PGS hyperBeam – rapid scenario-testing of velocity models to optimize depth imaging

Introduction

Depth imaging is now established as a key technology for producing optimal seismic images for the exploration and production of oil and gas resources. The improved focusing and accuracy in the depth images allows easier reference to wells, well-logs and production data in general. With an accurate velocity model in place, most depth imaging algorithms can produce very good images, even in areas with very complex geology, such as in the presence of salt and thrust folds. However, the fact that the velocity model needs to be of sufficient accuracy for it to enable accurate imaging reveals the key challenge for any depth imaging technology: how to derive an accurate sub-surface velocity model and image from a dataset recorded on the surface?

When searching for structures in an early exploration phase when there is very limited well control, the velocity model is again key, as it controls the wave propagation used in the imaging algorithm, and hence has a direct impact on the final structural image. There is a really important role to be played for a tool that enables us to do scenario testing of structural elements in the model, velocity profiles etc and provide data into an interactive 3D visualization suite for viewing and analysis by a cross-disciplinary team. We will illustrate that the integrated toolbox we have developed can allow for real-time investigation into this and other related questions, as it allows for a seamless interaction with the velocity model and the seismic image.

Rapid scenario building will also play an important role in the well planning and drilling process. Whereas currently operators tend to rely on a static seismic image, produced a long time ahead of the actual well planning process, a fast, accurate and integrated velocity model building tool can integrate measurements taken during drilling, such as MWD tools, salt boundary picks etc. In this way, it can allow for real-time updates to the surface seismic image.

Summary

As we finalise this TechLink, PGS has been named as the recipient of the E&P Meritorious Award for Engineering Innovation in Exploration Technology for its development of PGS hyperBeam, a fully integrated real-time model building and depth imaging workflow environment.

Depth imaging workflows can take days to complete with time spent not only running the various applications, but also with data and system management. PGS hyperBeam allows for real-time analysis and interaction with velocity models and seismic depth images and gathers. It provides scenario testing and real-time data analysis of all steps in the depth imaging workflow. The seamless integration with 3D visualization makes the tool ideal for collaborative work on depth image projects for exploration and well planning. The impact of model updates and changes can be analyzed real-time, in a setting that is familiar to such cross-disciplinary teams.

For example, when drilling a sub-salt well with an uncertain base, the full seismic image can be updated when the drilling process confirms the position of the base, allowing for improved imaging in the sub-salt target area.

Such rapid model building and updating as outlined above is hampered by many fundamental limitations in the currently available solutions. We describe an integrated solution that overcomes the drawbacks of conventional

systems and workflows to achieve rapid model building and fast interactive editing of models. This integrates seamlessly with migration modules to enable testing of a range of alternative depth images and understand their sensitivities.

PGS hyperBeam overview

PGS hyperBeam is a real-time velocity model-building solution developed around three core technologies: visualization, model building, and workflow.
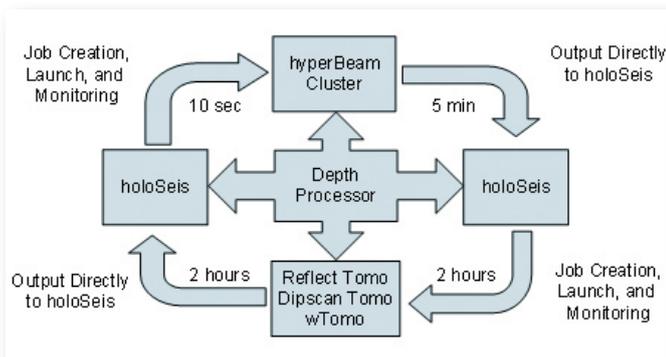
Figure 1. Overview of the PGS hyperBeam.

