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# ON THE INTEGRATION OF THROUGH-THE SENSOR GEOACOUSTIC INVERSION TECHNIQUES FOR ENVIRONMENTAL ADAPTATION SCHEMES IN LOW FREQUENCY ACTIVE SONARS

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***Abstract:*** *The environmental conditions in shallow water areas are known to strongly affect the performances of low frequency active sonars (LFAS). In particular, interactions of the acoustical field with the seabed interface have been identified as being a key factor that is felt to be well understood previously to any environmental adaptation scheme of those sonars. However, the assessment of the geoacoustic properties of the seabed still constitutes a challenging task. Whenever the seabed data bases are of poor quality in a given area, it is obviously of interest that efficient and robust methodologies be applied in order to assess those properties. One proposed approach to carry on that issue consists in applying geoacoustic inversion methodologies that only make use of the acoustical data available onboard an operational sonar, ie. by only using the data acquired along the receiving horizontal towed line-array of the sonar. This approach, known as through-the-sensor technique, probes the environment with the sonar itself and in the same conditions of use as those of the sonar. This paper aims at presenting some practical aspects coming out from the processing of several data set of the BASE'04 experiment that are hoped to assess whether that kind of methodology can be applied within the framework of an ASW operational scenario. In particular, inversions of real data sets are presented from which practical inversion strategies (from* a priori *parametrization of the inverse problem to final end checks) are proposed.*

**Keywords:** *Geoacoustic inversion, Through-the-sensor, Environmental adaptation*

## 1. INTRODUCTION

In May-June 2004, the Nato Research Center (NURC) has conducted the BASE'04 experiment Southward the Sicily Island in the Mediterranean Sea. One of the goals of that experiment was to collect acoustical data sets that would allow to evaluate the applicability of the through-the-sensor (TTS) concept to assess the seabed properties of shallow water environments with diverse range dependent seabed characteristics. Also, different graduation of difficulty were planned and the data sets were acquired on three sites with unequal levels of groundtruth knowledge. The basis of the TTS approach studied at NURC consists in using solely the acoustical data generated by an LFAS system and received by the associated horizontal line array (HLA). In a companion paper presented in the same proceedings [1], the application of the concept along the most well documented track of the experiment on the Malta Plateau has been presented. Along thata track, robust local seabed characterisation have been obtained when using relatively high frequency signals (frequency modulated sweeps of 1s between 800-1800 Hz) and a relatively short array (~35 m with few hydrophones). Several settings of the inversion algorithm have been tested, all giving consistent results with results of previous experiments along the same track and in good agreement with the available groundtruth data (see e.g. [2] and references herein).

This paper takes benefit of the conclusion of this first study in order to assess the applicability of the TTS approach within the scope of the more general context of a broadband environmentally adaptive sonar concept shortly described in the next section.

## 2. ABOUT THE BROADBAND ENVIRONMENTALLY ADAPTIVE LFAS CONCEPT

The basis of a broadband environmentally adaptive LFAS concept relies on the assumption that the settings of a given sonar can be optimized with respect to the environmental conditions that it encounters. Among other parameters the seabed characteristics in shallow waters appear as a key factor for the success of such a concept as they are known to strongly influence the sonar performances. Unfortunately, the ground truth knowledge is often lacking which implies that an assessment of the seabed conditions should be done previously or during any ASW operation. Within that context, the idea of using the sonar itself as a probe sensor of the environment together with inversion techniques, as sketched in Fig.1, is attractive, provided that the TTS inversion techniques can be handled within tactically relevant time frames. As a consequence, this requires that efficient and robust techniques of inversion be implemented, and that validation tools be available in order to supervise the inversion process. Those two practicability aspects of the TTS approach to be applied in nearly real time are addressed from different experimental viewpoints in the coming sections.

