Strategies for Environmental Monitoring of Marine Carbon Capture and Storage

News update

Spring 2018

Measuring bubbles in the ocean

Using the Panarea CO_2 seeps as a natural laboratory

In this issue:

Imaging and quantifying CO_2 bubbles

By Ben Roche, University of Southampton

In May 2018 a team from the University of Southampton travelled to the small Aeolian island of Panarea, just north of Sicily, to study naturally-occurring seabed CO_2 seep sites using a specially designed Acoustic Optical Lander (AOL). The goal was to test methods of measuring the amount of gas escaping into the water column.

Located just 20km southwest of Stromboli, Panarea has been a known source of hydrothermal activity since antiquity. Underlying silicic magma has resulted in CO_2 seeps of varying intensities forming throughout the area, in particular around Bottaro Island where a shallow submarine gas eruption in 2002 formed what is now known as Bottaro Crater. This is a unique site that has been the centre of many geochemical investigations and a natural target for investigating methods to determine gas flux.

The main aim of this fieldwork was to measure gas flux not just through direct sampling but with the use of simultaneous passive acoustic and optical techniques:

- Optical techniques work by placing two cameras in a stereo arrangement and filming the bubbles as they rise past a scale board. This footage can then be analysed to determine the size and rise rate of bubbles escaping the seabed.
- Passive acoustics work on the principle that each bubble vibrates at a distinct frequency depending on its size. So by recording the sound of a seep with special underwater microphones (known as hydrophones) we can determine the size and rate of bubble release.

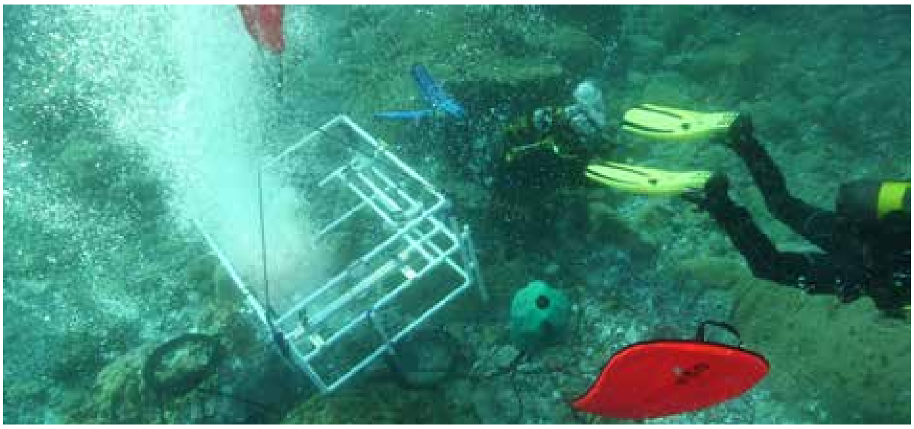
In order to collect both sets of data simultaneously a specialist Acoustic Optical Lander was designed and built. The design incorporates four hydrophones that can be attached at any position along the base of the lander, as well as four cameras configured in two stereo arrangements that focus on a single central point with scale boards positioned directly opposite. Created using specialist piping and three adjustable stilt-like legs, the AOL can be deployed from the side of a small boat and easily manoeuvred around the seabed by divers to place on top of any seep.

Above: The AOL positioned around a vigorous gas seep by Martina Gaglioti. Image courtesy Roberto Rinaldi.

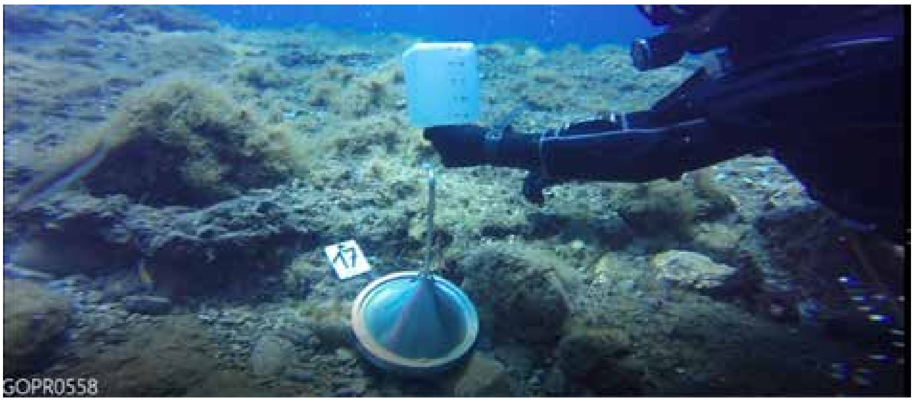
The trip was a huge success with the rig being deployed seven times during the week, targeting a variety of seep types ranging from slow single bubble release sites to thunderous bubble eruption sites. Bubbles observed were 1-3cm in diameter and appeared to be released in short bursts instead of the expected continous stream. Divers also carried out a simple "bubble box" experiment, timing how long it took gas from a single seep site to fill a 2-litre box.

Additionally, a multibeam seafloor survey was completed by the Italian Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS), providing us with both a detailed map of the seabed and images of the bubbles in the water column. We will investigate if there is any seabed fault control over the location of seeps.

