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Single-cell reservoir model for CO_2 storage planning

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ABSTRACT

This work presents a single-cell reservoir model (SCRM) [1] and its application to CO_2 storage planning. The model is based on the material balance equation (MBE) coupled with an analytical aquifer. We aim to demonstrate that such a fast and simple model is a powerful tool that can fill the gap between volumetric estimates and full-field reservoir modeling and support the latter.

The material balance equation is a classical approach to reservoir characterization. It relates 1) reservoir pressure, 2) fluid PVT properties, 3) in-place, produced, and injected fluid volumes, and 4) formation compressibility. Before the advent of numerical reservoir models, MBE-related concepts were essential for diagnosing reservoir behavior and production planning.

Our model assumes produced and injected volumes to be known and numerically solves MBE for pressure at each time step. The Fetkovich model can be coupled with MBE to calculate the aquifer influx. We employed a black oil formulation with oil, gas, water, and CO_2. The latter was assumed inert, i.e., not dissolvable in oil and water. This approximation is rather rough; however, we consider it acceptable for many potential use cases. More accurate and complex compositional formulations with advanced phase interactions are possible at the expense of user input simplicity and an increased number of assumptions, though an optimal trade-off can be considered for implementation in the future. Alternatively, CO_2 can be modeled as the gas phase if it is necessary to account for its solubility in oil. Several features were implemented for more nuanced control of gas dissolution: 1) maximal gas-oil ratio increase, 2) fraction of initially free gas that can ultimately dissolve in oil, and 3) dissolution tapering coefficient (applied at each time step). Oil properties are defined by three tables vs. bubble point pressure for 1) formation volume factor, 2) gas-oil ratio, and 3) compressibility.

The presented model dates to the earlier version utilized in the REPP-CO_2 project [2]. The code was further employed and matured in other projects, such as the Strategy CCUS [3] and, lately, in the CO_2-SPICER [4], from which we adopted the field case, Zar, a small oil and gas field in the Czech Republic, operated by MND. The reservoir has long been produced by pressure depletion with limited water injection and is currently evaluated for a CCS pilot. The SCRM was employed for three tasks illustrating its potential use cases: (1) as a fast proxy model to support a full-field model's design and history matching (HM), (2) to estimate storage dynamics, and (3) to evaluate storage capacity for different reservoir parameters and storage scenarios.

Figure 1 illustrates the first type of use cases. It features production/injection history, pressure measurements (different markers correspond to individual wells); simulated reservoir and aquifer pressures of two SCRMs; and reservoir pressure profile from a full-field model by a commercial simulator. Both SCRMs and the full-field model share the same set of parameters (in-place volumes, PVT properties, aquifer, and formation compressibility) with one exception: the first

SCRM operates on the historical produced/injected volumes, whereas the second one copies the volumes from the full-field model (which, being a trial run, does not match the history exactly). The second case almost ideally approximates the pressure dynamics of the full-field model, which confirms that SCRM is a good proxy model. However, the first case does not accurately match the pressure measurements, suggesting room for improvement of HM.

Figure 2 features the first and two new SCRM cases. The 2nd case has a larger gas cap and a larger yet poorly connected aquifer. The 3rd case has an even larger gas cap and no aquifer support. The new cases generally reproduce the pressure observations (mainly measured closer to the top of the structure - hence the actual average reservoir pressure may be a bit higher). The history is followed by a forecast of a one-year shut-in and five years of CO_2 injection. The 1st and 2nd cases show similar dynamics of reservoir pressures, whereas the aquifer pressures are quite different. The 3rd case seems to have a larger storage capacity as it accommodates the injected CO_2 with a lesser pressure build-up.

To estimate ultimate storage capacity (USC), the MBE can be solved for CO_2 volume at a given pressure. Figure 3 shows nine USC-pressure curves for the three cases (highlighted by similar colors) and three storage scenarios (sharing the same line types and markers). The storage scenarios are: 1) pure storage, 2) storage after producing the remaining gas cap, and 3) storage after CO_2EOR adds 10% to the oil recovery factor. The USC chart allows for 1) comparing and ranking different cases and scenarios and 2) visualization of sensitivities and uncertainties. For instance, for the given examples, USC varies due to reservoir conditions more than scenario-wise. Another takeaway from such an analysis may be ranking reservoirs by energy efficiency of CO_2 storage, as the target reservoir pressure is a proxy for the required compression work. I.e., with everything else being equal, the reservoir with a higher storage capacity will have less energy required per unit of CO_2 stored.