## 3. ABOUT THE EFFICIENCY OF THE INVERSION ALGORITHM

As explained in [1], the implementation of the inversion algorithm that have been used for the present study rely on the SAGA inversion package interfaced by the ray acoustical model GAMARAY. The whole package constitutes a rather efficient tool that allows to process in parallel several individual inversions of the same data set. A noticeable part of the efficiency of the algorithm is permitted because the small horizontal separation between the source and the HLA (typically few hundreds of meters for shallow water operations) authorises to consider locally the seabed as being range independent [2]. This allows to use efficient ray based model for simulating the acoustical fields that are compared to the measurements. Typical needed time for inversions with a 1-Layer model (ie. an upper sediment layer above a semi-infinite basement) with simultaneous inversion of the geometry and the seabed properties (11 parameters) with 4 parallel inversions on a 4 processor - Linux workstation ©Intel Xeon 3GHz, takes 5 to 10 minutes long without particular optimization of the inversion process or of its settings (dense array configuration with 21 hydrophones and 50 Hz frequency sampling between 850-1750 Hz). Improving the efficiency of the present implementation of the inversion process is obviously possible, e.g. choosing a sparse array configuration which saves heavy computational time by avoiding numerous eigenray calculations… This point will not be discussed further, but the state-of-the-art of the TTS tools indicates that present computational means allow to invert for acoustical data already quite efficiently.

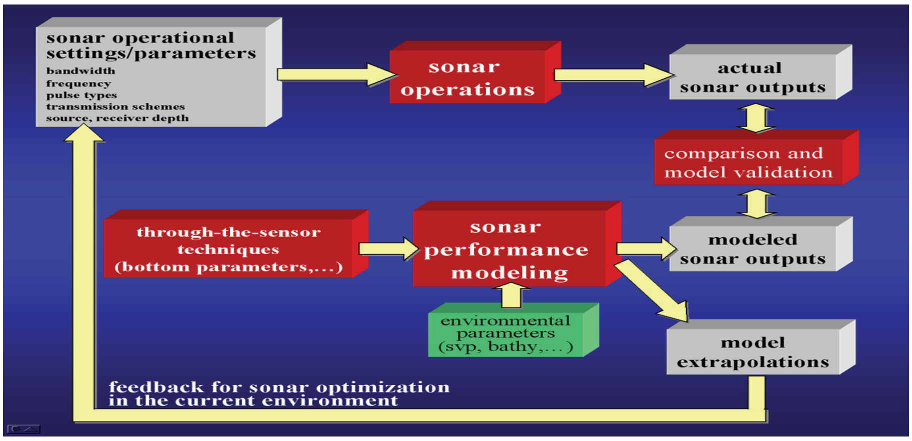


*Fig.1: General framework of the LFAS broadband environmentally adaptive sonar concept (Courtesy 4C program team)*

## 4. SOME ADDITIONAL LESSONS FROM THE MALTA PLATEAU TRACK

### 4.1. How to get some information about the seabed internal structure

One of the key points for getting rapid convergence of the TTS concept to relevant seabed characterization is the initial parametrization of the inverse problem. Among other aspects, the choice of an *a priori* form of the seabed structure, e.g. Semi-infinite half space, 1-Layer… In [1], several aspects about the settings of the inversion algorithm core have been addressed. Keeping in mind that the inversion process could have to be applied in a blind inversion context, it has been shown that iterative inversions starting with simple seabed assumptions about the seabed layering and then complexifying the model step by step after a ping-to-ping analysis is feasible. Having a look at the envelopes of the measured impulse response (matched filtering of the received signal) provides another means to assess those kinds of information quite pragmatically as shown in Fig. 2. This figure presents the comparison of the measured impulse responses of the waveguide by one hydrophone of the HLA with the simulated impulse responses obtained with the inverted ping-to-ping models for the Malta Plateau track (Semi-infinite half space with inverted water depth constrained to be around the true bathymetry, Semi-infinite half space with water depth free, one upper sediment layer above a semi-infinite basement and two upper-sediment layers above a semi-infinite basement). As in [1], those seabed models will be referenced as the SemiInfinite-WD Constrained, SemiInfinite-WD Unconstrained, 1-Layer and 2-Layer models. In real-time, such an historical stack of all past observed and simulated impulse responses using all past inversions can easily be processed. Visual comparison of the simulated and observed acoustical arrivals can indicate whether internal seabed layers exist. For example, it can be seen that the complex structure of the multiple bottom bounced arrivals at around 0.35s are replicated in a better manner when assuming a 1-Layer model or by fusing both impulse responses of the semi-infinite models. In the conditions of a blind scenario, it is thought that the analysis of the semi-infinite half space inversions could be quickly seen as missing some temporal features of the impulse responses. Combined with an on-the-fly analysis of the cost function value, a supervisor could be led to complexify the searched geoacoustical model to get better fits with lower cost functions and better agreement of the temporal structure of the impulse response. It thus also constitutes a practical way to assess, at least qualitatively, the relevantness of the inversions.

