GEODESEA-2019
An experiment of seafloor geodesy in the Bay of Brest

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Abstract

In the framework of the ERC FOCUS project, the *Geosciences Ocean* Laboratory (LGO) organized, from July 22 to 26, 2019, an experiment of seafloor geodesy in the Bay of Brest, entitled Geodesea-2019. The aim was to test acoustic beacons acquired for the FOCUS project and to test experimental protocols for seafloor positioning. The experiment was carried out from the Albert Lucas research station-vessel. The experiment was conducted in collaboration with the *Laboratoire Environnement et Sociétés* (LIENSs) from la Rochelle and the *iXBlue* company, in Brest.

Relative acoustic ranging was carried out during four days, each beacon ranging the other ones at a regular time interval, while acquiring auxiliary data (temperature, pressure, sound-speed) to be able to convert travel-times into distances. Absolute positioning of the beacons on the seafloor was also carried out using a small Unmanned Surface Vehicle (USV) on which a compact GNSS/Acoustic system was mounted, combining an Ultra Short Baseline (USBL), an inertial system (INS) and a GNSS receiver.

Keywords: Seafloor Geodesy, Acoustic ranging, GNSS/Acoustics, Unmanned Surface Vehicle (USV)

Experimental design and protocols

The experimental site was only 40 minutes away from the Brest harbor (Figure 1). Four Canopus acoustic beacons, developed by iXblue, were immersed for 5 days in 40m of water, forming a 40m quadrilateral (Figure 2 and Figure 3). The experiment took place during a neap tide period (coefficients 50 to 44).

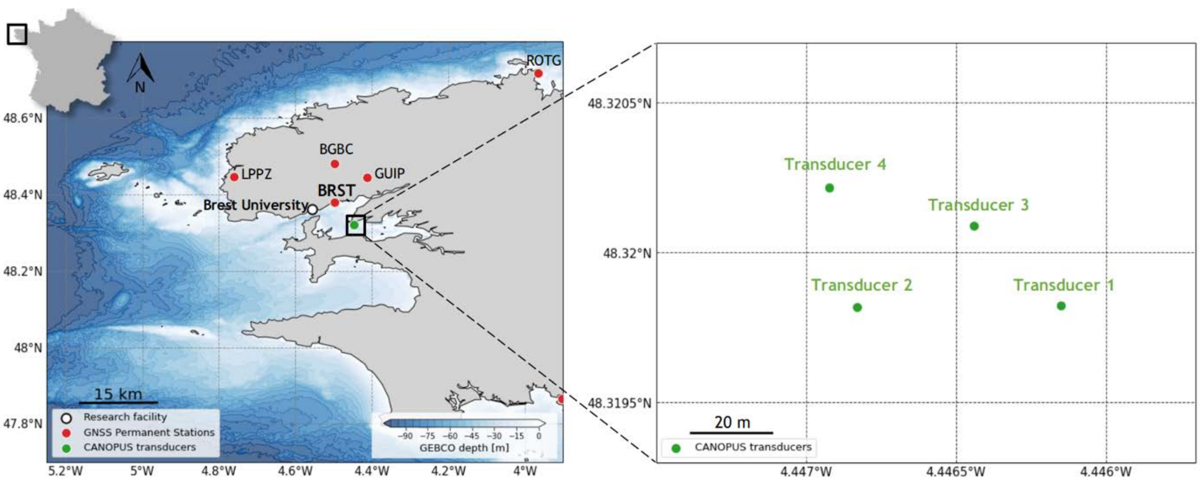

Figure 1: Location of the Geodesea-2019 seafloor geodesy experiment in the Bay of Brest. The map on the right show the layout of the 4 acoustic beacons.

Figure 2 : The 4 Canopus acoustic beacons in their fancy pink sleeves, mounted on tripods.

