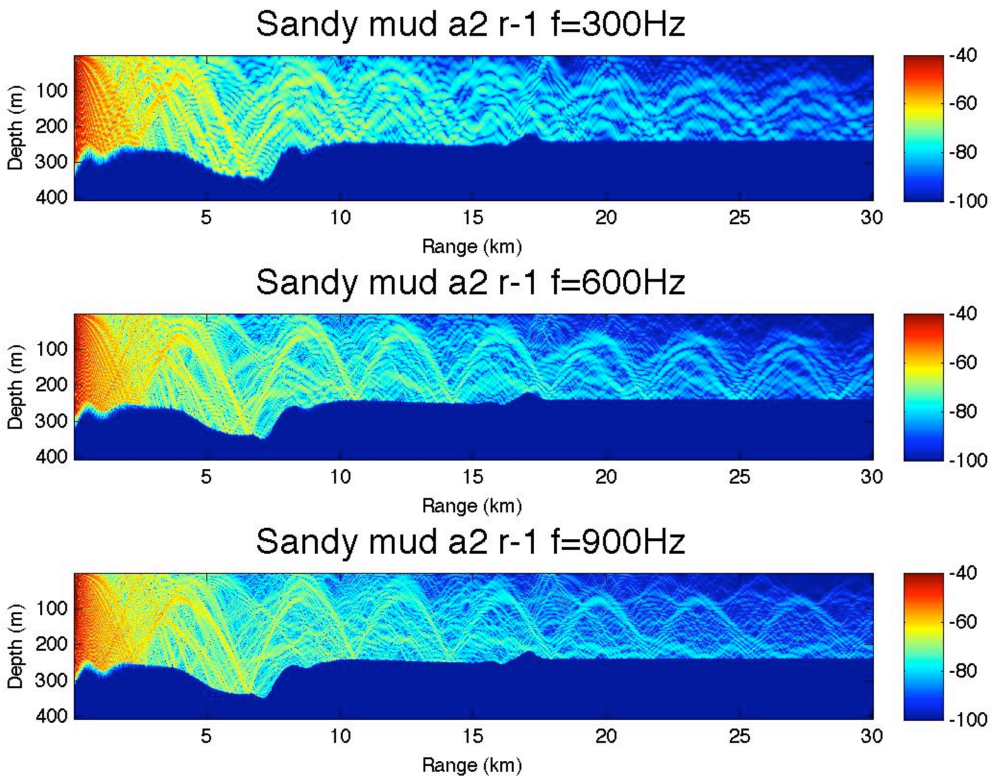

Figure 14. TL vs. range/depth for 250m isobath – reverse orientation

The lack of frequency dependence is visible if we plot the depth averaged TL.

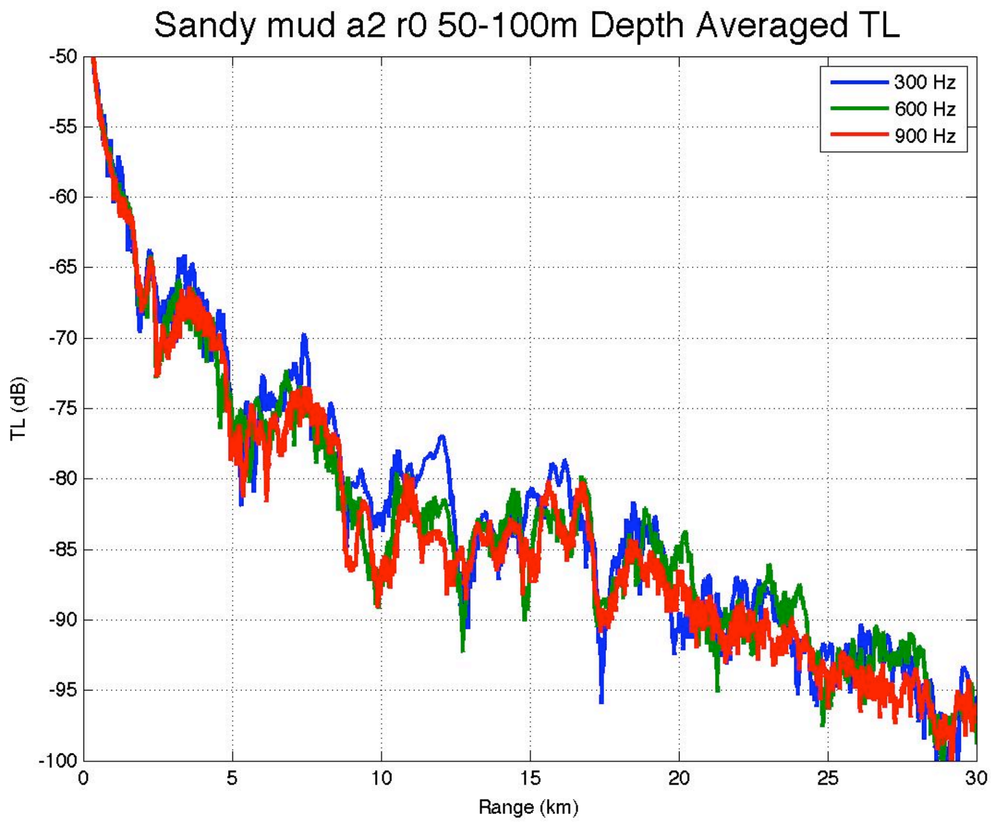

Figure 14. Depth averaged TL for the 250m isobath, sandy-mud.