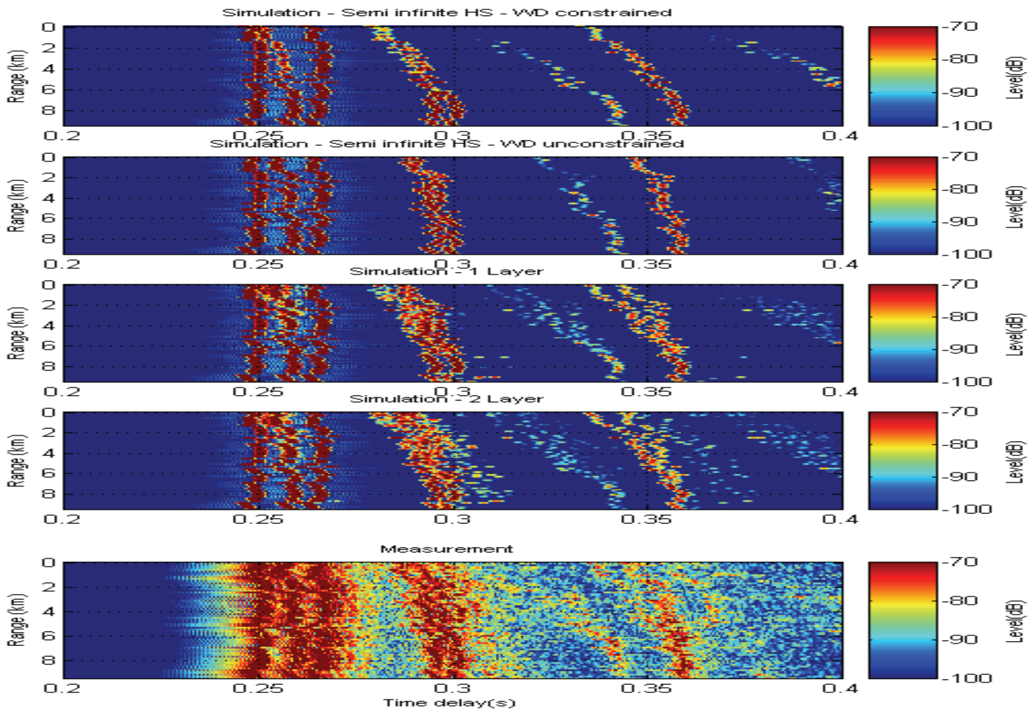


*Fig.2: Comparison of the measured and the simulated impulse responses at a single hydrophone or the Malta Plateau track.*

## 4.2. SOME HINTS ABOUT THE NEED OF INVERTING SEABED MODELS CLOSE TO GROUND TRUTHING

Rapidly validating the inverted seabed models is of primarily importance. The results shown before and in [1] indicate that minimal validation that is affordable in real-time should at least be based on checking whether the inversion algorithm has converged adequately and whether the inverted model can replicate the temporal structure of the measured impulse reponses. This analysis is confirmed when adopting an end-user viewpoint. The extrapolability of inverted seabed models at long ranges is important for sonar performances evaluation. In Fig.3, the acoustical parabolic equation model RAM has been used with the four inverted range dependent models of the Malta Plateau track. The transmission losses (TL) at mid-frequency for a source positioned at the beginning of the track and at mid-depth have been calculated. The 1-Layer and the 2-Layer models provide rather similar evaluations of the TL field. As they are both rather close to ground-truthing they are considered as the fields of reference. In [1], it can be seen that similar final cost function values were obtained with both models and also with the SemiInfinite – WD Unconstrained model. From that observation alone, it could have been deduced that this latest model could effectively have replicated the acoustical properties of the true seabed. Nevertheless, the comparison of long range TL indicate that this model strongly overestimates the TL especially in the upper part of the water column (the differences can reach 10dB locally). Indeed the reason of this overestimation is that the critical angle of that seabed model is overestimated which allows steeper rays to propagate with less bottom reflection losses than with the reference models. Though sufficient to replicate the acoustical field at close range (ie. along the HLA as measured by the low value of the cost functions and few hundreds of meters beyond), that model should not be used in any case for sonar perforamances evaluation. As mentioned before, this conclusion could have simply be assessed by following the minimal double check explained above.

