Predictive maintenance for CCS subsurface surveillance using focused seismic monitoring

Habib Al Khatib[1] Kevin Gestin[1] Tillmann Roth[2] Oleksandr Burachok[2] Elodie Morgan[1]

[1]SpotLight SAS, Massy, France
[2]Wintershall DEA, Hamburg, Germany

Abstract
This study introduces a novel surveillance approach for CO_2 geological storage, deviating from regular time-lapse measurements. The proposed workflow utilizes attributes derived from flow simulator output to identify critical locations in space and time to be monitored with focused seismic monitoring to effectively reduce uncertainties. The method serves as a frequent, environmentally friendly "trigger monitoring" tool that can be integrated into Monitoring, Measurement, and Verification (MMV) planning. Each spot's expected behaviour is known before measurement, adding transparency. This transparency, combined with higher monitoring frequency, can contribute to constructive discussions with regulators and enhance societal acceptability of CCS projects.

Key points

- Dynamic flow simulation linked with focused seismic measurements.
- Automatic Spot identification
- CCS trigger technology

Keywords: Light monitoring, CO_2 detection, Predictive maintenance, Saturation Intensity Map, flow simulation; MMV.

Introduction

Monitoring, Measurement, and Verification (MMV) are key components of any Carbon Capture and Storage (CCS) project. Driven by regulations, Carbon Capture and Storage projects will rely on monitoring solutions that not only need to be technically and economically viable but also environmentally sustainable for decades (Lumley, 2021).

In this paper, we present a methodology that integrates focused seismic methods (Ollivier et al., 2023) with dynamic model predictions of CO2 plume evolution. This approach helps to identify optimal times and locations for active seismic measurements to validate or invalidate injection hypotheses and further increase confidence in the dynamic model. Additionally, it enables the triggering of additional actions, if necessary, a concept we refer to as predictive maintenance. The concept of this study is inspired by the Greensand CCS project.

Methodology

Dynamic reservoir models are mathematical constructs designed to project the pressure and fluid saturation evolution of a given reservoir into the future. Drawing on geological data, well information, seismic interpretations, and legacy production parameters, these models serve as essential tools in planning and monitoring underground CO2 injection projects (Barros et al., 2021). Permit applications, risk assessments, and the economics of CCS projects are developed using these models, sometimes even before the first molecule of CO2 is injected into the subsurface. Therefore, it is crucial to design a technology capable of identifying the most critical areas of the subsurface in both dimensions space and time for frequent validation of these models. Such trigger technology can be integrated into the MMV plans and be updated on a yearly basis. A trigger technology is a light and agile solution capable of delivering frequent information about potential containment and/or conformance problems early enough to trigger additional actions such as model update or acquisition of denser data.

The described method proposes to employ dynamic reservoir models to automatically select preferential areas of interest (Spots) throughout a CO2 injection campaign. The accompanying illustrations (Figure 1) depict month-to-month deterministic CO2 saturation reservoir models based on a 12 months injection plan.

In this study, using dynamic models output from the CCS operator, we build differential CO2 saturation maps by calculating the variances between successive month-by-month models. These variations in CO2 saturation across the reservoir, while informative on their own, are strategically utilized for precise spot position selection both in space and time. The calculated variations are smoothed using a 2D Gaussian filter to disperse the changes within the reservoir. This smoothed saturation map is then applied as a filter to the CO2 saturation map of the previous month, resulting in the final Saturation Intensity Map.