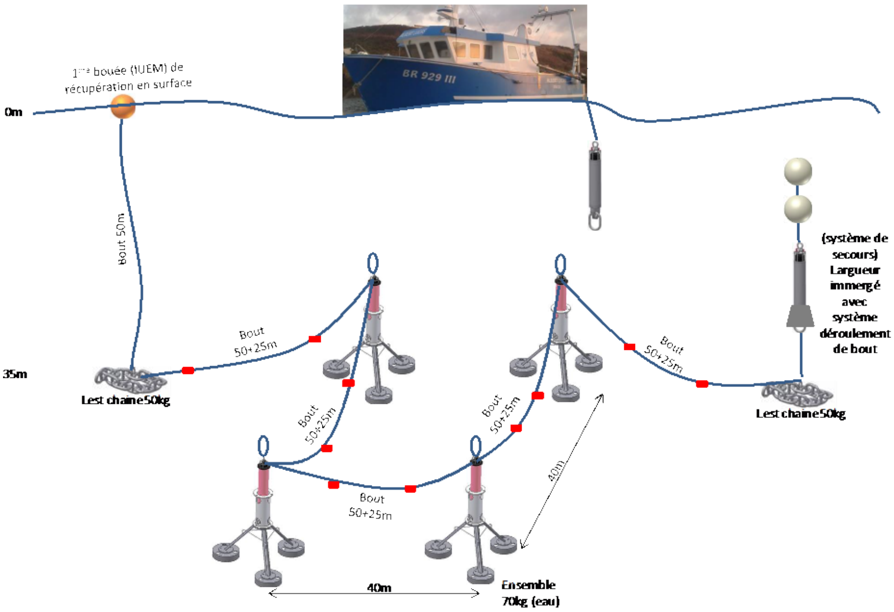

Figure 3 : Experimental set-up on the sea-bottom, designed by M. Beauverger (LGO)

In a first experiment of **relative positioning**, the beacons were programmed to ping each other every 6 minutes and record the travel times of acoustic signals between them. Each beacon also measured temperature, pressure and inclination. Two of them also had a sound velocity sensor. Such set-up monitors the distances between each beacon, and, in a real experiment, will detect possible relative movements, for instance between beacons on either side of an active fault. The expected accuracy in distance is a few millimeters (or a few microseconds in travel time).

In a second experiment of **absolute positioning**, conducted in parallel, the beacons were interrogated from the surface using an ultra-short baseline modem (USBL) coupled with an inertial system (INS) to correct for the ship's movements (roll, pitch). This allows to measure very precisely the distance and direction of each beacon on the seafloor. The implemented instrument was a GAPS from IXblue, commonly used on oceanographic vessels to position instruments in the water column or seafloor. With a GNSS receiver linked to the GAPS, it is then possible to position each beacon very precisely on the sea-bottom; this method of positioning is thus called GNSS/Acoustic or GNSS/A. The objective of this experiment was to evaluate the accuracy of the positioning with this equipment. Several acquisition protocols were tested: a series of circles (box-in) of 2/3 of the water depth in diameter around each beacon, or a static station above each transponder and above the barycenter of the quadrilateral or a triangle formed by the beacons (Figure 6). In a real experiment, repeated measurements over time would make it possible to measure absolute displacement, i.e. in a global reference frame, of beacons anchored to the seafloor for several years. For observing plate motions, in the order of a few millimeters or centimeters per year, the expected accuracy in longitude and latitude must be better than one centimeter.

An innovative aspect in this experiment was to mount the GAPS and a GNSS receiver on an Unmanned surface vehicle (USV; Figure 4 et Figure 5). The advantages of an USV are to avoid the ship's noise and to minimize the lever arms between the GNSS antenna and the GAPS. But mostly, such setting allows repeated positioning experiments in an identical configuration, independent of the support vessel.

An alternative way, tested on the 1st day, is to mount the GAPS on a rigid pole, attached to the side of the ship, with a GNSS antenna on a ship's mast. The pole, long enough to immerse the GAPS away from the propeller and engine noise, may bend as the ship moves. The lever arms (X, Y, Z distances) between the GNSS antenna and the GAPS can also be difficult to be accurately measured and, moreover, monitored during the experiment. Such setting then becomes vessel dependent, if not experiment dependent.

Figure 4 : The USV (named PAMELI) of the LIENSs laboratory in la Rochelle in action, followed by an intrigued visitor. The USV is a 3m-long over 1.6m-wide catamaran, weights 300kg, and is battery powered (8h autonomy).

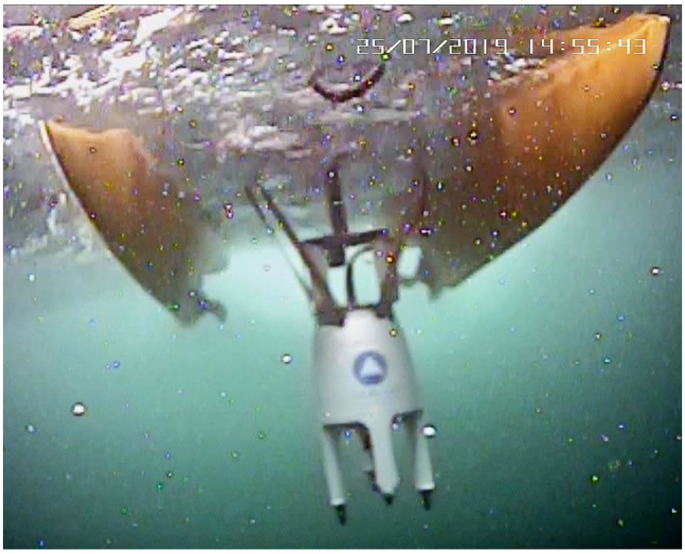

Figure 5 : Experimental mounting of the GAPS (USBL/INS) on the USV. The GNSS antenna linked to the GAPS is located directly above, on top of the vertically-adjustable black "daggerboard" (Figure 4).

