STEMM-CCS GHGT-14 Short Abstracts

Paper number	330
Title	**Constraining leakage pathways through the overburden above sub-seafloor CO2 storage reservoirs**
Authors	**Jonathan M. Bull**, Christian Berndt, Timothy A. Minshull, Timothy J. Henstock, Gaye Bayrakci, Romina Gehrmann,, Christoph Böttner, Bettina Schramm, Ben Callow, Mark Chapman, Naima Yilo, Marius Dewar, Baixin Chen, Umar Saleem, Hector Marin-Moreno, Giuseppe Provenzano, Anna Lichtschlag, Ismael Falcon-Suarez, Ben Roche, Rachael James, Douglas P. Connelly, Juerg Matter, Judith Elger, Jens Karstens, Angus I. Best
Affiliations	Southampton, GEOMAR, Edinburgh, Heriot-Watt, NOC
Short summary	The location and potential intensity of any possible CO_2 leakage at the seafloor are critically dependent on the distribution and permeability of fluid pathways in the sediment overburden overlying any putative storage reservoir. This talk will describe the results from two geophysical cruises to the Scanner and Challenger pockmark complexes in the North Sea. These pockmarks were known to be the locations of vigorous and persistent methane venting, were associated with bright spots at shallow depth, and had “chimney” structures imaged on seismic reflection data to depths of several hundred metres. Understanding the flow of methane from different depths in the sub-surface will facilitate an understanding of possible pathways of CO_2. The results described in this presentation will be relevant to storage operators, policy-makers and those keen to demonstrate that it is possible to constrain and fully understand the physical properties and possible fluid flow pathways in the sedimentary overburden above sub-seafloor CO_2 storage reservoirs.

Paper number	608
Title	**Establishing an effective environmental baseline for offshore CCS**
Authors	**Steve Widdicombe**, Veerle Huvenne, James Strong, Jerry Blackford, Gavin Tilstone
Affiliations	PML, NOC
Short summary	Understanding what is ‘natural’ or ‘normal’ in a marine system is essential when establishing criteria against which potential environmental impacts can be identified, monitored and quantified. Given the significant degree of heterogeneity in marine systems, both in space and time and the large spatial extent and longevity of storage complexes, there are a number of financial, logistical and methodological challenges associated with constructing such baselines. We will illustrate new approaches and opportunities for combining a variety of data types, including satellite images, previous environmental surveys and simulation models to extend environmental baselines through time and expand their spatial coverage. We will present an integrated, hierarchical approach to constructing an effective environmental baseline suitable for supporting offshore CCS activities in terms of leak detection monitoring, environmental risk assessment and impact quantification. Whilst each storage site will have a unique baseline due to *in-situ* bio-physical characteristics, the baseline quantification techniques and approaches presented here are designed to be generic, allowing them to be applied to the majority of offshore storage sites located within coastal shelf seas.

Paper number	189
Title	**Ensuring efficient and robust offshore storage – the role of marine system modelling.**
Authors	**Jerry Blackford**, Guttorm Alendal, Yuri Artioli, Helge Avlesen, Pierre Cazenave, Baixin Chen, Andy Dale, Marius Dewar, Kristian Gundersen, Matthias Haeckel, Sorush Khajepor, Gennadi Lessin1, Anna Oleynik, Umer Saleem.
Affiliations	PML, Bergen, Uni Res, Heriot Watt, GEOMAR

Short summary	This paper describes the utility of developing marine system models to aid the efficient and regulatory compliant development of offshore carbon storage. Using examples from several model systems we show that marine models allow us to characterize the chemical perturbations arising from hypothetical release scenarios whilst concurrently quantifying the natural variability of the system with respect to the same chemical signatures. Consequently models can identify a range of potential detection criteria, identifying the most sensitive discriminators applicable to a given site or season. Further, using models as in-silica testbeds we can devise the most cost-efficient deployment of sensors to maximise detection. Modelling studies can also contribute to the required risk assessments, by quantifying potential impact from hypothetical release scenarios. Finally, given this demonstrable potential we discuss the challenges to ensuring model systems are available, fit for purpose and transferable to CCS R&D across the globe.

