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Improvements in land seismic static calculation via simultaneous joint inversion and integrated earth modeling

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SUMMARY

A geological complex near-surface traditionally yields poor quality first arrival picks in land sesmic surveys making use of vibroseis sources. Uphole surveys can reduce the uncertainty, but are costly to undertake. Simultaneous joint inversion used as a static solver in combination with non-seismic data can reduce the number of uphole shots and improve the computed near-surface static solution.

Key words: simultaneous joint inversion, statics

INTRODUCTION

With the growth in geographic scale of land seismic exploration, increasingly complex near-surface modelling capabilities are being employed for static corrections in seismic data processing. In such particularly complex projects, a comprehensive static solution portfolio is crucial. The difficult task of reduction to a normal moveout (NMO)-like elementary formulation is demanded of static shifts that compensate for topography and shallow anomalies. To ensure the required robustness, statics are computed surface consistently rather than angle / raypath dependent. Practical results tend to prefer simple formulations that do not depart significantly from NMO formalism itself, rather than propagation-based techniques that compete with depth imaging.

Statics are primarily derived from seismic refractions or first arrivals, and strongly rely on the quality of gathers. At the initial stage of seismic processing, refractions are the single data input; the solution will be optimized later through reflections after velocity characterization around primary static values. Conventional techniques making use of first break arrivals tend to fail when first arrival quality is poor (as is common with vibroseis sources) and they are also challenged by geological complexity of the near surface such as presence of velocity inversions or low-velocity zones.

In common practise, inversions of first breaks are based on user's interpretation of early arrivals and, therefore, they are subject to systematic errors, especially if picking is automated as for large 3D data sets. In such circumstances, it is desirable to avoid overfitting of observations in inversion. Conventional approaches are missing quantitative criteria and rely on Gaussian statistics, which assume improbable randomness in all possible issues. An active criteria counter to systematic mistakes is presented here, based on statistical benchmarking against independent non-seismic measures.

METHOD AND RESULTS

Data weighting by a-posteriori anomaly consistency

In many cases, it is desirable to interrogate more than one source of information, even heterogeneous, to get arguments for the solution of a problem. For statics, this is implicit in standard methods at the level of a starting model and weathering velocity determination through upholes. Nevertheless, the starting velocity model is practically built in correlation with first break picking and, hence, no fresh information is added to the process at this stage; the model is often a spatial average of the breaks trend.

Upholes are fundamental for weathering velocity determination because normal seismic spreads do not sample the near offsets densely enough. In generalize linear inverse (GLI) refraction statics (Hampson and Russell 1984) or the generalized reciprocal method (GRM) (Palmer 1981), information on the velocity of the weathered layer is required. In the case of vibroseis acquisition, near-surface velocity information typically requires a separate uphole survey, with deeper information coming at the cost of deeper drilling.

While rock physics relations are normally unstable at the near surface, the qualitative concept of localized anomaly can be transported between various geophysical domains, as is normally done in prospect play evaluation. Anomaly distribution consistency between domains is here used as a discriminant of input data through a-posteriori inversion result benchmarking.

A static solver can, therefore, weight more the first break data, which are experimentally confirmed by several independent measurements, rather than contradicting data. Concordance is based on concordant anomaly generation in the a-posteriori inverted model.

This is not a new idea as all static solvers implicitly penalize, at each iteration, contributions of picks that are contradicted by many other seismic shots and confirmed by few or none. The addition of information independent from first breaks can provide an additional weight at decreased covariance with hashed solver information.

Simultaneous joint inversion statics

Each kind of seismic first arrival inversion suffers from velocity-depth ambiguity (Ackermann et al,. 1986); in the presence of vertical velocity inversions, an infinite quantity of equivalent models can generate the same first break distribution (Figure 1). In such a case, it is practically difficult to resemble velocity inversion in picking and the issue is transparent to automated pickers. In addition, other practical issues of conventional statics include the survey design for upholes when the acquisition is vibroseis; the budget is limited and the near-surface geology unknown.

