Integrating reservoir simulation with Time Lapse interpretation: An example from the Weyburn field

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Summary

Direct integration of seismic and reservoir simulation techniques has been used to reduce uncertainty in Time Lapse (4D) interpretation and history matching at the Weyburn field in Saskatchewan, Canada. Two main techniques were utilized; the first is a quantitative comparison of grid cells that indicate increased gas saturation in both the seismic and simulation models, and the second involves a comparison of injected and estimated CO_2 volumes derived from the 4D seismic interpretation. Integration between the reservoir simulation and 4D seismic interpretations helped to speed up the history matching process and also reduce non-uniqueness in the 4D seismic interpretation.

Introduction:

Time Lapse (4D) interpretation is inherently non-unique, with similar seismic differences being caused by a range of temperature, pressure and saturation changes in the reservoir. This non-uniqueness often reduces the value of the 4D seismic data, because the reservoir engineer is not able to derive the type of information required to understand the production process. When these problems occur, the seismic data is often ignored and therefore it does not deliver value to the production project.

The non-uniqueness in the 4D seismic response can often be reduced through a detailed understanding of the rock physics model and the material balance characteristics of the production process. One way of achieving these goals is a direct integration of the 4D seismic and reservoir simulation processes, which rigorously compares the spatial distribution and estimated volumes of injected fluids from the 4D seismic data to the reservoir simulation results.

An extensive time lapse seismic monitoring program was implemented to track the progress of injected CO_2 at the Weyburn field in Southern Saskatchewan as part of the IEA Weyburn CO_2 Monitoring Project. During the analysis of the 4D seismic data, it was determined that there was non-uniqueness between the seismic response to increasing pressure and gas saturation. This apparent ambiguity in interpretation reduced confidence in the data and initially made it difficult to incorporate the 4D data into the overall field management. This non-uniqueness was eventually resolved by directly integrating reservoir simulation results with the seismic interpretation.

Methodology

The first step in the integration process was to determine the nature of the 4D seismic response caused by CO_2 injection at the Weyburn field. Initial rock physics work, performed by Leo Brown, et al (2002) at the Colorado School of Mines, indicated that velocity in the reservoir would decrease by 4 to 6% when CO_2 saturation increased in the reservoir rocks. Pore pressure increases would also cause a decrease in velocity up to 3%. Later studies suggested that velocity reductions due to pore pressure increases could be as large as 35%. Since CO_2 saturation and pore pressure increases are both associated with injection wells, this resulted in an ambiguity in the interpretation of the seismic results.

The first step in reducing this ambiguity included a detailed modeling study which generated synthetic well logs to represent changes in pore pressure and saturation in the reservoir zone. Synthetic traces generated from these modified logs showed time delays and amplitude changes that were consistent with the measured seismic response at the injector well locations. Additional models were created to show the range of time delay due to velocity change in the reservoir. These models provided a range of solutions dependent upon reservoir pressure, CO_2 thickness and velocity decrease. Models which predicted time delays consistent with the measured seismic response (up to 2 ms) indicated realistic changes in velocity (6 to 10%) assuming a CO_2 thickness ranging up to 25 m. While these modeling results were non-unique, they nonetheless provided a framework for the interpretation of the 4D response. The most important step in reducing this non-uniqueness in the 4D interpretation came through a direct integration with the reservoir simulation process.

Fortunately, a new reservoir model had just been completed for the field. During the history matching of this model, the spatial distribution of CO_2 from simulation was compared to the 4D seismic anomalies. Maps of pressure change between surveys were also created and compared to the seismic maps. Through this process it was found that the pattern of 4D seismic anomalies correlated strongly with changes in gas saturation, but showed a weak correlation with pressure change.

As the reservoir model parameters were updated, traditional calibration to production was used in combination with a comparison between the spatial distribution of CO_2 in the 4D seismic and the simulation model. The comparison between the seismic and simulation results included two main steps.

First, a direct quantitative comparison of grid cells affected by gas was made and errors were calculated for several model iterations. This comparison was made by coding grid cells that indicated increased CO_2 saturation with a value of 1 in both models. This resulted in binary maps from both the seismic and simulation data. These maps were mathematically compared by multiplying the maps to highlight the areas where both techniques indicated gas saturation and subtracting the maps to show areas of disagreement. The subtraction maps provided a value of zero where both methods agreed (either gas or no gas), a value of positive one where the simulator predicted CO_2 but the seismic did not agree and negative one where the seismic alone indicated CO_2. Three types of error plots were generated from these maps; total error (percentage of pixels with a non-zero value), seismic error (percentage of seismic pixels that were unsupported by the simulator map) and simulator error (grid cells where the simulator indicated gas and the seismic results did not agree). These error estimates, made on a pattern by pattern basis, were created for several history-matching iterations to highlight areas of the model that improved or degraded with iteration.

Next, CO_2 volumes at each injection well were estimated based on the time lapse seismic response (to provide area), together with CO_2 saturation, thickness and porosity from the reservoir model. Comparison between these estimated and injected CO_2 volumes showed a strong agreement which further supported the assumption that the anomalies were primarily generated by changes in gas saturation rather than pressure.

These detailed, quantitative comparisons between reservoir simulation and 4D seismic results were made at several iterations during the history matching process. In general, areas of the field which indicated a larger error between seismic and simulation results also had a poorer match to production history. This correlation helped to speed up the history matching process by helping to focus on areas of the field where updates were most needed.

Conclusion:

An integrated approach, linking simulation history matching with time-lapse seismic analysis was applied to the Weyburn field. This integrated approach reduced non-uniqueness in the 4D interpretation and demonstrated that the 4D seismic response was caused primarily by increases in CO_2 saturation. The 4D seismic results also helped to reduce the number of iterations needed in the history matching process by highlighting areas of the field where CO_2 distribution from the reservoir model differed greatly from the 4D observations.

