Autonomous bottom landers

STUDY PROCESSES AT THE SEAFLOOR BY INCUBATION TECHNIQUE

Biological, chemical, and physical processes at the seafloor play an essential role to sustain ecosystem functioning of aquatic environments. In-situ incubations of sediment with overlying water provide consistent information on sediment-water solute exchanges and make it possible to do controlled experiments and simulate environmental changes. Making the measurements and experiments directly at the seafloor avoid artifacts created by bringing samples to the surface, including shaking, changes in pressure, temperature, light, oxygen, etc.

This application note presents four types of autonomous landers that all make sediment-water incubations at the seafloor.

The Gothenburg University landers have been deployed more than 300 times in water depths from 5-5600 m and made more than 1000 incubations with an average success rate of about 95 %. A recent publication summarizes 15 years of experience in the development and use of these platforms.

Typical deployment scenario: Before expeditions, the modular incubation chambers with syringe racks, 10 syringes per chamber, are acid-washed to avoid contamination. The landers are deployed autonomously with a carrier platform and ballast weight in deeper waters (Fig. 1). In shallow protected waters, the experimental inner frames are often deployed on a rope (Fig.2). After arrival to the seafloor, the incubation chambers are gently inserted to about half of their length into the sediment and left open to ventilate for hours. Incubations start when chamber lids are closed.

Depending on how biologically/chemically active the sediments are, the incubations last from 6 hours, in organic-rich sediments, to 48 hours in low active sediment. During incubations, a stirring device is mixing the incubated water, sensors are measuring inside and outside the chambers, and ten automatically triggered syringes in each chamber are used to inject or collect water samples. In the end, the incubated sediment is collected, the lander weights are remotely released, and the lander is recovered on-board. The sensor data is then checked to determine if the incubations/experiments were successful. This procedure typically takes about 10 min. If the sensor data indicate high-quality incubations, the water samples from the syringes and the incubated sediments are collected. Collecting samples and preparing a four-incubation chamber lander for a new deployment typically takes 2-3 hours for two persons. The sampled water is analyzed for different solutes depending on the goal of the measurements.

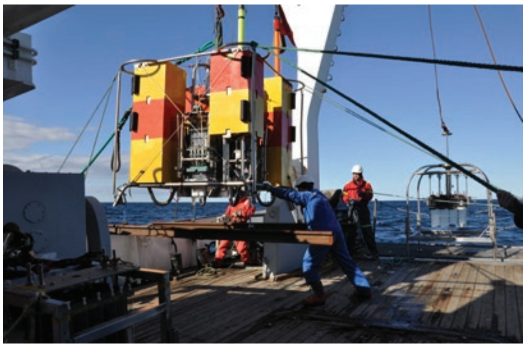

Figure 1: Deployment of 4 chamber lander with carrier frame and ballast weights. The total weight in the air is 1500kg. The weight of the ballast is 300kg. Negative buoyancy in water is 60-80kg, tuned to how hard the sediment is. The landers are made of titanium and plastics to avoid corrosion issues.

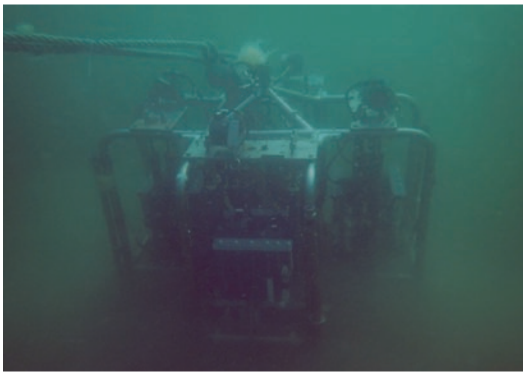

Figure 2: Lander inner frame in the murky waters below a mussel farm.

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Quality control with sensor: The landers are typically equipped with 10-20 water quality sensors placed both inside and outside the incubation chambers, including salinity, temperature, pressure, turbidity, oxygen, and on occasions, pCO2. Salinity is used to determine the incubated water volume and to detect if chambers are leaking. This is done by injecting a known volume of distilled water that lowers the salinity by a small increment. By simple dilution calculations, the volume is obtained. Pressure gives feedback on all the mechanical actions like lid closing, syringe injections, sediment sampling, and turbulence inside the chambers (Fig. 3).