Simultaneous joint inversion (Colombo and De Stefano, 2007) is an emerging tomographic technique that allows exploitation of multiple data types linked through the earth’s structural or petrophysical properties. Used as static solver, the tool allows even replacement of uphole shots by more cost-effective surface soundings such as gravity, electromagnetics, and/or Rayleigh waves from the seismic data set to constrain a velocity model. Single domain inversion of the individual data types are used to determine a statics starting model that is then refined through joint inversion with links provided by rock physics relations. This approach has proved effective and robust in overcoming local or systematic errors in seismic first break interpretation.

Examples

Frequently, complementary data provide themselves a solution in the sense of downweighting the inconsistencies. As it is introduced in the solver, with a starting model obtained by a first break tomographic method like tau-p refraction (Osypov, 2000) with questionable picks, we can easily obtain a good fit if the error in interpretation is more systematic than random (Figure 2, top). Stack images with statics derived from such models are usually inferior and show nongeological horizon topographies as a result of incorrect long-period anomaly distribution in the model. In such cases, EM (Mackie and Madden 1993), gravity gradiometry, and Rayleigh waves (Strobbia et al., 2010) may easily agree on a totally different anomaly distribution; all of these measures do not suffer from parameter inversion issues like velocity-depth ambiguities. Surface waves have a detail comparable to seismic upholes and can detect the base of fast refractors, which can be difficult for tomographic methods.

If EM, gradiometry, and Rayleigh waves are introduced as additional inputs in the solver, first break picks carrying information consistently contradicting support data are down-weighted while allowing larger error bars in rock physics trends. When this is applied, first break distribution of residuals usually expresses bad fit in large regions of offset and space (Figure 2, middle). When this effect is observed, seismic stack response to statics is inspected in comparison with an unconstrained tomographic solution. Often, the comparison is strongly in favour of simultaneous joint inversion statics (Figure 3 and Figure 4), which indicates that a bad fit of a first break is due to avoidance of overfitting bad first breaks; the solver was able to abandon the criteria of maximum data fit, discarding the erratic information, which otherwise would show up as coherent noise on stack images. Statics in simultaneous joint inversion gain independency from first breaks and from consistently wrong information that these may carry. The technique operates as a discrimination of information quality, based on mutual benchmarking of independent measures.

To summarize, SJI statics are a way to clean up first breaks of structurally (or petrophysically) inconsistent information. Evaluation of structural robustness is taken from direct measurements, avoiding interpretation, as happens with EM and full-tensor gravity. Even if they are not direct measures, picking of non-refracted waveforms like a dispersion curve for Rayleigh waves is performed independently from first break and, therefore, cannot correlate the errors across the two interpretations.

The same benefits are observed for the support data types; using a concordance criterion based on concordant anomaly generation in the a-posteriori model, those types benefit from first break and other measurements to penalize noise, equivalency in solution, or noise in parameter picking. While penetration depth and resolution vary with the type of complementary data available, the P-velocity obtained through SJI of surface data generally extends deeper than that required for static correction. Velocity models developed through this approach do not suffer from velocity-depth ambiguity and provide a well-resolved shallow model for seismic depth imaging.

CONCLUSIONS

Conventional approaches for statics lack a quantitative criterion for systematic error protection and rely on randomness of errors. An active criterion to counter systematic errors was presented. The technique is based on simultaneous joint inversion; therefore, a statistical benchmarking against independent non-seismic measures is done in a single solver.

REFERENCES

Ackermann, D., Pankratz, L., and Dansereau, D. [1986] Resolution of ambiguities of seismic refraction traveltime curves. Geophysics, 51, 223.

Colombo, D., and De Stefano, M. [2007] Geophysical modeling via simultaneous joint inversion of seismic, gravity, and electromagnetic data: application to prestack depth imaging. The Leading Edge, 26(3), 326-331.

Hampson, D., and Russell, B. [1984] First-break interpretation using generalized inversion. Canadian Journal of Exploration Geophysics, 20, 40-54.

Mackie, R. L., and Madden, T. R. [1993] Three-dimensional magnetotelluric inversion using conjugate gradients. Geophysical Journal International, 115, 215-229.

Osypov, K. [2000] Robust refraction tomography., 80th Annual International Meeting, SEG, Expanded Abstracts, 2032-2035.

Palmer, D. [1981] An introduction to the generalized reciprocal method of seismic refraction interpretation. Geophysics, 46, 1508-1518.

Strobbia, C., Vermeer, P., Laake, A., Glushchenko, A., abd Re, S. [2010] Surface waves: processing, inversion and removal. First Break, 28.