hyperConnect Workflow Engine

The goal of this workflow is for the model builder to access all tools and functionality within an internally developed visualization system. This might, for example include running velocity models on the computer cluster or using processing algorithms for Dipscan Tomography.
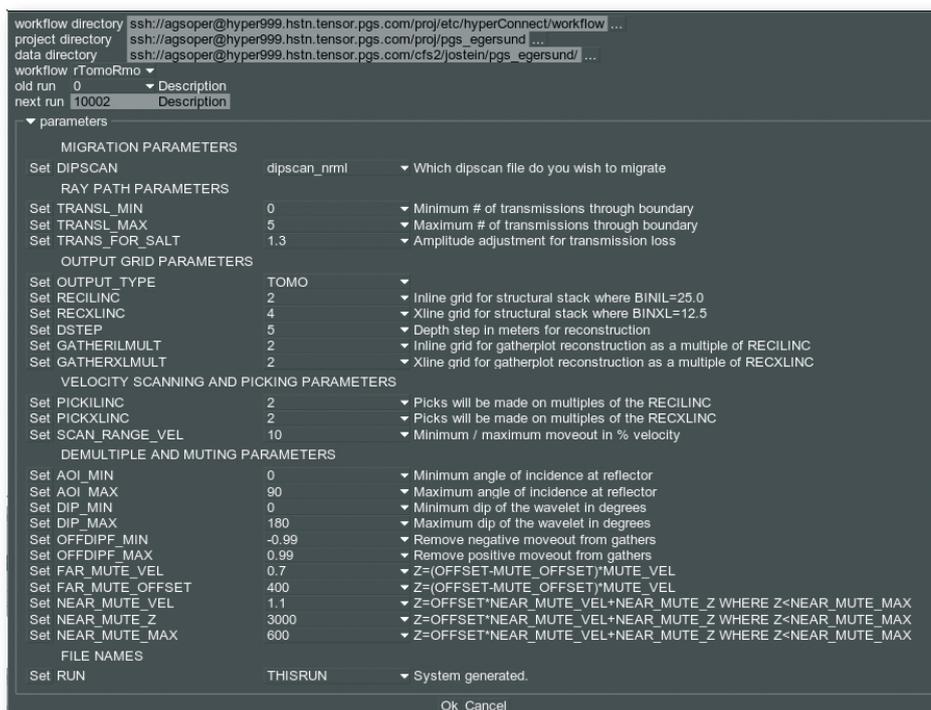
hyperConnect consists of three major components; system modules, workflow engine, and monitoring system. The workflow engine allows geoscientists to define high-level workflows that automate both simple and complex model building sequences. A workflow consists of one or more steps with each step consisting of one or more system modules.

The model builder accesses hyperConnect via holoSeis, PGS' 3D visualization and model building tool. When a workflow is selected, hyperConnect presents the user with the parameters and values required to execute each of the modules called by the workflow. Parameters that are used by multiple modules (grids, mutes, etc) only appear once, reducing training time, errors and simplifying the user interface.

With many previous velocity modeling solutions being difficult to use across exploration teams, simplicity and workflow control were a key driver for the user interface *(see figure 2)*.

System modules allow hyperConnect to directly interact with disparate seismic processing applications. Modules handle everything from QC'ing inputs, job creation, job launching, data conversion, load balancing, error detection, and system cleanup. Current modules include migration, reconstruction in time and depth, stack, velocity scanning, picking, reflection tomography, dipscan tomography, post-processing, and file output.

As a workflow is executing, hyperConnect's monitoring system directs each module's outputs directly to holoSeis. Output types include QC products (stacks, gathers, models, pick, gamma fields), error messages, and statistics. In the case of files, holoSeis automatically loads the file and alerts the user to its availability. Error messages are automatically displayed to the user.

The 3D visualization suite also plays a key role as the front end of the workflow, allowing for the viewing and analysis by cross-disciplinary teams and providing control and QC at every stage of the model building process.

Figure 2. An example of the user interface used to control the processing flow from within the visualization tool. Number of parameters are reduced to the essential geophysical parameters.