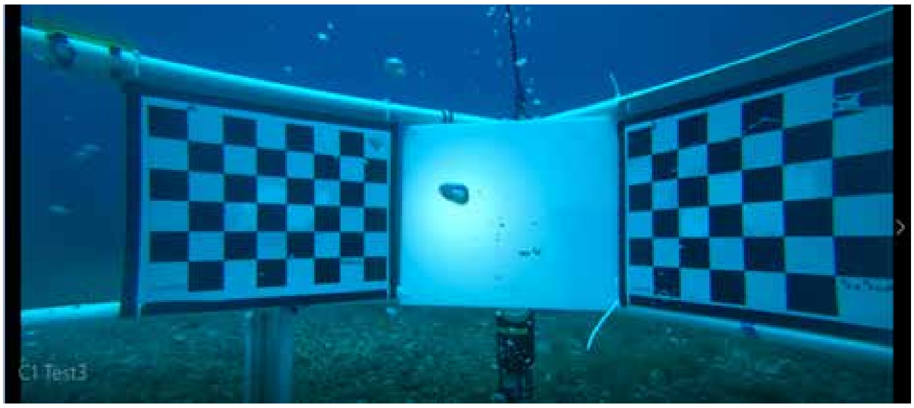
The team will now spend the coming months analysing the acoustic and video data to determine the gas flux in the area, and preparing for the STEMM-CCS injection experiment at the Goldeneye site in the North Sea in 2019.

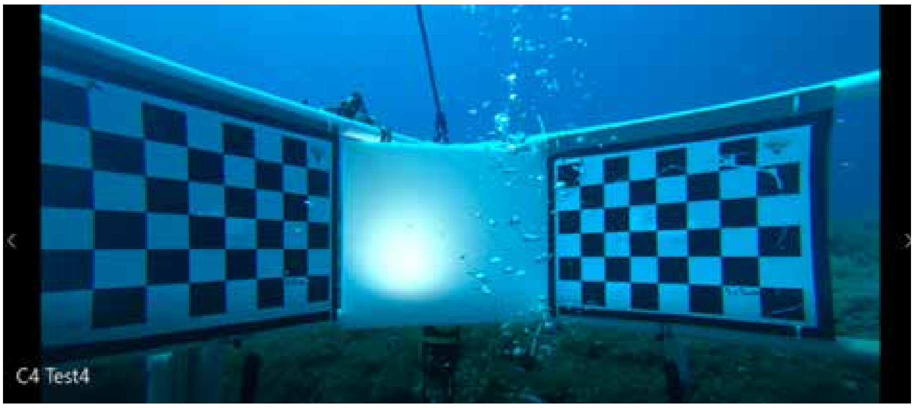


AOL positioned around a vigorous gas seep with hydrophones attahced. In this image Martina Gaglioti, Andrea Fogliozzi. Image courtesy Roberto Rinaldi.



Andrea Fogliozzi carrying out a "bubble box" experiment. It took this single vent just 53 seconds to fill the 2 litre box.





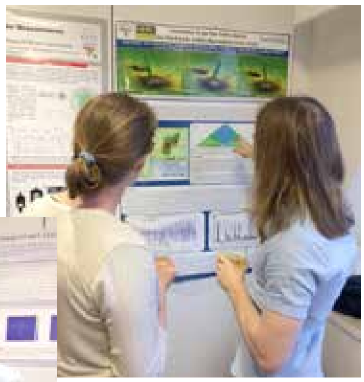
Bubbles rising against the backdrop of the scale board, as seen by a camera on AOL. Squares on the scale board are 5cm x 5cm.

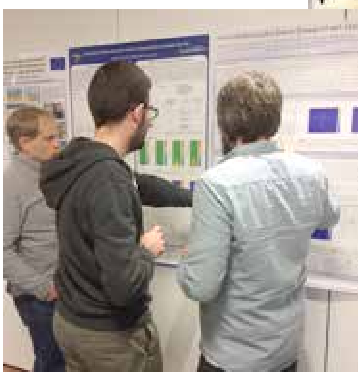
Half time: STEMM-CCS scientists gather in Spain

On 14-16 March 2018, some 50+ researchers from across the STEMM-CCS partnership gathered in Castelldefels on the NE Spanish coast to share results and discuss progress on the project to date. Now at the half-way point in the project, the teams are beginning to accumulate significant datasets, and are gearing up for another busy cruise season to collect all the baseline data they need ahead of the main controlled release experiment in May 2019.

The meeting comprised a series of presentations by work package leaders and individual scientists, which reflected on achievements to date but also offered the opportunity to look ahead to activities in the coming months. A significant amount of time was devoted to planning the strategies and logistics for seagoing expeditions coming up later in the year, which will collect further baseline data from the Goldeneye site. As well as scientists from across the Consortium, meeting participants also included representatives from the project's Stakeholder Advisory Board - Tim Dixon, Katherine Romanak and Mark Chapman - who gave very positive feedback on their impressions of STEMM-CCS' progress to date.

This year's annual meeting was preceded by a 2-day training event targeted at the young scientist contingent within the STEMM-CCS community. The course, which was attended by some 21 early career researchers, comprised a day of lectures from external speakers covering the full CCS cycle in order to enable our researchers to see and appreciate how their work fits within the wider CCS context. The speaker line-up included leading CCS specialists from major CCS operators such Shell (Owain Tucker) and Statoil (Anne-Kari Furre), the International Energy Agency's Greenhouse Gas R&D Programme (IEAGHG; Tim Dixon), and leading CCS academic institutions such as the University of Austin Texas (USA; Katharine Romanak). The course specifically included elements of CCS that the STEMM-CCS community may not come across during their everyday research - such as aspects of the CO_2 capture process (Kristin Jordal, SINTEF Energy Research), the challenges associated with transport of CO_2 from emission source to storage site (Chris Hendriks), factors in CCS site seelction (Roberto Martínez Orio, IGME) and emerging innovative geological storage techniques (Sandra Ósk Snæbjörnsdóttir, Reykjavík Energy). Legal issues surrounding the regulation of CCS monitoring (Cathrine Hetland, Thommessen AS), and the public perception of CCS (Leslie Mabon, Robert Gordon University) were also covered. Plenty of time was allowed for discussion following the presentations, with active participation encouraged. In fact, the questions and discussions after individual talks were so engaging that the formal discussion slots at the end of each session were abandoned in favour of allowing the informal discussions to run.

