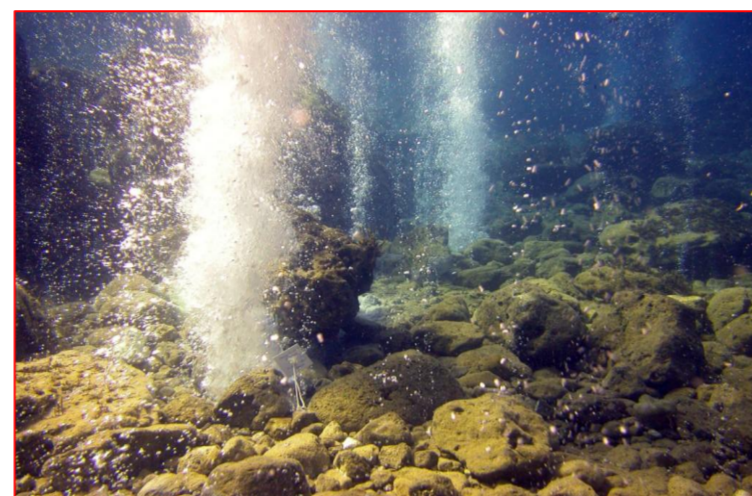


Introduction

The volcanic island of Panarea is characterized by the presence of continuous emission of volcanic gases from the seafloor. In November 2002 the system increased its flow of some order of magnitude and since then a steady release of gas is present generating bubble plumes that, in the shallowest points, reach the sea surface.

Due to the environmental conditions, the area close to the shore and shallow water can be utilized as a “natural lab” to study the effect of high levels of CO₂ on the marine realm by surface techniques and directly by means of SCUBA diving.

Since 2002, over one hundred hours of diving have been utilized to collect samples of fluids and sediments and to study the biota. After a first phase of volcanic surveillance, the island is more recently studied as a “natural analogue” for the development of reliable monitoring techniques for potential seepage from sub-seabed carbon storage sites. Hereby we present a synthesis of eight years of research in the area.



Natural release of CO₂ from the seabed

Methods

Following the experience gained during the research, some special sampling techniques have been developed in order to operate underwater and their reliability validated.

These techniques mainly regarded the sampling methods for free and dissolved gases and the use of a multi-parametric probe to make vertical logs along the water column above the gas emission (pH and Redox values) from a boat and also directly underwater by means of SCUBA divers. Biological observations were also conducted to identify the effects of CO₂ seepage on the biota.

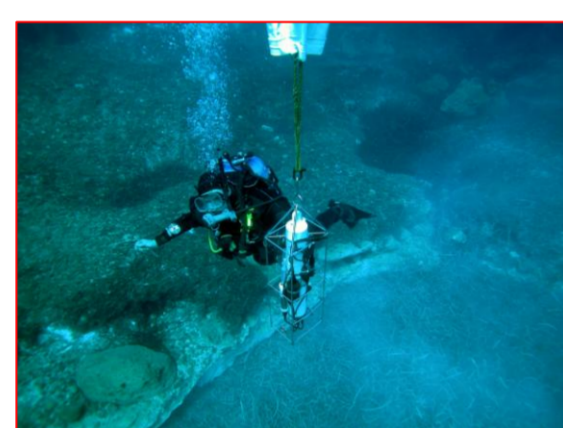
The direct observation by scuba divers allowed for a level of detail in the study that is not usually achievable by surface techniques.



