ID30- PRECISE OBS LOCATION AT THE SEA BOTTOM IN ACTIVE SEISMIC PROFILES USING THE AIR GUN SHOT RECORDS.

A. PAZOS[65], J.L. GRANJA BRUÑAA[64], J.M. DAVILA[68], A. CARBÓ-GOROSABEL[61], R. CABIECES[69], A. RODRÍGUEZ-ZURRUNERO[62], J. SANTOS LOAISA[67], J. M. GOROSABEL ARAUS[63], J. QUIJANO[66], M.AMBROS[212]

***Abstract** – The Norcaribe campaign, in November – December 2013, funded by Spanish Ministry of Innovation and Science (Norcaribe Project CGL2010-17715), was performed on board of the Spanish research vessel "Sarmiento de Gamboa" around the Hispaniola island, also with the participation of the Dominic Republic Navy patrol vessels and several Haiti and Dominic Republic institutions. During the campaign, a 200 km long, wide-amgle refraction seismic profile was carried out crossing the Beata ridge. The air gun signal (5100 ci) was recorded by 15 OBSs deployed along the seismic line in water depths between 2.300 meters and 4.320 meters. To obtain the section records, the OBS position is needed, usually the deployment location is used, but the OBS can drift while is sinking due to the deep oceanic currents. The recovery locations at surface could provide information about the drift, assuming a constant sea current since the deployment to the recovery, but it is imprecise. In this work we show a method to obtain a precise location of the OBS at the sea bottom using a high-resolution bathymetry and the OBS record of the closest air gun shots of the profile. Also, the preliminary results for the Norcaribe campaign (Beata ridge profile) are shown.*

***Keywords** – OBS, sea bottom location, seismic profile, shots.*

I. INTODUCTION

The Caribbean Plate arouses much interest in the geoscientist community for many reasons. Some of them are the amalgam and interaction of distinct tectonic terrains and the complex tectonic history. In addition, this densely populated region is exposed to significant geological risks as it was recorded in the geological record. The Spanish NORCARIBE project (Geodynamics Northern Caribbean: Dominican Republic – Haiti Sector) was funded, in 2010, by the Spanish Ministry of Science and Innovation, and it aimed to study the tectonics and its seismic hazard and tsunamigenic potential in the Hispaniola region.

The NORCARIBE project [1,2] was leaded by the department of Geodynamics of the Complutense University of Madrid (UCM) with the participation of the Royal Spanish Navy Institute and Observatory (ROA). Also, the Spanish Institute of Oceanography, the "U. S. Geological Survey" and local institutions, as the National Authority of Maritime Affairs and the Geological Survey of the Dominican Republic, were involved in the project. In addition, the Dominican Republic Navy supported the project providing three patrols vessels for deploying and recovering the OBS's and as chase boats for seismic experiments. Previously, the UCM and ROA leaded others Spanish projects in the northern Caribbean area. In 2005, GEOPRICO-DO campaign ("Structure and Geodynamics of the Caribbean plate: Puerto Rico microplate") was carried out on board of the Spanish R/V "Hesperides". In this project participed the Puerto Rico Seismic Network and the University of Mayaguez and the Dominic Republic Navy and the Autonomous University of Santo Domingo. In 2009, CARIBENORTE campaign (Analysis of Contact between the Caribbean plate and North America from the Beata Ridge to Anegada Passage), also on board of the R/V "Hesperides" and with the collaboration of the several Dominic Republic institutions and navy.

The NORCARIBE geophysical marine campaign (16th November – 17th December 2013) was carried out on board of the Spanish oceanographic research vessel "Sarmiento de Gamboa" around the Hispaniola island. During this cruise were recorded systematic swath bathymetry data, gravity and magnetics data, high-resolution seismic, multichannel seismic reflection and wide-angle seismic data (figure 1).

The present work is focused in the problem of the location of the OBS at the sea bottom. For making the section records and the 2-D seismic modeling is necessary the accurate OBS location. Generaly, the the coordinates of deployment location at the sea surface are used, but the OBS can drift while is sinking due to the deep ocean currents. Note the OBS sinking velocity rounds 60 meters per minute, it means that takes about 1 hour to reach the sea bottom for a depth of 4.000 meters.

