Probabilistic approach to CO2 plume mapping for prospective storage sites: The CarbonNet experience.

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Abstract

In CO2 storage, there is a requirement to predict the range of possible plume extents and travel paths and associate a probability with this range. This requirement is in the context that subsurface uncertainty is a given, and that no single plume prediction can be 100% precise. The probabilistic expectation of the plume at future times is used for project purposes and for regulatory assurance that the plume will remain within the defined storage boundaries (both geographical and stratigraphic) for the required period of time with an appropriate high level of confidence. In particular, Australian GHG storage regulations call for a prediction of all plume paths with more than 10% probability of occurrence (i.e. plume paths at P90 confidence level).

Here we outline a probabilistic approach based on reservoir modelling sensitivity and uncertainty analysis, adapted from the petroleum industry and suitable for high-mobility CO2 plumes in thick and well-defined reservoirs. The method can also be extended to other basins and geological circumstances. In the petroleum industry, it is commonplace to evaluate resources in probabilistic terms with some objective parameter such as oil in place, recoverable reserves, or nett present value. This methodology can be adapted easily to objective measures such as vertical ascent of a plume relative to a caprock or lateral approach of the plume to a permit boundary or other geographic feature to be avoided (e.g. a mapped fault). What is novel in our approach is to analyse plume paths (extents) in a statistical manner to generate probabilistic maps and cross-sections of plume extents to inform on containment risks and areas with key monitoring requirements.

In our approach, the reservoir layering must first be analysed and the principal hydrodynamic flow units (HFU’s) and the intervening seals identified. In the Gippsland Basin, multiple reservoir layers of 100-150m of multi-darcy clean quartz-dominated sands form the main reservoir units and are proven by over 1,500 hydrocarbon exploration and development wells and mappable on extensive 3D marine data beyond approximately 5 km from the coastline. The reservoirs are supported by an ideal, almost infinite aquifer which buffers pressure effectively and dissipates it regionally over short timescales (100 km in decades). In these reservoirs, CO2 plumes are highly mobile and must be controlled by either structural trapping, or by careful mapping and use of non-structural (saline aquifer) storage.
The CarbonNet Project aims to store a nominal 125 million tonnes of CO2 over 25 years in the same basin still in use for hydrocarbon extraction, and adjacent to an important onshore aquifer. Plume management and containment is therefore vital and high confidence must be placed on plume path modelling, including the analysis of rare statistical outliers. The initial geologic static model contains a description of the HFU’s and seals. A base case dynamic model with the most likely geological properties forms the basis of the sensitivity and uncertainty analysis. Subsurface uncertainty inevitably leads to potential variability of rock properties which will be expressed as different plume paths through time. A wide range of variability should be allowed in major properties such as Kv, Kh, porosity, residual saturation, relative permeability, etc.

A two-stage reservoir dynamic modelling process first examines each variable acting individually and identifies the key variable parameters compared to the base case - measured by key Objective Responses such as the vertical rise of the plume or lateral approach to a boundary. The second phase studies co-varying parameters using a formal Experimental Design, to identify the coupling of parameters and amplification of key responses, and define the weighting of a proxy model. Proxy models represent the outcome (the Objective Response, measured from actual reservoir dynamic simulations) as a simple mathematical consequence of the weighted and scaled input variable parameters and the coupling between them. It is thus a rapid way to explore parameter space and predict outcomes of different combinations of inputs at different strengths, without running many computationally intensive full reservoir simulations. It is important to check that the predictions from the proxy agree sufficiently well with actual simulations in selected scenarios, especially when multiple parameter extremes are simultaneously invoked.

The proxy model is used to statistically explore parameter space and define probabilistic plume outcomes (Objective Responses). An example of the approach is demonstrated for structural storage in the offshore Gippsland Basin, Australia and maps of 90% probability of the plume path from the actual dynamic simulation runs are illustrated to meet Australian regulatory requirements, as well as identifying statistical outliers with the closest approach to the lateral and vertical storage boundaries. In addition, volumetric upsides of the CarbonNet site are explored.

A discussion is also included of the comparative uncertainties for non-structural (saline aquifer) storage in the same basin. Application to other basins and geological contexts is discussed. In conclusion, the approach offers a method to quantify plume path uncertainty in terms of lateral extent (i.e. map view) and vertical extent (cross-section), offering 3D understanding of plume containment with an appropriate high level of regulatory and public confidence.