CCUS: 4186289

# Enhancing 2D Legacy Seismic Data Value for CCS Monitoring Using Predictive Maintenance

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This paper was prepared for presentation at the Carbon Capture, Utilization, and Storage conference held in Houston, TX, 03-05 March.



## Abstract

Carbon Capture and Storage (CCS) requires advanced geophysical monitoring tools to develop a robust Measurement, Monitoring, and Verification (MMV) plan, but in some fields, the reliance on a few 2D seismic lines could compromises monitoring potential due to insufficient coverage. To support the development of one of the potentially largest geologic storage sinks for CO2, a monitoring strategy guided by flow simulation forecasts, known as 'Predictive Maintenance,' is proposed. This paper highlights its application using only 2D seismic lines from a U.S. onshore project, offering a novel approach to evidence the safety of the carbon storage to regulators. This study uses saturation and saturation gradient maps from a CCS field to generate intensity maps. These maps highlight areas where CO2 saturation is expected at each timestep and predict its migration in subsequent timesteps. By combining the intensity time-lapse maps and 2D seismic lines, critical locations for measurement are identified to validate key assumptions about plume conformance that can be monitored with the spot seismic solution. Prior seismic data such as 2D seismic lines are essential to select the best source and receiver locations for each spot to monitor through time. The dynamic model of an Indiana storage was used at five different timesteps following the first CO2 injection. A full coverage predictive maintenance analysis was conducted to determine the optimal locations and timing of spot seismic measurements. The analysis was refined by incorporating the positions of the 2D seismic lines. Results showed that the 2D-constrained method is addressing key regulatory concerns, ensuring CO2 plume conformance and containment. The Predictive Maintenance strategy used as a CCS (Carbon Capture and Storage) surveillance system addresses challenges related to the sustainability of CCS projects, including environmental impact, public acceptability, and cost-effectiveness. As demonstrated in this paper this solution can provide an efficient monitoring solution for CCS projects that have limited legacy data, such as 2D seismic lines.

## Introduction

Carbon Capture and Storage (CCS) projects must integrate a reliable Monitoring, Measurement, and Verification (MMV) plan to advance to the Final Investment Decision (FID) phase. However, conventional subsurface surveillance solutions, originally optimized for oil and gas operations, are often oversized for the needs of geological carbon storage. To address this, sparse seismic acquisition systems like the spot seismic are being further developed to tackle the unique challenges and financial constraints of CCS while ensuring compliance with surveillance goals.

The spot seismic method has proven its efficiency in detecting $CO_2$ on the Weyburn field (Brun et Al., 2023), utilizing only one seismic source and receiver pair per monitored subsurface location. For spot seismic to be applicable, two types of data are required: first, legacy imaging data covering the Area of Review (AoR) to optimally place the source and receiver (Festucci et Al., 2024); and second, for the Predictive Maintenance approach where the flow model output to identify which spots in space and time are critical to monitor during the Life of Storage and after to ensure storage safety (Al Khatib et Al., 2024b).

The spot seismic solution was applied to one of the first Class 6 permits in the US in 2024, the Wabash project in West Terre Haute, Indiana. A monitoring strategy was developed using existing seismic data and the output of the preliminary flow model to monitor the field and comply with the state CCS regulation. The particularity of this project lies in the sparseness of the seismic data available, consisting of 2D lines acquired in 2019-2020. Ordinarily, spot seismic uses 3D seismic data, and this project demonstrates its adaptability with 2D lines and a preliminary flow model. The main advantages of the spot seismic application on the Wabash project include its triggering characteristics for other surveillance technologies, its operational lightness and agility to adapt to surface constraints, frequency of monitoring (several times a year) and the calibration of the flow model to reduce uncertainties and increase its predictiveness (Al Khatib et Al., 2024a).

## Theory and/or Methods

In CCS projects, dynamic models are paramount to predict the evolution of the $CO_2$ plume migration. The output of the flow model is also needed to deploy the Predictive Maintenance approach designing where and when it is critical to monitor the storage in specific spots locations.