Overall, the single-cell reservoir model has proven to be a valuable tool for screening, rapid testing, and making estimates. It can be used as a stand-alone tool if the full-field reservoir model is not available (e.g., due to data scarcity) or as its proxy model to support and speed up the simulation study. The code repository is available at https://github.com/alex11818/unicellar.

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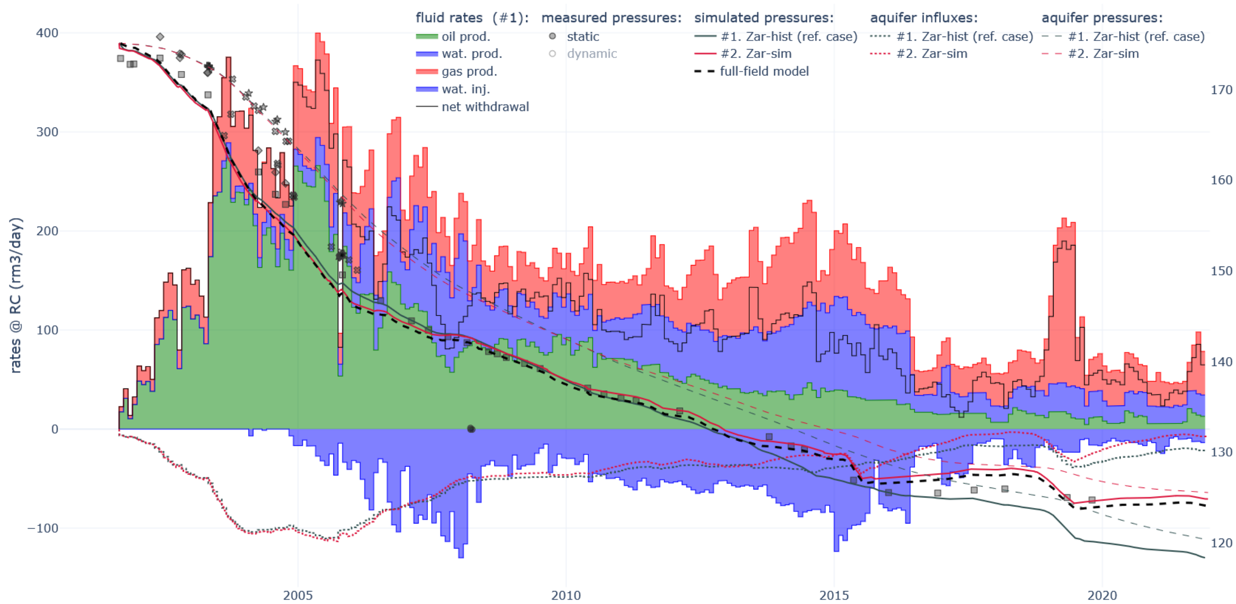

Figure 1. Field production history (at reservoir conditions) and comparison of SCRM cases with a full field model