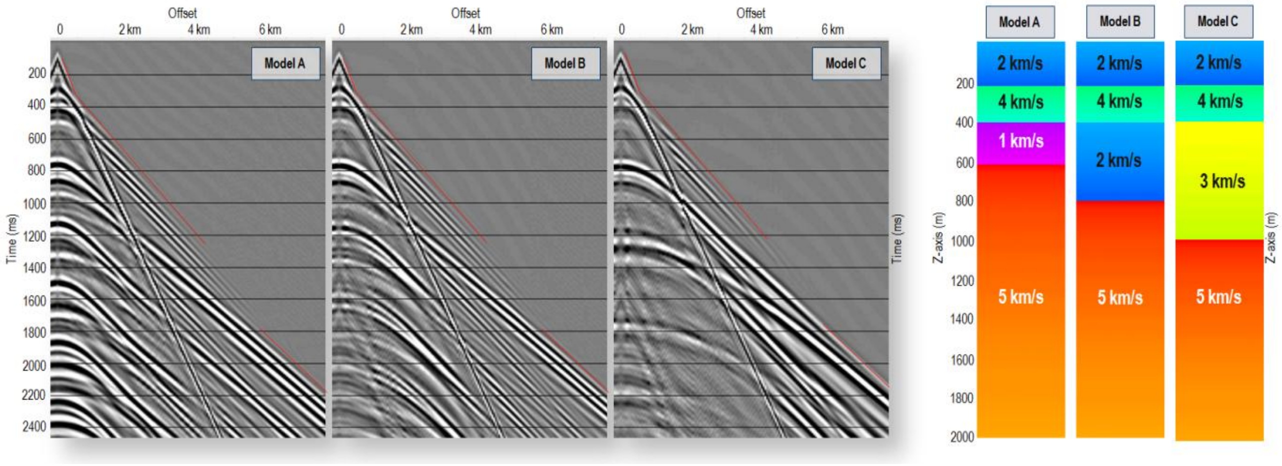

Figure 1. Shot gathers produced by three refraction-equivalent 1D velocity model (Right). The identical first break trend (picked in red) can be inverted obtaining equivalently model A, B, or C.

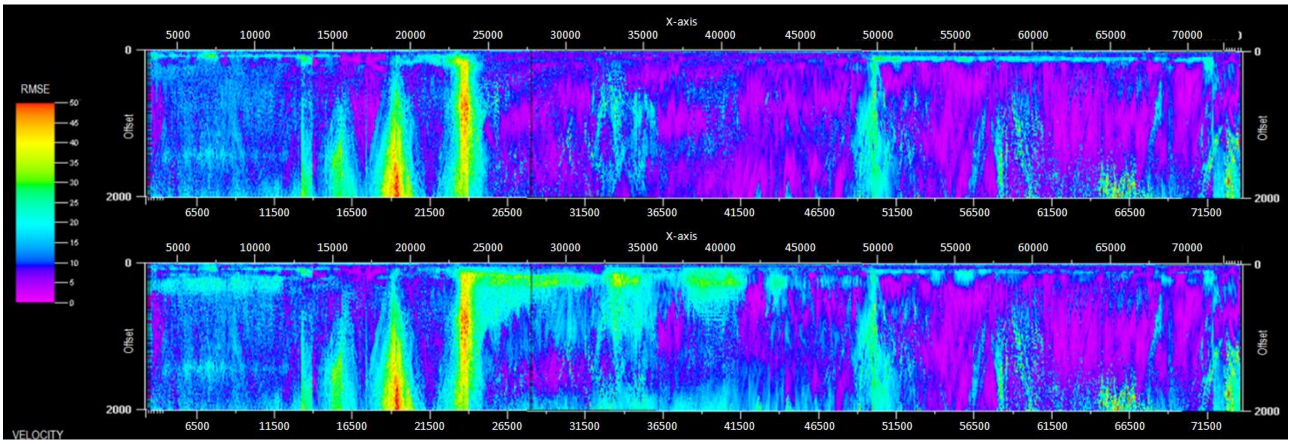

Figure 2. Result example of simultaneous joint inversion of first breaks and electromagnetic (EM) imaging, gravity, and Rayleigh waves; space-offset residual diagram of first breaks in ms for the unconstrained tomography case (top) and SJI (bottom). First Break (FB) residual in simultaneous joint inversion (SJI) is increased in left/centre of the line, corresponding to stack improvement in Figure 3.