Simplifying and Speeding Up a Complicated Workflow

Let's take an example of a traditionally complex workflow - estimating residual curvature on depth migrated CRP gathers as data input for reflection tomography. Such a workflow interacts with seven different applications including migration, reconstruction, stacking, velocity scanning, residual picking, and applying residuals to the input gathers. QC products from this workflow include:

- a course grid of gathers with and without residuals applied to QC the quality of the picks

- a pick volume allowing picks to be overlaid on the gathers and seismic. This volume can be edited within holoSeis to remove problem picks

- a gamma volume (percentage residual stacking velocity) generated from the pick volume. This is overlayed on the stacks and gathers to QC the velocity update on the structural seismic

This workflow typically takes 2-3 days due to its computational cost and complexity. Generating gathers, even on a coarse grid, with Kirchhoff is expensive. The velocity model is output from the visualization system and used to compute travel-time tables required for Kirchhoff migration. The output gathers are input into a stacking module and scanned for the given velocity range. The velocity scans (20+ files) and stack are input into the picking module, which in turn outputs RMO curves and slopes. The RMO curves are then applied to the original gathers and converted into a gamma volume. Each step in this process may require:

- the scheduling of compute resources
- interaction with one or more applications
- the conversion of file formats
- copying one or more files between systems
- entering parameters into a user-interface
- QCing job logs and output files

It should be noted that the grid and velocity parameters change many times during the model building sequence to capture both low-frequency and high-frequency velocity variation. Each parameter change requires the model builder to update parameters in one or more modules used in the flow, another time consuming and error prone process.

With PGS hyperBeam, all of the parameters required for the entire flow are entered into a single form visualized directly within the holoSeis interface. The hyperConnect workflow engine schedules the compute resources and flow the parameters and data from module to module. At the end of each step, run logs are scanned for errors and QC outputs loaded directly into the visualization for review by the model builder. Using PGS hyperBeam, generating all of these products for an 800km2 area takes from 5-10 minutes. This allows the model builder to test different pick grids, velocity analysis windows, and demultiple settings at each step in the model building resulting in an improved velocity model, more accurate depthing, and clearer structural imaging.

The result, as this example demonstrates, is a faster and better velocity model with reduced cycle times and a real-time interactive environment.

PGS hyperBeam provides additional workflows to automate model building. Scanning for eta is required for building anisotropic velocity models. The current workflow requires three migrations on a coarse grid, each with a different value of eta. Each scan has the overhead of typically days for setting up and executing a migration and generating gathers. The PGS hyperBeam workflow automates this process and provides the model builder with three full volume stacks and gathers for QC in 20 – 30 minutes.

Scanning for different velocity models is also supported allowing the model builder and interpreter to directly interact when the interpretation is being applied to the velocity model. This is particularly useful when there is a difficult horizon such as top/base salt/basalt/carbonate. Different horizons and their impact on the model can be evaluated in 1 or 2 hours instead of days or weeks.

PGS hyperBeam also provides workflows that access the wavelet attributes generated during dipscan and migration. Workflows for scanning for angle of incidence, dip, azimuth, and ray path of the reflector, allow the model builder to decompose the migrated wavelets into separate sections based upon one or more attributes. These sections can be used during the model building and also during interpretation.

Angle of incidence and dip attributes can be used to improve gather quality by removing unwanted events from the volume. An example would be removing angles over

50 degrees or dips over 70 degrees from a section prior to estimating residual curvature.

During interpretation, azimuth scans can separate criss-crossing events, allowing the interpreter to see each of the azimuths separately resulting in a better understanding of the structural picture. Attribute scanning takes between 5-10 minutes for three full volume stacks with gathers.

Model building

A three-dimensional subsurface model is generated by several building blocks: Horizon surfaces are used to define topologically robust 3D units that can be assigned a number of different properties. For example, in a TTI model relevant properties would be velocity, delta, epsilon, slope in X direction and slope in Y direction. Each 3D unit or building block is assigned values, either as a constant, values from a map, or a linear function Az+B where A and B may be a constants or assigned from maps, or the building block may get values assigned from an existing volume, e.g. a tomography run. Single-z, multi-z or a combination of these may be used in the building block generation process. This process is referred to as 'detection', and is described in detail in a later section.
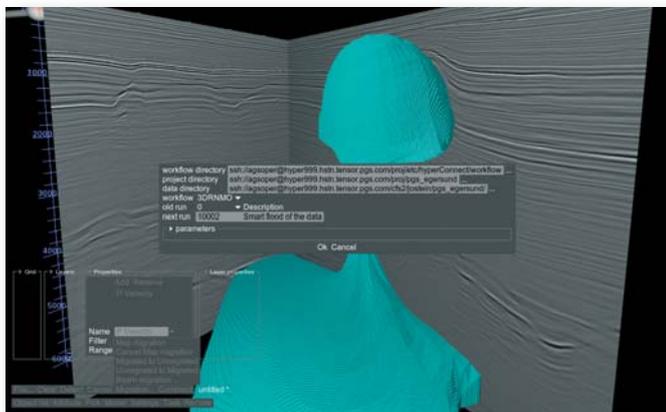
Figure 3. Note how the model of the salt structure exists together with the processing flow user interface. The cyan geobody is the result of a single pass 'Closed' detection on the multi-z top salt horizon and a single-z base salt horizon.

