

Ten Reasons why 3D Geo-modeling and Flow Simulation Must Be Integrated

Emmanuel Gringarten, Paradigm

Flow simulation is the reservoir engineer's tool of predilection, providing understanding of how fluid flows through the reservoir and how it can optimally be extracted. 3D integrated geo-modeling software is becoming the platform of choice for geophysicist and geologists who are slowly leaving their single discipline workstation. The 3D modeling environment provides ways to integrate all sorts of geophysical and geological data to provide a numerical representation of the reservoir architecture that is then used as input to the engineers' flow simulation.

Today, what links geoscientists and engineers is the hand-over of the 3D reservoir grid filled with petrophysical properties. This "link" is currently accomplished through awkward file exchange formats that lose all knowledge relating the creation of the final 3D model. Nonetheless, this is the model that will be used by engineers to estimate reserves and optimize development plans. It is accepted that the integration, which exists between the geosciences based on the concept of a shared earth model, has proven to be fundamental to the increased accuracy of reservoir models. Yet, at the most crucial stage of the process - the one where production decisions are made, multi-disciplinary software integration is often dismissed as being too cumbersome by both geoscientists and engineers.

We strongly believe that a direct integrated link between the two is fundamental to allow quick iterations that ensure consistent reservoir models. It is the logical next step after a decade of talking about integration, which started with the intro-

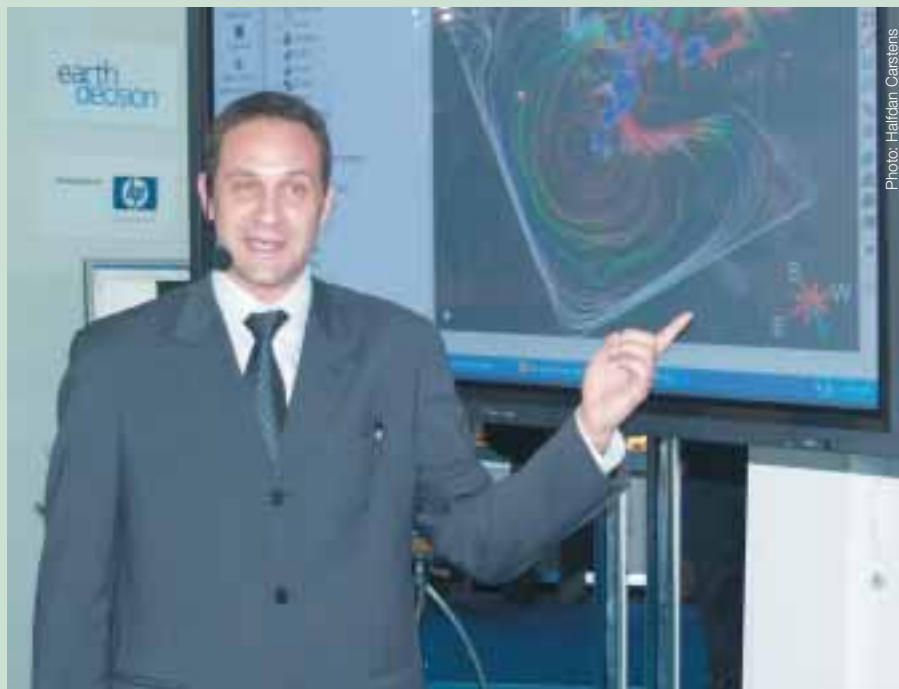


Photo: Haldan Carstens

Emmanuel Gringarten, demonstrating the Reservoir Simulation Interface module of the Earth Decision Suite at EAGE tradeshow in Vienna this June. Emmanuel Gringarten is Product Manager at Paradigm for the Reservoir Product Line of the Earth Decision Suite, powered by Gocad, focusing on the development of workflow-driven integrated applications for consistent construction of reliable 3D reservoir models. He holds a BSc in Mathematics from Imperial College, London, and Masters and PhD in Reservoir Engineering from Stanford University. Emmanuel has been involved in many reservoir modeling projects, specializing in geostatistical and uncertainty modeling.

duction of corporate databases. These enabled the smooth transfer of interpretation data between distinct disciplines, essentially geophysics, petrophysics and geology. To continue the smooth transfer of information, one must be able to launch flow simulations from the geo-modeling environment; routine-engineering tasks such as history matching and field development optimization must consider the geological model and, most importantly, the uncertainty inherent to that model.

