Ensuring efficient and robust offshore storage – the role of marine system modelling.

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Abstract.

Offshore storage options are available in many countries; however demonstrating robust storage poses some unique challenges in the marine environment. To comply with regulations and assure against false accusations, traditional seismic imaging of the storage complex and overburden should be complemented by monitoring at the sea floor for biochemical or physical anomalies, such as excess CO_2 concentrations or gas bubbles. Sea-floor techniques may have better sensitivity than seismics and contribute to all parts of the detection-location-verification-quantification process. Challenges to overcome include defining what constitutes an anomaly in a noisy time variant environment, and identifying optimal sensor combinations and deployment strategies to provide a sensitive, wide-ranging, accurate and economic monitoring system. Here we demonstrate how marine modelling approaches are addressing these challenges.

Developing a monitoring system requires that we meticulously understand the signals of leakage, and how these differ from natural, often highly dynamic variability. For example we need to predict the pathways of CO_2 transfer across the sediment-water interface, its phase chemistry under a variety of environmental conditions, the configuration of gas bubbles, their buoyancy and solubility, the movement and dispersion of dissolved CO_2 plumes and their impact on the marine chemistry. In addition, we need to characterise how the same chemical and physical attributes evolve due to natural biological and physical processes. Understanding this site-specific baseline is critical to successfully detect and quantify unintended emissions, apply corrective actions as well as protect from false alarms.

Sea floor marine systems are poorly described by direct observations, data is intermittent and sparse. However coastal regions are routinely described by marine system models – typically time evolving, 3D coupled hydrodynamic - biogeochemical systems which describe physical flows and biogeochemical fluxes, often explicitly modelling CO_2 chemistry and potentially hosting specialist modules, for example of bubble dynamics. These models provide terabytes of internally-consistent, evaluated, skill-assessed multi-variate data with comprehensive vertical, horizontal and temporal resolution – a virtual marine environment within which we can quantify baselines, simulate unplanned release and assess monitoring strategies.

Within STEMM-CCS and preceding projects, the research community has devoted considerable effort to developing and applying marine system models to advance offshore CCS. We can now articulate the following understanding, advances and tools that will underpin the expansion of CCS in the marine domain:

1) Model simulations allow us to characterize hypothetical release scenarios in the context of natural variability, thereby defining optimal detection criteria. In the absence of realistic analogues, models provide the only option to characterize the morphology of hypothetical release events (Fig 1a), and quantify detection targets. Natural variability of marine CO_2 (fig 1b) may mask the signal from an unplanned release, consequently criteria for defining anomalous behavior must be carefully chosen. Models enable us to quantify natural variability and its heterogeneity, due to water movement, depth, nutrient loading etc., and identify the most sensitive discriminators applicable to a given site or even season (Blackford et al 2017). As an example, short-term small variations in CO_2 may provide a highly sensitive discriminator with low failure rates (Fig 1c) and departures from natural covariance (e.g. CO_2-O_2-NO_3 stoichiometry) may also indicate anomalous chemistry. Detection at 50m distance for a 1T/day release scaling to 5km distance for a 100T/day release may be obtainable, although local hydrodynamics would cause significant variability in the detection length-scale.

