



Sub-seabed CO<sub>2</sub> Storage:  
Impact on Marine Ecosystems

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## Impact on Marine Ecosystems



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Framework Programme



## Introduction and Background

**E**CO<sub>2</sub> - Sub-seabed CO<sub>2</sub> storage: Impact on Marine Ecosystems is a large scale integrating collaborative project funded by the European Commission (EC) FP7 work program topic OCE-AN.2010.3 Sub-seabed carbon storage and the marine environment. The ECO<sub>2</sub> consortium consists of 27 partners - 24 research institutes, one independent foundation (DNV), and two commercial entities (Statoil AS and Grupa Lotos) - from nine European countries (Germany, Norway, U.K., Italy, the Netherlands, Poland, Belgium, Sweden, France). The project is coordinated by GEOMAR in Kiel, Germany. The entire lifetime of ECO<sub>2</sub> is from 1<sup>st</sup> May 2011 to 30<sup>th</sup> April 2015.

**C**arbon dioxide capture and storage (CCS) is regarded as a key technology for the reduction of CO<sub>2</sub> emissions from power plants and other industrial facilities at the European and international level. Hence, the EC will support selected demonstration projects to promote, at industrial scale, the implementation of CCS in Europe.

Consequently, several European states (U.K., Norway, the Netherlands, Italy) aim to store CO<sub>2</sub> below the sea-bed. However, little is known about the short-term and long-term impacts of CO<sub>2</sub> storage on marine ecosystems even though CO<sub>2</sub> has been stored sub-seabed at industrial scale in the Norwegian North Sea since 1996 (Sleipner) and in the Barents Sea since 2008 (Snøhvit).

**I**n consequence of this lack of knowledge, the EC supports the ECO<sub>2</sub> project to assess the risks associated with storage of CO<sub>2</sub> below the seabed. The project evaluates the likelihood of leakage, the possible impacts on marine ecosystems, and its potential economic and legal consequences by studying existing sub-seabed storage sites in saline aquifers in the Norwegian North Sea and the Barents Sea, and a potential storage site in a depleted oil reservoir as well as natural seeps at the seafloor (North Sea, Barents Sea, Mediterranean Sea, Okinawa Trough).



Panarea Study Site; Photo: Hydra

## Objectives

**T**o give consideration to this complex assignment the ECO<sub>2</sub> consortium defined the following 5 key objectives:

1. To investigate the likelihood of leakage from sub-seabed storage sites
2. To study the potential effects of leakage on benthic organisms and marine ecosystems
3. To assess the risks of sub-seabed carbon storage
4. To develop a comprehensive monitoring strategy using cutting-edge monitoring techniques
5. To define guidelines for the best environmental practices in implementation and management of sub-seabed storage sites

## Work performed within the first three years

**E**CO<sub>2</sub> studied the sedimentary cover and the overlying water column at CO<sub>2</sub> storage sites (Sleipner, Snøhvit, B3 field) to identify leakage pathways and locate seep sites. Cutting-edge monitoring techniques applied by ECO<sub>2</sub> failed to detect any CO<sub>2</sub> anomalies in bottom waters above the storage complexes and thus confirmed that CO<sub>2</sub> is safely stored at Sleipner and Snøhvit. However, high-resolution seismic data revealed a large number of vertical pipes and chimneys cutting through the overburden.

**C**O<sub>2</sub> release at the seabed was studied at three natural seep sites (Panarea, Jan Mayen vent fields, Salt Dome Juist) and via deliberate CO<sub>2</sub> release experiments conducted in the vicinity of the Sleipner storage complex. CO<sub>2</sub> gas bubbles and droplets were rapidly and completely dissolved in ambient bottom waters.

## Work performed within the first 36 months

**T**he response of different biota to bottom water and pore water acidification was studied at natural seep sites and in shore-based mesocosm experiments. A limited number of species, which are highly abundant at natural CO<sub>2</sub> seeps, are resilient to elevated pCO<sub>2</sub>, other more species are trying to avoid and escape CO<sub>2</sub> affected areas. Harmful effects of CO<sub>2</sub> include alteration in early ontogeny of echinoderms, a phenomenon overlooked in previous studies. The field campaigns within the first XX months included 23 marine expeditions to offshore storage and seepage sites with a total ship time of 320 days.

**S**eepage of natural gas (methane) from overburden into the overlying water column was detected at numerous sites above the Sleipner storage site and B3 potential storage complexes. Formation waters are released through the 3 km long Hugin Fracture, 25 km north to Sleipner while both natural gas and formation water are seeping through three abandoned wells located in the Sleipner area, as through many other old wells in the North Sea. The currently available data imply that gases and fluids seeping at the seabed in the vicinity of the storage complex originate from the shallow overburden while CO<sub>2</sub> stored at Sleipner and Snøhvit is fully retained in the storage formation.

**T**he environmental risks connected with CCS and how these may impact on the financial, legal, and political considerations accompanying future geological storage have been elaborated. Trust and context were investigated as two influencing factors regarding public perception.

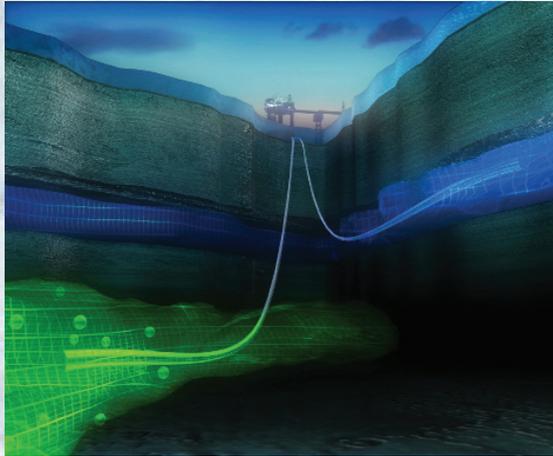
The investigations of ECO<sub>2</sub> will result in the first comprehensive assessment of environmental risks associated with sub-seabed CO<sub>2</sub> storage; a novel and comprehensive monitoring strategy for sub-seabed storage sites; and cost estimation for monitoring and potential leakage mitigation programmes.

## Study Sites

ECO<sub>2</sub> investigates storage sites and potential storage sites that cover the major geological settings to be used for sub-seabed CO<sub>2</sub> storage including depleted oil and gas reservoirs and saline aquifers on the continental shelf and upper continental slope. Field-work at storage sites will be supported by modelling and laboratory experiments at natural CO<sub>2</sub> seep sites.

### CO<sub>2</sub> storage sites and potential storage sites

- Sleipner (North Sea) - in operation since 1996 by Statoil, stores ~1 Mt of CO<sub>2</sub> separated from natural gas per year within the Utsira sand formation (saline aquifer) in ~900 m sediment depth in ~80 m water depth. More than 48 million m<sup>3</sup> of CO<sub>2</sub> have already been injected.



