Monte Carlo approach to assess the uncertainty of wide-angle layered models: Application to the Santos Basin, Brazil

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1. Introduction

Velocity models derived from wide-angle refractor/reflection seismics are the main tool to image the lithosphere, providing a 2D view of the velocity field. They tend to be regarded as error-free, but model uncertainties must be taken into account in order to establish the meaningful level of detail of their geological interpretation.

In the Santos Basin (Brazil), two parallel wide-angle reflection/refraction seismic profiles show different crustal structures (Figures 1a and 1b). SB02 shows moderate crustal velocity gradient, and a clear Moho with topography. SB01 has an anomalous velocity zone, and no clear Moho reflections. These differences are located over a clear gravimetric anomaly (Figure 1a). The different structures have large implications on the geological and geodynamic interpretation of the basin. Model uncertainties must be excluded as a source of these differences.

We propose VMONTECARLO (Loureiro et al., in press), a tool that provides a valuable insight on the uncertainties of wide-angle models by exploring the solution space around a preferred model, using unchanged input files from a RAYINVR-based modelling process.

II. VMONTECARLO

VMONTECARLO generates random models and scores them according to the number of rays they are capable of tracing and quality of fit (normalized χ² value) via a scoring function (Equation 1).

On SB01 and SB02, several thousand random models are generated by simultaneous perturbation of all parameters of interest (Figure 2) within given bounds. Maximum positive and negative allowable perturbations are set independently for each parameter.

Model quality dispersion is analyzed via superposition of 1D velocity-depth profiles of each random model coloured according to score. Cross-sections of these plots provide uncertainties on interface depths and propagation velocities at these locations (Figure 3). Histograms for each parameter of interest show the relationship between parameter value and score model (Figure 4). The maximum scores distribution plot (Figure 5) highlights the random models with the best scores.

VMONTECARLO can be used to search for better solutions by outputting the best random model (dashed line Figures 3 and 5).

III. Results and conclusions

All random models with similar or better fit than the preferred model’s are stored and used to calculate the global uncertainty plots, or the maximum and minimum deviations from the preferred model in the whole velocity field (Figures 6 and 7).

The 1D velocity-depth profiles of Figures 1c and 1d hinted that SB01 and SB02 are different, but without knowing the uncertainties of each model, it could be argued that they were the same structure imaged with large uncertainties. Comparing not only the 1D velocity-depth profiles but the overlap of the uncertainty band (Figure 8), we show that the crustal structure of both profiles has a region where it is different.

Using travel times alone, VMONTECARLO is able to distinguish different structures on the SB01 and SB02 profiles. Model uncertainty must be taken into account when interpreting wide-angle modelling results. VMONTECARLO provides a robust tool to assess model uncertainties and highlight or exclude alternative geophysical interpretations from the available data.

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References