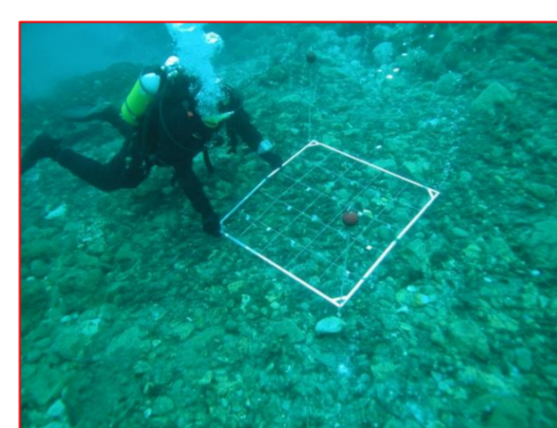
Free gas sampling



Dissolved gas sampling



Diver uses multi-parametric probe



Diver surveys the modifications of the benthic life-forms

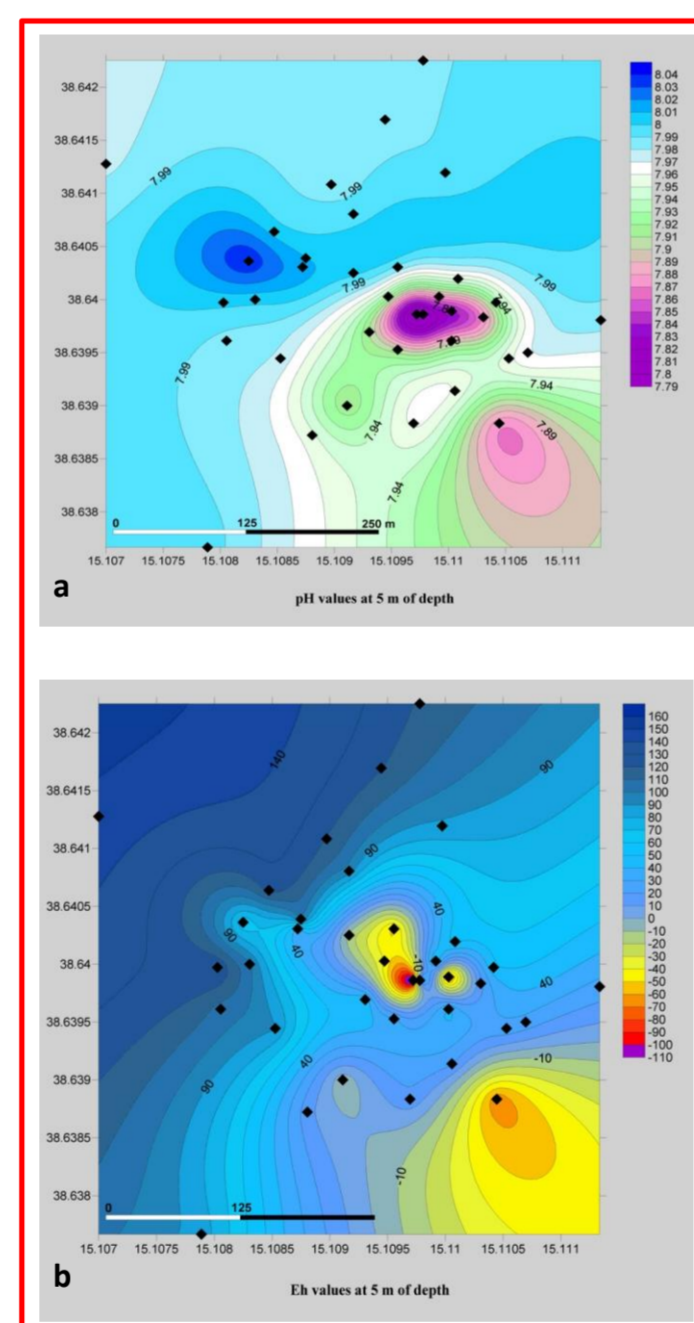
Environmental effects

The presence of the gas vents affected the chemistry of the seawater in the entire area, and modified some of the main parameters – such as pH and redox – with strong influences on the local environment and on the biota.