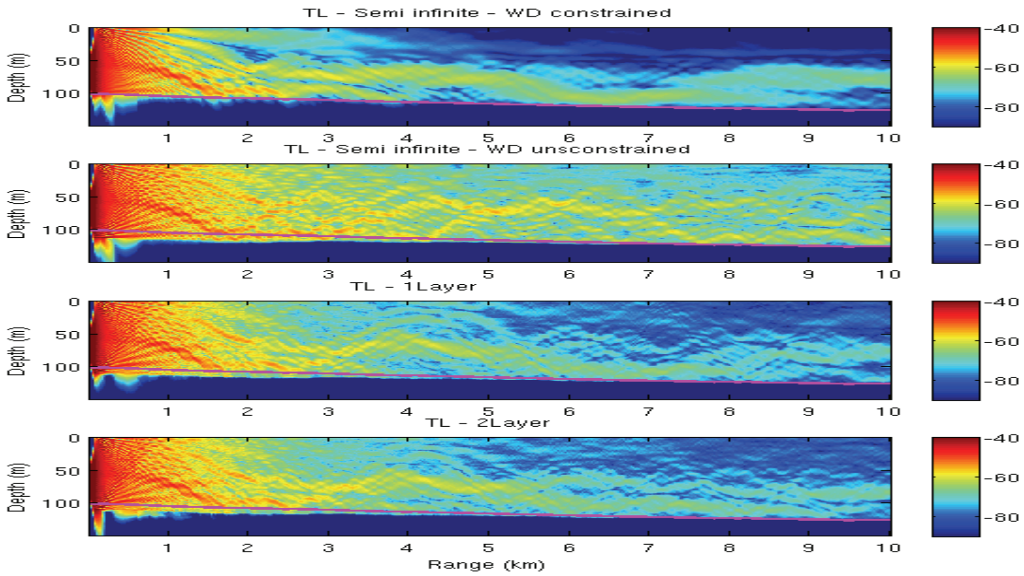


*Fig.3: Comparison of the simulated TL at 1200 Hz using the 4 inverted range dependent geoacoustical models.*

## 5. INVERSION OF THE ADVENTURE BANK DATA SET

The inversion of the Adventure Bank data set has revealed to be a very challenging task. Following the practical inversion strategy deduced from the Malta Plateau example, ie. 1. Stacking the measured impulse responses to assess a potential layered structure of the seabed 2. Proceeding to the inversions with standard inversion algorithm settings 3. Double checking final cost function values and good fit of the temporal structure of the impulse reponses, the inversion of the Adventure Bank track has been blindly identified as being unsuccessful. Before getting some groundtruth data very recently (Courtesy FWG during the joint NURC/FWG BABO'06 experiment in May 2006), very little groundtruth data existed along the Adventure Bank track at the time the data have been processed. Interestingly however, before having the subbottom profiler data set shown in Fig.4 (a), the simple observation of the impulse responses in Fig.4 (b), had led to the assumption that a strong and highly reverberant event such as an internal gassy pocket existed. On Fig. 4 (b), this event is seen to produce a strong and time-spread acoustical return at around 0.3s for example. Indeed, considering the subbottom profiler data set, that assumption is very plausible for ranges beyond 2 km where every internal layers suddenly disappear. None of the inversions that have been performed has ever managed to replicate that kind of return. Whatever the algorithm settings, the present implementation of the TTS algorithm failed to assess even effective parameters of the seabed. From an environmentally adaptive sonar concepts of course, these results could be considered as a failure of the concept. Nevertheless, it is thought that this failure provides some useful information for the sonar operator. As a by-product of the TTS failure, the sonar operator would at least be warned that any sonar performances evaluation should be considered cautiously since an effect of the actual seabed could not be taken into account. As a consequence any induced tactical decision based on the sonar performances evaluation should be analysed cautiously.