Carbon storage at Sleipner; photo: Alligator film / BUG / Statoil

- B3 field site (Polish Baltic Sea) - potential storage site in ~80 m water depth that is currently exploited for oil by the Polish companies Grupa Lotos and Petrobaltics; exploitations will be closed by 2016. The Polish operators plan to store CO<sub>2</sub> from a nearby oil refinery in the depleted B3 field site oil reservoir.

### European ECO<sub>2</sub> study sites at a glance

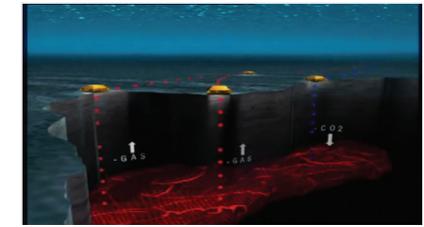


- ★ CO<sub>2</sub> storage sites and potential storage sites
- ★ natural CO<sub>2</sub> seep sites

Plus potential CO<sub>2</sub> storage sites off Australia and natural seeps off Japan

## Study Sites

- Snøhvit (Barents Sea, Norwegian continental slope) - in operation since 2008 by Statoil, stores ~0.7 Mt of CO<sub>2</sub> separated from natural gas per year within a saline sandstone formation in ~2.6 km sediment depth in ~330 m water depth. The high pressures and low temperatures at the seabed allow for solid CO<sub>2</sub> hydrate formation.



left: Snøhvit LNG Prosjekt by Statoil.  
On youtube a short video explanation of how Snøhvit is operated is available.

### Natural CO<sub>2</sub> seep sites

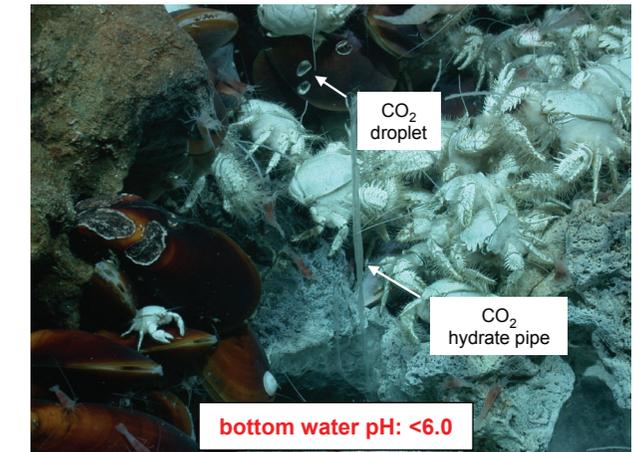
- Panarea area (Southern Tyrrhenian Sea) - is part of the Aeolian Arc north of Sicily; it is a submarine exhalative field located east of Panarea Island. The gas vents are aligned along tectonic features and emit CO<sub>2</sub> originating from degassing magma.



Naturally seeping CO<sub>2</sub> at the Panarea study site; photo: GEOMAR

- Jan Mayen vent fields (North Atlantic) - are situated on the Western Jan Mayen fracture zone in ~550 to 700 m water depth; its hydrothermal fluids are characterised by high carbon dioxide but low methane and hydrogen concentrations.

- Salt Dome Juist (SDJ; North Sea) - is located in the southern German North Sea in ~30 m water depth above a Salt Dome; it is a sedimentary seep where CO<sub>2</sub> levels are ~10-20 times above background.
- Southern Okinawa Trough (NE off Taiwan) - is a back arc basin hosting several hydrothermal fields. Three of these seeps emanate liquid CO<sub>2</sub> droplets at a water depth of ~1300 m and CO<sub>2</sub>-hydrates form in the surface sediments.



CO<sub>2</sub> droplet release and CO<sub>2</sub>-hydrate formation at hydrothermal CO<sub>2</sub> seep sites in the Okinawa Trough; photo: ROV Quest, MARUM Bremen

## Research Expeditions conducted

Study site	Research vessel	Cruise	Date	Lead institute
Sleipner / SDJ	RV Alkor	AL374 <sup>*,1</sup>	17 days - May/June 2011	GEOMAR
Panarea	Small Boat	ECO2-2 <sup>*</sup>	17 days - May/June 2011	MPI
Jan Mayen vent fields	RV G.O. Sars	CGB-ECO2-2011 <sup>*</sup>	14 days - June 2011	University of Bergen
Sleipner	RV G.O. Sars	CGB-ECO2-2011-B <sup>*,2</sup>	9 days - June/July 2011	University of Bergen
Snøhvit	RV Helmer Hanssen	2011003 <sup>*</sup>	14 days - July 2011	University of Tromsø
Panarea	RV Urania	PaCO2 <sup>#,3</sup>	6 days - July/Aug 2011	GEOMAR
Sleipner / SDJ	RV Heincke	HE377 <sup>#</sup>	9 days - April 2012	MPI
Panarea	Small Boat	ECO2-3 <sup>*</sup>	20 days - June 2012	MPI
Panarea	Small Boat	ECO2-4 <sup>*</sup>	6 days - June 2012	Uni Roma1 / OGS
Sleipner	RV G.O. Sars	CGB-ECO2-2012A <sup>*,2</sup>	9 days - June 2012	University of Bergen
B3 field	RV St. Barbara	StBar-2012-1/2/3 <sup>*</sup>	35 days - June 2012	Uni. Gdansk / Gr. Lotos
Jan Mayen vent fields	RV G.O. Sars	CGB-ECO2-2012B <sup>*</sup>	12 days - July/Aug 2012	University of Bergen
Sleipner / SDJ	RV Celtic Explorer	CE12010 <sup>#,1</sup>	18 days - July/Aug 2012	GEOMAR
Panarea	Small Boat	ECO2-5 <sup>*</sup>	5 days - Aug 2012	Uni Roma1 / OGS
Sleipner	RV James Cook	JC077 <sup>*,4</sup>	27 days - Sep 2012	NOC
Panarea	Small Boat	ECO2-6 <sup>*</sup>	13 days - Oct 2012	Uni Roma1 / OGS
Eckernförder Bay	RV Alkor	AL404 <sup>*</sup>	8 days - Nov 2012	GEOMAR
Sleipner / Blow out site	RV Alkor	AL412 <sup>*,1</sup>	18 days - Mar/Apr 2013	GEOMAR
Panarea	Small Boat	ECO2-7 <sup>*</sup>	10 days - May 2013	Uni Roma
Panarea	Small Boat	ECO2-8 <sup>*</sup>	12 days - June 2013	MPI
Snøhvit	RV Helmer Hanssen	2013007 <sup>*</sup>	13 days - July 2013	Uni Tromsø
Panarea	RV Poseidon	PO S469 <sup>*</sup>	20 days - May 2014	GEOMAR
Panarea	Small Boat	ECO2-9 <sup>*</sup>	16 days - May 2014	Uni Roma / OGS
North Sea	RV Alkor	AL447	15 days - Oct/Nov 2014	GEOMAR

Research Vessel Helmer Hanssen; photo: Uni Tromsø

<sup>\*</sup>national funding

<sup>#</sup>EuroFleets funding

<sup>1</sup>This research expedition was conducted in cooperation with the site survey 22-4b (Blow out site British North Sea) assigned by DECC.