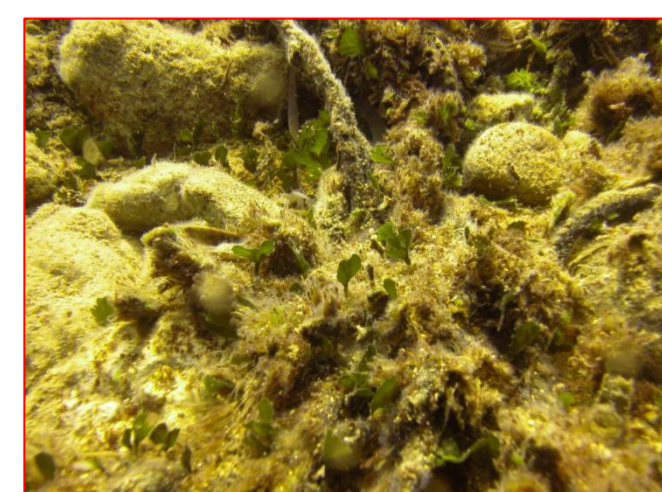
An area characterized by diffuse degassing from the seafloor in shallow water (maximum depth 15 m) was chosen to perform a series of 38 vertical logs of pH and redox values. The logs, arranged in a grid centred on the degassing area, show a clear “low-pH signal” in proximity of the gas emissions. The minimum value measured was 7.20, highlighting a reduction of about 11% in respect to the 8.07 value of the water column not affected by the gas release. The pH trend shows a direct relation between proximity to the gas emission and increased acidification. An important feature of this trend is a threshold depth of the values that corresponds to the thermocline. The diffusion of the water driven by the rising plume, and therefore more affected by the presence of the CO₂, is limited by this density border. This behaviour can play an important role in controlling the extent of the area potentially affected by a CO₂ leakage from a sub-seafloor storage site. The redox values highlighted reducing conditions in the water column close to the gas emissions. These are caused by the reduction of CO₂ and, mainly, by the reduction of sulphur that is present in gas seeping from the seafloor.

The acidification of the water caused by the presence of CO₂ affected the local biota with a strong reduction of the life-forms based on calcareous skeletons or shells. General damage to the sea grass *Posidonia oceanica* has also been observed. Algae are developing over the depleted *Posidonia* fields. Microbiological observations highlight the presence of bacteria that is typical of hydrothermal springs (chemolithoautotrophs i.e. *Thiomicrospira* sp) with a major effect on the viral community. These bacteria are most present close to an active hydrothermal vent characterized by the deposition of sulphides. These are first observations aimed to identify bio-markers to be used as tracers for the prompt identification of CO₂ seepage in the marine environment.

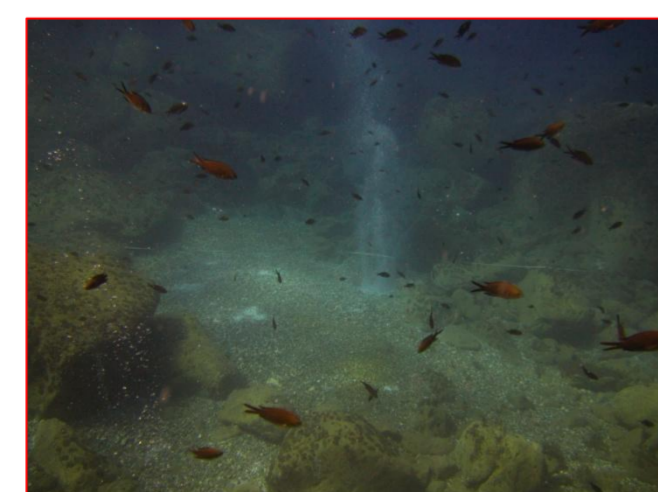
Even if the strong increasing in CO₂ emission followed the 2002 event is still affecting the local biota, a general healing of the system has been observed during the years with the adaptation of several life-forms to the changed environment. Even from a biological point of view, Panarea can therefore be considered a valid field-lab to study the medium and long-term effects of ocean acidification.