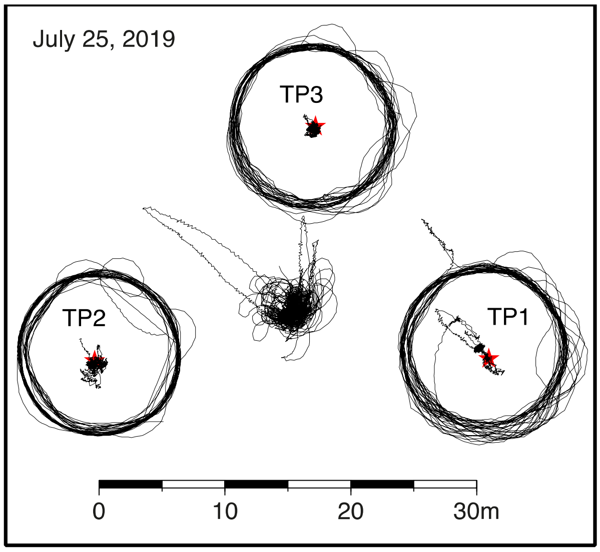

Figure 6: Data acquisition tracks of the USV for absolute seafloor positioning. Transponders (TP) are shown by red stars.
The USV was on auto-pilot while acquiring data at the fixed stations or along the circled-paths. Circles around the beacons were run both clockwise and anticlockwise.

Results

The data acquired by each acoustic beacon (travel times and auxiliary sensors) are of very good quality. During this beautiful week, the temperature at 40m depth increased by nearly one degree (18˚ to 19˚C) and shows diurnal variations. As a result, the sound speed increased and the travel-times between beacons decreased throughout the week. Unsurprisingly, pressure sensors recorded the tide signal (±2m). No sound-speed measurements were acquired (faulty sensors). The two-way travel-times show a dispersion between 5 and 10 microseconds depending on the baseline considered (between 3 and 7 mm). Measurements from a given pair of beacons (A to B or B to A) overlap perfectly.

This experiment provided a unique dataset to test our methods for inverting seafloor geodetic data and determine the best experimental protocol for absolute positioning measurements (Sakic et al., 2021). The absolute real-time positioning showed a dispersion of less than 70cm, or even 50cm (diameter of the point cloud). After post-processing, the repeatability improved by a 10-fold factor and reached ~5 cm in the transponder locations.

The coordinates of individual transponders were derived from the recorded two-way-travel times, and direction of arrival (DOA) of acoustic rays from the transponders to the USV, and from the GNSS positions of the USV. Using a least-squares inversion, we show that DOAs improve single transponder positioning both in box-in (circles) and static acquisitions. Post-processing the GNSS data also significantly improved the two-way-travel times residuals compared to the real-time solution (Sakic et al., 2021).

The attached data set provides:

- the raw acoustic-ranging data from the four transponders: two-way-travel times between pairs of beacons, auxiliary sensor data recorded at each transponder (temperature, pressure);
- the real-time and reprocessed USV navigation tracks above or around beacons TP1, TP2 and TP3 (Figure 6; TP4 was not used in the inversion);
- the controlled two-way-travel times, and direction of arrival (DOA) of the acoustic rays from the three transponders to the USV.

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- IXblue: Paul Urvoas, Pierre-Yves Morvan, Yoann Caudal, Corinne Le Guicher
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References

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Sakic, P., Chupin, C., Ballu, V., Coulombier, T., Morvan, P.-Y., Urvoas, P., Beauverger, M. & Royer, J.-Y. (2021). Geodetic seafloor positioning using an Unmanned Surface Vehicle - Contribution of direction-of-arrival observations, *Frontiers,* In press. [DOI en attente]

Additional documentation

- Canopus beacons: https://www.ixblue.com/products/canopus
- GAPS USBL/INS: https://www.ixblue.com/products/gaps-pre-calibrated-insusbl-system
- USV: https://www.asvglobal.com/product/c-cat-3/
- SV Albert Lucas: https://wwz.ifremer.fr/flotte_en/The-Fleet/Station-vessels/Albert-Lucas

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