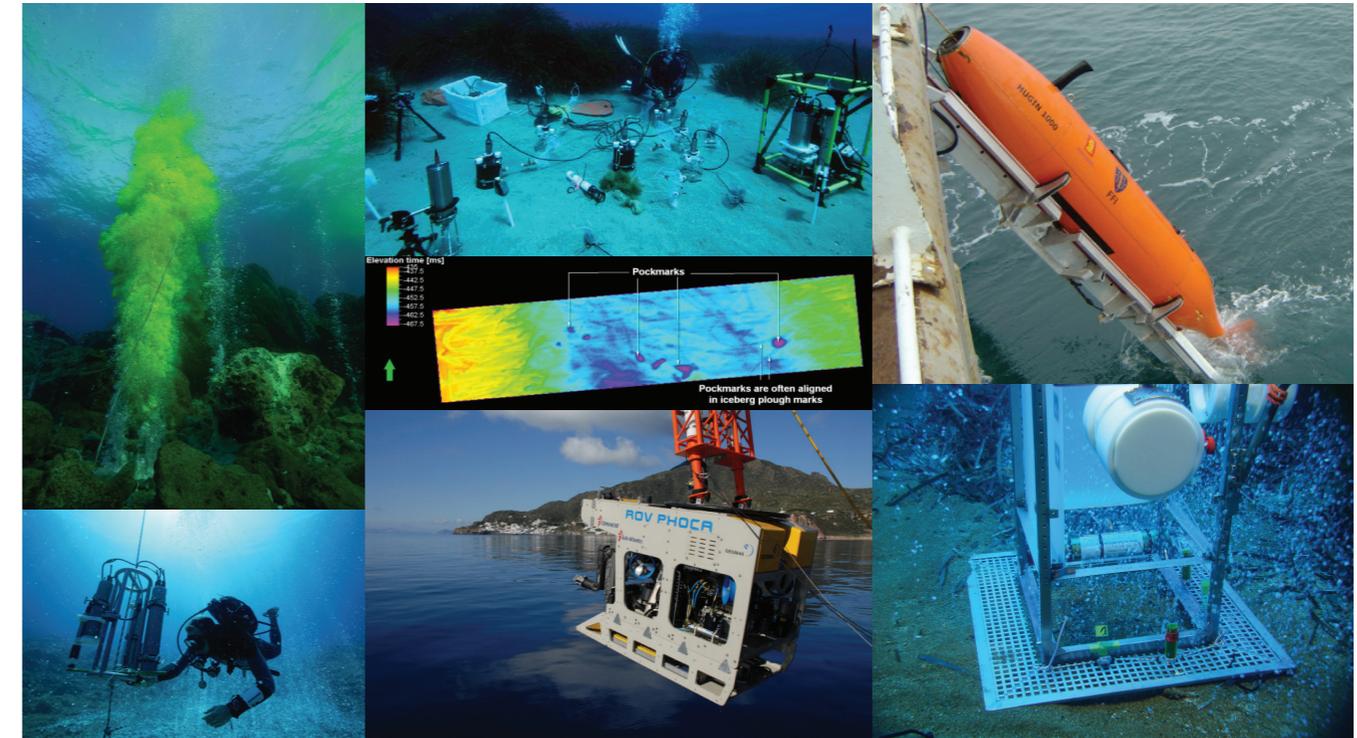
<sup>2</sup>This research expedition was conducted in cooperation with the Norwegian project SUCCESS (SUbsurface CO<sub>2</sub> Storage- Critical Elements and Superior Strategy).

<sup>3</sup>These research expeditions were conducted in cooperation with the FP7 funded project RISCs (Research into Impacts and Safety in CO<sub>2</sub> Storage).

<sup>4</sup>Japanese researchers from the National Institute of Advanced Industrial Sciences and Technology and the University of Kyushu were participating in this research cruise.

## Equipment used at Sea

During the 23 research expeditions conducted so far, ECO<sub>2</sub> scientists investigated the sedimentary cover at active and potential CO<sub>2</sub> storage sites using novel geophysical baseline studies and monitoring techniques to better understand the mechanisms of CO<sub>2</sub> migration. The project evaluates the effects of leakage of CO<sub>2</sub> through the sediments at storage sites and natural analogues and quantifies the fluxes across the seabed and into the water column by means of sophisticated monitoring techniques.



Compilation of figures illustrating the operation of technical equipment and monitoring procedures during research expeditions with figure contributions from University of Bergen, HYDRA, GEOMAR and University of Tromsø.

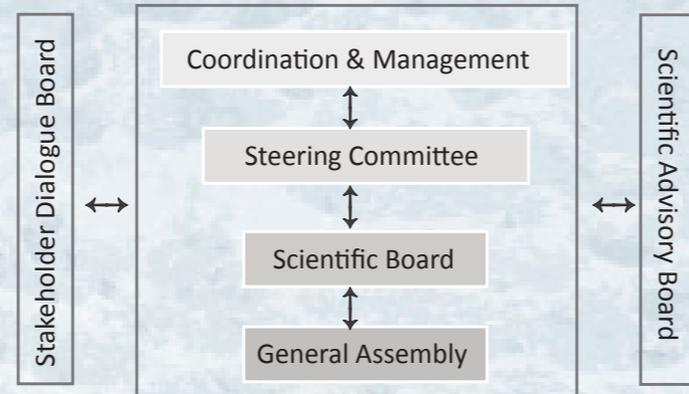
## Scientific Work Structure

The ECO<sub>2</sub> investigations cover a wide range of approaches from basic marine research to ocean governance. The work is divided into seven work packages (WPs) and four cross-cutting themes (CCTs) forming a matrix structure. The WPs are cross-cut by four themes to support information flow and strengthen cooperation across the WPs. Additionally, the CCTs provide vital ECO<sub>2</sub> products by integrating and evaluating the results of the individual WPs.

- WP1: Integrity of the sedimentary cover
- WP2: Fluid and gas flux across the seabed
- WP3: Fate of emitted CO<sub>2</sub>
- WP4: Impact of leakage on ecosystems
- WP5: Risk assessment, economic & legal studies
- WP6: Public perception
- WP7: Coordination & Data Management
  
- CCT1: Monitoring techniques & strategies
- CCT2: Numerical Modelling
- CCT3: International collaboration
- CCT4: Best environmental practices

## Management and Communication

The Project Coordinator will be supported by the Project and Data Management Office, the Steering Committee and the Scientific Board to ensure the project remains focused.



