Amplitude and traveltime inversion for mono-channel Boomer surveys

A. Vesnaver, L. Baradello

Department of Geophysics, Istituto Nazionale di Oceanografia e Geofisica Sperimentale - OGS, Trieste, Italy

INTRODUCTION

Mono-channel recording systems with a Boomer seismic source are very cheap and can be easily deployed in sensitive environments such as lagoons or busy harbours (Zecchin et al. 2008). The price paid for these advantages is the lack of signal redundancy typical of multi-channel records, which makes it possible to estimate wave propagation velocity and angle-dependent reflectivity, and to improve the signal-to-noise ratio by stacking or migration. In this paper, we show that some of this information can be obtained by inverting the amplitudes and traveltimes of shallow primary reflections and their multiples, using a single offset in a Boomer survey.

Amplitudes and traveltimes can in principle be inverted separately, but doing so we do not use the information redundancy embedded in the velocity: it determines both the traveltimes along the ray paths and the amplitude of primaries and multiple reflections via the acoustic impedance contrasts at the layer interfaces. Therefore, the coupling of these two inversion algorithms can extract more information from our minimal data set. The possible ambiguities of one inversion can be limited by constraints coming from the other inversion, so improving the stability of both.

AMPLITUDE AND TRAVELTIME INVERSION

The simplest object function we can create for a joint inversion of amplitudes and traveltimes is the sum of the squared differences between measured and modeled data, minimizing it as a function of the Earth model parameters:

$$\mathbf{Object}(T_j, A_j, V, L, \rho) = \sum_j [T_j - t(V,L)]^2 + \sum_j [A_j - a(V,\rho)]^2 \quad , \qquad (1)$$

where T_j and A_j are the measured traveltimes and amplitudes of primaries and multiples in a single trace. We assume a 1D Earth model, with the data compensated for the geometrical spreading – (e.g., by a t^2 gain function). We note that the modeled traveltimes $t(V, L)$ depend on the layer velocity V and the layer thickness L, but not on the density ρ. Similarly, the modeled amplitudes $a(V, \rho)$ do not depend on the thickness L. Therefore, a separate inversion of amplitudes and traveltimes can avoid cross-talk between density and thickness. On the other hand, the velocity V influences both the amplitude (via the acoustic impedance $I = \rho V$) and the transit time in a layer (via the ratio $LV = L / V$). Since the Earth model must be consistent with both data sets, the velocity value must be the same for both inversion solutions. Another condition for the two inversion algorithms is the stability of the acoustic impedance I and the transit time LV against random noise, which we found in several tests with synthetic data. Therefore, each of these values is a well-constrained part of the two separate solutions, and we imposed that they are kept constant, while we perturb the values of velocity, density and thickness.

APPLICATION EXAMPLE

To test the stability of this coupled inversion, we built an Earth model (Figure 1) that mimics a mud volcano. Its cone makes the water depth variable, while the water density and velocity are constant and known (1500 m/s and 1 gr/cc, respectively). Our target is the first layer below the seafloor, which consists of sediments with P velocity and density that vary laterally and reach a minimum in the center of the volcano. The basement is again homogeneous. We simulated by ray tracing only primaries and multiples from the seafloor and the sediment layer base, with an offset of 10 m between source and receiver.

For the velocity inversion we need the two primaries of the latter ones, plus one or more multiples as peg-leg, intrabed or “simple” (Vesnaver and Baradello 2022a, b). The more, the better, because redundancy can reduce random noise due to picking errors and spurious events. For the amplitude inversion, we instead used only the primary and two reverberations between seafloor and sea surface to limit our solution space to the only two parameters we want to estimate, i.e., sediment velocity and density (Vesnaver and Baradello 2023). Including the amplitude of the other multiples is not so helpful: doing so, we would also have to calculate the velocity and density of the bedrock, leading to further unknowns and instabilities in our inversion.

Figure 2 shows the inversion results obtained by adding random noise of 0.1% to the amplitudes and traveltimes of 300 seismic traces, which corresponds to only a few samples. To improve the stability of the inversion, we also introduced a lateral smoothing filter with a window length of 31 samples. The instability in the initial estimates (solid blue line) is completely removed by the smoothing and scaling (dotted red line), so that this curve practically matches that of the true model (dashed yellow line).

When the random noise increases to 0.5% (Figure 3), the estimated velocity is definitely unstable, but again the smoothed, scaled version (dotted red line) is not too far from the correct solution. The weakest estimate is that of density, which still correctly identifies a minimum value at the center of the mud volcano.

CONCLUSIONS

The lack of redundancy of a minimal survey, such as a mono-channel Boomer system, can be partially compensated for by interpreting and inverting the amplitudes and traveltimes of primaries and multiples. However, such an inversion requires a separate but coupled inversion of the dynamic and kinematic data to limit the crosstalk of physically independent variables.

The results obtained with different noise levels show that we can obtain an encouraging estimate even for density when the signal-to-noise ratio is very good. This information is important for offshore engineering and marine geology.

References

Vesnaver A., Baradello L.; 2022a: *Shallow velocity estimation by multiples for monochannel Boomer surveys*. Applied Sciences, **12**, 3046. https://doi.org/10.3390/app12063046.

Vesnaver A., Baradello L.; 2022b: *Tomographic joint inversion of direct arrivals, primaries and multiples for monochannel marine surveys*. Geosciences, **12** (6), 219. https://doi.org/10.3390/geosciences12060219.

Vesnaver A., Baradello L.; 2023: *Sea floor characterization by multiples' amplitudes in monochannel surveys*. Journal of Marine Science and Engineering, **11**, 1662. https://doi.org/10.3390/jmse11091662.