For the Sand sediment the depth averaged TL is:

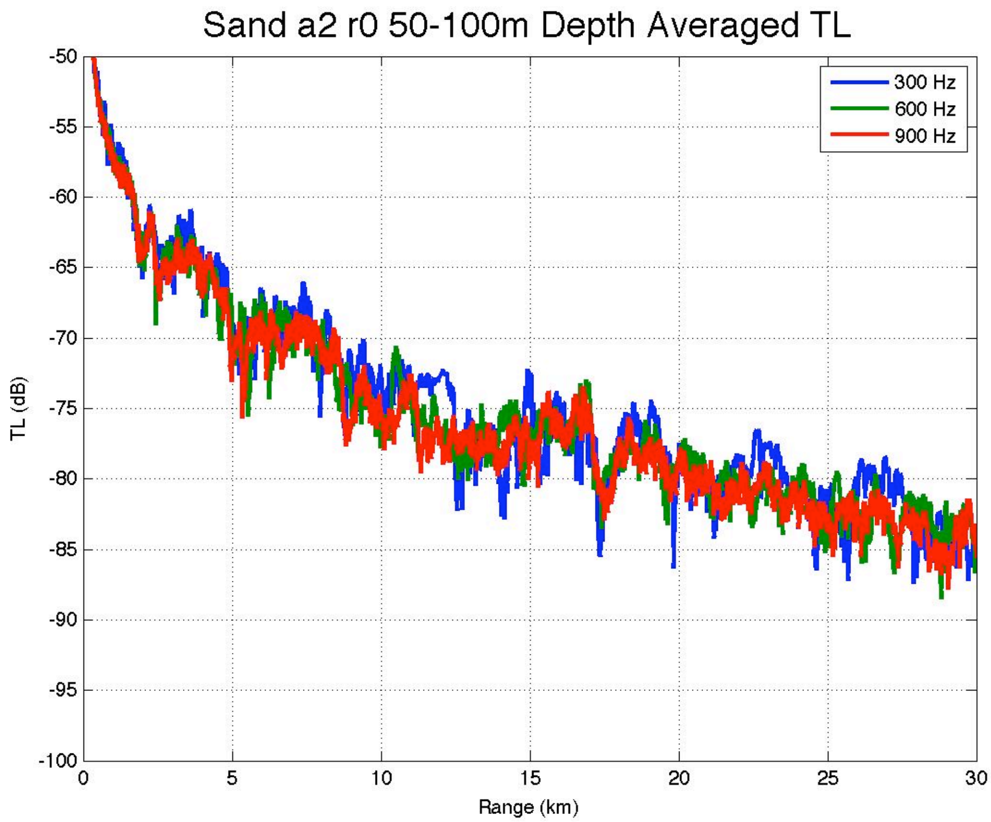

Figure 15. Depth averaged TL for the 250m isobath, sand sediment.

For this sediment there is little evidence of the canyon and no frequency dependence. And for the silty-clay sediment:

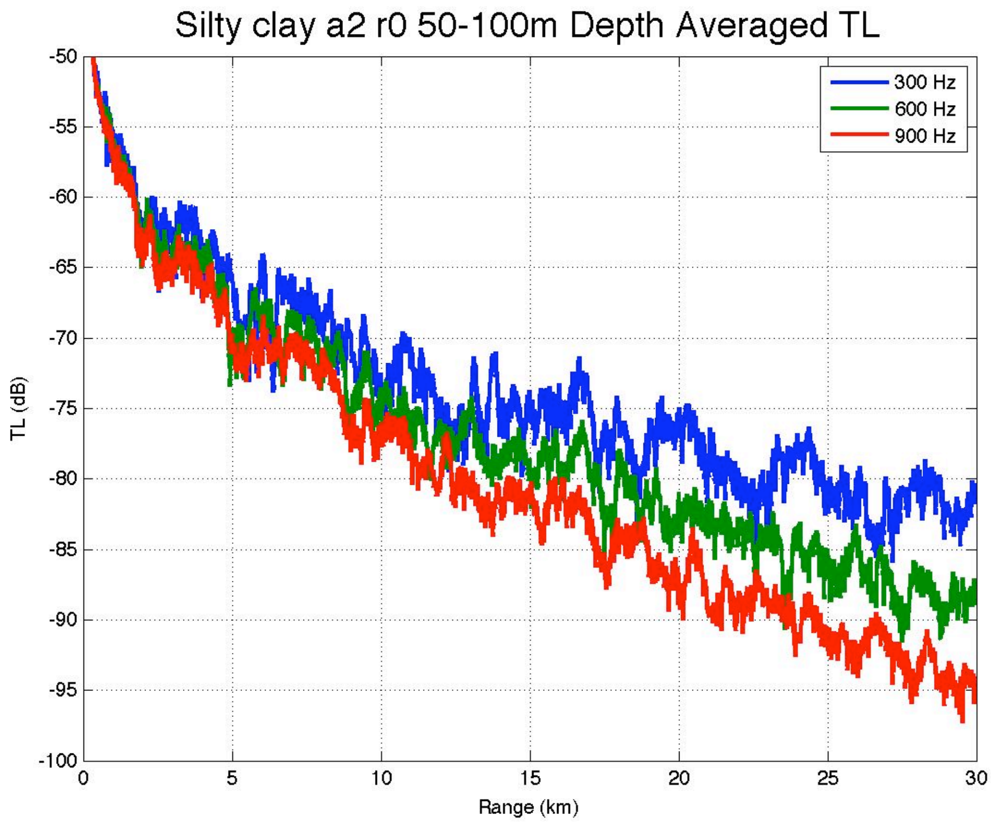

Figure 16. Depth averaged TL for the 250m isobath, silty-clay

Again, this sediment shows fairly strong frequency dependence. The comparison of the geo-acoustic classes at 600 Hz for the 250m isobath is shown in Fig. 17.

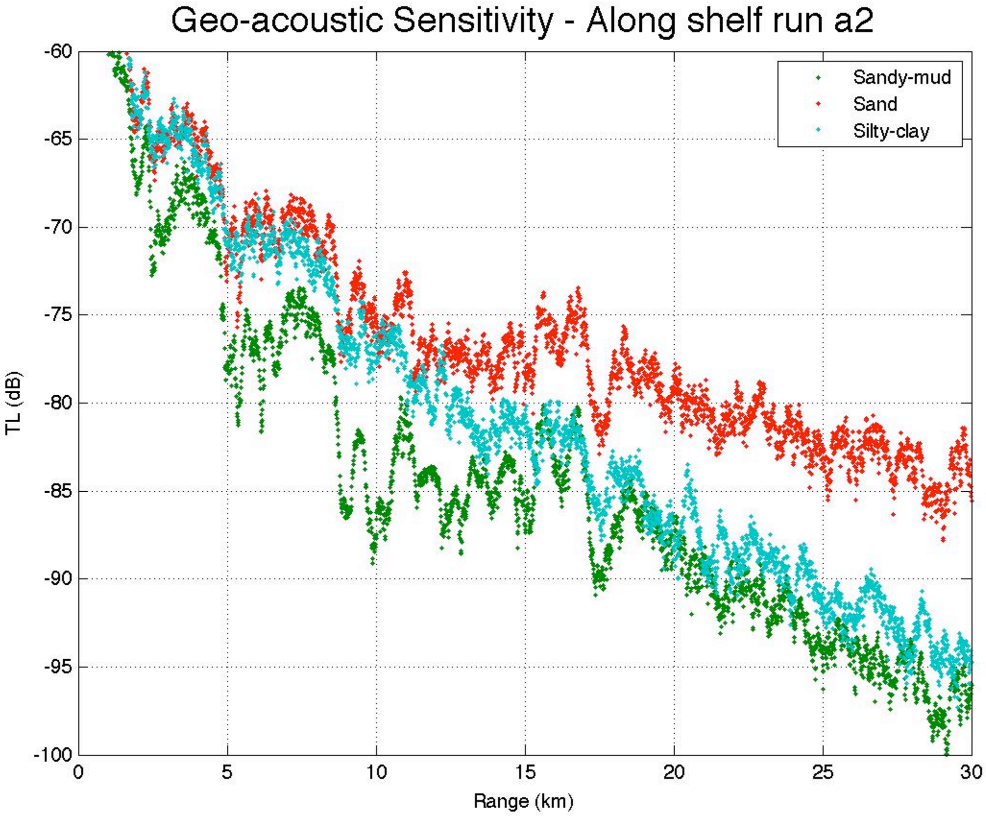

Figure 17. Depth averaged TL for the 250m isobath, for 3 sediment types.

As stated above, the presence of the canyon is only visible for the softer sediment. There is less sediment sensitivity at the 250m isobath than the 120m isobath (as is expected from the longer cycle distances).