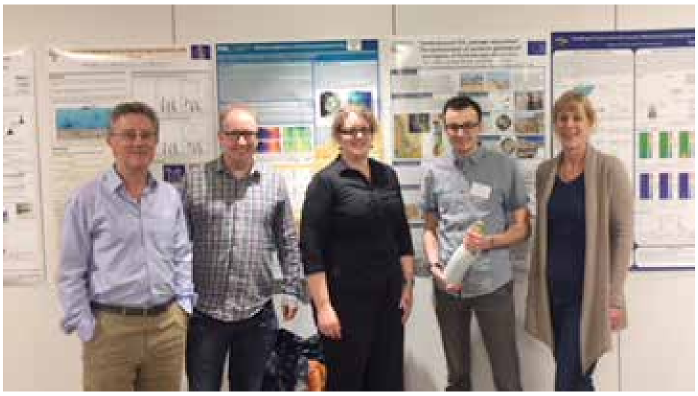




STEMM-CCS young researchers present and discuss their work at the project poster session

The day of lectures and discussion was followed by a half-day practical exercise in which participants worked in teams to examine data relating to a theoretical CO_2 anomaly detected close to an onshore CCS project. The teams were given some background data and then had opportunities to purchase various survey datasets, with the objective of determining the source of the CO_2 and whether it could be attributed to the CCS project. The scenario was made more complex by the periodic introduction of "wildcards" - changes in situation or circumstance that necessiatated an adjustment of approach or reassessment of assumptions. The winning team was determined not only through a correct diagnosis or attribution of the leak, but also by how much money they spent on acquiring the necessary data.

The training event was rounded off by a lively poster session on the first evening of the main meeting, where young researchers presented their work to the rest of the project community. The Stakeholder Advisory Board members carried out an undercover assessment of the posters, and awarded the prestigious bragging rights for Best Poster to Ben Callow from the University of Southampton, for his poster on "*Underground CO_2 storage assurance: the assessment of onshore geological analogues of fluid escape structures*". The National Oceanography Centre's Allison Schaap also received an honourable mention for her poster on "*A lab-on-chip sensor for measuring total alkalinity*".



Clockwise from top left: Presenting team conclusions from the practical exercise; teams discuss which datasets to invest their budget in; Best Poster winner Ben Callow (holding the bottle) and runner up Allison Schaap (left of Ben) with STEMM-CCS Advisory Board members Tim Dixon (far left), Mark Chapman (second left) and Katharine Romanak (far right); throw in a wildcard and observe the teams reassessing their assumptions! Below: the STEMM-CCS group on the beachfront at Castelldefels.

Using turbulence to quantify dissolved CO_2 emission from the seafloor

By Dirk Koopmans and Volker Meyer, Max Planck Institute for Marine Microbiology

Overview

Engineers at the Max Planck Institute for Marine Microbiology have adapted a marine sensor so that it can be used in a highly specialised application for quantifying dissolved CO_2 emission from the seafloor. It will be useful for monitoring carbon capture and storage, but it also has broader uses for examining the carbon balance of aquatic ecosystems.

Carbon capture and storage, for the newcomer, is technology that can help offset anthropogenic CO_2 gas emissions. The approach is to capture CO_2 gas at a point source, such as a fossil fuel generation facility, and then store it permanently in a geologic formation. Geologic formations that are well-suited to the task include depleted oil and natural gas reservoirs. With 500 offshore oil and natural gas platforms worldwide, marine carbon capture and storage has a lot of potential reservoirs to work with.

For marine carbon capture and storage to succeed, techniques must be developed to identify CO_2 leakage at the seafloor, should it occur. When CO_2 gas meets seawater it dissolves, forming aqueous CO_2 which reacts with water to generate bicarbonate and hydrogen ions. Bicarbonate is naturally enriched in seawater, so the addition of bicarbonate from a CO_2 leak would be difficult to detect. Instead, dissolved CO_2 leak detection has focused on the reduction in seawater pH caused by a CO_2 source. Low pH would be an indicator of a CO_2 source. To quantify the source, additional technology is needed.

The standard technique – benthic chambers

The standard approach for measuring CO_2 emission at the seafloor is to use benthic chambers. Natural CO_2 emission and seawater pH reduction by marine sediments is an important component of the global carbon cycle. Researchers have been studying benthic carbon exchange by placing a chamber into marine sediments and measuring the depletion of oxygen, or the depletion of pH, or the enrichment of dissolved inorganic carbon (DIC) within them. This works for natural benthic exchange, but it is less useful for quantifying a seep of aqueous CO_2. Benthic chambers are small, so it takes a lot of them, or a lot of time, to characterise a heterogeneous source.

The new technique – eddy covariance

Marine scientists have recently started using a popular micrometeorology technique underwater. The technique is called eddy covariance, and the aquatic version was introduced by Berg et al. (2003). Turbulence drives the vertical fluxes of solutes near the seafloor. A parcel of water in contact with sediments will have a lower dissolved oxygen concentration than one in overlying water. Turbulence mixes the oxygen-depleted water upwards, and the oxygen-enriched water downwards. The benthic oxygen uptake can be calculated from the covariance of the turbulent fluctuations in vertical water velocity and oxygen concentration.

To make these measurements we use an acoustic Doppler velocimeter to measure turbulent water velocities. It detects 3D movement of water at a discrete point 20 cm above the seafloor. Right beside this point we position chemical sensors to measure solute concentrations. A challenge of the technique is that the sensors have to be fast. An ideal 90% response time for a sensor is 0.25 seconds. The technique is used with miniature dissolved oxygen sensors, but there are no effective, equivalent sensors for dissolved inorganic carbon.