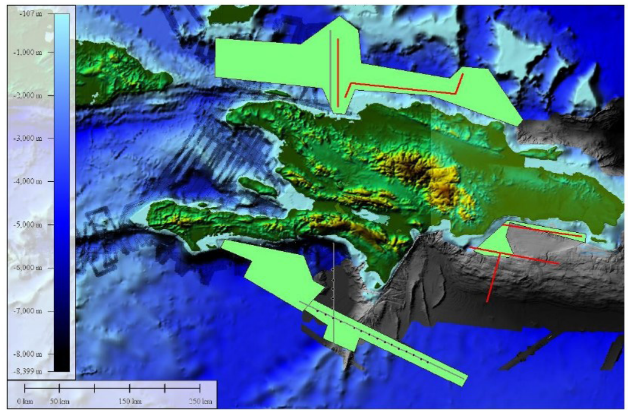

Fig 1. NORCARIBE campaign. Green areas: systematic surveys (bathymetry, gravity and magnetic). Red lines: multichannel reflection profiles (6 km streamer). Grey lines: wide-angle refraction profiles. Black dots: OBS.

II. THE PROBLEM

The OBS are deployed at the selected sites along the planned seismic profile (or in a grid points for 3-D seismic studies), although the location has a good precision (GPS) at surface where the ship is placed, as it was previously mentioned, the OBS drifts due to the deep ocean currents, that varies along the sinking path. This drift can reach even several hundreds or thousands meters.
An estimation of the OBS position, at the sea bottom, could be done comparing the deploying location and the recovery location of the OBS, but a constant current during the deployment and the recovery times should be assumed. It means that the OBS should be located at the sea bottom just in the middle point. But the recovery location is not well determined due

	Deployment		Recovery		
	Lat.	Long.	Lat	Long.	Diff. (m)
OBCB 14	16° 35'.963 N	70° 52'.738 W	16° 36'.069 N	70° 52'.670 W	**230**
OBCB 13	16° 38'.377 N	70° 57'.682 W	16° 38'.546 N	70° 57'.982 W	**617**
OBCB 12	16° 41'.250 N	71° 03'.384 W	16° 41'.323 N	71° 03'.534 W	**298**
OBCB 11	16° 43'.913 N	71° 08'.867 W	16° 43'.720 N	71° 09'.510 W	**1195**
OBCB 10	16° 46'.462 N	71° 14'.491 W	16° 45'.717 N	71° 13'.850 W	**1788**
OBCB 09	16° 49'.293 N	71° 20',532 W	16° 49'.325 N	71° 20'.573W	**93**
OBCB 08	16° 51'.392 N	71° 25'.349 W	16° 51'.437 N	71° 25'.393 W	**114**
OBCB 07	16° 54'.230 N	71° 31'.277 W	16° 54'.208 N	71° 31'.396 W	**214**
OBCB 06	16° 57'.207 N	71° 37'.533 W	16° 57'.016 N	71° 37'.598 W	**372**
OBCB 05	16° 59'.825 N	71° 43'.620 W	17° 00.103 N	71° 43'.946 W	**773**
OBCB 04	17° 02'.370 N	71° 49'.054 W	17° 02'.056 N	71° 53'.085 W	**7161**
OBCB 01	17° 12'.632 N	72° 10'.977 W	17° 12'.535 N	72° 11'.462 W	**876**
OBCB 15	17° 15'.312 N	72° 17'.107 W	17° 15'.277 N	72° 17'.686 W	**1026**

Table 1. Differences between the deployment and recovery location for the OBS in the Norcaribe campaign.

It must be mentioned that, during the Norcaribe cruise, there was a bad general weather during the recovery for all OBSs, so it took (in general) over half an hour to recovery some of them.

Therefore, a precise location of the OBS at the sea bottom can not be determined only by estimating the middle point between the deployment and the recovery locations.

III. A THEORETICAL SOLUTION

A theoretical and more precise location can be obtained using the travel times of the direct wave of the shots arriving to the OBS. Multiplying the travel time for the wave velocity in the water (1500 m/s), the range between the air guns and the OBS is obtained.

The OBS location is over a down semi-sphere of radius equal to the obtained distance and a center located in the position of the shot (with a known depth below the surface). The location is the common point of at least three of these semi-spheres. This is, the solution of the a system composed by "n" equations (one for each used air-gun shot) as the following one:

where the subscript "i" means the shot position for each equation, "zo" is the depth of the air guns, and "di" is the distance (radius) for each shot. The solution is the exact location of the OBS laying over the sea floor.

$$(x+x_i)^2+(y+y_i)^2+(z-\ z_o)^2=d_i^2 \qquad (1)$$

In figure 2 an schematic diagram of this solution, for a 3 spheres, is shown.