Cross-shelf Runs

We now look at one of the cross shelf runs (only the modified run is presented, 3 cross-shelf runs were computed). The modified run (x3) is the furthest from the canyons and is shown in planview in Fig. 18.

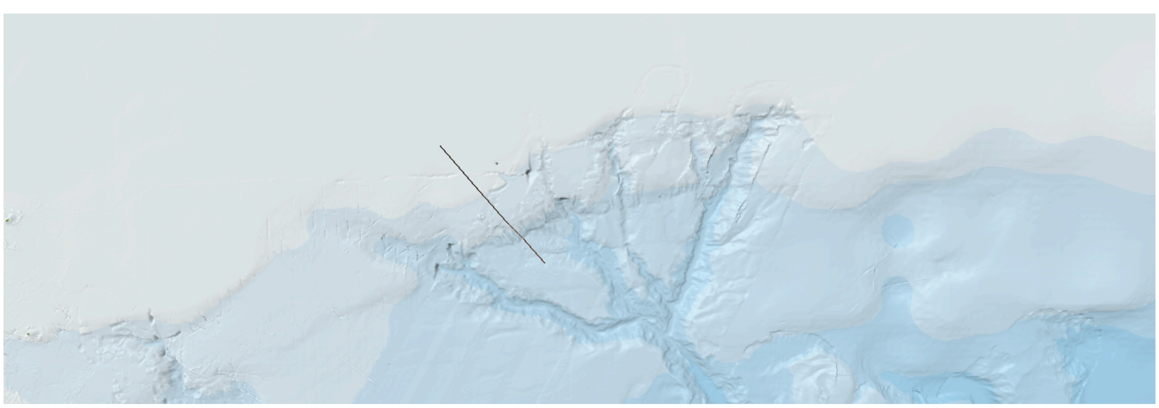

Figure 18. Plan-view of cross-shelf path.

We first look at the TL using the Hybrid geo-acoustic scheme (which is expected to be the closest to reality).

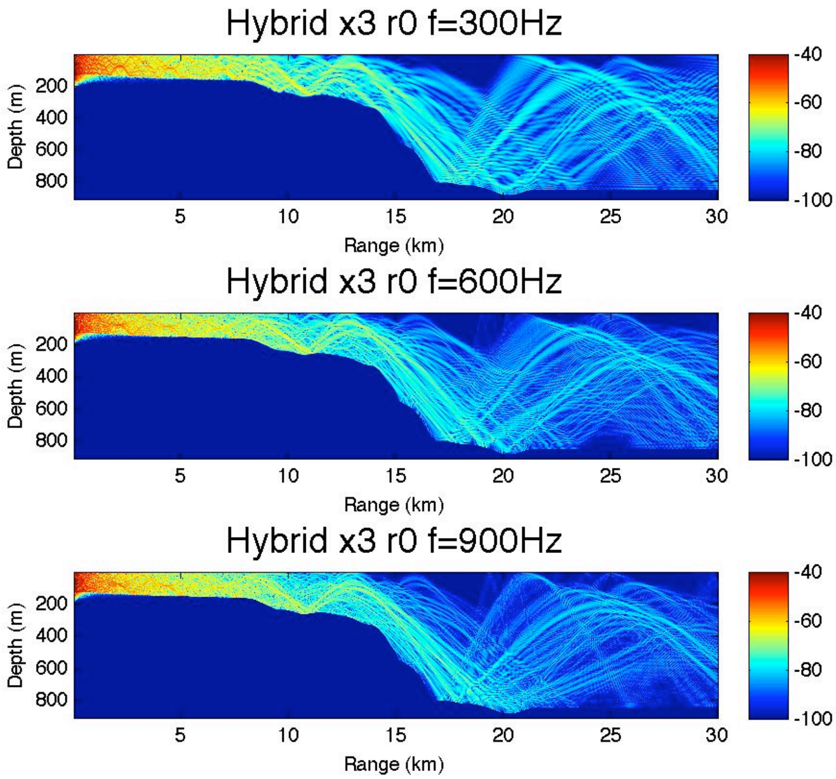

Figure 19. TL for the cross-shelf (x3) path using hybrid geo-acoustics

For this path we see that bathymetry dominates the received level, in particular leading to the strong shadow at 18 km. The bottom reflections beyond 20 km are incorrect because the profile ends and the PE assumed a flat bottom from there out. There is some frequency dependence but only in tightness of the rays for this sediment. Much of this path is below 200m depth so the hybrid solution and the sand solution will be the same. Looking at the TL for the sandy-mud solution we have:

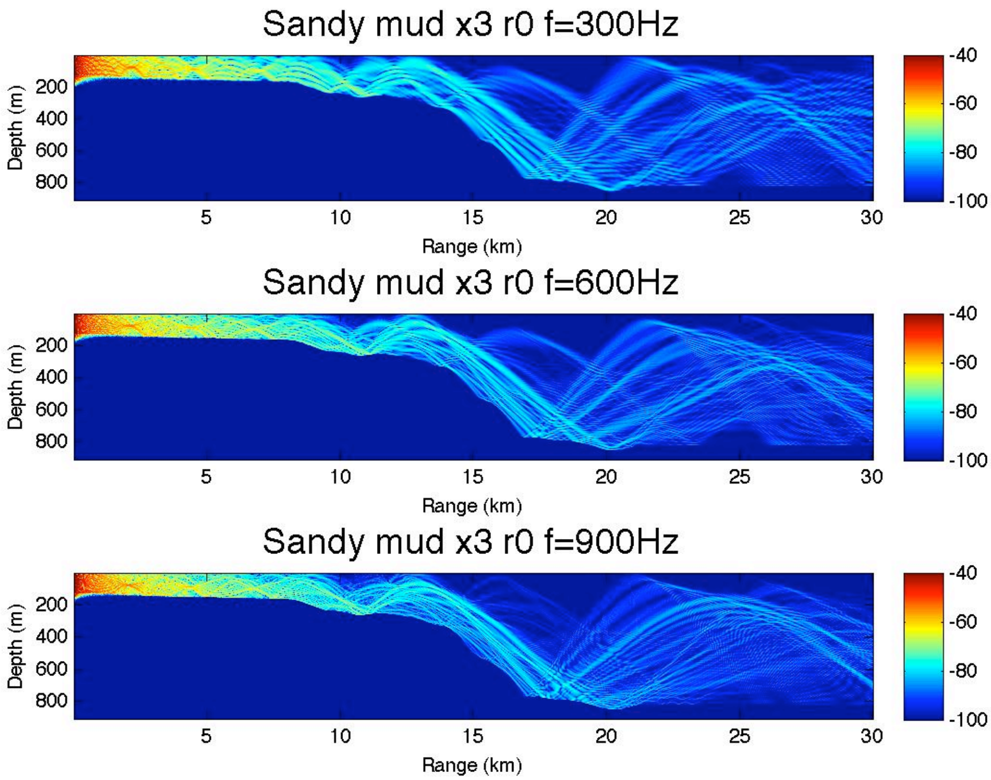

Figure 20. TL for modified cross-shelf run (x3) for sandy-mud sediment.

The TL for this sediment is much higher, as is evident by the deeper shadow zone. Looking at TL vs. range for the 600 Hz signal

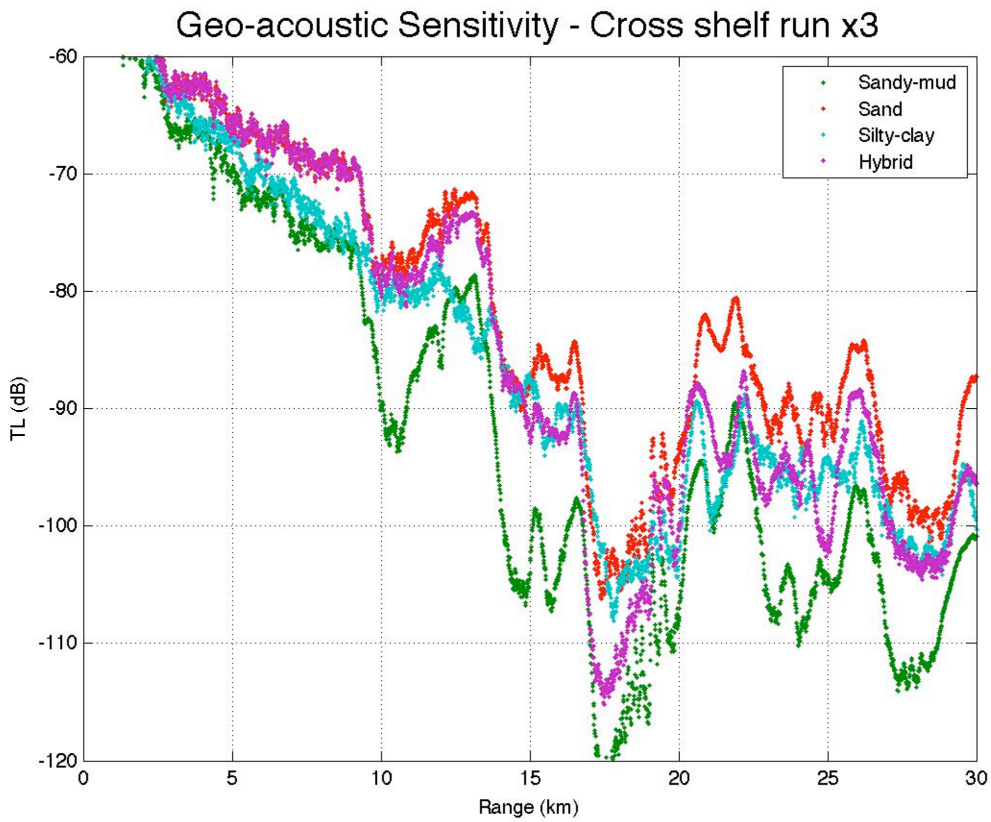

Figure 21. Depth averaged TL for the cross-shelf run (x3), for all 4 sediments

From this figure we see that the hybrid solution is expected to have low TL (as is the sand sediment) until 10-15 km where it drops significantly. The softer sediment on the slopes is attenuating the sound.