Management and governance structure of the ECO<sub>2</sub> consortium

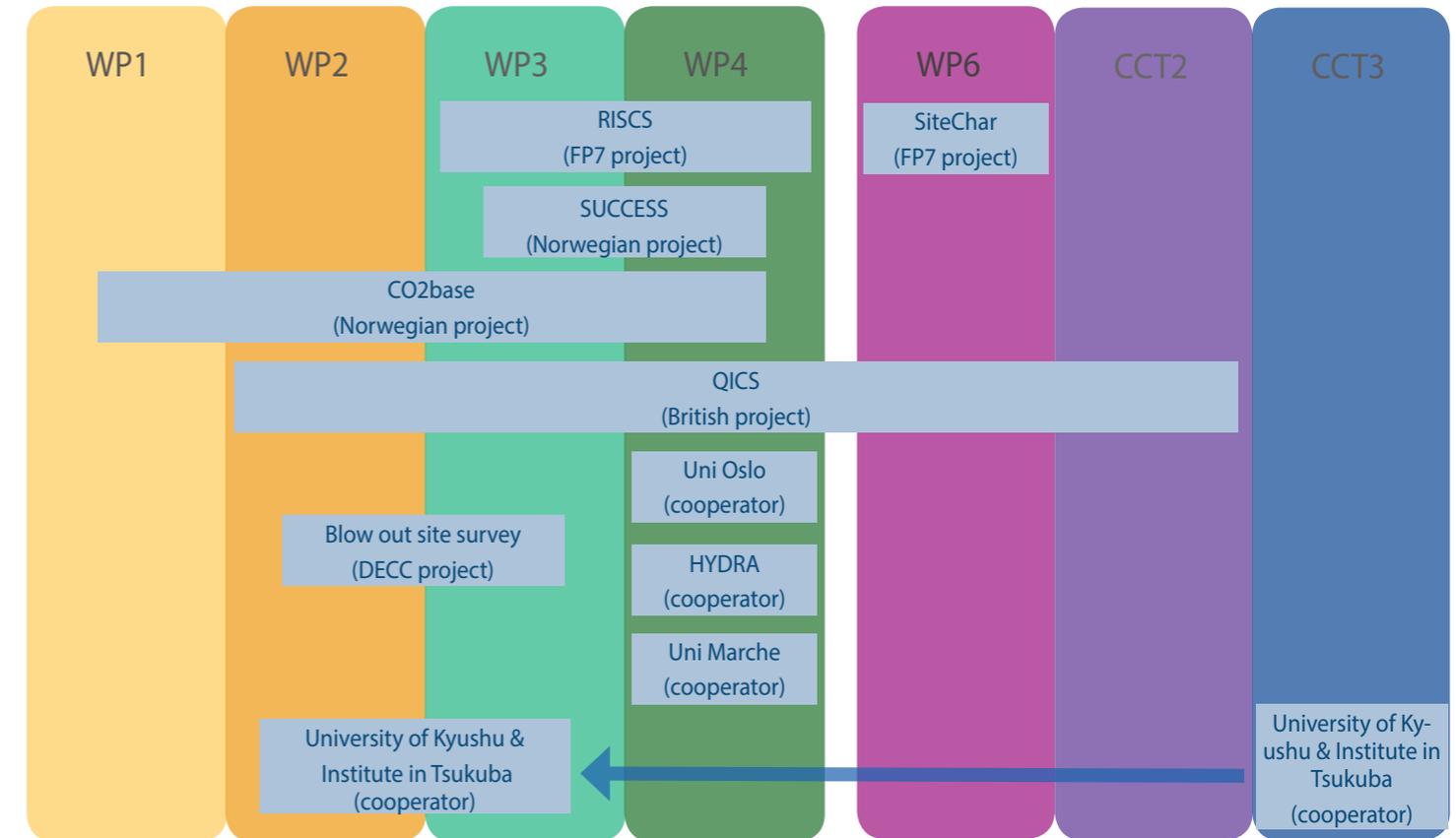
The internal management structure will be supplemented scientifically by the Scientific Advisory Board (renowned scientists covering the ECO<sub>2</sub> research fields) and politically by the Stakeholder Dialogue Board (high-level policy consultative group).

## Cooperations and interactions

ECO<sub>2</sub> built up various cooperations and interactions within the different work packages with several FP7 and national projects as well as with expert groups at well-established research institutes.

The EuroFleets cruise with RV Urania in 2011 was conducted in cooperation with the FP7 project RISCS and the scientists accomplishing the RV James Cook cruise in 2012 invited two Japanese colleagues to deploy and test high-end sensors. The partner University of Bergen established cooperation with two Norwegian projects, SUCCESS and CO2base (environmental

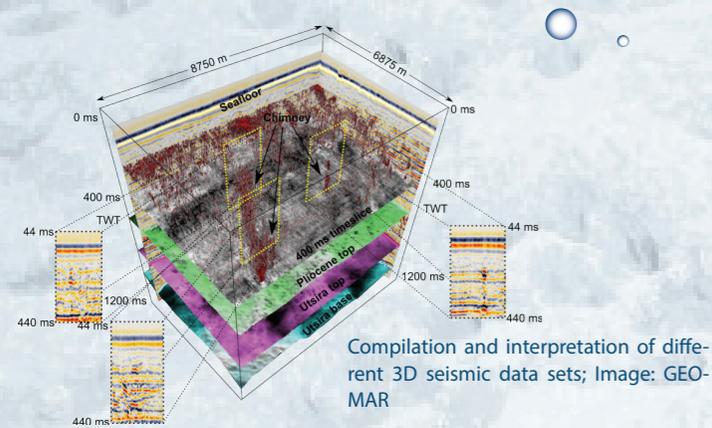
baseline study Sleipner). Work package 4 established cooperation with the Polytechnic University of Marche regarding mesocosm experiments and with HYDRA regarding investigations at Panarea. Work package 6 and CCT2 partners established cooperation with the British project QICS (Quantifying and Monitoring Potential Ecosystem Impacts of Geological Carbon Storage). WP6 furthermore established cooperation with the FP7 projects SiteChar (Characterisation of European CO<sub>2</sub> Storage) and NearCO2 regarding public perception research.



## WP1 - Caprock Integrity

### Architecture and Integrity of the Sedimentary Cover at Storage Sites

will undertake geophysical acquisition, modelling, and hydro-acoustic monitoring to characterise the range of performance and efficiency of sub-seabed geological CO<sub>2</sub> storage, including existing and potential storage sites as well as natural CO<sub>2</sub> seepage sites. State-of-the-art technology will be employed for an enhanced imaging of the seafloor and its sub-surface at unprecedented resolution.