There is an alternative approach: miniature, fast pH sensors exist, and they have been used for eddy covariance pH fluxes and for estimating dissolved inorganic carbon flux from the seafloor (Long et al. 2015). Adapting the sensors for the task requires engineering.

The new sensor

Ion-sensitive field effect transistors (ISFETs) were developed 40 years ago and have recently been used for stable, long-term monitoring of seawater pH. They are small: the sensor is a 3mm square of metal oxide beneath a thin film that is permeable to hydrogen ions.

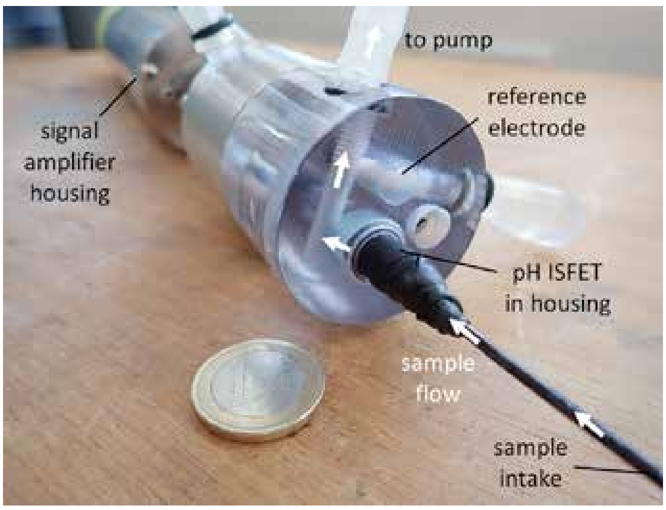


Figure 1. The pH ISFET housing designed by engineers at MPIMM

As pH decreases, hydrogen ions bind to the metal oxide surface. Their charge creates a weak electrical field that reduces the resistance to an electric current flowing just beneath the sensor face.

To make them work for eddy covariance, custom-built amplifiers were adapted to isolate the sensors from electronic noise. Operating current had to be tuned to each individual sensor and temperature corrections were applied. A housing was designed to protect the sensor from ambient light, and a pump was added to draw water past the protected sensor. A custom reference electrode was also designed and integrated into the path of pumped flow.

On the seafloor

In September of 2017 we left the port of Bremerhaven on the RV Poseidon for a cruise to the Goldeneye platform in the North Sea, 100km off the coast of Scotland (see the Autumn 2017 edition of the newsletter for a full account of POS 518). The cruise had multiple objectives; ours was to deploy the eddy covariance system on the seafloor near the Goldeneye platform to measure natural oxygen uptake and DIC production at the seafloor. The deployment relied on a remotely operated vehicle (ROV) to carry the eddy covariance instrument frame to the seafloor and retrieve it after data were collected.

The weather was rough, but on a sunny afternoon we positioned the instrument frame in the manipulator arms of the ROV. The ROV was hoisted off the deck using Poseidon's A-frame then lowered into the sea, making the 110m descent in a few minutes. At video monitors, GEOMAR engineers used the ROV manipulator arms to lift the eddy covariance frame off of the ROV's deck, and deposit it on the seafloor. Then it backed away. An hour later the ROV returned, collected the frame and ascended to the surface. By nightfall the ship was on its way to shelter in the Moray Firth to wait out a storm.

The eddy covariance instruments gave us high-frequency measurements of water velocity, oxygen concentration, and pH, all measured 15cm above the seafloor. At this height, the benthic footprint of the technique is approximately 10m^2 (Berg et al., 2007). Tidally, the predominant current on the seafloor generally sweeps through every point on the compass. The footprint of the technique always points at the predominant current, so over a long (> 13 hours) deployment the footprint of the technique would be a circle around the instruments with an area of about 300m^2, a big improvement from the area of a benthic chamber.

Oxygen uptake was calculated from the fluctuations in vertical velocity and dissolved oxygen. Similarly, the production of hydrogen ions was calculated from fluctuations in vertical velocity and pH. A GEOMAR scientist on board the vessel, Dr Mark Schmidt, determined seawater alkalinity and dissolved inorganic carbon to characterise the carbonate system. With these values, we could calculate the flux of dissolved inorganic carbon from the flux of hydrogen ions. The technique worked. The natural uptake of oxygen and production of DIC mirrored each other with high precision. That the O_2 and CO_2 fluxes were the same (but opposite) shows that the CO_2 is produced by natural mineralisation processes and not by seeps, as expected. When the measured CO_2 flux exceeds the O_2 flux, seepage is indicated. We are confident that our method is a robust and sensitive way to detect CO_2 leaks.

Figure 2. Retrieval of the oxygen and pH eddy covariance system from the seafloor by a remotely operated vehicle. The Goldeneye platform is visible on the horizon.

Looking ahead

This new technique is promising for quantifying biotic and abiotic aqueous CO_2 fluxes. Benthic fluxes are measured over a large area and under in situ hydrodynamic conditions. Longer-term measurements could be useful for monitoring locations where a risk of CO_2 leakage is considered high. Significantly, the technique can also be used to investigate the carbon balance of aquatic ecosystems under variable environmental conditions. With this technology, one could watch as ecosystems respond to changes in temperature, light, dissolved nutrients, or seawater pH. As a result, the technique can be used to improve predictions of an ecosystem's response to environmental change.

