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Integrating Petro-elastic Seismic Inversion and Static Model Building

P. Gelderblom* (Shell Global Solutions International BV)

SUMMARY

This presentation focuses on various aspects of how the results from stochastic, petro-elastic seismic inversions can be used in 3D static models. Scale issues can be handled in the inversion, in a downscaling step, or by working on a single scale. For an update to be consistent in both time and depth, the inversion should also do geologically meaningful structural updates. The uncertainty estimates provided by the stochastic inversion should drive the amount of variability in the static model(s).

The structural part of a static reservoir model is always built using seismic data, but seismic data can deliver more than structural information: it can also provide information to drive the facies distribution and properties in a static reservoir model. Seismic interpretation will generally provide the coarse structure (in time) of the reservoir model, but not the properties. Seismic inversion potentially can deliver property information. Promise (Leguijt, 2001, 2009; Gelderblom & Leguijt, 2010) is a Shell proprietary stochastic model-based petro-elastic seismic inversion algorithm. In this presentation we'll look at various aspects of how the results from such an inversion can be used in 3D static reservoir models.

Vertical scale

The first decision to make is the vertical resolution at which the static model will be built. Figure 1 shows that different choices are possible here. Often, static reservoir models will have a vertical scale finer than the inversion model (e.g. 1 versus 30m). But this is not always a given. For *first pass modeling*, it is preferred in many cases to build a coarse scale static model (at the acoustic scale) first. In that case, properties derived in the inversion can be used directly in the static reservoir model. Refining the static model is only warranted if modeling the fine scale heterogeneity will deliver permeability contrasts relevant for subsequent reservoir modeling. If a fine scale static model is needed, some form of *downscaling* will be needed to use acoustic scale inversion results in the fine scale static model. Alternatively, it is conceivable to run the seismic inversion itself on a fine scale model. As the seismic data does not contain enough resolution to constrain the model at that scale, it is important to include continuity constraints in the fine scale inversion. In earlier work (Gelderblom & Leguijt, 2010) we have shown how 2D variograms can be included in petro-elastic inversion. For fine-scale inversion, 3D variograms will also be required.

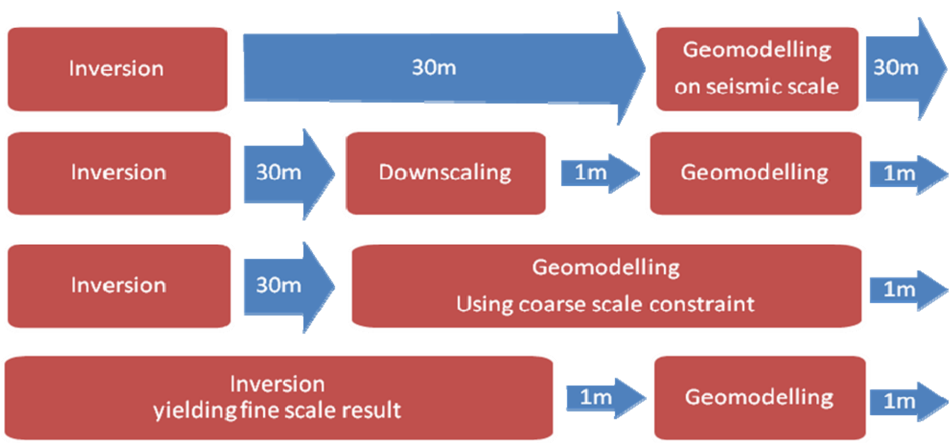

Figure 1. Different ways to handle scale when combining seismic inversion and static reservoir modelling.

Time/depth match and thickness updates

A petro-elastic inversion tries to update the geological properties of layers in a model (e.g. porosity, net to gross, fluid content) in such a way that the synthetic response of that model matches the observed seismic. Updates of reservoir or fluid properties usually imply velocity changes. This means that -in order to match the travel times on the seismic data- updating a property implies the layer thickness must also be changed. This is not a fundamental problem, but it can be a problem in established workflows where construction of the structural model and filling in layer properties model are done sequentially. This is illustrated in the top two sections in figure 2. A pre-inversion model in depth is shown at top left. This model is based on time-interpreted horizons. Time to depth conversion has been performed using a velocity cube derived from processing velocities and checkshot data. In the depth domain, infill layers have been created, initial property modeling has been performed and a petro-elastic model has been assigned. When we use the velocities computed using the petro-elastic model from the model properties (porosity etc.) to do a depth-time conversion, the match with the interpreted time horizons (shown top right) is no longer perfect. This is caused by the difference between the velocities used in the velocity cube and those computed from the static model. Seismic inversion must yield a result that matches the time-interpreted events (shown in the time sections on the right as purple lines) as well as the seismic wiggles (not shown here), using one property model. If we would only allow the properties to change, we would implicitly specify that the thicknesses are exactly known. This is not true away from the wells, and it would lead to unrealistically large property updates.