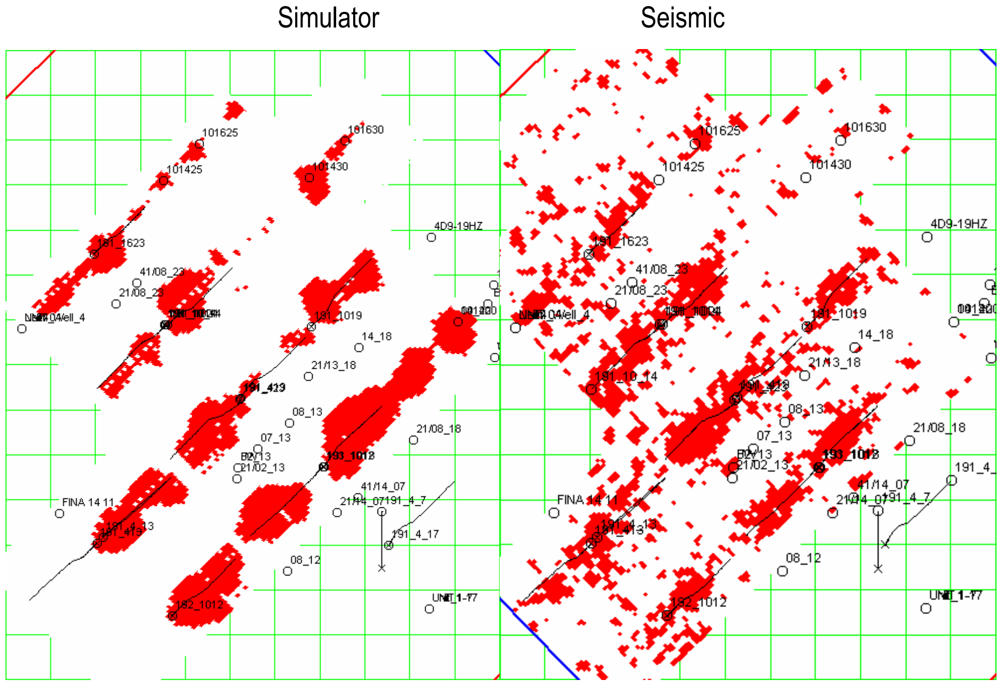

Figure 1: Binary maps with grid cells corresponding to increased CO_2 saturation shown in red for both the reservoir simulation and 4D seismic data.

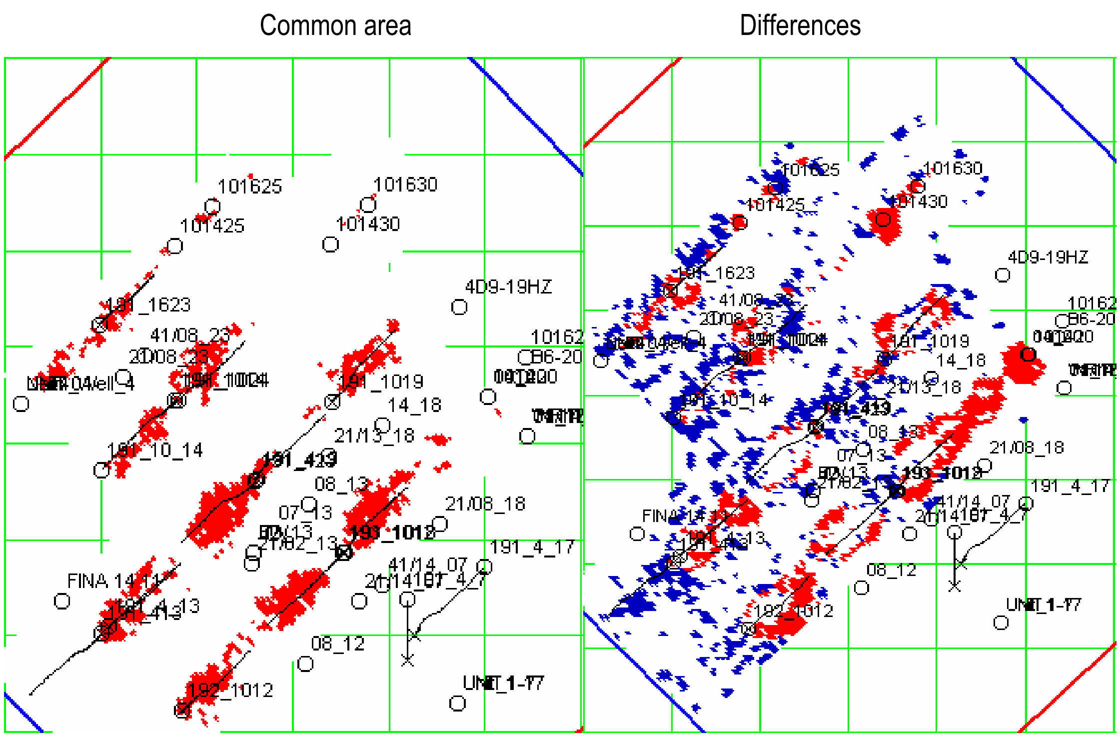

Figure 2: Grid cells where both the seismic and simulator indicate increased CO_2 saturation are shown in red on the left map. Grid cells where the seismic and simulator model disagree are shown in the map on the right. Grid cells shown in red indicate that CO_2 saturation is indicated in the simulator but not confirmed with the seismic. Blue cells show areas where the seismic indicates CO_2 saturation but the simulator model does not agree.

References:

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