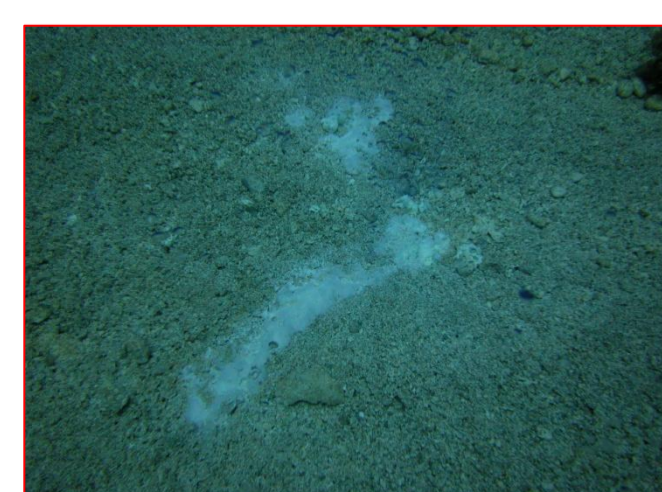
Map of the pH (a) and Redox (b) values in the surveyed area



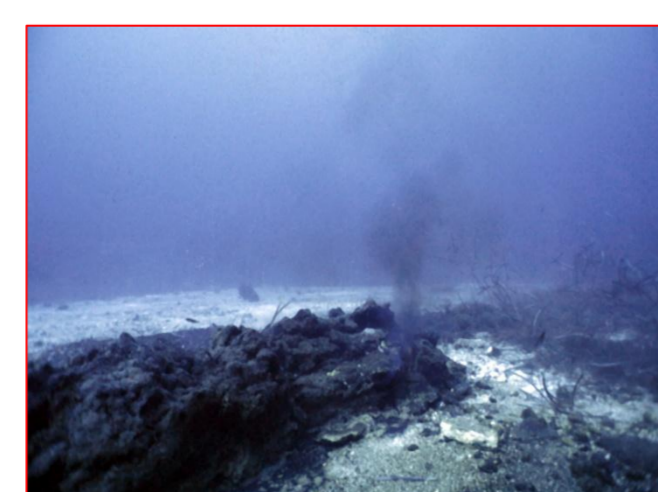
Development of algae (*Udotea petiolata*) over a patch of dead *Posidonia*



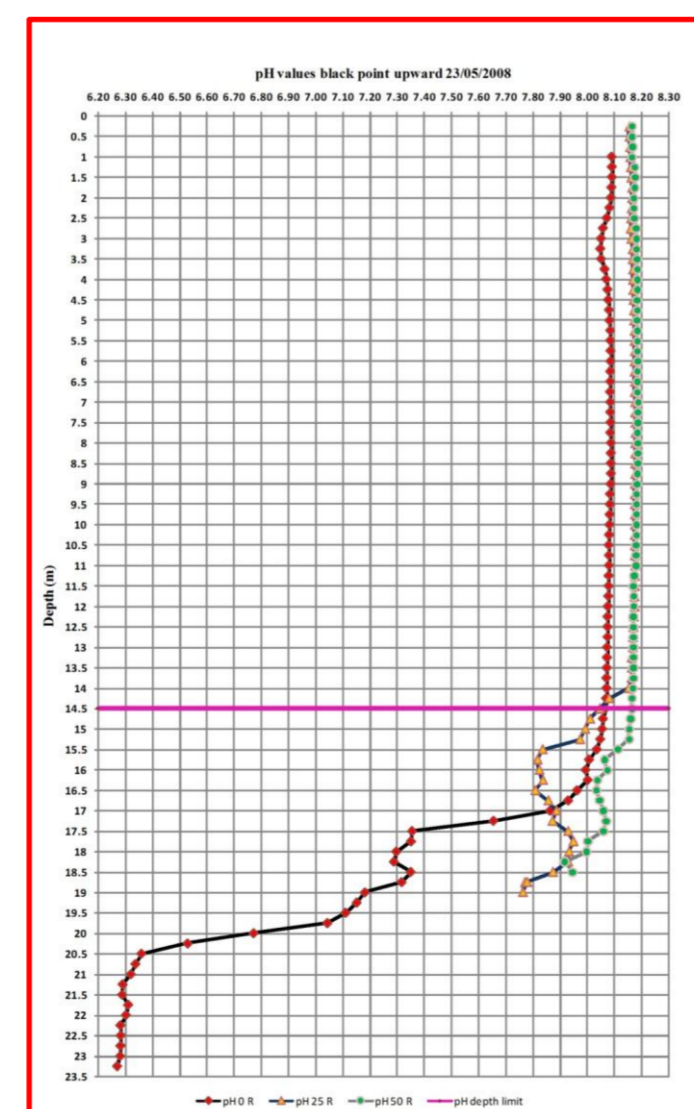
Fish (*Chromis chromis*) swimming around a CO₂ plume