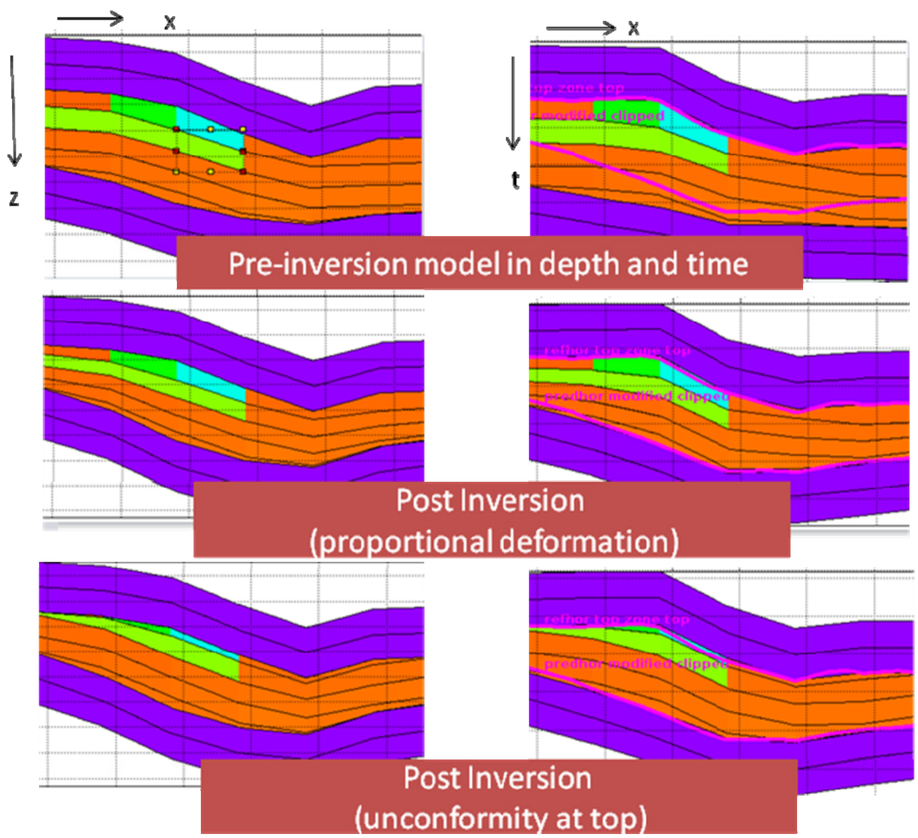

Figure 2. Maintaining geological integrity in inversion using different perturbation methods.

Model perturbation methods

If we do allow structural updates during the inversion, it is important that these updates are geologically meaningful. If we just make all layer thicknesses variable, the inversion result may be ‘jumpy’ and/or geologically unrealistic. The inversion needs to be provided with information on how the geological integrity of the model can be maintained while perturbing the thickness between major acoustic events. In Figure 2, we show an example of how this can be accomplished. If we make all thicknesses independently variable, the fit in time will be accomplished but the thickness relationship between the layers may be compromised. In figure 2, it is shown how thicknesses can be perturbed while keeping geological integrity by choosing a *thickness perturbation method* for a package of layers. Two out of several perturbation methods are shown: one that simulates an unconformity at the top of the package, and one that perturbs all layers proportionally. Geological insight is required in the choice of the perturbation method. The perturbation methods shown here are relatively simple: there may be depositional structures for which such a method is not applicable. In addition to that, these simple perturbation methods only modify an initial model, but they do not generate alternative models that may also be plausible given the available data (e.g. 3 channels instead of 2).

Downscaling and propagating uncertainty

When inversion is run on a coarse scale and the results need to be incorporated in a fine scale static reservoir model, some form of *downscaling* is required. The uncertainty estimates provided by stochastic inversion should drive the amount of variability in the static model(s). We have investigated how well different downscaling methods can provide uncertainty propagation, when the geological constraints are defined by 2-point geostatistics. Results for 2 algorithms are shown in figure 3.