The following 10 points will highlight some of the key reasons why 3D geo-modeling and flow simulation must be part of the same software package.

1 - Validation of up-scaled reservoir models

Up-scaling is a required step in most reservoir studies; it consists of creating a

3D reservoir grid at a resolution coarser than the geological model then averaging the rock properties (generally rock type indicators, porosity, and permeability) distributed on the finer scale model, to the resolution of the coarse scale flow simulation model. This step is done most of the time by the geoscientist who constructs the geological model. Yet, there are two very important aspects of this task which require engineering input. The first one is the construction of the flow simulation grid; it must address fluid flow issues and conform to the direction of flow, unlike the geological model which must be aligned with the depositional processes. The second is the up-scaling of permeability, which is a dynamic property, whose non-linear coarsening behavior must be assessed using small-scale fluid flow simulation.

The coarse flow simulation grid is an abstraction of the detailed geological

model into which much data integration and geological expertise has gone. It mimics geological reality. Therefore, the one thing that one should ask from the up-scaled model is that it honors key features of the geological model and the only way to truly assess this is to guarantee that they have the same dynamic behavior, i.e. simulating flow on both grids should give similar results. Of course the fine scale model may be too big for full field, full history simulation, but the model can be decomposed into smaller pieces and/or computationally less expensive flow simulators such as streamlines can be used. The number of iterations that this process may require means that flow simulation must be launched from the same place the grid coarsening and property up-scaling is done, i.e. the geo-modeling environment.

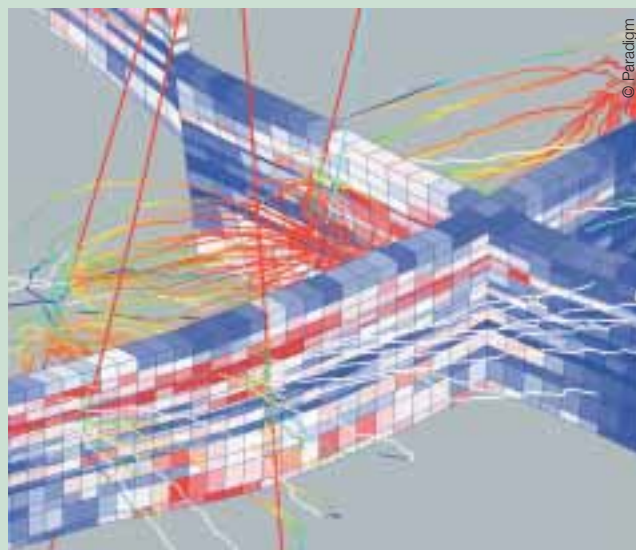
2 - Assessment of grid quality

For convergence purposes, conventional flow simulators require that the cells of the reservoir grid be "well-behaved", i.e. they should be hexahedral with orthogonal edges, and each row or column should have the same number of cells. However, the geological structure of reservoirs can be fairly complex. Any accurate "corner-point" geometry representation of faulted environments will deform the grid cells. Typically, engineers will manually null the cells that give numerical convergence problems and this can be a very cumbersome and time-consuming task. It is of course possible to check static measures of grid cell quality but the best way is to run the flow simulation. Having a flow simulator integrated to the geo-modeling software where the 3D grid is built, allows to rapidly assess the flow ability of the grid and either iterate on the way the grid is constructed or easily tag the problem cells as not active. As a result, flow simulator "problem-free" grids are created.

3 - Understanding of the behavior of reservoir models

The main purpose of constructing a geological model is to use it as input to a flow simulator. Therefore, features of that model are really only important if they influence fluid flow. A great deal of details can be built into the geological model since geology can be interpreted at different scales. This results in large parts of the reservoir study being spent on pieces which, in the end, may have no real impact.

Flow simulation grid showing non uniform grid layering defined from a geostatistically distributed 3D permeability field. This gridding approach guarantees that thief zones and flow barriers are captured during the upscaling process and provides more accurate flow simulation models.



