Can we use departure from natural co-variance relationships for monitoring of offshore carbon storage integrity?

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Carbon capture with offshore storage may take place at various geographical locations, characterised by diverse physical and biogeochemical properties and dynamics of the overlying water.

In order to ensure storage integrity, baseline conditions, including any periodic (e.g. seasonal) and episodic (e.g. due to lateral advection) temporal variability, must be carefully assessed for each potential storage area, which will allow design and deployment of optimal monitoring and sampling programmes. Baseline characterisation is also necessary to establish appropriate site-specific criteria for anomaly detection, to allow timely reaction and necessary remedial measures.

In terrestrial systems, departure from rigid co-variance relationships of a few easily measurable variables has been successfully used to indicate anomalies which may result from a CO$_2$ release (Romanak et al., 2012). Here we assess if this approach could work in a marine context.

Detailed characterisation of any marine region requires simultaneous assessment of many variables over a sufficiently long time period, which is usually a costly and time consuming task. However, coupled hydrodynamic-ecosystem models set up for an area of interest, can produce high amount of data at appropriate spatial and temporal resolution, including physical dynamics, as well as concentrations and fluxes of biogeochemical variables, allowing description of the system at a level of detail not attainable with traditional sampling techniques. This makes modelling products, carefully validated against observational data, particularly applicable for the selection of appropriate variables to describe baseline variability and, consequently, strategies for the following monitoring.

To illustrate the applicability of models for this task, outputs of a well-established biogeochemical-ecological model ERSEM were applied for baseline characterisation at a potential CCS site at the Goldeneye Field in Central North Sea. Model results have shown that strong correlation between near-bottom pCO$_2$ and dissolved oxygen, which was proposed as a storage site integrity criterion earlier, do not always hold in this area due to high environmental variability. Therefore we applied multivariate linear regression in order to identify which combinations of modelled variables best predict local variability in pCO$_2$. Since our ultimate aim is to inform monitoring strategies, we excluded from our analysis those variables which are costly to sample and analyse (e.g. porewater nutrients, POM, microbial biomass).

Using combinations of two variables, a pair of oxygen saturation and ammonium was identified as a best predictor of pCO$_2$, explaining 61% of its variability (Fig. 1). Thus, high correlation between the
predicted and modelled pCO₂ any point in time would lead to some level of confidence of storage integrity, while lower correlation (i.e. lower predictor skill) could indicate a possibility of leakage. Notably, this correlation is not uniform through time: it is lower in autumn-early winter season due to intense vertical mixing and higher in summer when the water column becomes stratified. This has implications for leakage detection. For instance, a difference above 15 µatm between the modelled and predicted pCO₂ was never detected in June, but was present 24% of the time in October, which might imply high probability of false leakage detection in autumn for the selected threshold.

In order to assess the choice of detection sensitivity levels in relation to seasonality, hypothetical, highly simplified leakage scenarios were applied to the time-series by increasing pCO₂ by 10% in October or in June. Generally, imposing stricter detection limits led to an increase in identification frequency of true leak cases, but also to an increase in false leak detections. Based on this analysis, we have identified that choice of a threshold slightly below 20 µatm will lead to maximum true positive to false positive detection ratio.

In addition to using two variables, multivariate regression using three variables to explain pCO₂ variability was tested. A combination of salinity, oxygen saturation and ammonium led to 69% of pCO₂ variability explained. Notably, this is the same set of parameters as identified in 2-variable analysis, augmented by salinity. This combination allowed for further improvement of predictability, slightly increasing percentage of true positive and decreasing false positives compared with 2-variable approach.

We conclude that hydrodynamic-biogeochemical models are invaluable tools for informing cost-effective monitoring strategies on optimal number and combination of parameters surveyed and for establishing appropriate anomaly criteria for each potential storage location.

Figure 1. Time-series of near-bottom pCO₂ at a location corresponding to Goldeneye Field in the North Sea: modelled (blue line) and predicted from oxygen saturation and ammonium concentration (green line).