Single-Z horizons and Multi-Z horizons

Editing and handling of single-z horizons is currently a common work practice in the industry. A combination of 3D and 2D automated and manual horizon picking has been developed as part of the model building capabilities of the new solution.

One can start with a single-z horizon and easily convert it to a multi-z horizon if required. In our solution multi-z horizons are built up by a set of multi-z segments ('sticks'), which in turn are constructed of a string of control points. A stick can have any number of control points, and a multi-

z surface may consist of any number of sticks. The editing of the multi-z surface is done by manipulating the control points in the 3D space. This editing is fully interactive, and is optimized by performing the triangulation of the surface as a multi-threaded process in the background. As a result the user can create any 3D shape and deform it in an efficient and interactive manner.
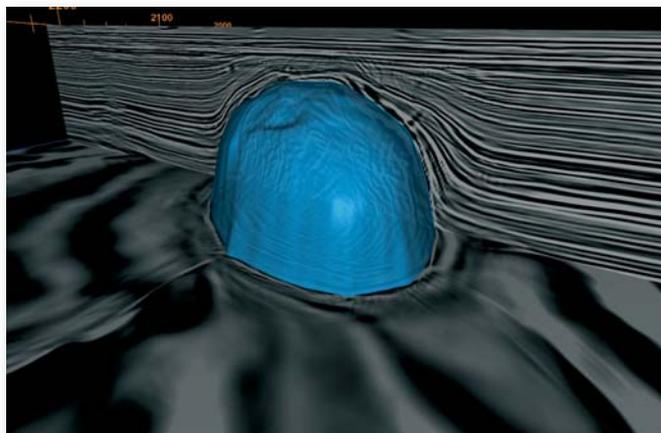
Figure 4. An example of a single-z horizon. This horizon was used to generate the basis of the multi-z top salt horizon shown in figure 5.

Figures 3, 4 & 5 demonstrate examples of single-z and multi-z horizons in salt structures. The performance is better described by watching a video rather than reading text. A video describing this editing in real time is downloadable from pgs.com

(http://www.smartcom.no/pgs/embed/hyperBeam.php)
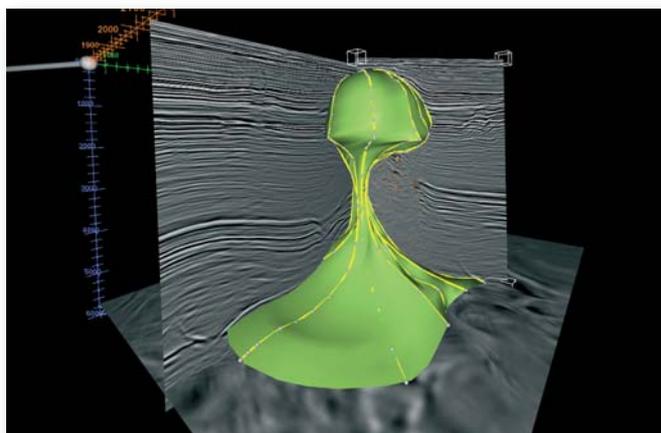
Figure 5. Multi-z horizon representation of a salt structure on a Norwegian North Sea dataset. The grey spheres along the yellow lines are control points. These control points may be interactively edited.