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How to shrink a sensor

By Allison Schaap, National Oceanography Centre UK

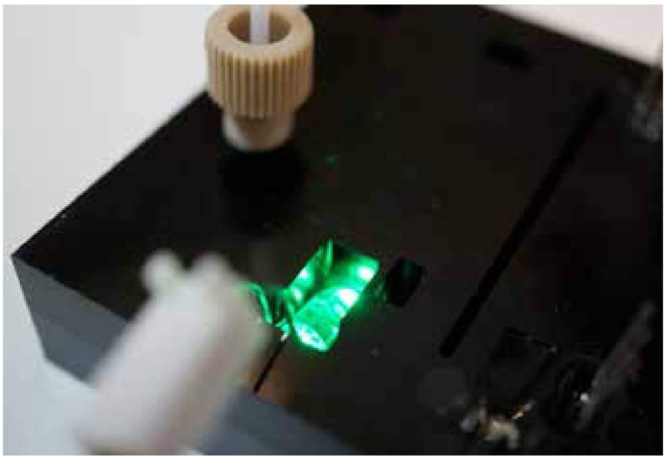
Miniaturising the lab

One of the key outputs of STEMM-CCS is the development and deployment of new oceanographic sensors. Engineers at the Ocean Technology & Engineering Group at the National Oceanography Centre in Southampton have been developing miniaturised autonomous chemical sensors for around a decade. For STEMM-CCS we will be providing a suite of sensors to measure biogeochemical and carbonate parameters before and during the controlled release experiment at the Goldeneye site in 2019. To accomplish this, we're providing some sensors that have been developed through past projects - those measuring nitrate[1], phosphate[2,3], and pH[4] - and also developing new sensors to measure total alkalinity (TA) and dissolved inorganic carbon (DIC) in situ.

How the sensors work

The NOC sensors use an approach called lab on a chip, which aims to take a full laboratory-based procedure and miniaturise it onto a single small device. The lab on a chip field has been rapidly developing over the past two decades; much of the funding and effort internationally has been aimed at developing new biomedical technology but other applications – for example, analytical and synthetic chemistry, plant science, and environmental monitoring – have been growing alongside. Lab on a chip technology is characterised by having very small fluidic channels (tens or hundreds of micrometers in height and width) formed inside a solid piece of material in which some chemical or biological measurement takes place.

The NOC sensors are designed to implement standard assays used in chemical oceanography labs. Most of the sensors pump in some seawater, mix it with one or more colour-forming reagents, and then perform an optical absorbance measurement (Fig. 1) to determine the concentration of the analyte of interest in the sample.



The major advantage of this approach is that any single measurement consumes only a very low volume of chemicals. On the NOC sensors, for example, a calibrated measurement of the concentration of a chemical in the seawater produces only a few drops of waste, which are collected and stored on the sensor for later disposal. A few litres of reagents and standards can therefore last for months of hourly deployments; these are typically carried above the sensor in flexible bags (Fig. 2). The other big advantage of lab on a chip technology is the low power consumption inherent in the small sensors. The NOC technology uses less than 2W while doing a measurement – about 5% of the power consumed by a small laptop.

Tiny physics

Working on the microscale can offer unique challenges and opportunities in physics and engineering. The ocean is not a clean environment and small channels can easily clog up if the samples are not filtered – we use 0.45μm filters on the sensors to avoid this problem. Machining components with such small sizes also requires specialised manufacturing equipment and processes.

However, we can also use the physics of microscale fluids to our advantage. As you scale down in size, physical effects that are dominant on the large scale (such as turbulence, gravity, or inertia) can become irrelevant in comparison with other effects like diffusion, viscosity, or friction. When fluid is passed through such small channels as those on our sensors the flow is always laminar (i.e. there is no turbulence) and we can use highly predictable diffusion and dispersion effects to our advantage. The pH sensor, for example, uses the reliable dispersion of a plug of pH-sensitive dye to create a titration curve inside a single long channel. On the nitrate chip, a unique microfluidic mixer uses the centrifugal force created on fluid passing around a tight curve to mix sample with reagents.

How to miniaturise a sensor

STEP 1: Pick an assay. As much as possible, we try to base our sensors on analytical methods which have been developed, optimised and accepted by the oceanographic community. We'll test the assays in the lab for their suitability to be adapted into lab on a chip device and adapt the assays if necessary. For example, the NOC nitrate+nitrite sensor uses the well-established Griess (NEDD) assay and the phosphate sensor uses a slightly modified version of the molybdenum blue assay.

Figure 1 (left): LED integrated into a simple microfluidic chip for assay testing.

Figure 2: Complete lab on chip system with reagents in a transparent housing above the sensor, about to be deployed off the side of a small ship.

STEP 2: Design the system. As much as possible, we try to re-use components, methods and subsystems that have been developed for other chemical sensors. This is known as a platform approach, which minimises the time and cost for developing new sensors. Many of our standard components were developed in-house, such as the standard pumps and the electronics that provide power, control, and communications ability. We use commercial valves, LEDs and photodiodes. However, some sensors will require a unique layout of fluidics to enable the necessary chemical reactions and this new chip is drawn out in computer-aided design software and matching custom electronics produced to fit the need.

STEP 3: Manufacturing and testing. The heart of the sensors is a micromachined plastic chip patterned with fluidic channels that are nearly as small as a human hair. These are all produced in-house at the NOC. Subsequently, optical components are glued into the chip to align with the fluidic channels and the rest of the components – pumps, valves, circuit boards – are assembled on top. The complete sensor systems are tested after manufacturing. For routine/existing sensors this is a matter of running a standard set of checks to ensure that the hardware is working and that the chemical performance is as expected. For new sensors, this means testing both the device's hardware and identifying standard analytical performance metrics such as a limit of detection.

Figure 3: Fixed-location deployments to date of the NOC lab on a chip sensors.

STEP 4: Throw it overboard! The NOC lab on a chip chemical sensors have been used all over the world in lakes, estuaries, rivers, and oceans (Fig. 3). They've been deployed on underway systems, CDT casts, moorings, AUVs such as the AutoSUB and SeaGlider, docksides and river stations, buoys, and on Argo-style floats (Fig. 4 below). Our longest deployment to date has been a year underwater, and the deepest down to 4800m. We've deployed sensors in conditions from the Arctic to coastal tropical waters.