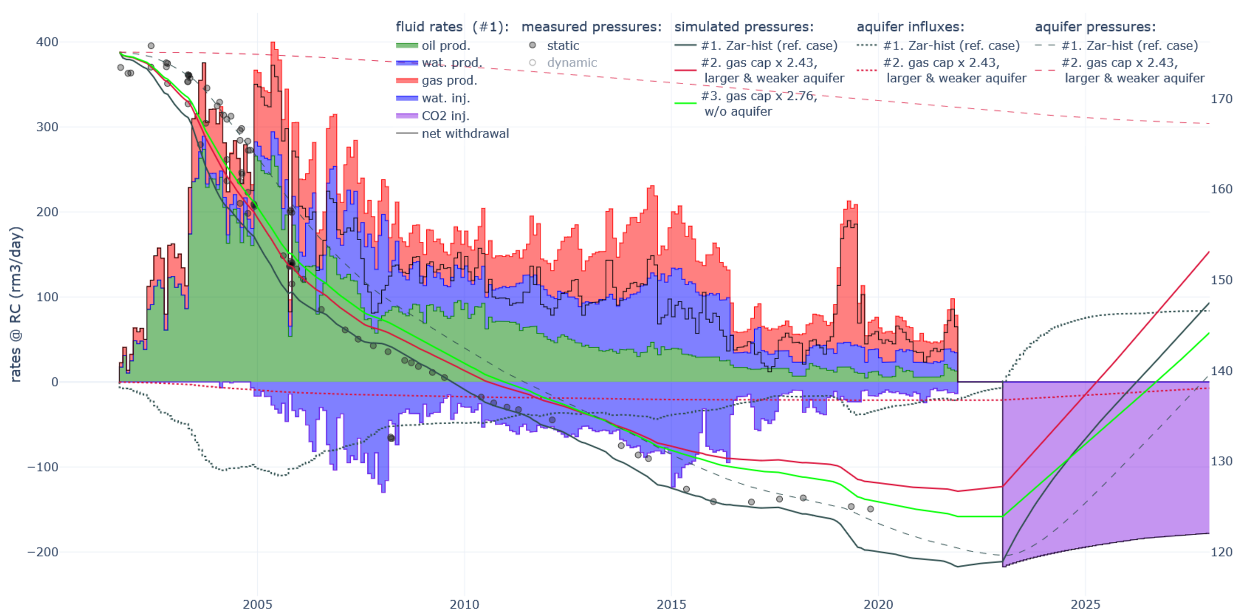

Figure 2. Additional SCRM runs to test different HM concepts and forecast CO_2 storage

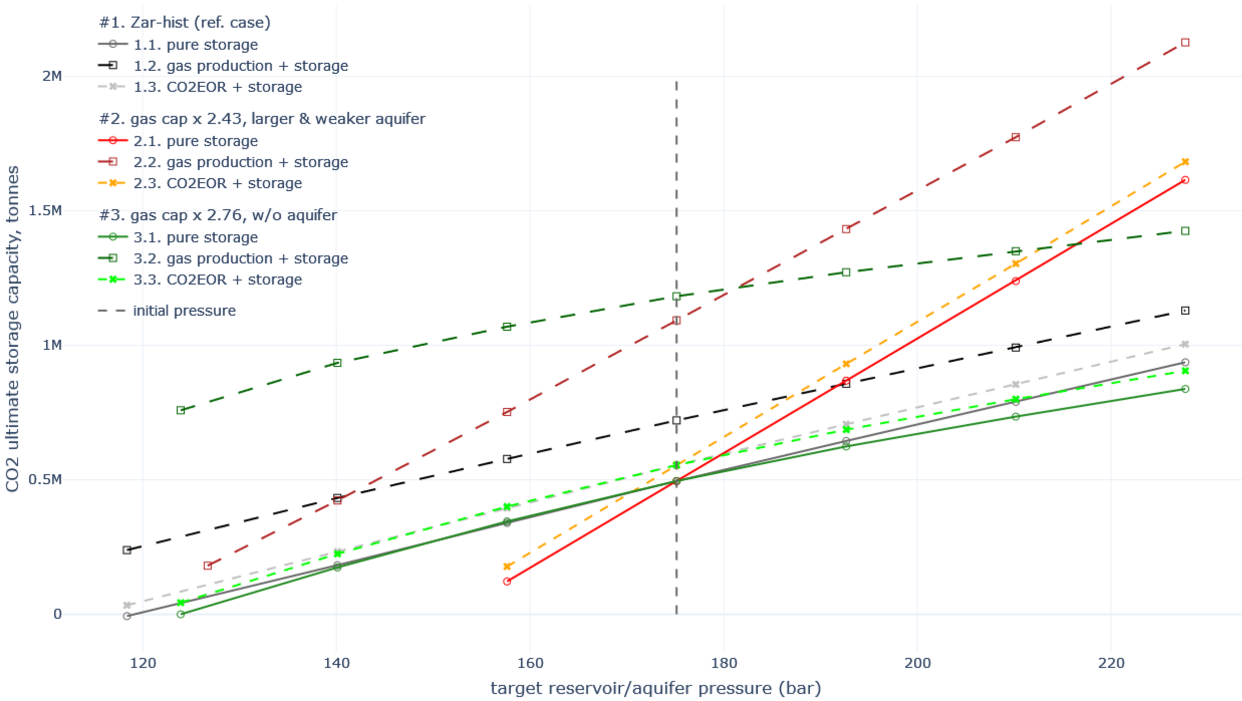

Figure 3. Ultimate CO2 storage capacity for the cases from Figure 2 and various storage scenarios