Looking at the reverse path TL for the hybrid sediment:

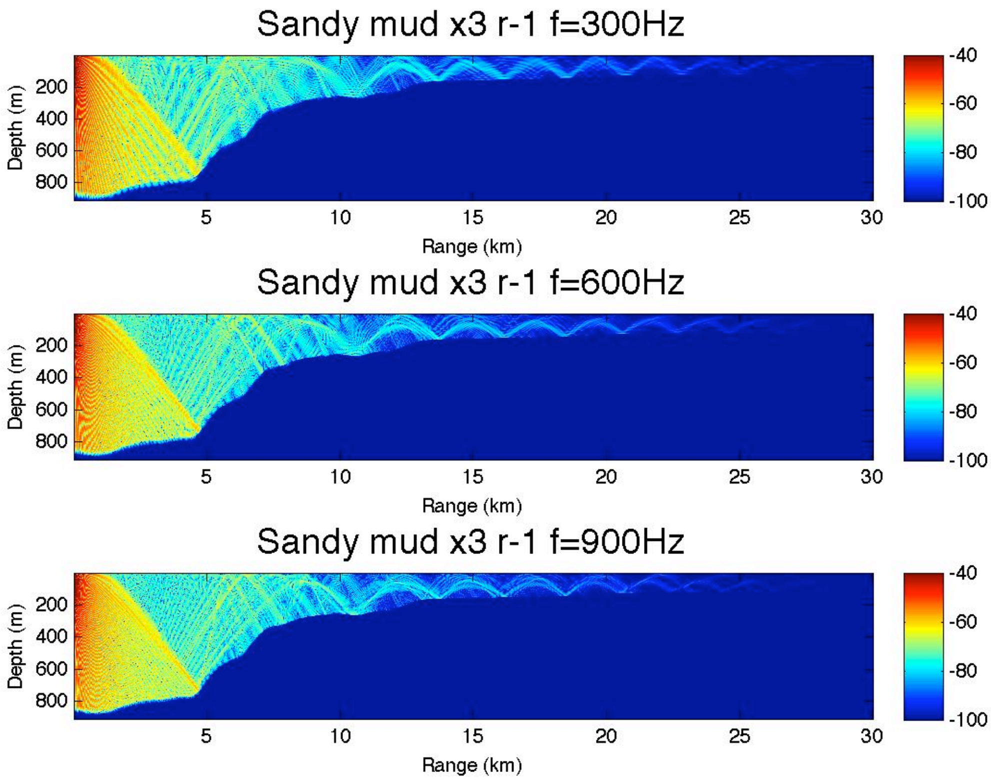

Figure 22. TL vs. Depth for the reversed cross-shelf (x3) run.

Cross-Canyon Run (c1)

We now look at the canyon run. The plan-view bathymetry is shown in Fig. 23. This run is expected to be effected by 3D propagation, but only 2D downslope (and upslope) PE modeling is done here.

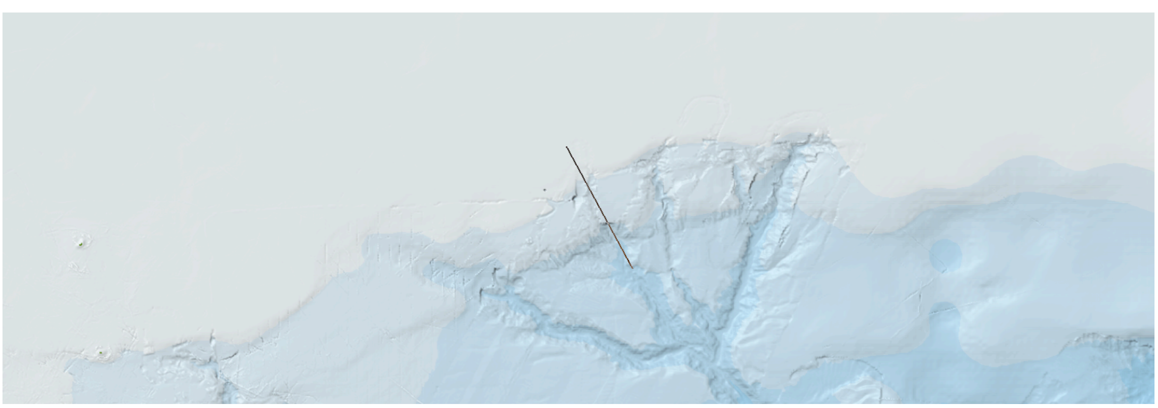

Figure 23. Plan-view bathymetry with canyon run.