For STEMM-CCS the sensor suite will be placed on multiple landers – both the baseline lander and some of the newer ones being developed within the project – and on the ROV and AUVs during the experiment.

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Oportunity knocks: STEMM-CCS Researcher Placement Scheme is open for business

The STEMM-CCS Knowledge Sharing team is pleased to annouce the launch of its Researcher Placement Scheme, which provides support and funding for project researchers to pursue short-term placement opportunities with external organisations, industry, regulatory bodies, companies or academic/research institutions outside the STEMM-CCS project partnership. The scheme is intended to bring a wide range of knowledge exchange benefits to both the researcher and to the host organisation. The researcher on placement will benefit from expanding their knowledge and gaining valuable experience, whilst the host organisation will benefit from closer links to the STEMM-CCS research and its emerging techniques and technologies.

Individual researchers interested in taking advantage of this scheme should identify an organisation or company with whom they would like to explore the possibility of undertaking a placement position. They can either make the initial approach themselves, or request the support of the STEMM-CCS Knowledge Exchange leader, Dr Vikki Gunn, to do this. Once contact is established and a placement arrangement is considered a viable possibility, the researcher should submit an application to the scheme, comprising a case for support that outlines the rationale, benefits and costs of undertaking such a placement arrangement. Applications will be assessed by a dedicated internal review panel.

Any STEMM-CCS researcher employed by or PhD student registered in a STEMM-CCS consortium institution is eligible for the scheme. Whilst the scheme is open to researchers of all levels, priority will be given to applications from PhD students and post-doctoral researchers.

Successful applicants are required to write a short summary report of their placement experience within 3 months of completion, and contribute an article to the STEMM-CCS project newsletter.

For more details of the scheme please contact Dr Vikki Gunn (vikki.gunn@seascapeconsultants.co.uk)

CCS headlines at NOC's Public Open Day

The 2018 NOC Open Day saw nearly 2000 members of the public exploring what goes on at the National Oceanography Centre. STEMM-CCS Coordinator Doug Connelly, along with project scientists Ismael Suarez, Ben Roche and Andrea Munoz, were there to ensure everyone heard about important work we are doing for marine carbon capture and storage.

Doug oversaw the event, introducing the public to the STEMM-CCS project and discussing the upcoming controlled release cruise that will carry out a CO_2 injection experiment at the Goldeneye site in the North Sea in 2019.

Ismael and Andrea exhibited the experimental setup we use in NOC's Rock Physics Laboratory for CO_2 storage simulations at the laboratory scale. They explained how important is to characterise the main reservoir properties and monitor changes during and after the injection of CO_2 to guarantee the stability of the geological system.

Ben ran a stand where people learnt about the use of underwater microphones to measure bubbles and discussed his recent field work in Panarea (see article on page 2) and its potential use as a seep detection system. This proved very popular with children who all enjoyed singing (and screeching) into the microphones before they were used to record nearby bubbles.

The whole team was very impressed with the level of engagement from the public and excited about doing more events to promote STEMM-CCS to the public in the future.

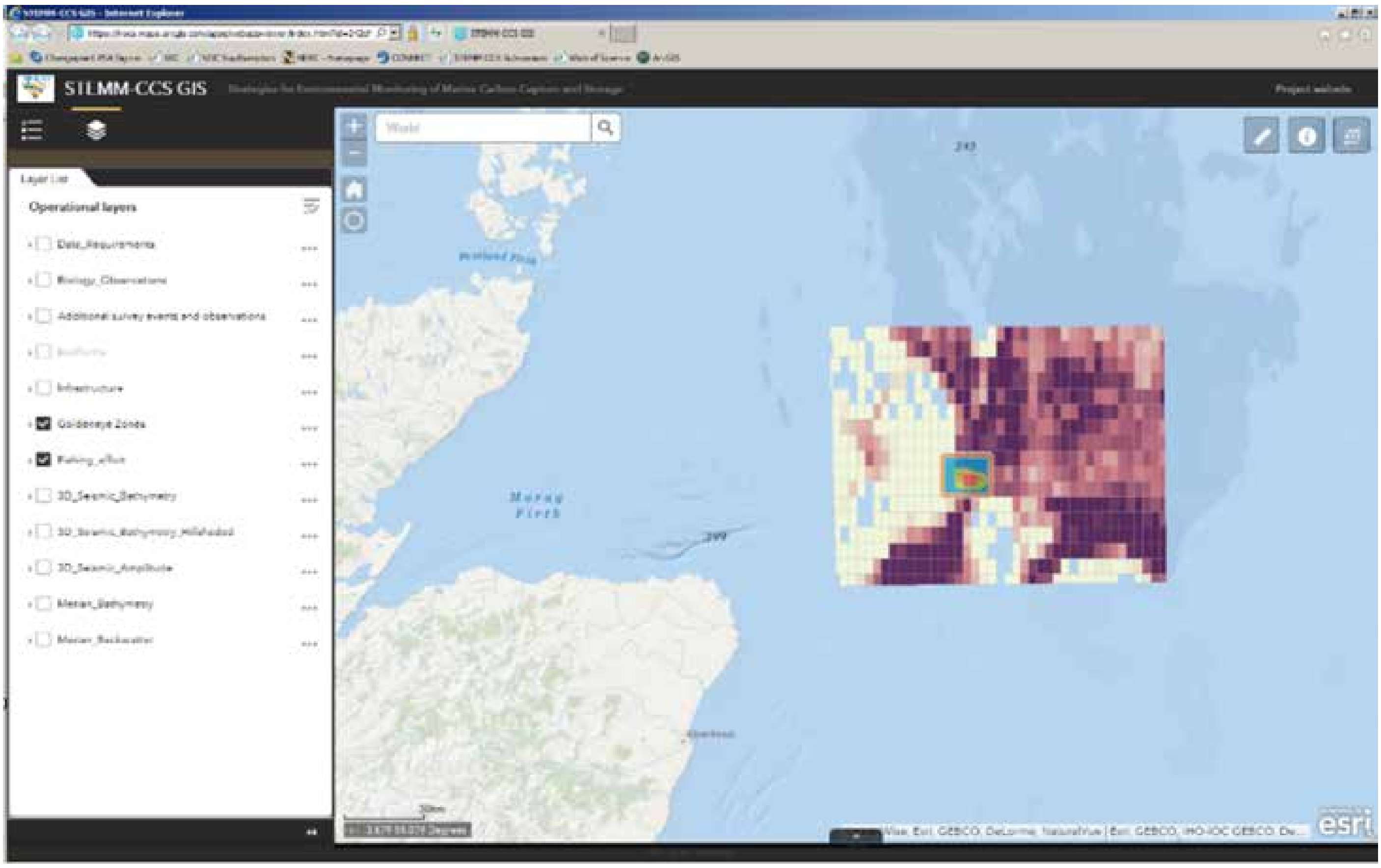
Above: NOC PhD student Ben Roche demonstrating the finer points of underwater bubble measurement to a young enthusiast. Image courtesy NOC.