Turbidity serves to verify if unintentional resuspensions occurred but has also been used in several projects to deliberately study the effects of sediment resuspension events. The stirring speed is increased so that the incubated sediment is re-suspended, which often leads to increased oxygen consumption, phosphate binding to the sediment, and pollution release. Outside the chambers, acoustic doppler current sensors, profiling or single point, and wave sensors have been included to assess currents, mixing, particle resuspension, and checking if the landers are tilting/moving. Sensors are logged with +25-year-old Aanderaa DL7 loggers or, more recently, with a SeaGuard II instrument, where one instrument can record all sensors simultaneously at different time intervals. All pre-programmed mechanical actions are activated by an Arduino-based controller built and programmed at the University.

From nutrient-loaded and contaminated coastal sediments to the abyss: Several projects have focused on oxygen consumption and the release of nutrients. The eutrophicated Baltic Sea sediments can contribute up to 80 % of the phosphate to the water, leading to cyanobacterial blooms in the summer. The phosphate release is governed mainly by the oxygen conditions at the bottom. When oxygen drops too low levels, phosphate is released (Fig. 4). Several types of contaminated sediments have been studied, ranging from mercury-rich cellulose fiber banks outside paper mills and sediments leaking arsenic at munition dumpsites. When working on deep-water sediments like on the abyssal plains (4000 m) and in trenches (4000-6000 m), the main focus of the measurements has been on understanding which role such sediments play in the global carbon and nutrient cycles. It is essential to know how much carbon is stored in the deep-sea sediments, covering about 50 % of the earth.

Performing manipulative experiments at the seafloor: The landers can be programmed to do manipulative experiments on the bottom, like letting the oxygen levels drop to 0 and create resuspension as described above. Injections into the chamber water is also an option to study processes at the seafloor. The nitrogen cycle has been studied by injection of labeled 15N nitrate. In another manipulative seafloor experiment, lime-rich clay called marl which is a bi-product from cement production was injected into the chambers to assess if this could be a possible method to bind phosphate (Fig. 5) permanently.

The FLUXSO (Fluxes on Sands Observatory) bottom lander system was developed to measure benthic turnover processes on permeable sandy coastal sediments. Such sediments are subject to re-working by waves and currents and are often consolidated, containing remains of shells, and are often biologically very active. Incubation experiments in such environments have been challenging because regular incubation chambers cannot adequately penetrate the stiff sediments. The FLUXSO lander has overcome this difficulty by developing an innovative system that gently wiggles the two incubation chambers into the sediment (Fig. 6).

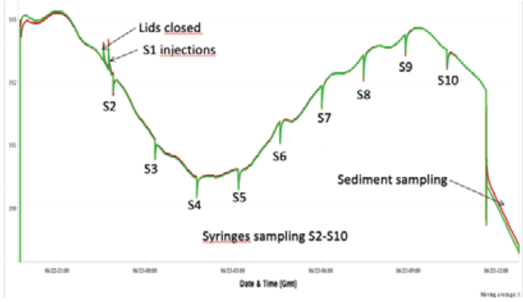

Figure 3: Pressure measurements inside two parallel incubations chambers. The sensitive pressure sensors give feedback on the correct mechanical operations like lid closing, syringe injections/sampling, and sediment sampling. The scale is in kPa.

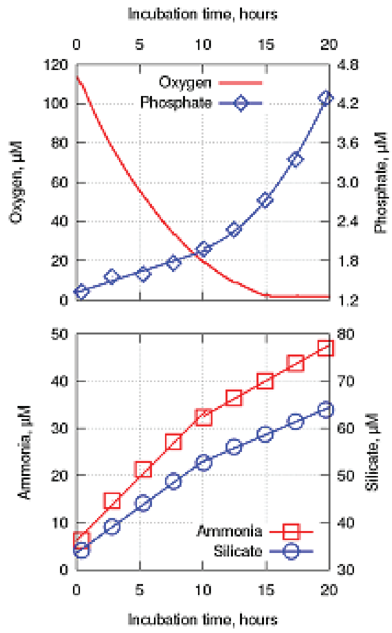

Figure 4: Example of how the nutrient release (phosphate, ammonia, and silicate) from the sediment change when the oxygen concentration approach 0. Such in-situ experiments were done in the Baltic Sea, where bottom oxygen conditions often reached 0. In the example, lower oxygen leads to increased phosphate release and a decrease in ammonia and silicate leakage to the overlying water. Nutrients are analyzed, after lander recovery, from discrete water samples collected by pre-programmed sampling syringes.