For the Wabash flow model output, the spot seismic surveillance information can verify any deviations from predictions, triggering corrective measures and calibrating the model. To begin with, saturation gradient maps are created from successive dynamic models' average maps. Gradient maps highlight the areas where saturation changes between successive timesteps. The saturation map is smoothed to extend the area and is then applied as a filter on the saturation map of the previous timestep. The resulting map is called the intensity map and highlights the areas where saturation is expected in each timestep and will migrate in the vicinity of that area in the following timestep. The Predictive Maintenance selects, for each timestep, a set of critical spots locations where the amplitude of intensity is locally the highest.

Two types of spots can be defined: containment and conformance spots. Containment spots are set in the vicinity of "risky" areas such as faults or legacy wells while conformance spots are set to validate or invalidate the dynamic models. Finally, a spot is set at the injection well to calibrate the $CO_2$ detection and compare with well information, and another spot is set outside of the plume to calibrate noise level.

The spot seismic solution requires legacy data availability implying that spots must be located on the 2D lines available to perform the active seismic survey design with source and receiver located over the legacy seismic layout. This adaptation is done by adding an additional filter built from the seismic lines to the intensity maps. Results are shown in the next section.

## Results

This work focuses on 4 average saturation maps at different timesteps: 3, 6, 12 and 22 years after the beginning of injection with Figure 1 presenting the results of the Predictive Maintenance. On this figure black dots represent spots positions automatically selected by the predictive maintenance for the current timestep, and grey dots represent spots position for the next timestep. From an acquisition point of view, grey dots stand for baseline spots and black dots stand for monitor spots. The resulting Intensity Maps generated with the Predictive Maintenance method shows that those conformance spots are positioned evenly at the border of the $CO_2$ plume.

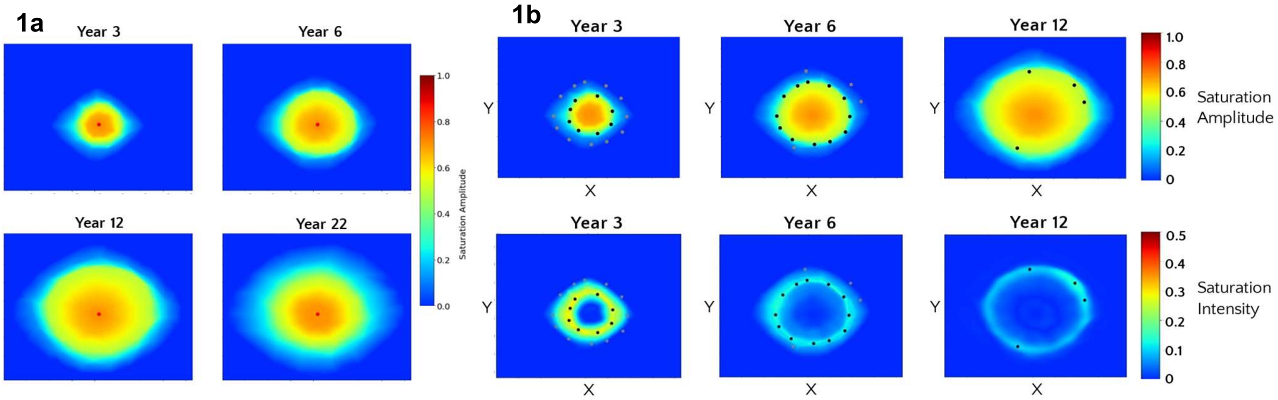


Figure 1a (left): Average saturation maps for every timestep. The red dot corresponds to the injection well position. Figure 1b (right): Results of the Predictive Maintenance algorithm. Top: Saturation Map; Bottom: Intensity Map. Black dots are spots chosen by the method on each timestep. Grey dots highlight spots positions for the next timestep.

The spot seismic method utilizes spots position and legacy data to build a cost efficient and environmentally friendly monitoring solution using standard equipment. However, spot positions and legacy data must overlap, such that the migrated seismic section coverage includes spot positions. In this case study, legacy migrated data consists of regional 2D lines. The resulting spots revealed by the Predictive Maintenance will be located within the regional 2D migrated seismic coverage to be monitored with one optimal seismic source and receiver (Festucci et Al., 2024). The 2D lines constraints are included as a mask for the Intensity Map. The results of the constrained Predictive Maintenance are shown in Figure 2. The resulting spots lie on the legacy 2D lines as well as being on the edge of the saturation map.