(a) (b)

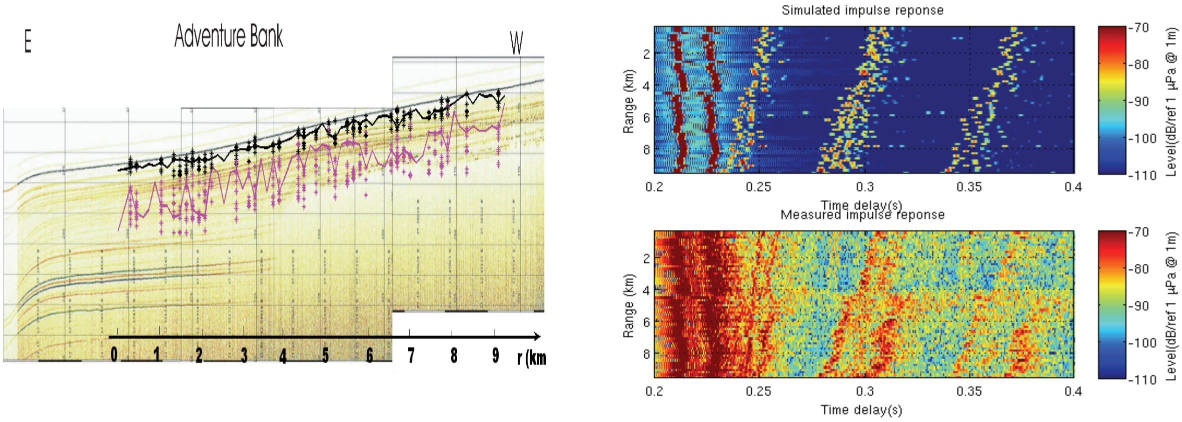


*Fig.4: Inversions of the Adventure Bank track – (a) Best seabed inverted model with a sparse array configuration – Seismic profile provided courtesy Dr. D.Milkert (FWG) – (b) Comparison of measured impulse responses and simulated ones with the inverted models.*

## 6. INVERSION OF THE MEDINA BANK DATA SET

The third data set acquired during the BASE'04 experiment was processed in real blind conditions without any groundtruth knowledge. The blind inversion principles explained so far have been applied for the inversion of the Medina Bank track. Obviously, no ground-truth confrontation has been performed either, so that we have to decide whether the inversion is satisfying or not. The initial study of the impulse responses (Fig.5 (b)) exhibits long tails of the impulse response that indicate rather hard properties of the bottom (ie. high compressional speeds). No obvious indication of an internal layer can be really noticed. Both indication allows to parametrize the inverse problems and to get rather low cost function values (Fig.5 (a)). Interestingly, the 1-Layer model provides slightly better cost functions. Also, it can be noticed that bottom bounced arrivals have slightly greater time spread with the 1-Layer, as seen with the measured impulse responses. At this point the question is to see whether an internal upper layer makes sense. By plotting the stacked ping-to-ping inversions (Fig 5 (c)), it can be observed that both inverted water depths of the SemiInfinite and the 1-Layer model are very close one from another and that the inverted upper layer is rather smooth. Moreover, when having a look at the stacked compressional speeds in Fig.5(d) , it can also be noticed that the upper sediment properties are similar with both models and that the properties of basement with the 1-Layer model are rather consistent from one ping to another. Moreover, Fig.6 provides another viewpoint for single ping inversion validation through scatter plots that provide a qualitative measurement of the convergence of the inversion algorithm for single parameters. Inverted sharp bell shapes provides indications that the algorithm has converged toward a single value for a given parameter. Not requiring additional computation time since it only uses the results of the inversion, this kind of plots is thought to provide confidence about the obtained geoacoustic values. In our case, both compressional speeds of the upper layer and the basement presents such a pattern, which allows to consider at that point that the TTS approach performed well and that a 1-Layer seabed structure is plausible.