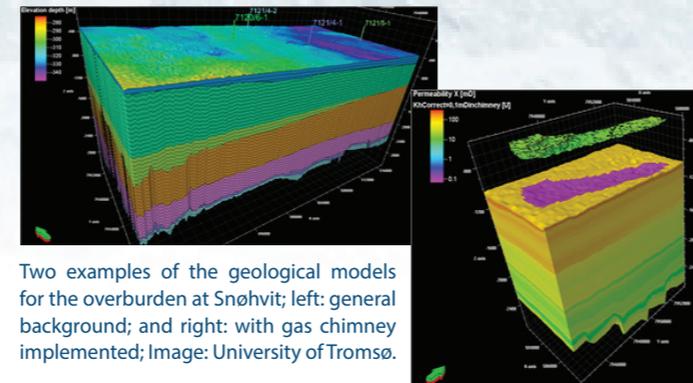


#### Objectives:

- to characterise the sedimentary cover to better assess CO<sub>2</sub> migration mechanisms and pathways
- to optimise existing techniques and tools for monitoring CO<sub>2</sub> migration
- to provide a catalogue for possible leakage scenarios, to document the key elements of effective risk management
- to constrain potential leakage pathways

### Highlights in WP1

- Detailed evaluation of high-resolution and conventional 3D seismic data to identify potential pathways for fluid and gas seepage through the overburden
- AUV survey with full spatial coverage using hydro-acoustics, bathymetry and back-scatter imaging to locate seep sites at the seabed
- Repeated AUV surveys to identify new seeps and leakage sites
- ROV-based determination of gas and fluid flow rates at seep sites
- Repeated high-resolution 3D seismic surveys to detect gas migration through the overburden
- Several leakage scenarios have been developed for Sleipner and Snøhvit based on identification of fluid flow features and an understanding of geological processes governing the origin of these features



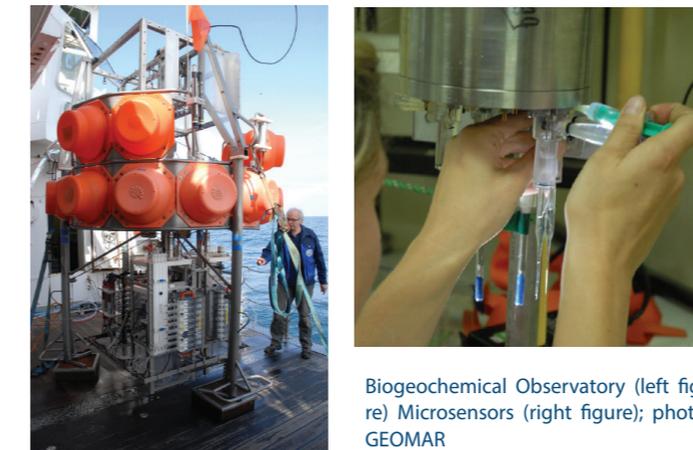
## WP2 - Fluid and Gas Flux Across the Seabed

### Fluid and Gas Fluxes across the Seabed at Storage Sites and Natural CO<sub>2</sub> Seeps

will carry out a program of fieldwork at existing storage sites as well as natural CO<sub>2</sub> seeps, including analysis of the chemical composition of reservoir fluids. Fieldwork will be supplemented by laboratory studies focussing on CO<sub>2</sub>-induced mobilization of toxic metals and the ability of CO<sub>2</sub>-hydrate formation to seal leaks. A key part of the work will be to assess the utility of various high-end sensor systems.

#### Objectives:

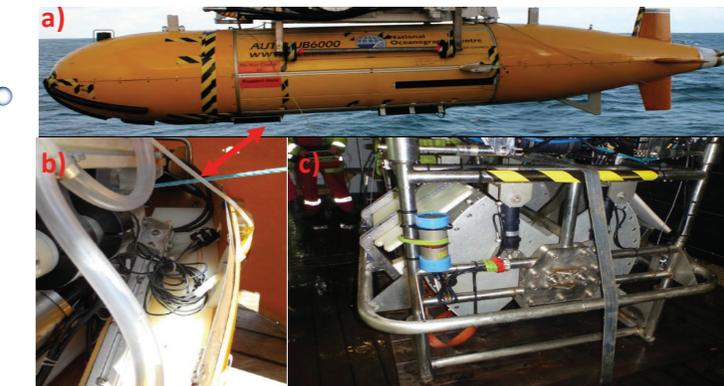
- to identify effective tracers of leakage
- to develop a monitoring strategy to quantify leakage rates
- to assess the potential for mobilisation of toxic metals
- to quantify fluxes of CO<sub>2</sub> and other chemicals across the seabed and reactions in the surface sediments
- provide numerical models that can be applied to predict fluxes of CO<sub>2</sub> (and other) across the sediment-seawater interface under different leakage scenarios



Biogeochemical Observatory (left figure) Microsensors (right figure); photos: GEOMAR

### Highlights in WP2

- Measurement of benthic fluxes of chemical species at two natural CO<sub>2</sub> seep sites, Panarea and Salt Dome Juist
- Investigation of fluid and gas seepage from seafloor fractures and abandoned wells in the vicinity of the Sleipner CO<sub>2</sub> storage site



Sensors mounted on (a, b) an AUV and (c) a ROV for monitoring of pH, pCO<sub>2</sub> in the benthic boundary layer and water column; photos: NOC

- Direct sampling of gases emitted from the seafloor at the natural CO<sub>2</sub> seep Jan Mayen vent fields
- Monitoring of pCO<sub>2</sub> emissions from the seafloor at the natural CO<sub>2</sub> seep site Panarea
- CO<sub>2</sub>-fluid-sediment interaction experiments under in-situ conditions

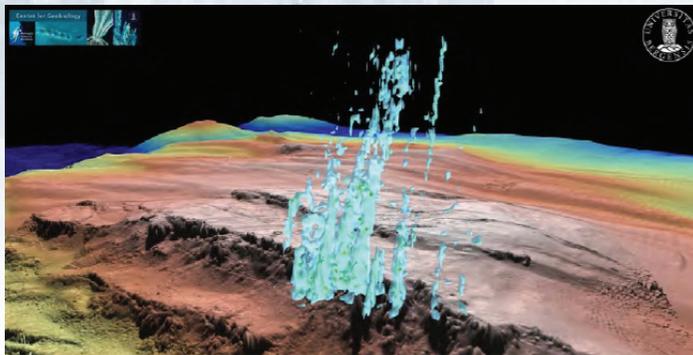
## WP3 - Fate of Emitted CO<sub>2</sub>

### Fate of CO<sub>2</sub> and other Gases emitted at the Seabed

will conduct process studies and model simulations to underpin impact assessments of potential leakage from CO<sub>2</sub> storage sites in the water column. An Ocean General Circulation Model (OGCM) considering the various processes will be used to simulate local and regional oceanic dispersion of CO<sub>2</sub>. Natural CO<sub>2</sub> seeps, as analogues of storage leakage, will be used to improve process and model understanding, and to test instrumentation.