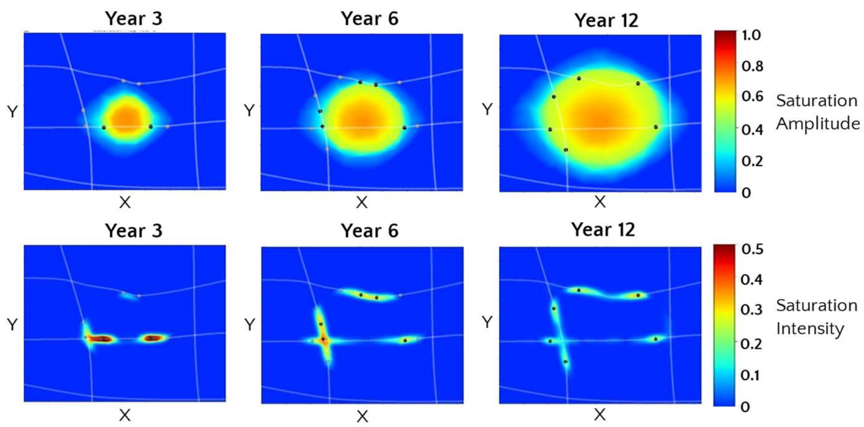


Figure 2 Results of the constraint Predictive Maintenance algorithm. Top: Saturation Map; Bottom: Spot Position Intensity Map. Black dots are spots chosen by the method on each timestep. Grey dots highlight spots positions for the next timestep. White lines are regional 2D seismic lines.

## Discussion

As a spot quality control, results of the constrained Predictive Maintenance are compared with the spatial 3D one. Spots locations constrained by 2D lines results highlight the fact that it is still optimal to monitor the $CO_2$ plume conformance as shown in Figure 4.

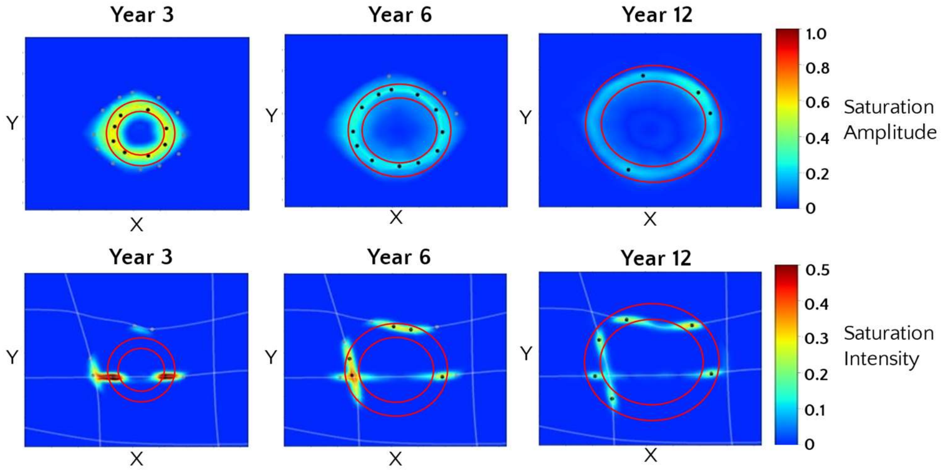


Figure 4 Spots Position Intensity Maps. Top: Standard / Bottom: 2D lines constraint. Red rings are the same on each timesteps.

## Conclusions

A yearly monitoring strategy using a light agile and cost-effective spot seismic solution was designed over the Wabash project in West Terre Haute, Indiana using 2D lines legacy seismic data showing its adaptability using 2D legacy seismic. The flow model output was used at different timesteps to identify specific spots locations to be monitored in the storage.

This approach brings value to MMV plans by allowing early detection of potential modelled $CO_2$ plume deviation. Focused monitoring of those spots allows for quick and environmentally friendly calibration and verification of dynamic models. Spot seismic detection may trigger update of the dynamic model and/or new acquisitions when the monitoring observations are no longer according with the expected evolution of the $CO_2$ plume. This frequent surveillance increases reliability of models and $CO_2$ storage safety.

**References**

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