Macro-bacteria on the seafloor



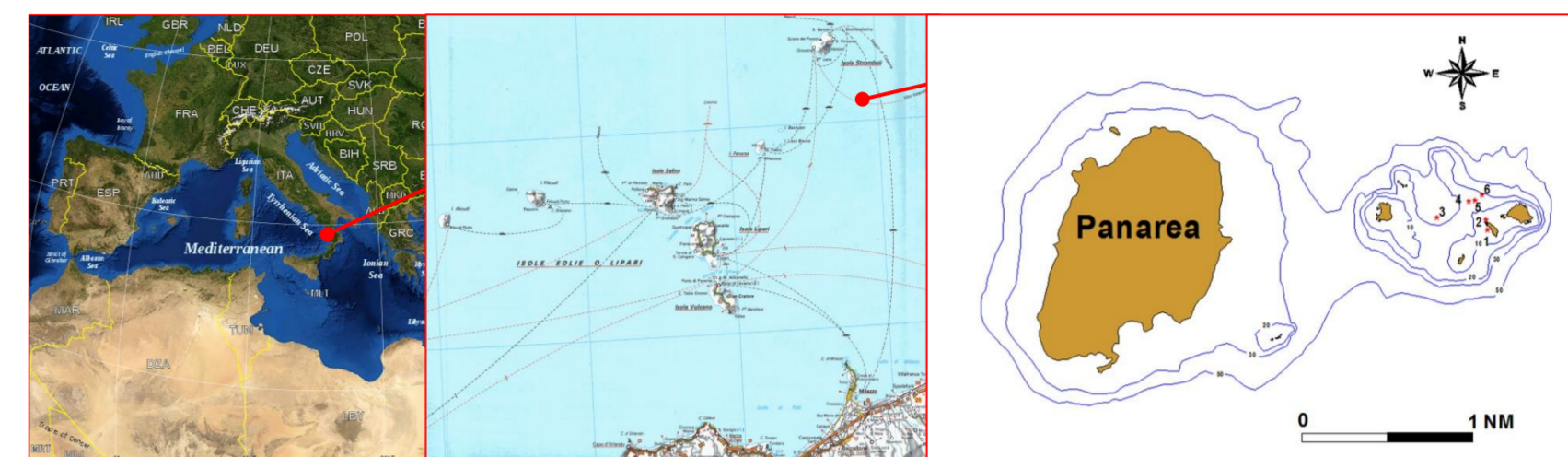
Sulphides deposition from an active hydrothermal vent



pH measured at different horizontal distance from a gas plume. The threshold depth (violet) coincides with thermocline

The studied area

The studied area is located in the Southern Tyrrhenian Sea near the volcanic island of Panarea (Aeolian Islands, Italy). The degassing area lies two nautical miles east of the main island and is surrounded by several islets and shoals. Here, CO₂ flows steadily from the seafloor in shallow water (10 to 40 metres deep), originating areas of diffuse seepage and several spots of higher gas flow with the formation of bubble plumes. The area, even if not suitable for CO₂ storage, can be considered as a field-lab where it is possible to study the effects of high levels of CO₂ on the marine realm and validate measuring, monitoring and verification (MMV) techniques for sub-seabed CO₂ leakages.