#### Objectives:

- to understand CO<sub>2</sub> transport mechanisms
- to develop appropriate monitoring methods for leak detection and CO<sub>2</sub> flux quantification
- to develop a simulation framework for impact assessment
- to develop best practices for detecting CO<sub>2</sub> leakage to the water column

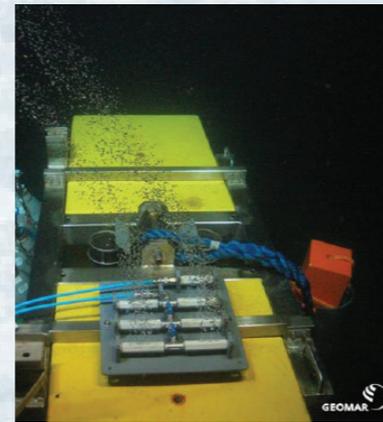


Multibeam echosounder (MBES) water column image of the Troll Vall venting system at the Jan Mayen fields ; image: University of Bergen

### Highlights in WP3

- Characterisation of the carbonate systems at Panarea
- Strong temporal variability of gas emissions at Panarea control the distribution of dissolved CO<sub>2</sub> within the water column

CO<sub>2</sub> release experiment, Carbon dioxide and Krypton were released on top of the elevator lander over 10 to 15 hours at varying flux rates; photo: GEOMAR

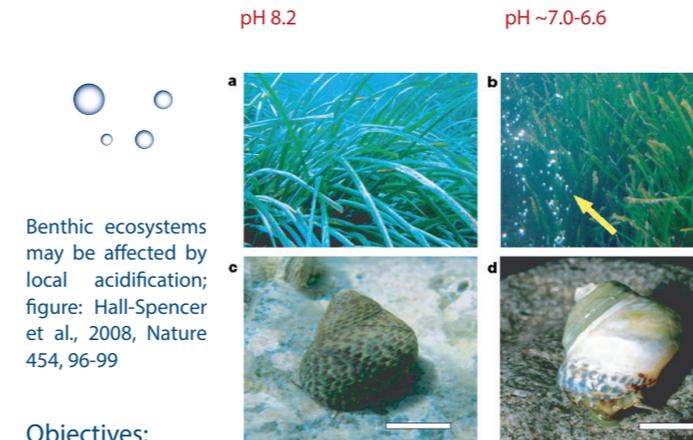


- Investigation of the rapid nature of mixing and dilution of the CO<sub>2</sub> signal within the water column
- Visual and hydro-acoustic investigation of bubbles rising through the water column at Sleipner and Jan Mayen vent fields
- Conduction of a CO<sub>2</sub> release experiment in the Norwegian North Sea
- CO<sub>2</sub> release experiments indicate that the spatial footprint of CO<sub>2</sub> leakage will be minor and rather local
- MetOcean data for Sleipner compiled and test runs performed

## WP4 - Impact of Leakage on Ecosystems

### Impact of Leakage on Benthic Organisms and the Marine Ecosystems

will determine the biological impacts and risks associated with CO<sub>2</sub> leakage by controlled exposure experiments or in-situ observations at natural seeps, and identify appropriate methods to monitor the marine environment above a storage site.



Benthic ecosystems may be affected by local acidification; figure: Hall-Spencer et al., 2008, Nature 454, 96-99

#### Objectives:

- to quantify the consequences of CO<sub>2</sub> leakage for the health and function of organisms
- to assess the ability of organisms to adapt to locally elevated CO<sub>2</sub> levels
- to increase our capability to predict ecosystem response to leakage
- to identify biological indicators for CO<sub>2</sub> leakage
- to formulate environmental best practices for monitoring, protection and management of marine biota at offshore CO<sub>2</sub> storage sites

### Highlights in WP4

- Observation of some species that are highly resilient to elevated pCO<sub>2</sub>
- Exposure to elevated pCO<sub>2</sub> can induce alterations in early ontogeny of echinoderms
- Behavioural avoidance of high pCO<sub>2</sub> plumes appears to be a consistent behavioural biomarker that might be used for monitoring
- Identification of microbes specifically adapted to a high CO<sub>2</sub>-low pH environment
- CO<sub>2</sub>-rich hydrothermal plume collected at the Jan Mayen vent fields revealed a planktonic fauna distinctive from the surrounding waters
- Development of an explicit depth structured benthic model component of ERSEM

Control, 400 ppm, pH 8.00      20,000 ppm pCO<sub>2</sub>, pH 6.50



Photo: Elizabeth A. Morgan; University of Southampton

Quantifying the respiratory response of the urchin *Paracentrotus lividus* to chronic hypercapnia investigating a Carbon Capture Storage leakage scenario has shown that the urchin exhibited an uncompensated respiratory acidosis when exposed to elevated pCO<sub>2</sub> conditions.

## WP5 - Risk Assessment

### Risk Assessment, Economics, Legal Studies and Policy Stakeholder Dialogue

will consider the environmental risks associated with CCS and how these risks may impact on the financial, legal, and political considerations surrounding the future geological storage of CO<sub>2</sub>.

#### Objectives:

- to conduct an environmental risk assessment (ERA) including the entire operational life cycle, closure and post-closure of the reservoir
- to estimate the potential costs associated with monitoring, intervention in the case of CO<sub>2</sub> leakage, compare against the economic and environmental benefits deriving from CCS activities, and assess the financial risks
- to review the existing legal framework with respect to the precautionary principle and the polluter pays principle
- to determine the potential applicability of liability with respect to CCS activities
- to communicate the knowledge produced in ECO<sub>2</sub> to relevant implementation bodies to improve transparency of decision-making for CCS

### H Highlights in WP5

- Hazard identification workshop undertaken with participation from WP1 to 5
- Consequence methodology workshop undertaken with representatives from WP2 to 5
- Preparation of a propensity to Leak Model
- Development of a model to economically assess carbon dioxide storage under uncertainty
- Development of a comprehensive review on the development and legal situation of marine CO<sub>2</sub> storage and on liability rules under public international law
- Compilation of three ECO<sub>2</sub> briefing papers
- Scientific briefing event held in the European Parliament to inform stakeholders about ECO<sub>2</sub> and the scientific progress regarding offshore CCS
- Participation in the CCS directive review survey



Third scientific briefing at the European Parliament; photo: Kristin Hamann, KDM

## WP6 - Public Perception

### P Public Perception Assessment

will investigate two important factors influencing the configuration of public perception patterns: trust and context. Intensive interaction with the public and major stakeholders will be sought to promote dialogue, while at the same time increasing knowledge and awareness of the different public and stakeholders' perspectives. As a result of this process a common framework for CO<sub>2</sub> storage communication and understanding will be proposed.