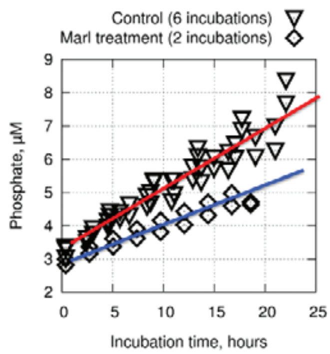

Figure 5: Marl injection in bottom water leads to a lower leakage (blue) of phosphate from anoxic sediments in the Stockholm Archipelago (Sweden)

The two chambers are equipped with oxygen and CO2 Optodes (Fig. 7). A pH sensor and a conductivity sensor for volume determination and leakage control. A stirrer disk with variable speed and direction allows the simulation of advective or diffusive flow regimes in each chamber by creating rotationally symmetric pressure gradients between the center and the circumference of the enclosed sediment surface. The shape and magnitude of the pressure gradients closely resemble natural conditions.

Two syringe samplers with ten syringes in each are used for injections and sampling from the chambers. Water sampled from the syringes is analyzed for nutrients and DIC (Dissolved Inorganic Carbon) after recovery. Ambient water parameters outside the chamber are measured with a CTD with sensors for fluorescence, turbidity, light (PAR), an Oxygen Optode, a pH sensor, and a Doppler Current Sensor.

The lander is lowered to the seafloor on a rope and released with an acoustically triggered hook. Recovery is achieved using two acoustically released "pop-up buoys," (one as a backup) that brings a lifting line to the surface.

This lander system (Fig. 8) is operated by the Helmholtz Zentrum Hereon and was developed in a collaboration between researchers at this center and from the Max Planck Institute in Bremen, where the electronics that controls the operations of the lander and that logs the sensors was developed and manufactured. KUM manufactured the lander frame and the chamber mechanics.

This lander has been successfully used on sandy sediments during multiple expeditions in the North Sea.

National Institute of Oceanography (NIO) in India developed and operates a compact two-chamber lander to measure mineralization rates on the western Indian continental shelf. This is one of the most productive coastal systems in the world ocean. It is an ecosystem that frequently experiences extreme changes in its oxygen regime. Here sediments are often soft and very reactive.

The lander consists of two squared Plexiglas chambers (LxBxH = 30cm x 30 cm x 35cm; targeted sediment penetration 10-15 cm, water volume 18 l, covered sediment surface 0.09 m2 per chamber), each equipped with a paddle stirrer and sensors to measure salinity, temperature, turbidity, and oxygen (Fig. 9). The same suite of sensors measures on the outside of the chambers. In addition, currents, waves/water level, and Chlorophyll A are measured. All sensors are logged by a SeaGuard instrument that can be started and stopped from the outside, and that has an external serial connection to download data and change settings in-between deployments without removing the instrument from the lander frame. With the plug-and-play abilities of the SeaGuard platform, it will be easy to add other sensors to the lander in the future. The lander and the electronics to control mechanical actions e.g., the closing of lids, running of stirring motors and syringe triggering was built by KC Denmark.

During deployments, the shelf bottom water has often been low in oxygen concentrations, near-suboxic as expected during the summer monsoon period in this region. Measured sediment oxygen consumption rates have been high, around 40-50 mmol O2 m-2 d-1, similar to the rates observed earlier at this site through shipboard intact-core incubations. Soon, fieldwork is planned on the outer shelf of western India, which is dominated by permeable sandy sediments.

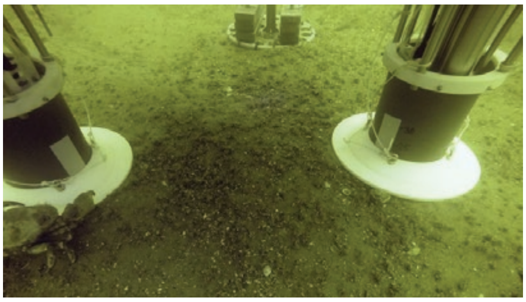

Figure 6: FLUXSO lander on the bottom after chambers have been "wiggled" into the sediment.

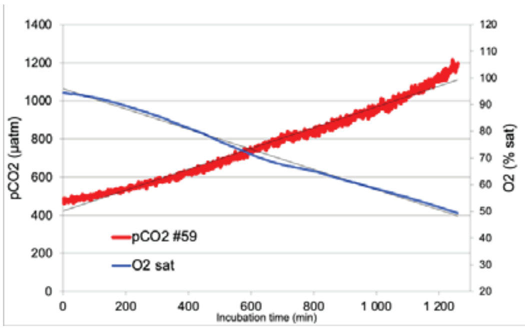

Figure 7: Example of incubation results measuring oxygen and pCO2.