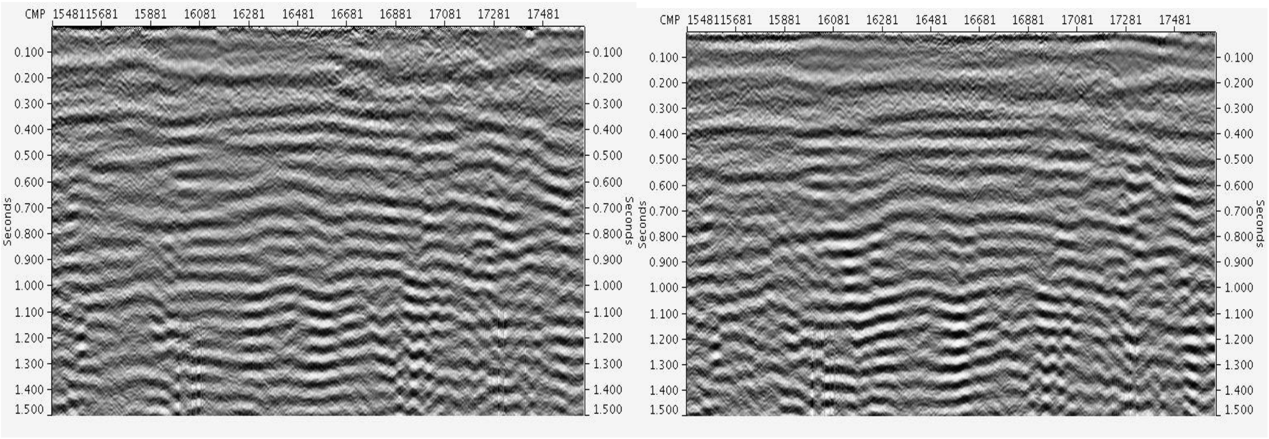

Figure 3. Result example of simultaneous joint inversion of first breaks and EM, gravity, and Rayleigh waves; statics time section for the unconstrained tomography case (left) and SJI (right), for the left/centre portion of model in Figure 2. Right side of line is equivalent across the methods.

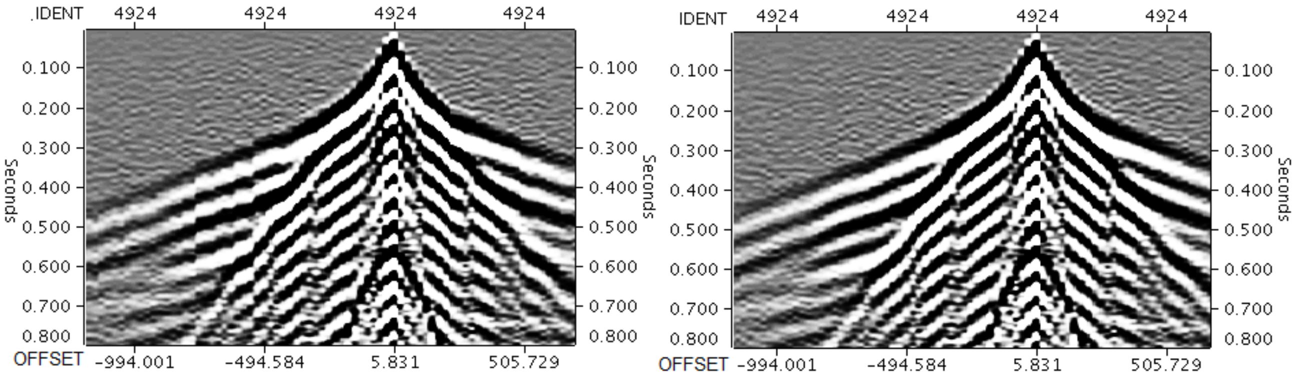

Figure 4. Result example of simultaneous joint inversion of first breaks and EM, gravity, and Rayleigh waves; shot gather after statics application for the unconstrained tomography case (left) and SJI (right). Prior to velocity analysis, short wavelength methods such as Rayleigh waves drive the SJI solver to an improved high resolution static.