STEMM-CCS and Goldeneye spatial data now available online for all partners

By James Strong, National Oceanography Centre UK

The team at the National Oceanography Centre has been collating spatial data from the Goldeneye site for inclusion in a STEMM-CCS GIS project. It is anticipated that the GIS project will become the main repository for historical survey information as well as new data collected during the project. It currently contains numerous layers grouped under human (anthropogenic), physical, chemical and biological headings. Human data sources include fishing activity (extracted from Vessel Monitoring System and reflective of effort around the Goldeneye site) as well as oil and gas infrastructure. Physical data includes various bathymetric and backscatter datasets, particle size observations and bedform delineations. Pre-existing survey reports provided by Shell have been scanned to retrieve historical seabed chemistry observations and are presented alongside the point samples contained in the UK Benthos database. Finally, biological observations from various surveys, fisheries cruises and (inter)national databases (e.g. Marine Recorder, MERMAN, EMODnet Biology Portal) have been merged into the same GIS project. Derived products from the project have already been used to (i) examine the distribution of anthropogenic pressures across the Goldeneye site, (ii) model the surficial sediments within the study area. It is hoped that the online system will allow project partners to visualise many of the spatial patterns and processes occurring across the site.

NOC has also released a streamlined version of the STEMM-CCS GIS project online so all project partners can visualise and download the information (Figure 1). Current limitations associated with the online system mean that it is not possible to host all of the spatial data online - project partners can request additional information from NOC directly (contact James Strong jamstr@noc.ac.uk). However, the online version contains many of the most important or currently relevant layers. The online GIS project can be accessed via the partners' area on the STEMM-CCS website (scroll to the bottom of the 'Our Work' tab). Project partners are welcome to recommend amendments to the format of the project, and please send us any new datasets that you have recorded, or any existing information that is missing (see email above).



Example images from the online STEMM-CCS GIS project (fishing activity (2007 – 2015 composite of VMS) and zones within the Goldeneye site).

STEMM-CCS on the road to Melbourne

Since its first event 25 years ago, the Greenhouse Gas Control Technologies (GHGT) conference series has established itself as the premier international technical conference addressing carbon capture and storage (CCS), charting the significant progress and growth in the science behind CCS. GHGT conferences attract around 1000 delegates from academia, industry and policy, drawn from 35 or more countries. As such GHGT conferences are key to spreading scientific and technical advances internationally and into the stakeholder community. GHGT conferences are held every two years, rotating between North America, Europe and Asia; GHGT-14 will be held in Melbourne, Australia on 21-26 of October 2018. GHGT-14 will be the last conference of the series held within the timeframe of the STEMM-CCS project; as such it is an important opportunity for us to present the work of STEMM-CCS on an international stage. STEMM-CCS will be contributing 11 presentations out of the approximately 800 talks and posters accepted for the conference, as well as hosting an exhibition stand to showcase our work.

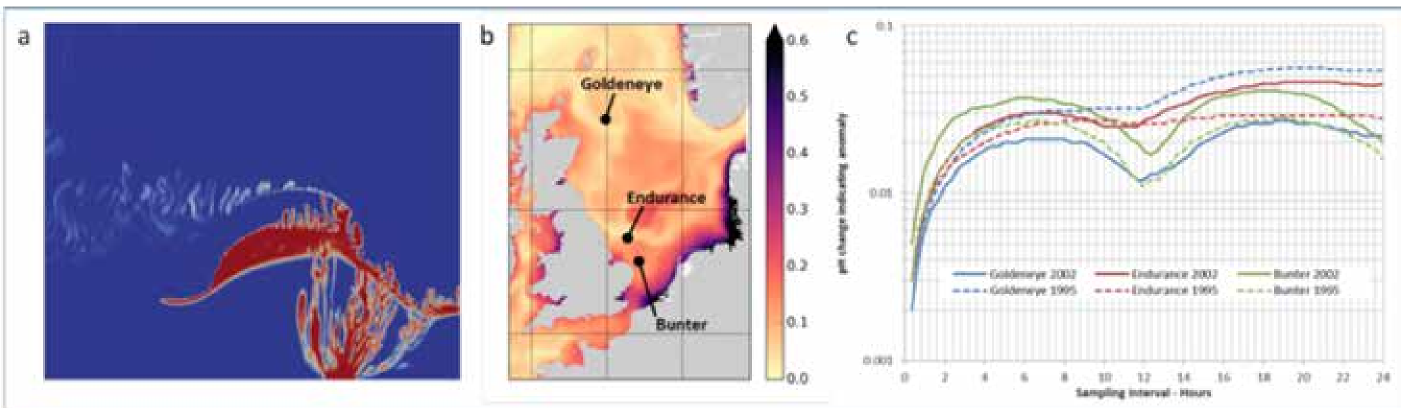
STEMM-CCS will have a presence in the main conference exhibition hall, with a stand highlighting the project's aims and objectives, early results and drawing attention to the controlled release experiment that will take place at the Goldeneye site in the North Sea in spring 2019. The stand will feature a large screen to show a series of short films about the project and the forthcoming 2019 cruise, including interviews with project scientists, footage from fieldwork and animations of the concept of the experimental cruise.