Paper number	
Title	**Biogeochemical sensors for offshore CCS reservoir integrity verification**
Authors	**Matt Mowlem**, Socratis Loucaides, Doug Connelly, Dirk Koopmans, Dirk de Beer, Jerry Blackford, Sergey Borisov, Birgit Ungerboeck, Moritz Holtappels, Eric P. Achterberg, Mario Esposito, Martin Arundel, Alex Beaton, Alison Schaap, Geraldine Clinton-Bailey, Chris Cardwell, John Walk
Affiliations	NOC, Max Planck, PML, Graz, AWI, GEOMAR
Short summary	Monitoring for biogeochemical changes in marine systems will provide an important additional monitoring approach with high sensitivity, is independent of bubble formation and provides an ability to verify fluid flows as CO_2 which acoustic technics cannot. Here we present recent advances in both biogeochemical sensor technology for CCS reservoir integrity verification and understanding of the analytical performance and data manipulation required for detection and quantification of suspected leaks. Advances include: the first generation of reagent based chemical analysers with sufficient performance for CCS applications that can measure pH, nitrate and phosphate and can be deployed on low-power autonomous vehicles; new optodes for Oxygen and pH; and novel estimation of benthic dissolved inorganic carbon fluxes using i) eddy covariance and fast O2 and pH sensors; or ii) chemical gradients in the turbulent boundary layer. We also outline a roadmap for development of further technologies including sediment profiling systems and sensors for total alkalinity and dissolved inorganic carbon.

Paper number	683
Title	**Combining models and machine learning techniques to design leak detection monitoring.**
Authors	**Kristian Gundersen**, Anna Oleynik, Guttorm Alendal, Hans J. Skaug, Helge Avlesen, Jarle Berntsen, Jeremy Blackford, Nello Blaser, Pierre Cazenave
Affiliations	Bergen, Uni Res, PML
Short summary	In recent years the so-called “deep learning” methods have received much attention. They have dramatically improved the state-of-the-art in speech recognition, visual object recognition, object detection and many other domains such as drug discovery and genomics. Machine learning techniques are well suited to analyse large data sets collected from sensory systems that are ubiquitous today. To utilize deep learning in CO2-leakage monitoring, it is important to have vast amount of data for the learning process, hence combining in-situ measurements with model data to learn the framework. Goldeneye will be used as site of study. The in-situ data gathered in preparation for the 2019 experiment, baseline simulations and leak scenarios from the Plymouth Marine Laboratory model framework will be supplemented with leak scenarios simulated with an advection-diffusion reaction model. In this presentation we discuss how machine learning can be used to classify streams of monitoring data, and classify the stream to be within natural variability or as indications of a CO2-leak, and further discuss how to design leak detection monitoring based on these methods.

Paper number	697
Title	**Simplified modelling as a tool to locate and quantify fluxes from a CO2 seep to marine waters.**
Authors	**Anna Oleynik**, Kristian Gundersen,Guttorm Alendal,Hans J. Skaug, Helge Avlesen, Jarle Berntsen, Jeremy Blackford, Nello Blaser, Pierre Cazenave.
Affiliations	Bergen, PML, Uni Res
Short summary	Transport of contaminants, such as CO2, in the ocean is typically modelled using General Circulation Models (GCMs) with additional transport equations for tracers. These models are generally very computationally demanding and, thus, can not be directly used for parameter estimations. Under the assumption that the contaminant is a passive tracer, i.e., does not influence on the water density, the tracer transport equations can be integrated off-line. The GCMs can be used to produce characteristic spatial and temporal velocity fields, accounting for tides, storm events, and topographic steering of the currents. With such current statistics in place, the computational cost of integrating the transport equation alone is sufficiently modest and allows the use of classical and Bayesian inverse problem methods. In this talk we discuss how these methods could be used for locating and estimating unknown seep locations and fluxes based on measurements.

Paper number	791
Title	**Cseep as a stoichiometric tool to distinguish a seep signal from the natural variability.**
Authors	**A. M. Omar**, M. I. García-Ibáñez, and G. Alendal
Affiliations	Uni Res, Bergen
Short summary	For CCS to be classified as a climate change mitigation option, an efficient, safe and enduring storage needs to be verified through site-specific monitoring programs. In the case of offshore geological storage, the high spatiotemporal natural variability hinders the interpretation of leakage signals. By characterizing the spatiotemporal natural variability through baseline studies, the stoichiometric Cseep technique minimizes the natural variability of the inorganic carbon pool and isolates the effect of leaked CO2. The technique takes advantage of the fact that the production and consumption of seawater CO2 by natural process can be modeled/computed from non-CO2 variables that are not impacted by CO2 leakage. For instance, biological production of CO2 is always associated with a certain amount of oxygen consumption and nutrient production while CO2 leakage has no specific effect on oxygen and nutrient levels in ambient bottom waters.