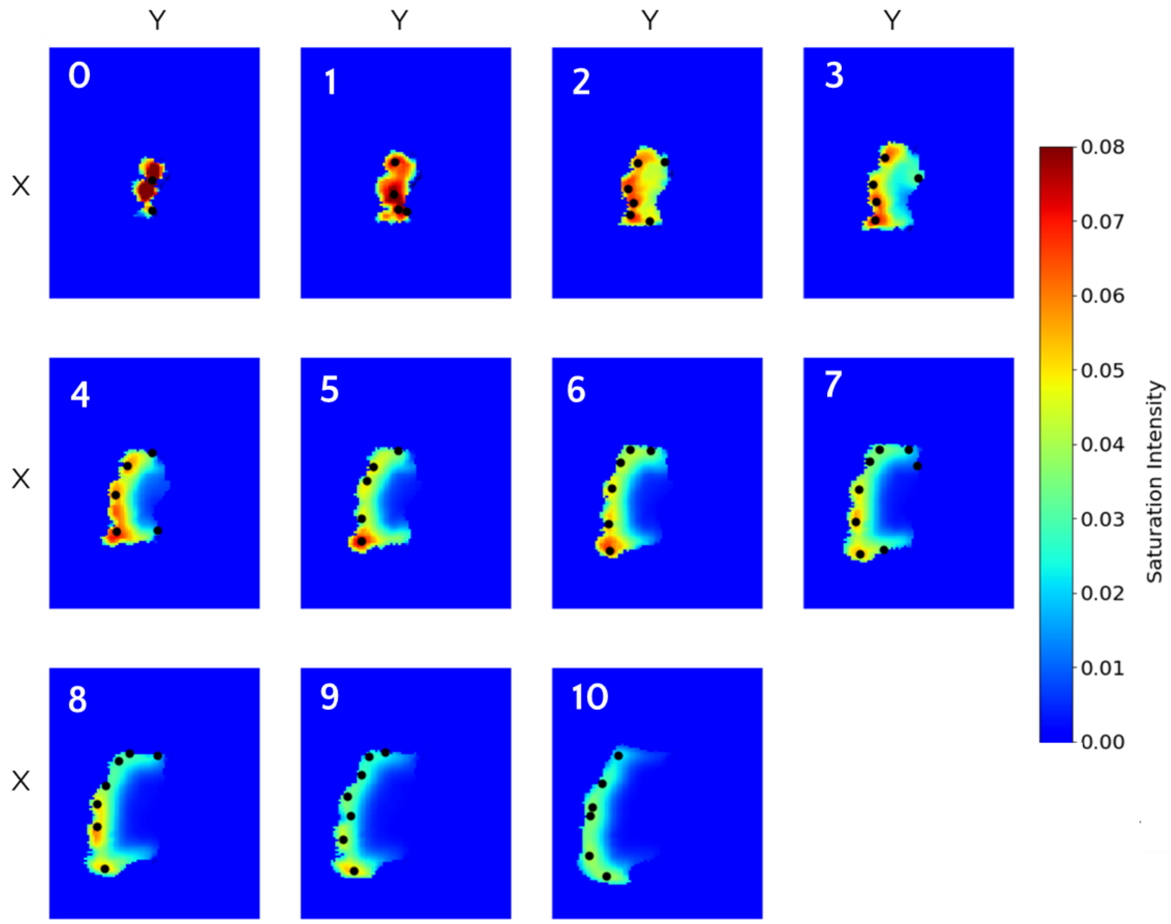

Figure 1 *Saturation Intensity Map (colored background, no dimension) for every month simulated with spot positions (black dots). Number of month is written in white on the maps. Spot positions are automatically computed.*

The Saturation Intensity Map highlights areas where, on one hand, CO2 saturation is present in a given month and, on the other hand, CO2 saturation is expected to spread in the vicinity of this area in the next month. Spot positions are determined using an optimization algorithm to locate local maxima in the saturation intensity map. If the saturation intensity at the resulting position exceeds a specified threshold defined as the "detectable CO2 saturation" (Rappin et al., 2023), the spot position is validated. A final selection step is performed to group together spot positions that are too close to each other. Saturation Intensity Maps for each month are illustrated in Figure 1.

Results

The CO2 saturation intensity value at each spot position is extracted. Subsequently, a plot depicting the maximum saturation intensity value versus the month is generated. (Figure 2). The months with the highest saturation intensity values are easily detectable. This enables CCS operators to optimize monitoring efforts and reduce further environmental footprints by prioritizing the most CO2 active spot position.

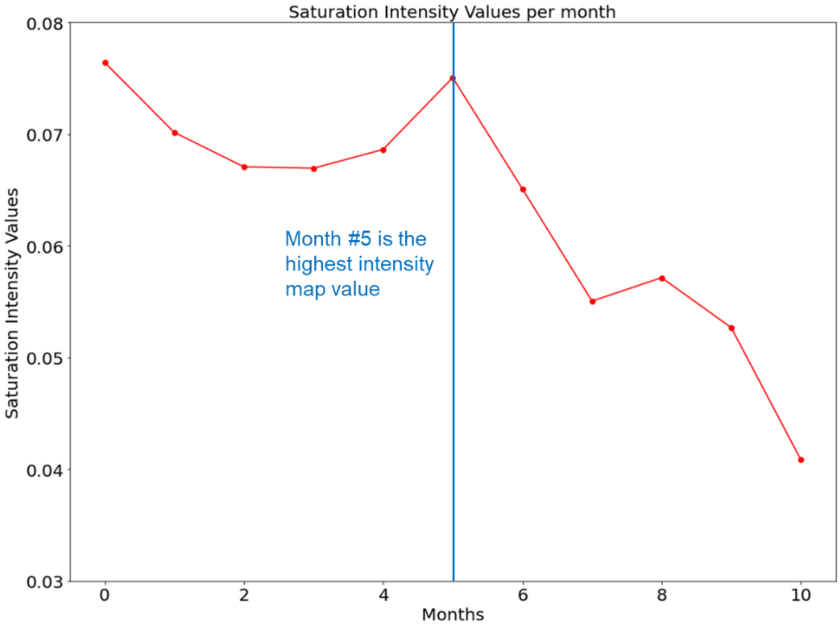

Figure 2 *Saturation intensity values for the spot with the highest intensity value per month*

In this specific study, first injection (month 0) and month 5 are identified as suitable for monitoring to assess the conformance of the CO2 plume. In this approach, first injection and more broadly injection points are always used as calibration points.