STEMM-CSS presentations at the conference will cover the range of project activities, with four of the presentations designed to summarise the projects activities and outcomes:

- Jon Bull and colleagues will present a paper demonstrating our advances in understanding and constraining fluid flow pathways in the sedimentary overburden above sub-seafloor CO_2 storage reservoirs. This is crucial to understanding leakage risk and optimising both seismic and surface monitoring for assurance.
- A presentation by Steve Widdicombe and colleagues on establishing effective environmental baselines will describe how we can effectively measure sufficient environmental conditions to enable assurance monitoring, without the expense of comprehensive offshore surveys.
- Matt Mowlem and co-authors will describe the advances in sensor technology and their deployment options for assurance monitoring.
- Finally STEMM-CCS's modelling community will detail the many ways in which we can use mathematical approaches to define criteria for identification of anomalous signals and design optimal search patterns to ensure that monitoring is both highly sensitive and cost effective, in a presentation from Jerry Blackford and colleagues.

This last paper is supported by seven further presentations which describe the detail of the modelling techniques we are developing for stakeholder use (see also figures below). These include identification of anomaly criteria (Abdir Omar et al., Gennadi Lessin et al.); the design of monitoring deployments (Anna Oleynik et al., Pierre Cazenave et al.' Kristian Gundersen et al.); the development of very high resolution multi-phase models to predict fluid flow (Marius Dewar et al., Umer Saleem et al.)

STEMM-CCS researchers look forward to meeting the international CCS community in Melbourne. For more information about the GHGT-14 conference, please visit www.ghgt.info/ghgt-14.



Above: Some of the modelling outputs that will be presentated in Melbourne: 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 North Sea sites.

Coming up: expeditions to revisit Goldeneye area to extend mapping of baseline conditions

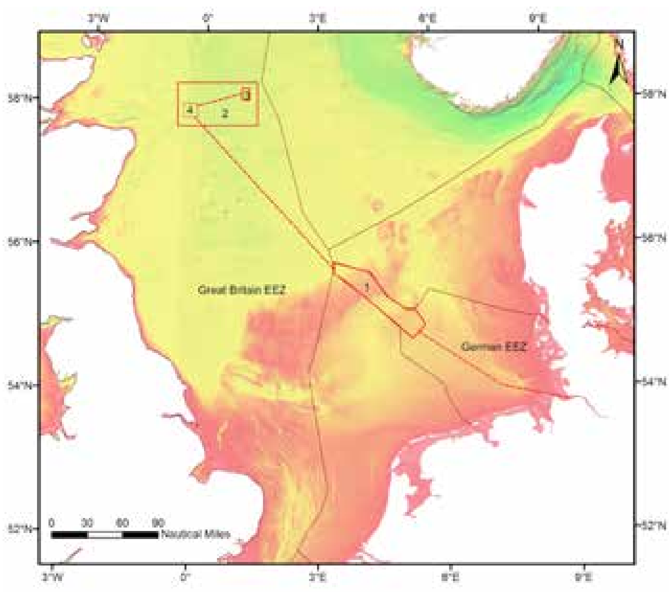
The STEMM-CCS cruise programme continues later this summer, when Principal Scientist Eric Achterberg (GEOMAR) will lead the team aboard the German research vessel RV Poseidon to extend the project's baseline studies at the Goldeneye experimental site in the North Sea.

Departing from Kiel in mid-August, the ship and its crew will spend just under 3 weeks carrying out detailed environmental measurements that will provide information on the background conditions in the region, against which to monitor for CO_2 emissions during the STEMM-CCS controlled CO_2 release experiment in spring 2019.

The main objectives of this cruise are:

1. Pre-define and measure sensitive and robustly measurable environmental background variables which provide an indication for subsea CO_2 leakage;
2. Provide water column measurements of trace gases, nutrients and carbonate chemistry variables to assess baseline conditions in the study region. Collect under natural (baseline) conditions a geochemical porewater dataset to provide a quantitative, process-based interpretation of porewater and benthic fluxes using a state-of-the-art numerical model. This baseline data will be used for comparison with measurements taken during the controlled CO_2 release experiment in the same area in spring 2019;
3. Undertake benthic ecology baseline measurements, to compare against conditions with perturbations from the controlled CO_2 release experiment;
4. Test novel chemical sensors, and hydroacoustic detection systems for measuring benthic and pelagic carbon fluxes (i.e. by using lab-on-a-chip technology, optodes, eddy co-variance techniques for O_2 and pH, 3D-visual bubble imaging, and (multibeam) echosounder quantification).
5. Retrieve, service and re-deploy the project's benthic lander, including downloading of data from sensor measurements over the last 12 months, and cleaning and refurbishing sensors before redeployment of lander for near-seafloor measurements over the coming year.

Progress of cruise POS527 (and other project cruises taking place later in the autumn) can be followed via the STEMM-CCS expedition pages at http://stemmccs.blog



Above: Map of the region in the North Sea showing planned study areas for expedition POS527: (2) Area of interest in British EEZ; (3) Seepage area Block 15/25; (4) Goldeneye area. Proposed transit lines with echosounders active are shown as dotted red lines.