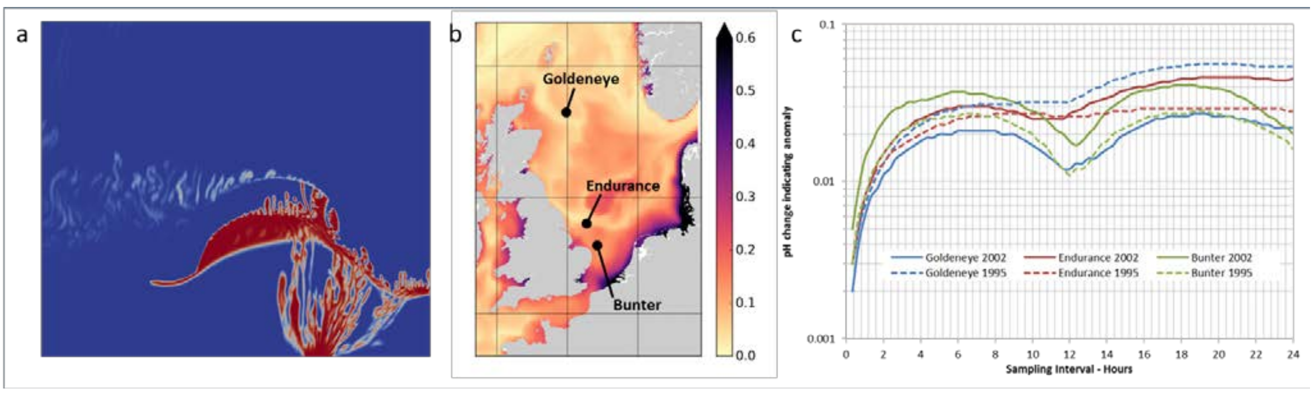

Fig 1. a) Flow through sediments (red) and water column (white) by a Navier-Stokes Darcy model; b) Annual range of seafloor pH (indicating CO_2 concentration) in the N. Sea using the NEMO-ERSEM model; c) Model derived anomaly indicators relative to sampling interval for N. Sea sites.

2) Models allow us to devise the most cost-efficient deployment of sensors to maximise detection. By quantifying how water movement impacts dispersion of CO_2 plumes, models can predict the minimum number of sensors and their optimal locations, or the optimal deployment of Autonomous Underwater Vehicles to maximise the likelihood of detection (Alendal, 2017, Fig 2).

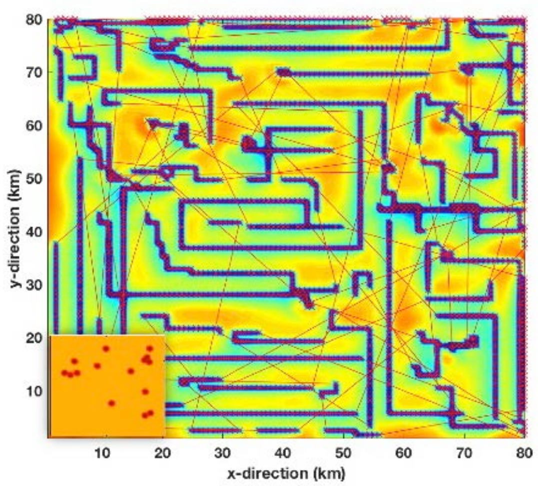

Figure 2 - Optimal AUV route for rapid detection in an area with 15 wells (lower left corner) derived from Bayesian analysis.

3) Marine modelling contributes to required risk assessments, by quantifying potential impact from hypothetical release scenarios. Model scenarios of unintended seeps at varied scales quantify the relationship between leak rate and the scale of potential impact, contributing to site specific risk assessment. Even though studies to date show that the potential impact from a small CCS leak will be local (Fig 3), this might add to the stress already imposed on the marine environment, causing vulnerable areas to reach a tipping point.

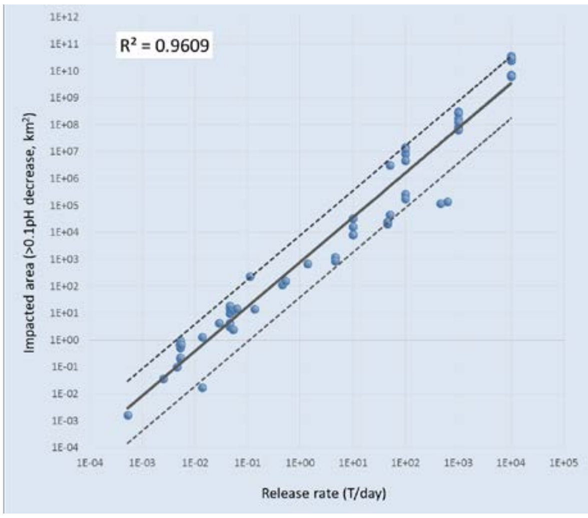

Figure 3. Model ensemble relationship between CO_2 release rate and impacted area.

4) Models are an efficient and cost-effective method for site characterisation, but require some real-world observations to ensure validity. Using appropriately skilled models to derive baseline understanding, explore release scenarios and optimal site specific detection criteria is far more cost effective than deploying large observational programmes. However model evaluation and quality assessment require in-situ environmental data, and establishing environmental baselines should be intrinsic part of site characterisations. To assure adequate yet inexpensive baseline observations, early involvement of the marine modelling community is recommended.

We argue that it is critical to ensure that the computationally expensive underpinning model data products that are often delivered by national science programmes for a variety of uses are adjusted for CCS applications. Open source software tools that extract bespoke analysis on a site by site basis can then be developed, providing the base data requirements are met.

In this presentation we will, using illustrative examples from the model community within the STEMM-CCS consortium, define the research front and its translation to operational status, establishing open questions for the immediate future in order to assure effective and efficient implementation of offshore CO_2 storage on large scales.

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