Model detection

There are three different methods when doing detection. Basic detection will look for horizons and generate a new building block when crossing a horizon. This method is typically used when building layer based velocity models. The 'Between' method of detection

takes two horizons as input, one top and one base. The detection will then build up one building block between the top and base horizon. This is useful when working with salt structures described by single-z horizons. The third method of detection is the 'Closed' method. This method searches for any geological body that is completely enclosed by a combination of horizons, including multi-z horizons. It is typically used on salt structures that are described by a multi-z horizon.

The detection can work on the entire volume, or parts of the volume. Typically in a layer based model, the layers above the current working one will be fixed, and the detection algorithm will not go through those layers again. This can also be useful when working with a very complex model. Parts of the model may be best detected with one method, and other parts with another method. Fixing a layer after the first detection makes it possible to combine these methods.

When the detection is complete, building blocks may be merged or deleted. Merging building blocks is useful in the event where the detection generates a more complex model than desired.

Model editing after detection

A complete velocity model may also be edited by interacting with the velocity volume directly. Selecting voxels is either done by making a polygon of interest on a depth slice or selecting a range of existing values in the volume to edit.

The polygon selection can be further restricted by giving a top and/or bottom limit, typically a depth horizon. When the geobody or range is selected, new values can be assigned by manually giving a new value as a constant, or by interpolation. The interpolation uses surrounding values and works on a depth slice by depth slice order. However, if the surrounding values are located above the top horizon used as limit or below the bottom horizon used as limit, then the interpolation is rather done on a down up or up down basis. This is to ensure that velocities that belong to a different geological structure do not "leak" into the geobody that is edited. A vertical linear interpolation is also available. This method will use values directly above and

below the geobody that is edited and linearly interpolate on a trace by trace basis.
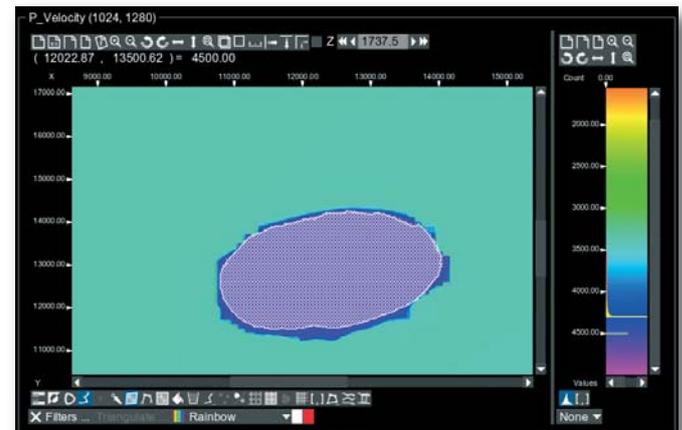
Figure 6. Volume editor. An area is selected on a depth slice. This area will create a cylinder like shape in the 3D display. The top and/or base of this shape can be limited by a horizon, thus a full 3D geobody is created. The histogram on the right may be used to select a range of values in the volume, rather than a geometric shape.

Traces in the velocity volume may also be edited manually on a trace by trace basis. This method allows for fine tuning of the model when required.
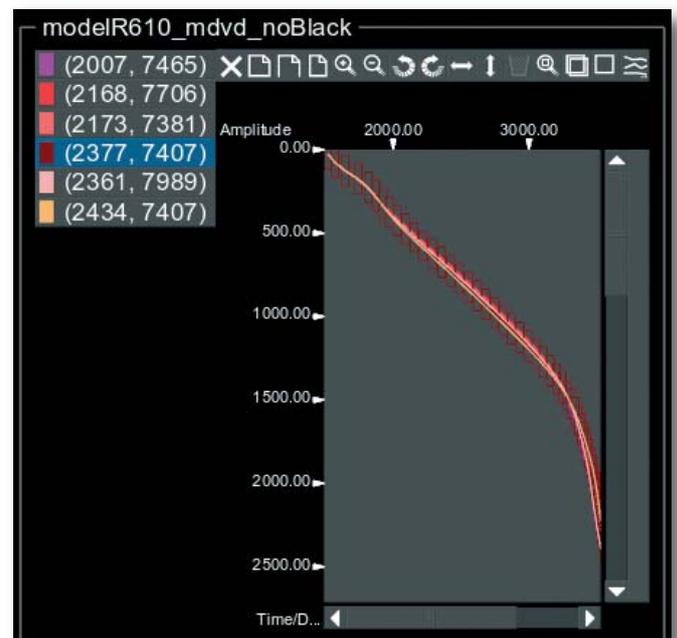
Figure 7. The trace editor. If desired, individual traces and samples may be edited manually. The figure shows six traces and their velocity profile. The highlighted trace (2377,7407) is displayed with boxes around each sample. Single samples may be edited or a new trace may simply be drawn in place of the existing one.