The TL for the Hybrid sediment model is shown in Fig. 24.

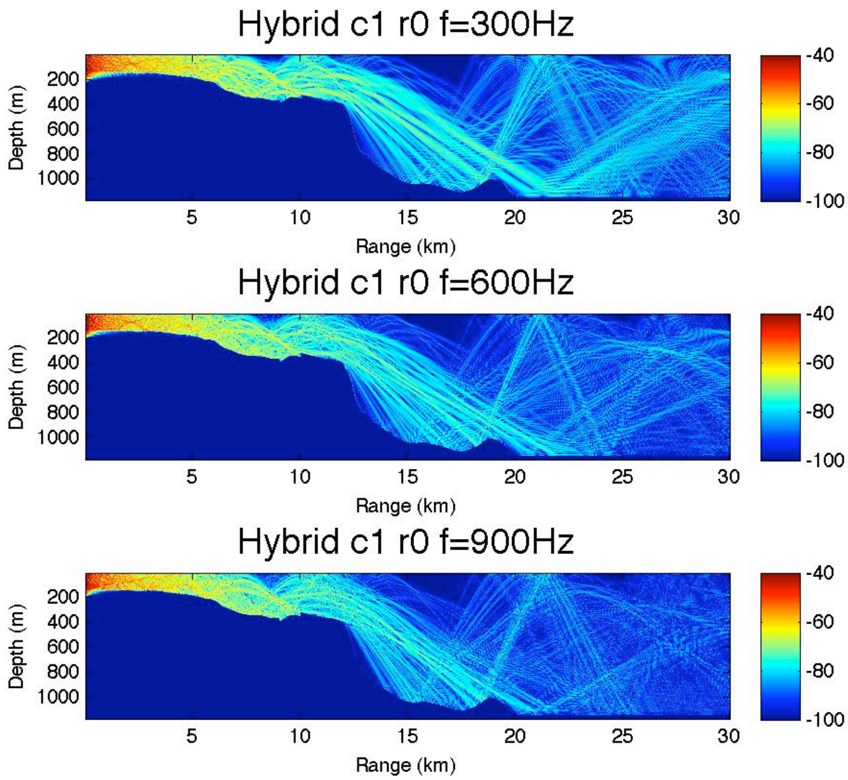

Figure 23. TL for Canyon run (c1) with hybrid sediment model

The bathymetry is seen to strongly affect the propagation, leading to a shallow shadow zone at 9 km and 17 km as well as a bottom reflection at 21 km. The energy is seen to propagate down the shelf, hugging the bottom from 12-14 km. The frequency dependence for Sand is shown in Fig. 24.

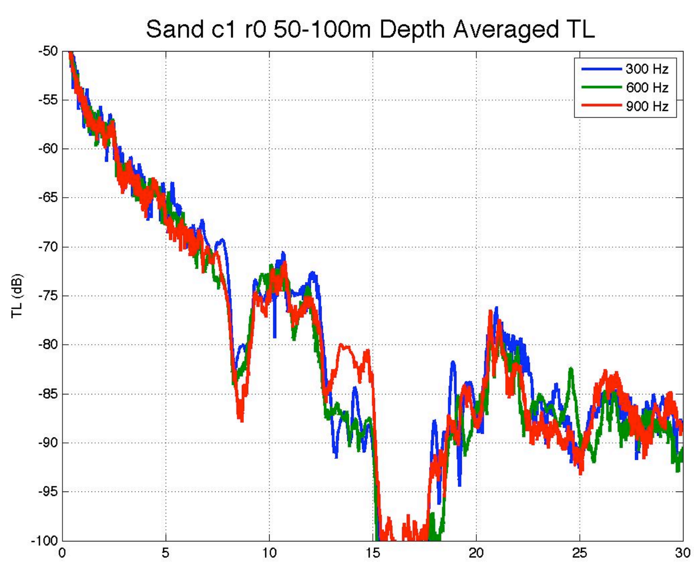

Figure 24. Depth averaged TL for the cross-shelf run (x3), for all 4 sediments

From this figure we see that the frequency dependence is minimal for Sand (as in the shallow iso-bath case). For silty-clay, however, it is not.