#### Objectives:

- to identify the core factors and processes that influence public perception of CCS
- to understand how these factors and processes interact within the public context in relation to the costs-benefits of CCS as perceived by different social components
- to provide guidance on how to devise and implement effective public and stakeholder communication plans to meet public information needs and concerns

### H Highlights in WP6

- Development of a glossary to improve communication about offshore CO<sub>2</sub> storage
- On-going reflection on literature blind spots with regard to public issues on CO<sub>2</sub> storage



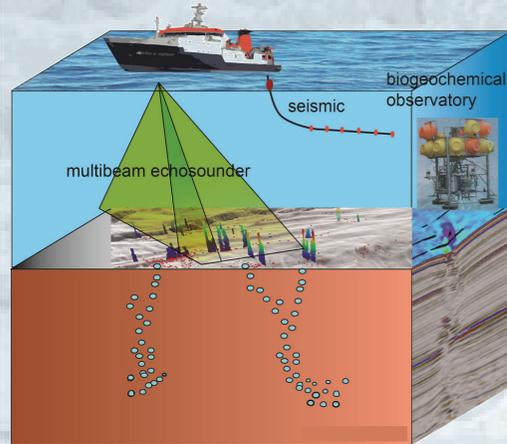
Discussion about CCS perception; photo University of Edinburgh

- Interviews with members of the public in Italy and Scotland to investigate the relevant emotional and content dimensions evoked by CCS
- Exploration of the cultural dimensions implied in the perception of CO<sub>2</sub> storage and identification of areas for exchange, discussion and learning
- Empirical study of public perception of a real-world CO<sub>2</sub> intentional release in a sub-sea context in cooperation with the British project QICS
- Exploration of perceptions of CCS with science communicators (science writers/journalists and master students of 'Science and Communication')

## CCT1 - Monitoring Techniques & Strategies

### Monitoring Techniques and Strategies

will provide a focus for the synthesis and integration of knowledge towards the optimisation of monitoring methods for different scenarios of CO<sub>2</sub> leakage.



Sketch illustrating different monitoring techniques; figure: GEOMAR

### Objectives:

- to develop guidelines for innovative and cost-effective monitoring strategies to detect and quantify potential leakage of CO<sub>2</sub> from storage sites and its effects on the marine ecosystems

### Highlights in CCT1

- Definition of a basic set of parameters to be measured during all ECO<sub>2</sub> cruises

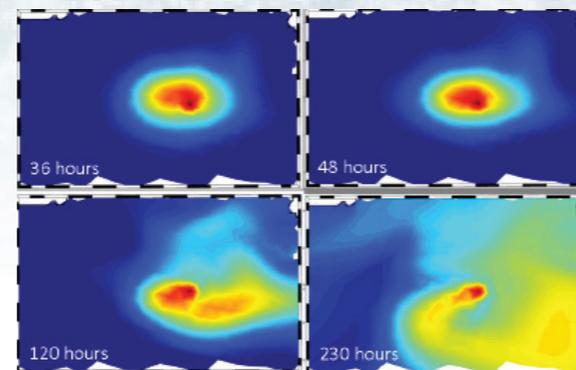
## CCT2 - Numerical Modelling

### Interfacing of the Numerical Models

intends to model the whole system from reservoir leakage through to CO<sub>2</sub> transfer into the ocean and to the atmosphere, including biological impacts. Subsequently, the physical, chemical and biological knowledge will be transferred into an economic valuation of the costs of leakage, monitoring, and mitigation measures as well as underpin a concept for risk management.

### Objectives:

- to identify model synergies, overlaps and interfaces, and the development of the appropriate computational coupling tools to support data transfer
- to quantify and evaluate the geological, physical, chemical and ecological risks, impacts and associated uncertainties of key CO<sub>2</sub> leakage scenarios
- to implement coherent methodologies to assess model performance and uncertainty



Dispersing CO<sub>2</sub> plume (domain: ~ 4x7 km<sup>2</sup>); graphic: PML

## Highlights CCT2

### Highlights in CCT2

- Definition of 'end to end' model chain covering CCS integrity, i.e. geophysical flows - sediment chemistry - ecosystem impacts - economic costs
- Definition of a scenario baseline, identifying the range of plausible scenarios

## CCT3 - International Collaboration

### International Collaboration

will enhance the international profile of European environmental CCS research.

### Objectives:

- to enhance collaboration with Australian CCS research groups, with specific topics of sub-seabed storage monitoring technology and legal concepts and principles, including environmental liability
- to expand collaboration with Japanese CCS research groups, with specific topics of theoretical modelling of CO<sub>2</sub> plume and deep-sea biogeochemistry of natural CO<sub>2</sub> vent sites in Japanese waters
- to strengthen collaboration with US CCS research groups, particularly those working on experimental submarine CO<sub>2</sub> release and theoretical CO<sub>2</sub> buoyancy constraints and benefits of sub-seabed storage at water depth of >3000 m.

## CCT3 - International Collaboration

### Highlights in CCT3

- Presentations and collaborative meetings in Australia at the major Australian CCS research groups
- Presentations and collaborative meetings in Japan at the major Japanese CCS research groups
- Participation of two Japanese researchers on the RV James Cook research cruise 2012 to deploy newly developed Japanese chemical sensors

## CCT4 - Best Environmental Practices

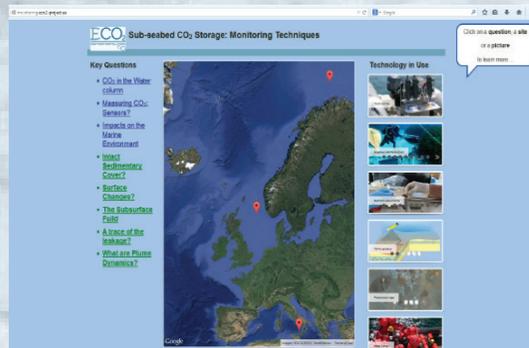
Framework of Best Environmental Practices of Offshore CO<sub>2</sub> Injection and Storage will utilise the knowledge of the ECO<sub>2</sub> consortium to identify considerations associated with operating storage facilities and managing the potential environmental impact of CO<sub>2</sub> storage.

### Objectives:

- Utilise the knowledge contained within the ECO<sub>2</sub> consortium to identify relevant issues and considerations associated with managing the potential environmental impact of offshore CO<sub>2</sub> geological storage
- draft the outline of the best environmental practice guide and discuss the content within the consortium

The Click and Learn Tool is a web-application which allows the user an insight into the different experiments on monitoring conducted in ECO<sub>2</sub>. It was set up for the exhibition at the European Maritime Day 2014 and is available online on the ECO<sub>2</sub> website.

It provides information about the study sites, photo galleries about different experiments and explains the main key questions on monitoring in comprehensible storylines.



Welcome Page of the Click and Learn Tool, available online at : [monitoring.eco2-project.eu](http://monitoring.eco2-project.eu); image: GEOMAR

All workpackages contributed to the implementation of the Click and Learn Tool with photomaterial or in the composition of the research questions which are answered in comprehensive storylines on the website. In this way users can get a small insight into the work that was conducted within ECO<sub>2</sub>.