But, unfortunately, there are several uncertainties:

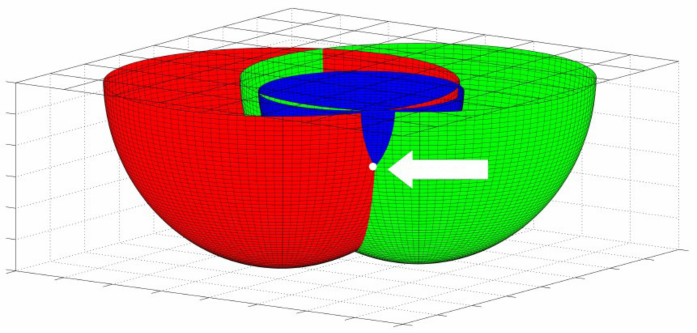

Fig 2. An schema of the solution of equations (1) for three shots.

- Shot location error. The location of the shot is obtained translating the vessel GPS antenna (precise) to the shot generation point, some meters at the stern of the ship (figure 3). Although the estimation is quite precise, the GPS error remains.
- Direct wave travel time error. Although the direct wave can be picked with precision using the shot records, there are always some error, at least one period between samples.

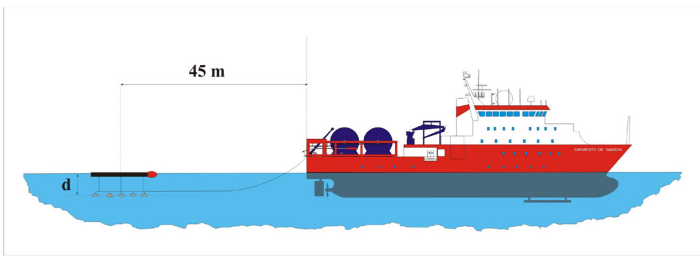

Fig 3. An schema of the location of the shot point and the vessel "Sarmiento de Gamboa" during the NORCARIBE campaign. In the schema, "d" represents the shot depth (zo). The distance between the GPS antenna and the stern of the vessel is well known.

- The shot time has a small error. The shot is produced with the selected GPS pps pulse (one each 90 seconds) and there are some delays due to the system and the GPS receiver. This error is usually less than a microsecond and can be negligible.
- Finally, the shot wave velocity in the water is assumed as 1500 m/s, but it is not exact neither constant along the path.

All these uncertainties made the equation system has not a unique solution, not all semi-spheres has a common point. Therefore any algorithm to minimize errors could be used to obtain the most probable solution (for example, the classical minimum square mean error [3], or minimizing any behavior index as in [4]).

As the OBS is placed at the sea bottom, the bathymetry surface could be used to constrain the problem. So, only those solution places over the sea bed should be considered.

IV. THE NUMERICAL PROPOSED METHOD

The proposed method is based on the numerical minimum square mean error. The accuracy will depend of the resolution of the used bathymetry. Nevertheless, due to the OBS deployments are selected where the sea bed is quite flat, to avoid the OBS could move down along the slope of the sea floor, a grid interpolation could be done to improve the resolution of the final position.

The method was programmed in MATLAB script. The stages of the method are as follow:

- Obtain the bathymetry file (xyz) and if it necessary interpolate to get a regular grid (latitude and longitude in degrees and the depth in meters) of several km around of the OBS location. A matrix "D", with the depth in each grid point, of X raws and Y columns is obtained. Raws correspond to the latitude and the columns to the longitude.
- For each point of the matrix "D" the theoretical travel time is determined. This is, first the distance between the shot point and each grid point of the bathymetric surface is calculated, and then, dividing by the velocity in the water the travel time is obtained (matrix "M" of size XY).
- Select the shots. Several shots (N) close to the OBS deployment position should be selected. The first arrival to the OBS will correspond to the direct wave for the closest ones. If some selected shot is some faraway from the OBS the direct wave arrival must be identify carefully. In figure 4 a piece of a section record is show, where the direct wave can be observed as the first arrivals for the closest shots, but arrivals from other phases come first as we move away from the OBS position.

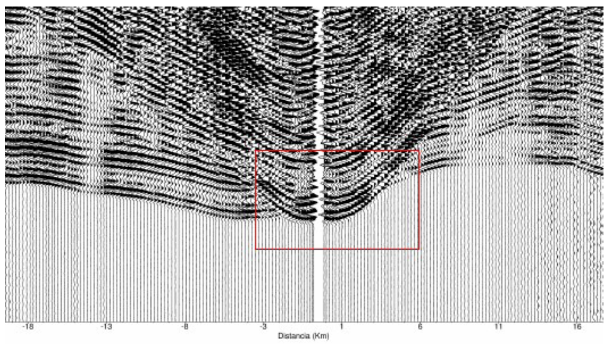

Fig 4. A piece of a section record. In the center part of the red box the first arrival correspond to the direct wave.