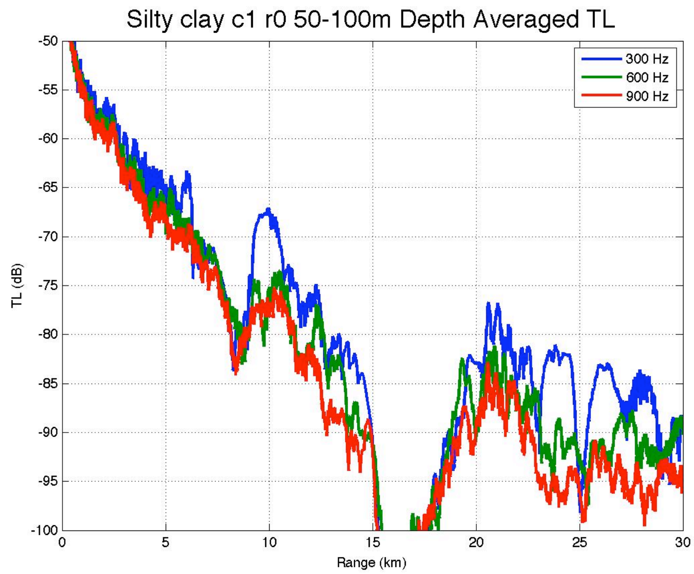

Figure 25. Depth averaged TL for the cross-shelf run (x3), for all 4 sediments

The effect of sediment type can be seen in Fig. 26, where the 4 sediment models are compared at 600 Hz.

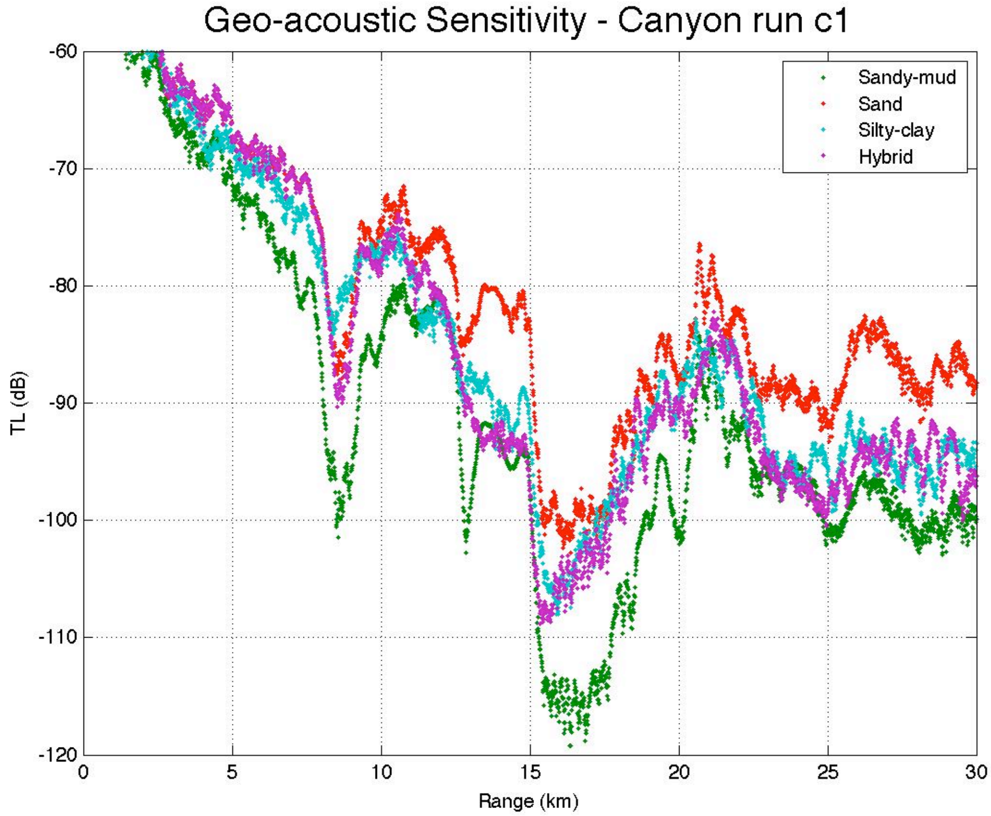

Figure 26. Canyon run (downslope) for Sandy-mud (green), silty-clay (cyan), hybrid(maroon) and sand (red).

From this figure we see that there is 10-15 dB difference in TL for the various sediment types. The Sandy-mud sediment clearly has the deepest nulls. The depths of these nulls will be a strong indicator of sediment type (if it is very lossy).

Conclusions

Analysis of propagation for along-shelf (120m/250m isobaths), cross-shelf and canyon runs has been performed in preparation for the QPE Pilot Cruise. The sensitivities to bathymetry, run orientation and sediment type have been performed. The presence of deep nulls is driven entirely by bathymetry. Frequency dependence is visible only for very soft sediments. There is a 10-25 dB sensitivity of depth averaged TL to the geo-acoustic parameters in shallow water.

We will now turn our attention to examining the sensitivity to local sound speed profiles and range-dependence in the sound speed field.