Not all features have consequence on fluid flow and this is often difficult to know *a priori*. Understanding which aspects of geology impact, in a significant way, reservoir production under the recovery schemes considered can make the construction of the geological model more efficient. Thus, interpreters and modelers can focus on what matters and model it accurately from the beginning. Additionally, it allows screening various conceptual geological models and identifying the ones that should be rejected immediately. This can only be done routinely if modelers can easily launch flow simulations as they are building the reservoir model.

4 - Uncertainty assessment and geological scenarios

Constructing multiple geological models is now an almost accepted practice in order to tackle the inevitable uncertainty associated with reservoirs and volume estimations. Yet, when it comes to flow simulation (and therefore reserves assessment) all these geological models are rarely considered. One, sometimes three, but rarely more models are selected; they will be assumed to represent either the most likely model or be representative of the variability in possible reservoir models. Criteria for choosing representative models are usually "static" volumes. However, oil-in-place and reserves are not necessarily correlated since different parameters contribute to their quantification, e.g. permeability and fault transmissibility are not considered when computing hydrocarbon volumes, but they play a key role in the modeling of fluid flow. Furthermore, it is

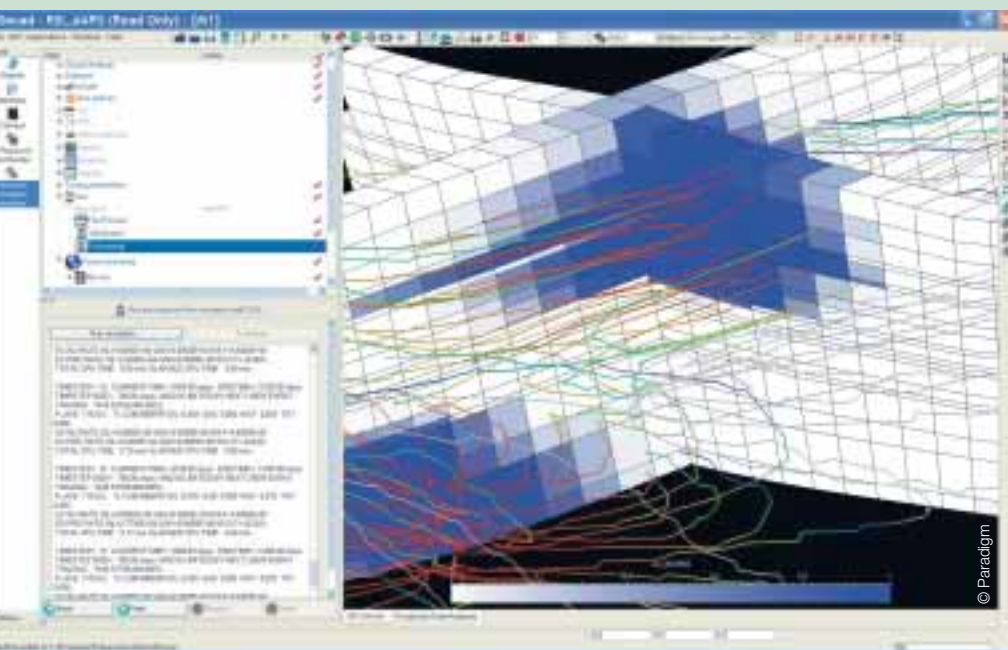
necessary to ensure that the scenarios and realizations considered yield a large enough spectrum of production responses in order to properly estimate the uncertainty in reserves. The only way to properly assess the representativity of the selected models and insure that the range of uncertainty is thoroughly swept is to perform a flow simulation on all the different geological models. This can only be done in a software environment which can generate and manage these multiple geological models.

5 - Screening of reservoir models

For fields under production, it is important that the reservoir model reproduces historical production data, yet there is still uncertainty in the geological model, and it is still quite difficult to guarantee *a priori* that the multiple models generated will match history. Performing systematic flow simulation enables screening of multiple realizations to identify those that would be more easily history matched.