Location of the studied area; the red stars represent the sampled vents

Fluids chemistry

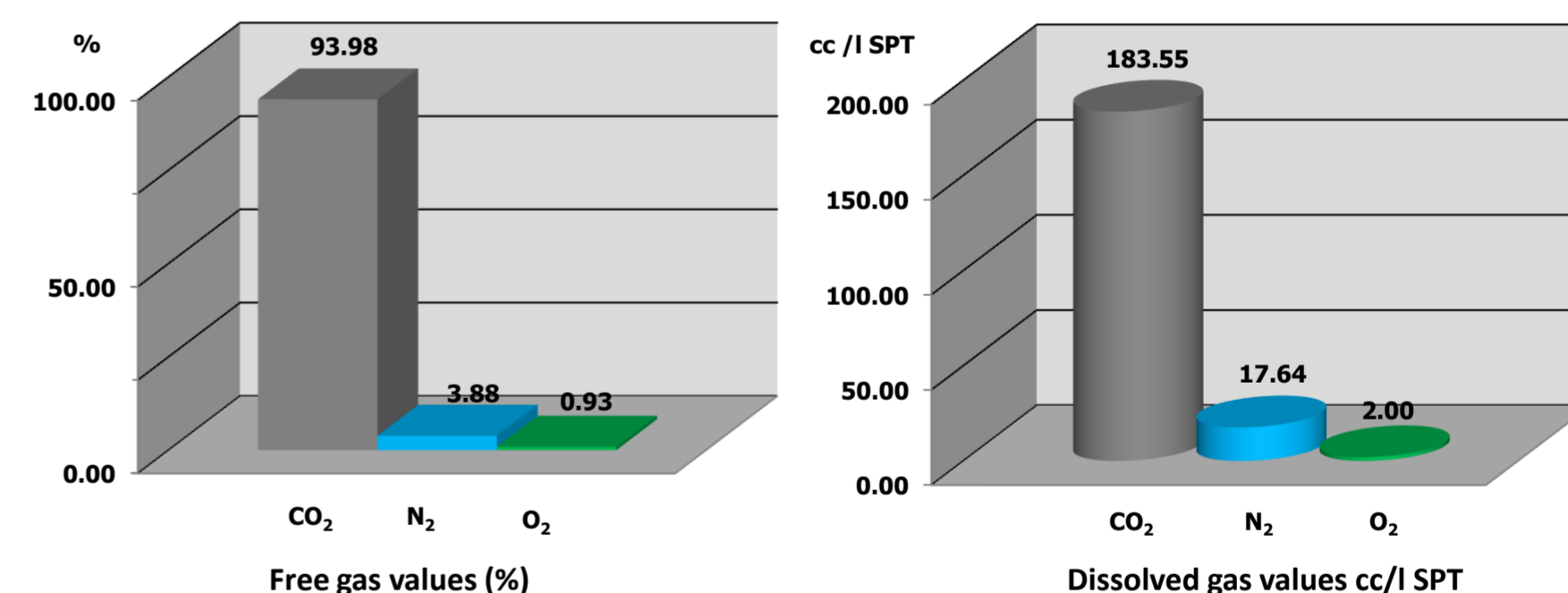
High concentrations of CO₂ were detected as free and dissolved gas, and small amounts of H₂S are also present in the fluids.

Six different vents were investigated by collecting over 100 samples of free and dissolved gas since 2003. The values were averaged to obtain a general picture of the composition of the fluids. The main component of the free gas is CO₂. H₂S is also detected in low concentration (Tab. 1). Nitrogen and oxygen are present in small percentages. The principal component of the dissolved gas is CO₂ followed by nitrogen and oxygen. These values strongly differ from the gas values in seawater in areas not affected by any anomalous presence of CO₂. The presence of CO₂ seepage can be identified from anomalous values of dissolved gases even without the presence of bubbles.