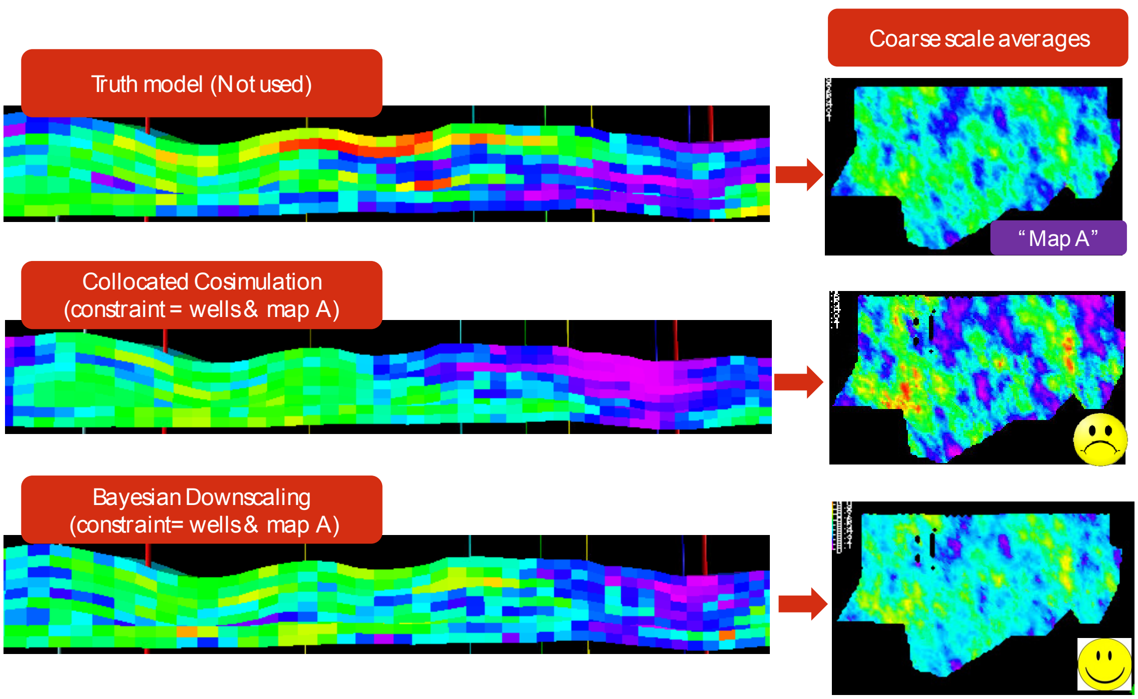

Figure 3. Comparison of two downscaling algorithms on synthetic data.

The top row in this picture shows a section out of a truth model, generated using a 3D anisotropic variogram. This property realization is considered our 'truth model', but it is not used in further computations. Just like in reality, only partial data will be available to the algorithm being tested. The following data is available as input to the downscaling algorithms:

- For 10 vertical wellbores, we have extracted pseudo-well data from the truth model
- A coarse scale property map derived by vertically averaging the truth model. ("Map A" in Fig 3.) This represents our coarse scale seismic inversion result.
- An estimate of the uncertainty of the seismic inversion result

- The variogram used to create the truth model

The results for conventional collocated co-simulation (CCS) and Bayesian Downscaling (Doyen, 1997) (BDS), are shown in figure 3. The results of Bayesian Downscaling have a better fit with the coarse scale map, and better control over this fit by specifying the coarse scale standard deviation. CCS does provide a 'knob' that allows control over the amount of influence the secondary variable has on the end result, but it does not work as well as specifying the standard deviation in BDS. Also, the reproduction of the vertical variogram is better in BDS. The reason is that CCS copies the coarse scale map to all individual layers and then uses it as if it were a fine-scale constraint. This introduces more vertical correlation than desired, as can be seen in figure 3: the heterogeneity pattern of the BDS realization is more similar to the truth model.

Discussion and conclusions

We have discussed various aspects of coupling stochastic petro-elastic seismic inversion and 3D static reservoir modeling. It is important to make proper decisions about the scale at which inversion and modeling are performed. These decisions require input from multiple disciplines: geophysics, geology and reservoir engineering. Acoustic scale inversion is simpler, but it may require a downscaling step after the inversion if the static reservoir model is on a finer scale. Fine scale inversion may not require subsequent downscaling, but it is generally under constrained and therefore needs more regularization, e.g. in the form of 3D property variograms. Independent from the scale chosen, for any property-based inversion, property changes will imply velocity changes. As a result, such inversions will always require perturbations to the structural model. We have shown how such updates can be done while maintaining geological consistency. If the inversion is on a coarse scale and the static reservoir model on a finer scale, a form of downscaling will be required. Bayesian Downscaling is better at reproducing the uncertain inversion results at fine scale than collocated co-simulation.

References

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