6 - History matching

Too often History Matching consists of tuning (or tweaking) parameters of the flow simulation model and locally applying multipliers to geological parameters, essentially on pore volume, permeability, and fault transmissibility, sometimes leading to geologically unrealistic models. This assumes that the (up-scaled) geological model has the correct connectivity from the start; therefore, it should have been screened and selected amongst alternative realizations. (Assisted) history



Reservoir Simulation Interface workflow that allows launching flow simulations from within the Earth Decision Suite. The flow simulation grid displays water saturation during a waterflood process. Streamlines that show where the water actually moves from injectors to producers are also displayed. The flow simulations were performed using the streamline simulator 3DSL® from Streamsim Technologies.

matching must consider the impact of the geological scenario assumptions at some point in the process and ensure geological consistency at the end of that process. Current attempts to perturb or deform the geological model require a direct link between the software platform where the model is constructed (the 3D geo-modeler) and the tool used to assess the goodness of each iteration (the flow simulator). In the end, the geological model is still intact and the simulations match the production history.

7 - Field optimization

Optimal well placement, whether for early development planning or infill drilling, cannot be correctly assessed on a single representation of the reservoir's geology. Uncertainty on the geological model must therefore be considered. Any optimization algorithm should therefore have access to the alternative geological models (and more efficiently, to the way they are created) and, similarly to history matching, to the flow simulator.

8 - 4D seismic

Integration between geosciences modeling and flow simulation is undeniably obvious when considering 4D time-lapse seismic and reservoir monitoring. In addition to the tools required for constructing the 3D geological model, 4D seismic

studies require the integration of geophysical tools such as velocity modeling, inversion, and rock physics.

9 - Collaborative environment

3D integrated modeling software provides, above all, a collaborative environment: a place where all subsurface data can co-exist and be visualized simultaneously. This environment stimulates discussion and provides multi-disciplinary understanding and agreement. Reservoir engineers and geoscientists can jointly construct a reservoir model, and constrain the model to exhibit the observed dynamic behavior. They can pin-point the "plumbing" of the reservoir by appropriately representing large scale features, such as fault zones and fault blocks, channel belts, etc. Working in a 3D environment has the important advantage of advanced visualization tools and algorithms, routinely used for seismic interpretation, which can now bring new understanding and insight to the engineers' view of the reservoir.

10 - Full preservation

A good 3D modeling software comes with a workflow-oriented approach that captures the audit-trail and manages scenarios. The way to insure that reservoir engineers have the necessary knowledge to make decisions is for them to be aware of the choices made by the geologist and

the reasoning behind them. Having integrated software is the best way to access such information that is recorded during each step of the geological modeling construction. The workflows can generally be replayed automatically when parameters are modified, furthermore ensuring that all the information about the multiple iterations between geological modeling and flow simulation are tracked.

Conclusion

As discussed above, it is crucial to have strong links between geo-modeling software and flow simulators. Reservoirs come in different forms, with opposite geology, fluid composition, recovery mechanisms, questions asked, and decisions to be made.

Few would argue that commercial multi-purpose flows simulators are truly that, i.e. acceptably accurate at numerically modeling all aspects of fluid flow and production. Furthermore, flow simulation models must be scalable, balancing speed of results, number and size of models to screen, and precise modeling of fluid flow physics. Geological modeling software must be able to seamlessly connect to different flow simulators, enabling fit-for-purpose solutions. An integrated environment is key to future advances in sub-surface modeling processes. As it also promotes the integration and collaboration of fairly opposite disciplines, each one must be at ease in the software environment. The solution is pre-defined, yet flexible, workflows that enable the geoscientists to easily launch flow simulations and analyze the results, and where the engineers can be confident that modifications to the flow simulation model can be quickly done and that all the options needed are available. These workflows greatly enhance productivity, consistency, quality, communication, and audit trail.

Integrating 3D geo-modeling and flow simulation guarantees more accurate reservoir models and reduces the turn around time of model validation.

Paradigm will release later this year a Reservoir Simulation Interface that allows geoscientists and engineers to prepare, launch, and analyze flow simulations from within the Earth Decision Suite environment by connecting to commercially available streamline and conventional flow simulators.

For more information:
www.earthdecision.com