Photo galleries give an impression of the technology which was used in the experiments. Also videos are impeded.; image: GEOMAR

The Click and Learn Tool aims to centralize the work performed on monitoring in ECO<sub>2</sub> in one tool and to provide easy accessible information for everyone interested in CCS. Due to its comprehensive structure it can be applied for dissemination with different stakeholders and can be used to introduce a large part of the work performed within ECO<sub>2</sub>.



RV Poseidon in front of the vulcano Stromboli at the Panarea study site; photo: Maike Nicolai, GEOMAR

The Glossary:  
The language of CCS - Explanations and Definitions

- fulfills the objective to standardise commonly used terms and concepts in CCS research to facilitate effective communication
- supports a process of sharing, discussion and clarification of terms
- developed within ECO<sub>2</sub>, but has also been useful within the partner projects QICS and RISCS
- The Glossary is available in a printed version and online: [www.eco2-project.eu/glossary.html](http://www.eco2-project.eu/glossary.html)



The Glossary; image: GEOMAR

Briefing Paper:  
One objective within WP5 is to compile Briefing Papers which summarize the work conducted in ECO<sub>2</sub>. Each publicaiton is supported by a briefing held at the European Parliament to present the content to stakeholders and decision makers. The Brussel's office of the German Marine Research Consortium (KDM) has edited all four Briefing Papers in cooperation with the ECO<sub>2</sub> consortium. So far three Briefing Papers have been published; with the last one available in 2015:

"The Scientific Basis for Offshore CCS":

- Introcudes the ECO<sub>2</sub>-Project
- focusses on the field work activities carried out within the first project year

"Potential Impacts of CO<sub>2</sub> leakage from sub-surface storage on seabed biology":

- presents the first results of WP4

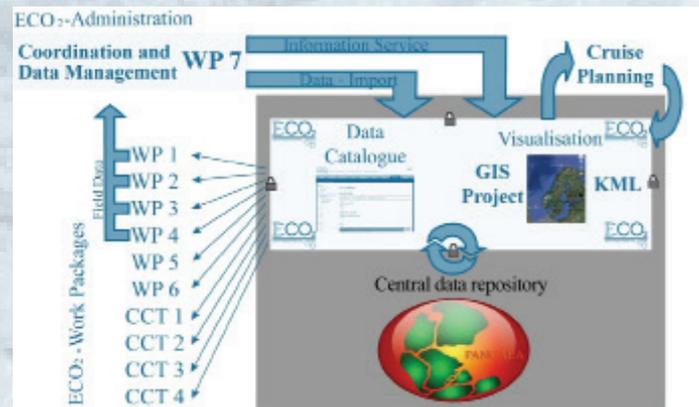
"Assessing the Risks, Costs, Legal Framework and Public Perception of CCS":

- serves the purpose to inform about the social concerns in offshore CCS
- covers the research done to assess the risks, legal framework and economic implications of offshore CCS

All Briefing Papers are available online: [www.eco2-project.eu/info-material.html](http://www.eco2-project.eu/info-material.html)

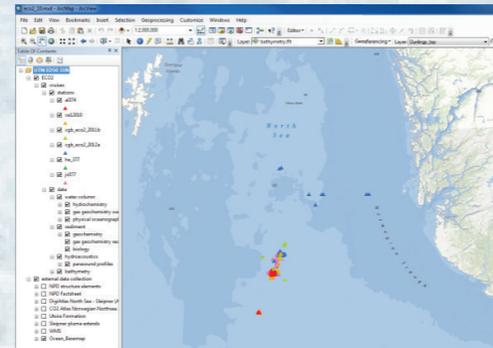
## Data Management - PANGAEA

The data management facilitates the flow of data from field work, lab experiments and numerical simulations to all WPs and CCTs. The central data repository is part of the PANGAEA data library with all benefits through a distribution via web services, search engines, portals and library catalogues. Two years subsequent to the end of the project all ECO<sub>2</sub> data will be public.



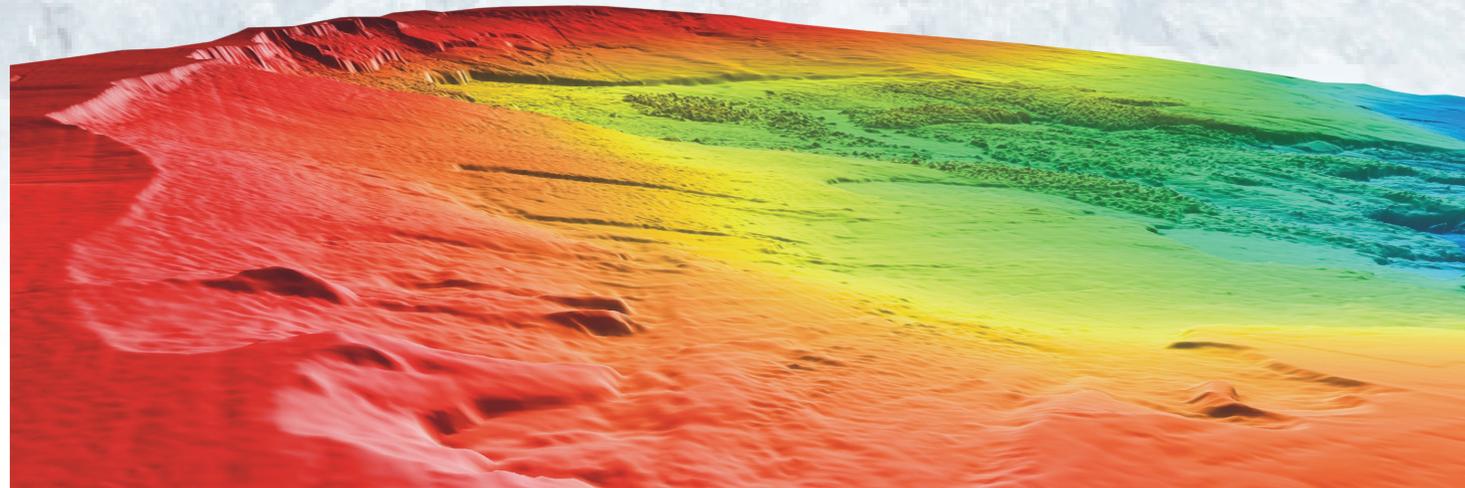
ECO<sub>2</sub> data management concept; illustration: GEOMAR

To support all ECO<sub>2</sub> scientists conducting research expeditions a KML file for Google Earth has been compiled including all ECO<sub>2</sub> data and external data sets available for ECO<sub>2</sub> study sites. Furthermore, a collaborative ArcGIS project combining all data of the CO<sub>2</sub> storage site Sleipner, which is one of the main targets of ECO<sub>2</sub> investigations, has been initialized.



ArcGIS project, Sleipner; illustration: GEOMAR

Data management is combined with project management to guarantee the required data delivery for this multi-disciplinary project with alternating dependencies.



## ECO<sub>2</sub> Consortium



ECO<sub>2</sub> consortium; photo: GEOMAR