With the combined power of the efficient model editing tools described above and the rapid migration, workflow and visualization tools described previously, we now have a vehicle for full volume, depth-imaging scenario testing.

Scenario testing

Reduced cycle times enable multiple velocity model scenarios to be tested within existing budgets and timeframes, leading to more accurate and robust models.

The new tool has the ability to rapidly develop and test different velocity models all the way from reflection tomography to salt and chalk interpretation. We also have workflows for testing of more processing related parameters such as mutes, and target oriented de-multiple. The latter can be guided by reflector dip, again opening up for scenario testing in areas of bad signal and conflicting dips in the images.

One problem we have been dealing with in salt provinces is related to salt geometry. Our workflows and tools allow us to rapidly modify and sculpt salt geometry, produce an updated velocity model, and then see the impact the model change had on the image. This enables testing of multiple salt geometries and scenarios, and the resulting models can be used for subsequent RTM and WEM imaging.

The next step of this development is to integrate the imaging and analysis tools into a stochastic inversion framework, eventually providing us a much better handle on the uncertainties in the images we produce.

Measured impact of integrated visualization and computation

Feedback from PGS hyperBeam users has been positive. The first PGS hyperBeam projects were focused on two narrow azimuth surveys (6km offset) between 600 and 800 km2. The project team consisted of geophysicists, model builders, and interpreters. They completed 51 workflows in 3 days, including 14 full model migrations, six full model updates, and re-interpreting horizons in targeted areas. The project team estimated that three weeks of work was completed during this time and that the PGS hyperBeam session resulted in a superior product due to the compressed timeframe and constant interaction between interpreters and geophysicists.

Conclusion

Direct integration of the model building system with the compute environment provides a unique new tool for exploration teams. By automating the flow of data and parameters through efficient processing systems, we can finally work interactively with model building systems, allowing interpreters and geophysicists to efficiently interact during the model building process. The integrated collaborative workflow ensures that a fragmented workflow is a thing of the past and brings the geologist and geophysicist closer together. The resulting model accuracy improves the focusing in all imaging algorithms which in turn improves the geological understanding of the area, simplifies references with well data, and reduces drilling uncertainty.
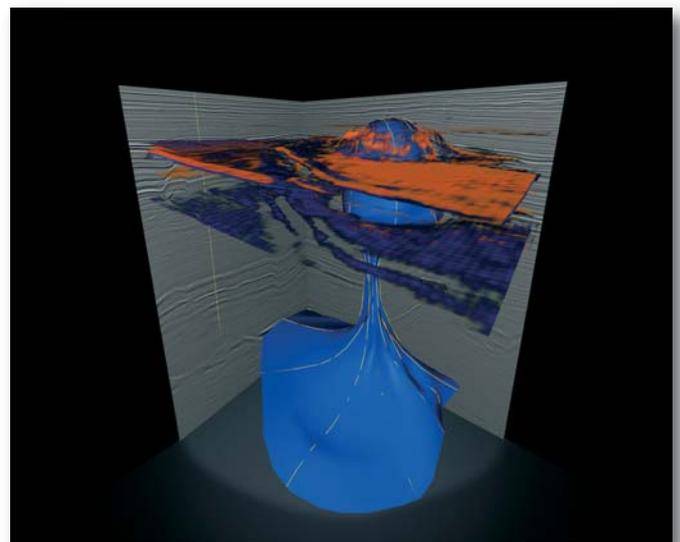
PGS hyperBeam is a tool for building better and more efficient velocity models such as this one from a salt structure in the North Sea.

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