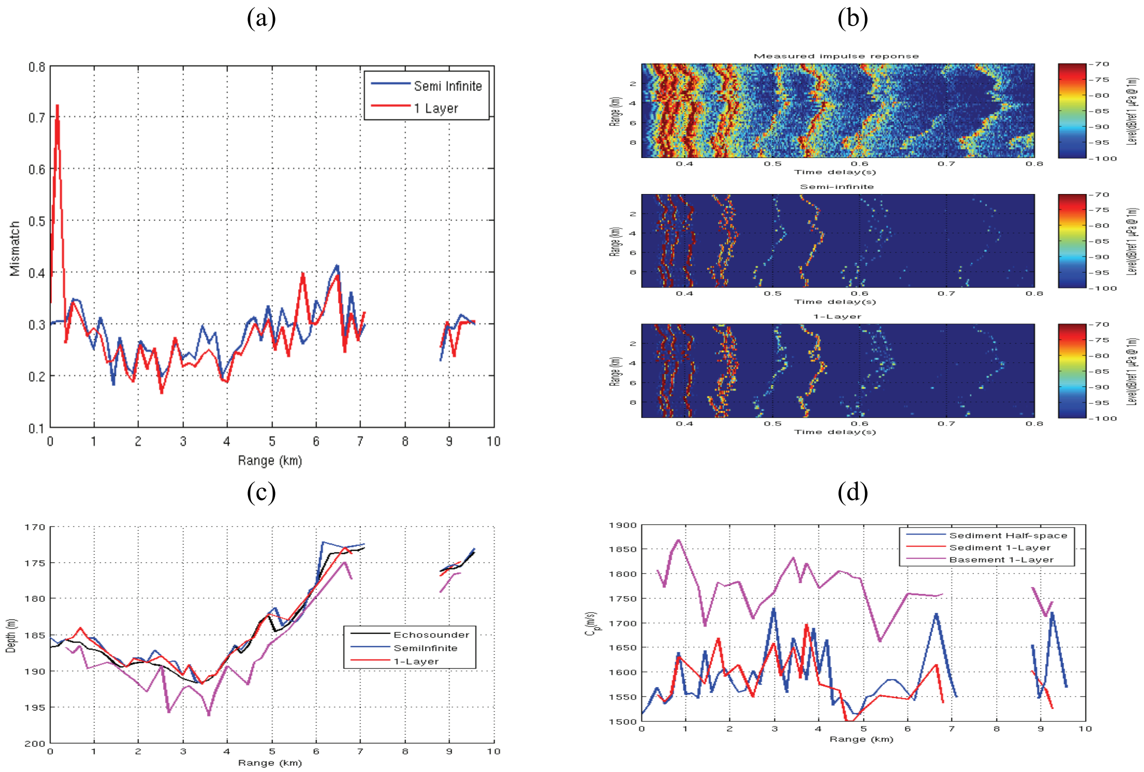


*Fig.6: (a) Final best cost function – (b) Stack of measured impulse responses at a single hydrophone compared with simulated ones obtained with inverted seabed models. (c) Inverted seabed structure compared to measured bathymetry – (d) Associated inverted compressional speed.*

## 7. CONCLUSION

The implementation of a TTS approach internally an overhat Broadband Environmentally Adaptive Sonar Concept has been addressed from a very practical point of view. Real-time implementation of such an approach is believed to be feasible. Applied with three different data sets, the analysis of acoustical data and/or the use of inversion algorithms have shown to always lead to more or less complete information about the geoacoustical properties of the seabed. Whatever the achieved level of environmental assessment, the information that was gathered was felt to be of interest within the scope of ASW operations either to assess better quantitative sonar performances estimation (when seabed characterization is complete) or to assess expectations about the quality of these estimations when TTS fails. The panel of expert rules exposed in the present paper is far from being complete. However it is hypothesized that more extensive work could convey to complete and formalize them in a better manner that could be used within a decision aid framework.

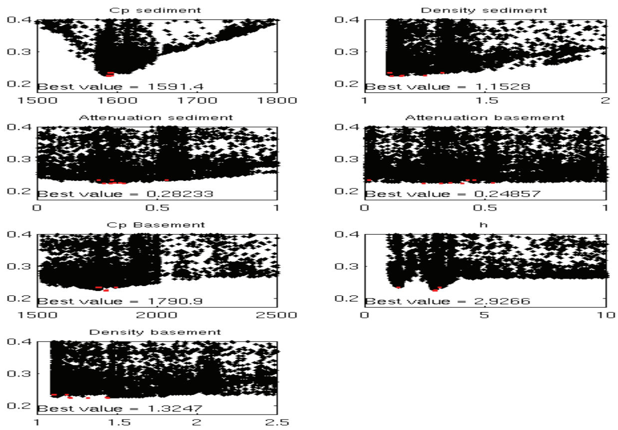


*Fig.6: A typical scatter plot of a single ping inversion with a 1-Layer model.*

## 8. ACKNOWLEDGEMENTS

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