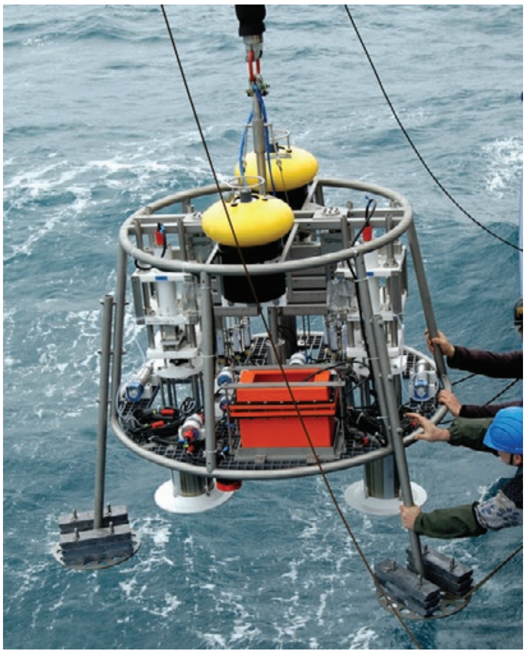

Figure 8: FLUXSO lander being deployed from the ship.

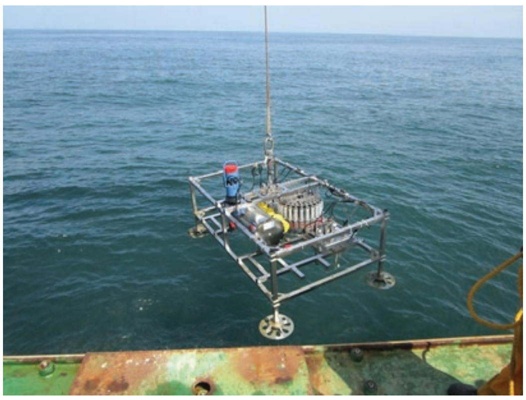

Figure 9: NIO lander deployed from the ship.

GEOMAR operates a fleet of landers to do targeted seafloor studies. For example, to place the landers at a precise location close to a spot where gases are seeping out from the seafloor, a cabled real-time video release system was developed. It is attached to the top of the lander frame during the descent (Fig. 10). By moving the ship at the surface and watching the images, the lander can be precisely released at a location of interest. Recovery is made by releasing ballast weights acoustically once the experiments are finished.

There are two main types of GEOMAR landers. The Profiler lander can move sensors, such as micro-electrodes for chemical measurements, in the XYZ-directions, making it possible to do 3D sediment profiling with micrometer resolution.

For sediment-water incubations, the BIGO (Biogeochemical Observatory) landers are used. These carry two circular chambers with a diameter of 28.8 cm that are gently inserted into the sediment with motors. Waters samples, 8 in each chamber and eight outside, are taken with glass syringes, and oxygen consumption is measured with optodes.

Conductivity/salinity/temp sensors are also included inside the chamber for volume determination and leakage detection. A unique gas sampling system for pCO2, N2, and Argon was developed in which glass sampling vials are gently filled with a peristaltic pump. Another advanced system that was made at the institute keeps oxygen in the incubated water at a constant level. Recently a similar system was developed for the regulation of nitrate inside the benthic chambers. At the end of the deployments, the incubated sediment is collected with minimal disturbance using a motor-operated shutter. The electronics used to control the lander operations and to log sensors were developed in-house at GEOMAR. The mechanical constructions, mainly in titanium and plastic, were made by KUM.

BIGO landers have been used in many different projects covering various ecosystems, including oxygen minimum zones off Peru, Mauretania, Namibia, and the Baltic Sea, exploring cold-seep sites, mud volcanoes, and the deep Atlantic Ocean. The landers further have been used for applied research to develop monitoring tools for Carbon Capture and Sequestration sites in the North Sea or to monitor the effects of bottom trawling in the Baltic Sea.

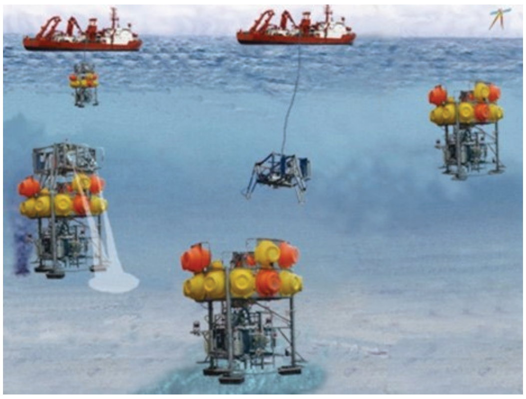

Figure 10: Geomar's real-time video release system makes it possible to place the lander precisely on the seafloor.

Figure 11 A. GEOMAR BIGO Lander (Biogeochemical Observatory) for benthic flux measurements with Launcher unit mounted on its top, B. detail view of one benthic flux chamber, C. detail view of scientific payload and the 8 channel peristaltic pump for water sampling.

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