Zecchin M., Baradello L., Brancolini G., Donda F., Rizzetto F., Tosi L.; 2008: *Sequence stratigraphy based on high-resolution seismic profiles in the late Pleistocene and Holocene deposits of the Venice area*. Marine Geology**, 253**, 3–4, 185-198. https://doi.org/10.1016/j.margeo.2008.05.010.

Figures

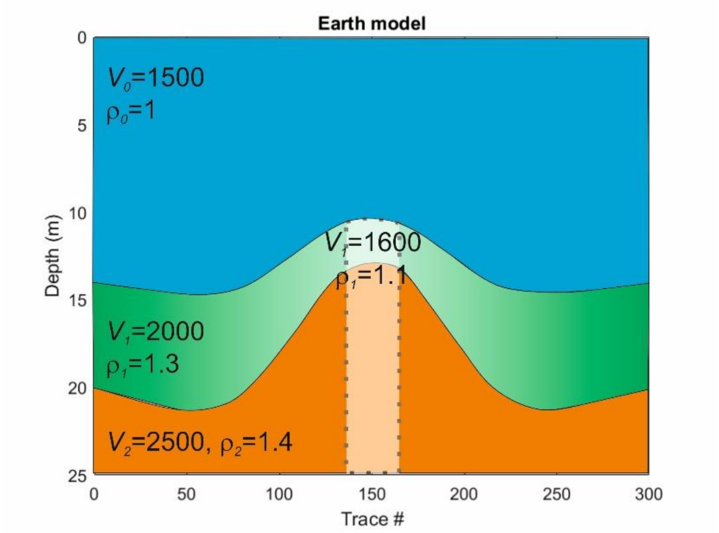

Fig.1 – Earth model simulating a mud volcano. Although the model is 2D, the simulation and inversion are carried out in 1D only, so assuming just slow lateral variations.

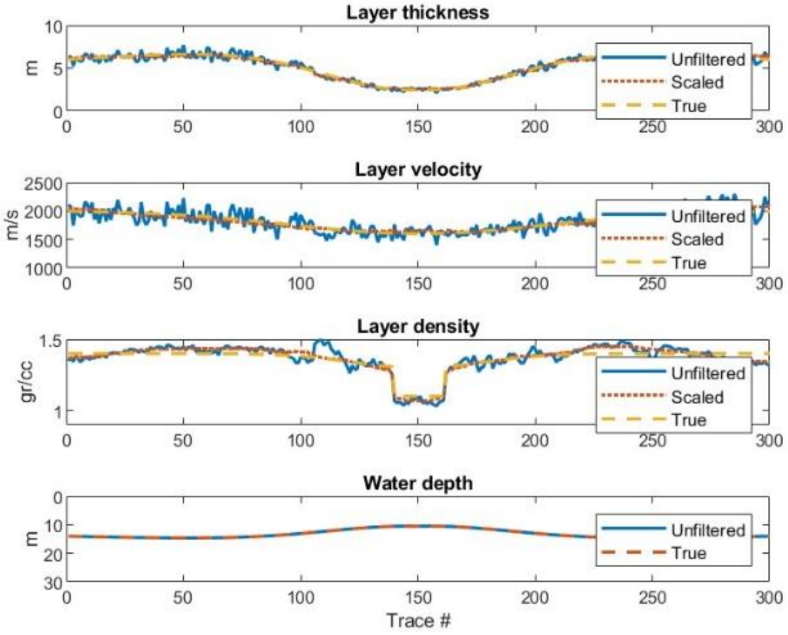

Fig.2 – Amplitude and traveltime inversion when a random noise percentage of 0.1% is added to the synthetic data. The smoothed, scaled estimate (dotted red line) fits well the true model (dashed yellow line).

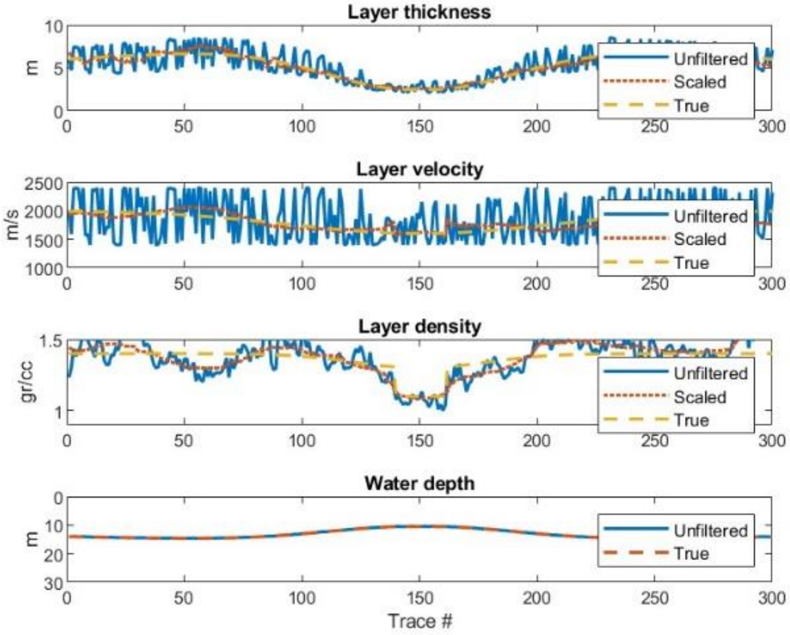

Fig.3 – Amplitude and traveltime inversion when a random noise percentage of 0.5% is added to the synthetic data. The unfiltered estimate (solid blue line) becomes unstable, especially for the velocity, but the smoothed, scaled version for all estimates (dotted red lines) remains fairly good.