Dissolved gas sensors are therefore a valid tool for CO₂ leakage detection and Panarea represents a unique field-lab for data validation.

Tab. 1 Average values of the free gas composition

Date	ID	He (ppm)	H ₂ (ppm)	O ₂ (%)	N ₂ (%)	CH ₄ (ppm)	CO ₂ (%)	H ₂ S (%)
2003-2007	1	1.300.70	69.36	0.88	3.25	28.06	94.97	1.87
2003-2007	2	12.11	5.63	1.20	6.23	15.39	91.61	3.07
2003-2007	3	53.49	39.83	1.00	4.31	613.77	94.31	0.65
2003-2007	4	918.91	519.59	1.10	3.27	27.91	93.69	2.84
2003-2006	5	7.00	808.04	0.72	2.99	9.62	94.77	3.93
2006-2007	6	15.42	28.37	0.69	3.26	25.90	94.53	0.86

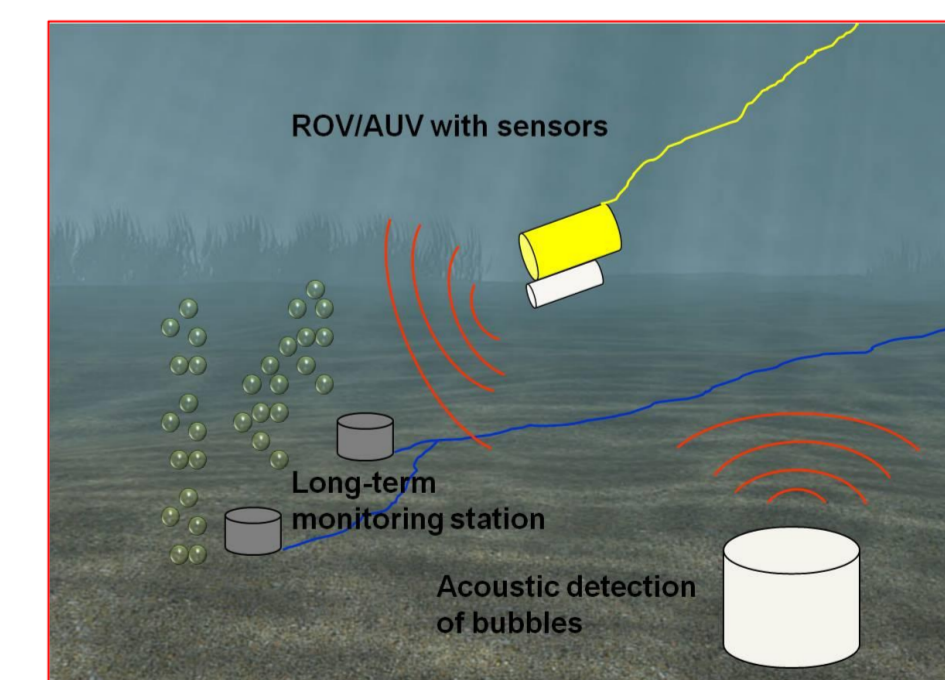


Conclusions and future developments

The studied site shows excellent characteristics to be used as a natural field-lab for the development and testing of monitoring techniques for sub-seabed CO₂ seepage both during short-term and long-term deployments. There is a widespread presence of vents that mimic several different scenarios of potential leakages, from small seepage to gas eruption.

These first results can be used as basic input for the development of reliable monitoring systems for CO₂ leakage. These systems should include dissolved gas sensors as well as pH probes and active acoustic instruments for bubble detection.

It will be possible to use and evaluate mobile platforms – such as ROVs and AUVs – to host the new sensor systems.



Rendering of sensors suite for sub-seabed CO₂ monitoring

Acknowledgements

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