Figure 3 shows month 5 Saturation Intensity map where 5 spots are automatically identified. It clearly indicates the initiation of a south-oriented CO2 evolution in the southern part, which is continued in the following months, as shown in Figure 1. This demonstrates that the proposed methodology successfully identifies the most critical timing to validate the conformance of the CO2 plume as predicted by the model.

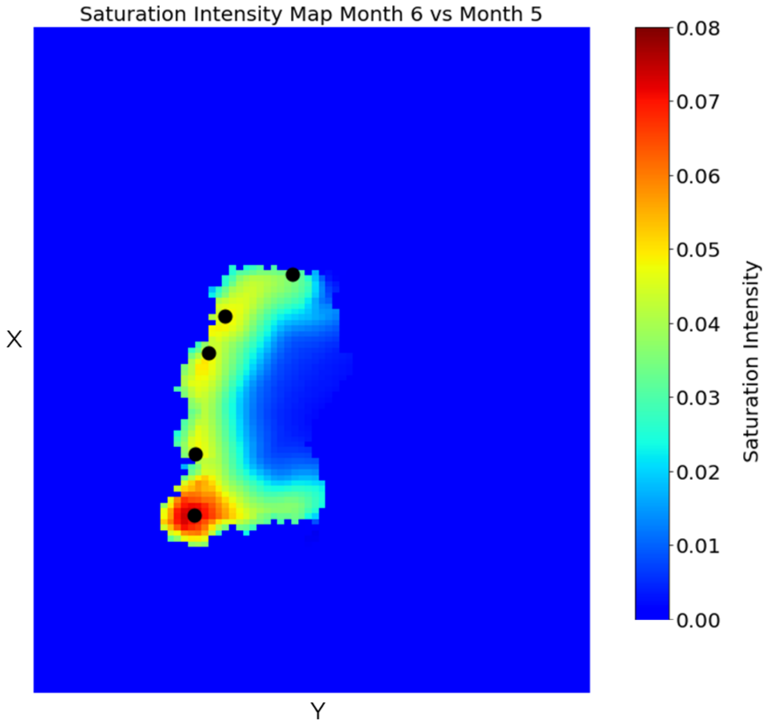

Figure 3 *Saturation Intensity Map (colored background) and automatic spot positions (black dots) for month 5.*

Way forward

A Focused seismic operational model as described by Ollivier et al. 2023, can acquire approximately 10-20 Spots per day. As a result, if planning a monitoring at month 5, five to fifteen additional spots can be located for the first monitor survey. To locate them, we can propose the following rational:

1- Calibration Spots: The injection well and/or any observation well serve as ideal calibration locations since wells are measuring changes in pressure, saturation, and temperature.

2- Control Spots: Away from the injection areas, these spots serve as background noise measurement locations.

3- Containment/Risk Areas: When necessary, additional spots can be placed in identified risk zones. These spots are intended for specific monitoring of these risks such as faults or abandoned well locations to check early enough if CO2 might reach any of these areas.

Every year or following a significant flow model update, the methodology could be rerun to identify new and/or updated spots in space and time. If applied to a 'stochastic' flow model where several different scenarios are computed, the method becomes even more valuable, as it can be used to discriminate between scenarios and thereby enhance the robustness of the overall flow models.

Conclusions

We have introduced a workflow that utilizes attributes derived from flow simulator output to pinpoint the most critical locations in space and time. This approach answers one the most important MMV question: “how often and when do you need to monitor ?” by taking into account the CO2 dynamic in the reservoir. When coupled with focused monitoring, this method provides a frequent, environmentally friendly 'trigger monitoring' tool that could be incorporated into most MMV planning.

When the model is deviating from the spot seismic measurement, the method may trigger remediation actions such as flow model updates or the acquisition of new data: walkaway VSP or full 3D monitoring survey. The method can synergize with other continuous or frequent monitoring technologies like microseismic.

For each spot, the expected behavior (change or no change) is known prior to the measurement. We believe that this transparency, coupled with higher monitoring frequency, can add value to discussions with regulators and ultimately enhance the societal acceptability of CCS projects.

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