- Pick the onset direct wave arrival from the shot record (the vertical component or the hydrophone is generally selected). In figure 5, an air-gun shot record of the vertical component of an OBS is shown.

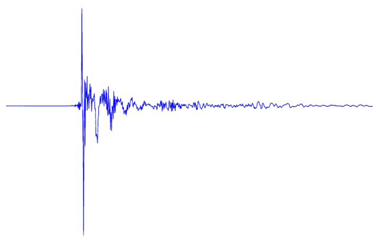

Fig 5. A shot record for the OBCB15 (vertical component).

- Calculated the travel time ("ti"). For each shot the travel time is calculated by subtracting the shot time to onset arrival time (picked), obtaining a vector of size "N".
- Calculate the mean square error matrix (E):

$$E_{i,j}^2=\frac{1}{N}\sum_{i=1}^{N}(M_{i,j}-\ t_i)^2 \qquad (2)$$

• Finally, the best OBS position is the grid point with the minimum mean square error (equation 3). To estimate the OBS position error, is only necessary to multiply this minimum error (seconds) for the wave velocity in the water.

$$E_p = v_{w^*} \, min\left(\sqrt{E_{i,j}^2}\right)$$

where Ep is the rms position error and vs is the wave velocity in the water. The latitude and longitude is the corresponding to the minimum value.

V. RESULTS

The described method has been applied to the OBS from the Beata ridge profile made during the NORCARIBE campaign.

In the table 2 the obtained positions and their rms errors in meters are shown.

	Lat.	Long.	Rms error (m)
OBCB 14	16° 36'.1131 N	70° 52'.6096 W	**88.57**
OBCB 13	16° 38'.4579 N	70° 57'.5725 W	**01.13**
OBCB 12	16° 41'.1421 N	71° 03'.4315 W	**24.21**
OBCB 11	16° 43'.7309 N	71° 08'.8737 W	**98.59**
OBCB 10	16° 46'.3168 N	71° 14'.5044 W	**93.42**
OBCB 09	16° 49'.2886 N	71° 20',5132 W	**08.00**
OBCB 08	16° 51'.3788 N	71° 25'.3249 W	**64.97**
OBCB 07	16° 54'.0092 N	71° 31'.3863 W	**25.46**
OBCB 06	16° 57'.1038 N	71° 37'.5800 W	**47.48**
OBCB 05	16° 59'.9101 N	71° 43'.6596 W	**29.24**
OBCB 04	17° 02'.3843 N	71° 49'.0367 W	**40.00**
OBCB 01	17° 12'.6007 N	72° 10'.9627 W	**85.00**
OBCB 15	17° 15'.4229 N	72° 17'.0621 W	**86.16**

Table 2. Best OBS positions and their rms errors.

The results show a rms error less than 100 meters in all cases and much less than the differences between the deployment and recovery positions.
In figure 6, the rms error grid for the OBCB05 is shown.

VI. CONCLUSIONS

The problem of the location of the OBS at the sea floor has been described and a numerical method, based on the minimum square mean error, using the shot records of a seismic refraction profile, has been shown.

The results show the goodness of the proposed method. The results of the method for the Beata ridge profile of the NORCARIBE campaign show an error less than 100 meters.

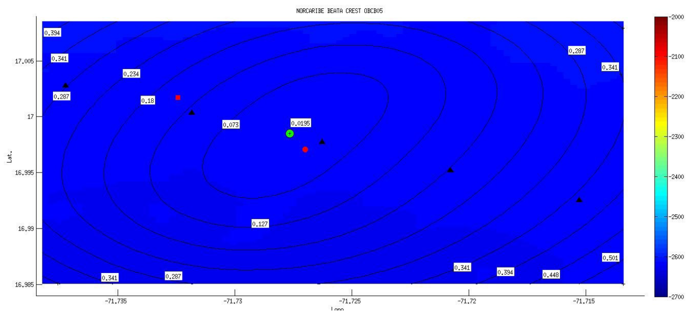

Fig 6. Result of the method for the OBCB05. Green dot: best position. Red dot: deployment position. Red square: Recovery position. Blck triangles: selected shots. Labels indicate the rms errors

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