Paper number	188
Title	**Regional modelling to inform the design of sub-sea CO_2 storage monitoring networks**
Authors	**Pierre Cazenave**, Ricardo Torres, Jerry Blackford, Yuri Artioli
Affiliations	PML
Short summary	To design optimal monitoring networks for a range of leak scenarios, we use the Finite Volume Community Ocean Model (FVCOM) coupled with with the European Regional Seas Ecosystem Model (ERSEM) to provide 3D simulations of the water column around Goldeneye. These simulations include hydrodynamic, atmospheric, carbonate chemistry and biogeochemistry. This model system can therefore simulate the chemical signature of a range of hypothetical leakage scenarios within the context of natural variability of the system. This combination is crucial as the key challenge is to distinguish anomalous signals from what can be considerable natural variability. To create the monitoring network, a weighted greedy set algorithm is applied to the leak runs. The sets are created by comparing the dissolved inorganic carbon (DIC) signal from locations within the grid with those in the surrounding sea to

	gauge what proportion of the domain is represented by a single point measurement. The weighted greedy set algorithm then maximises the coverage of the sampling stations whilst minimising the number of stations needed. In this manner, a monitoring network can be designed which will provide the maximum likelihood of identifying a leak of sub- sea CO2.

Paper number	51
Title	**Prediction of Greenhouse Gas Leakages from Potential North Sea Storage Sites into Coastal Waters by an Unstructured, Multi-Scale and Multi-Phase Flow Model**
Authors	**Marius Dewar**, Umer Saleem, Sorush Khajepor, Baixin Chen
Affiliations	Heriot-Watt
Short summary	This talk describes the development of a multi-phase, multi-scale oceanic model for the fate of CO2 leakage into the water column based on the Unstructured Grid Finite Volume Community Ocean Model (FVCOM). The “multi-phase” allows the prediction of the fate of leaked bubbles, liquids and/or solid hydrates and the distribution and impact of the dissolved solution, measured in a number of ways including pH, pCO2 and DIC. The “multi-scale” provides analysis of the fate of the leakage plume in millimeters to meters, and in the water column local impacts the meter to kilometer scale, with further impacts measured in the coastal scale up to thousands of kilometers. This model, known as FVCOM-MP has been specifically designed for the Goldeneye site that has the potential to store carbon and where the STEMM-CCS experiment will be carried out in 2019. However, the leakage site can be moved and applied to analyse impacts from various sites within the North Sea or other seas and oceans as required.

Paper number	556
Title	**Numerical Modelling of CO_2 Flow through Sediments into Water Column**
Authors	**Umer Saleem**, Marius Dewar, Baixin Chen
Affiliations	Heriot-Watt
Short summary	This research focuses on development of a numerical model to predict the characteristics for migration of CO2 through sediments and residues in the seabed coupling the ocean turbulence, aiming to enhance the understanding of dynamics of gas leakage initiating from a storage site. The models is an N-S Equations based two-phase flow model (AND2P) for momentum and mass transportations of fluids through the sediments with various rock flows into the turbulent ocean floor. It has been demonstrated that the developed model is able to predict the fluids momentum exchanges, the gas plume development in heterogeneous sediments, while, the challenges of the study are modelling of fluids and fluids-pore-solid interactions; for instance, the modelling of effective interfacial areas and gas dissolution. Fundamental studies from Lab exp and LBM will be investigated and implemented to the development of the challenging models, which will be reported further.

Paper number	52
Title	**Can we use departure from natural co-variance relationships for monitoring of offshore carbon storage integrity?**
Authors	**Gennadi Lessin**, Yuri Artioli, Jorn Bruggeman, Jerry Blackford
Affiliations	PML
Short summary	The poster demonstrates potential applicability of coupled hydrodynamic-biogeochemical models for multivariate baseline characterisation within storage region and identification of anomalies via departure from natural co-variance relationships, focusing on CCS site in Central North

	Sea. Modelling approach can produce high amount of data, allowing description of the system at a level of detail not attainable with traditional sampling techniques. Multivariate linear regression showed that a combination of near-bottom oxygen saturation and ammonium is the best predictor of pCO2, explaining about 2/3 of its variability. Departure from strong correlation between the predicted and modelled pCO2 could indicate a possibility of leakage. Using simplified leakage scenarios, we demonstrate implementation of different threshold levels to minimize number of false leakage detections and discuss impact of natural system seasonality on leakage predictability. Further explaining pCO2 variability based on three variables, a combination of salinity, oxygen saturation and ammonium led to slight improvement in leakage predictability.