Divisão de Geologia Marinha e Georecursos Marinhos
Relatório Técnico
INGMARDEP 01/2014 – 14/02/2014

# TAGUSDELTA Cruise Final Report

Tagus River Delta, 29 Nov. - 10 Dec. 2013


Ship Noruega, from the Instituto Português do Mar e da Atmosfera, offshore Cascais, with the two 12m outriggers mounted to tow the seismic equipment.

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IPMA, 2014

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# 1 INTRODUCTION

## 1.1 Scope

The TAGUSDELTA 2013 campaign was carried out in the scope of research project **TAGUSDELTA (3D high resolution seismic stratigraphy of the Tagus Delta – imaging of tsunami and earthquake evidence for natural hazards assessment, PTDC/MAR/113888/2009)** funded by the Fundação para a Ciência e a Tecnologia (FCT). This project was prepared and submitted to the FCT financing program by the Dr. Henrique Duarte through the Marine Geology Department of the Laboratório Nacional de Energia e Geologia (LNEG). In 2013, with the extinction of this LNEG department and the transition to the Instituto Portugês do Mar e da Atmosfera (IPMA) of the majority of the researchers that work in that area, the project Tagusdelta was also transferred to the IPMA. Presently the project is coordinated by Dr. Pedro Terrinha of the “Divisão de Geologia Marinha e Georecursos” from the IPMA.

The Tagusdelta project is focused in the tsunamic hazard of Lisbon. It aims to decipher the stratigraphy and sedimentary architecture of the frontal part of the Tagus delta, to correlate the evidences of mass transport features with tsunamigenic events and model the tsunamic hazard of the area. To feed the tsunamigenic mathematical models with realistic quantitative data with precise location of the events, it is necessary to image these mass transport features with very high resolution multichannel 3D seismic reflection data. However, a classical 3D seismic survey is impractical in the area due to its high cost and the technical and safety problems related with the coastline proximity, low water depths, high ship traffic and the abundance of fishing gear regularly deployed in the area. To overcome this problem and obtain the required 3D seismic reflection data, it is proposed within this project framework a new revolutionary method for 3D seismic reflection data acquisition.

The proposed method for acquisition of 3D seismic reflection data relies on new a geometry setting that uses two streamers set up in a "V" shape. This geometry is achieved by using in each streamer a port buoy as head buoy to maintain the “V” aperture and linking the two streamers at the same tail buoy that defines the vertex of the "V". The 3 streamer buoys has autonomous GPS receivers to determine their position and the seismic source is locate at a mid-distance in line with the two head buoys. This system will allow the acquisition of seismic volumes with a horizontal resolution of 1m and a vertical resolution of 15cm, and a signal penetration of 50 to 150 meters. The system is scaled for deployment in small coastal research vessels (12 to 25m long) allowing for cost-effective coverage of 10-20 km2 areas, at 5 to 200m water depths, in 10-20 survey days.

The Tagusdelta campaign is the backbone of the Tagusdelta project since that this cruise will allow to perform the proof of concept of the proposed 3D seismic reflection system and the acquisition of 2D and 3D data to image the landslide structures in the Tagus delta and pro-delta. Imaging the mass-transport deposits and related erosive scars morphologies with 3D seismic will allow quantification and precise location of the events, thus enabling modelers to play with quantitative parameters of unprecedented realism.

## 1.2 Campaign Objectives

The Tagusdelta campaign had technical and scientific objectives. The main technical objective was to make the proof of concept of the new proposed method for the acquisition of 3D very high resolution seismic reflection data. The accomplishment of this objective included:

- Deployment and data acquisition systems tests;
- Positioning uncertainty assessment;
- Seismic and positioning data processing for the 3D seismic volume generation.

From the scientific point of view the main objective was to acquire very high resolution seismic reflection data that allow the characterization of the frontal area of the Tagus ebb-tide delta seismic stratigraphic facies arquitecture. A special focus was placed in the:

- Identification, characterization and mapping of mass wasting features, in order to allow a first trial of the Pleisto-Holocene mapping and chronostratigraphy of these features in the Tagus delta;
- Imaging the morphologies of landslide structures with 3D seismic, particularly in what concerns the landslide already identified with the previous data, to allow the quantification and precise location of the events, to generate data of unprecedented realism that can be fed into the tsunamigenic mathematical models.

## 1.3 Previous works

There are several old seismic reflection data-sets collected in the continental shelf area offshore the Tagus River (Figure 1). The GSI dataset is the only one with multichannel data. However, this old oil industry low resolution multichannel data don't intersect the ebb-tide delta since that are located further offshore. The other datasets in the area are single channel high resolution data, essentially boomer and sparker data. The Lisboa98, Lisboa98A (from 1998) and Tesa-b (from 2003), boomer datasets were the first's ones to allow some significant insight into the Tagus ebb-tide delta internal structure. Based in these data it was possible to plan the Pacemaker campaign in 2011. The Pacemaker very high resolution sparker dataset, already with a regular rectangular grid and a better penetration, allowed a much better imaging of the Tagus ebb-tide delta internal structure, leading to the identification and partial mapping of a possible land slide features and an area interpreted as gas blanking (Figure 2 and Figure 3).

The Tagus prodelta area was sampled with gravity and box cores during the Poseidon 287 and Discovery 249 cruises. It is believed that the signature of the 1755 and 1969 earthquakes was identified in these cores (Abrantes, Lebreiro et al. 2005, Abrantes, Alt-Epping et al. 2008).

Taking into account the location and interpretation of the previous geophysical and sampling data, it was possible to accurately define target areas to the Tagusdelta campaign were the new very high resolution 2D and 3D multichannel seismic reflection data should be acquire.

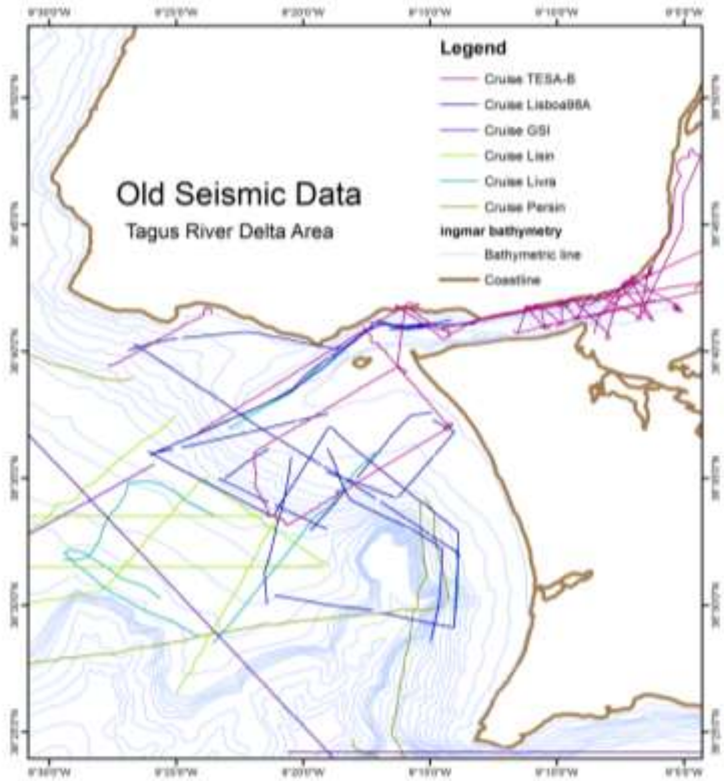



**Figure 1 – Old Seismic reflection data in the Tagus river ebb-tide delta area**

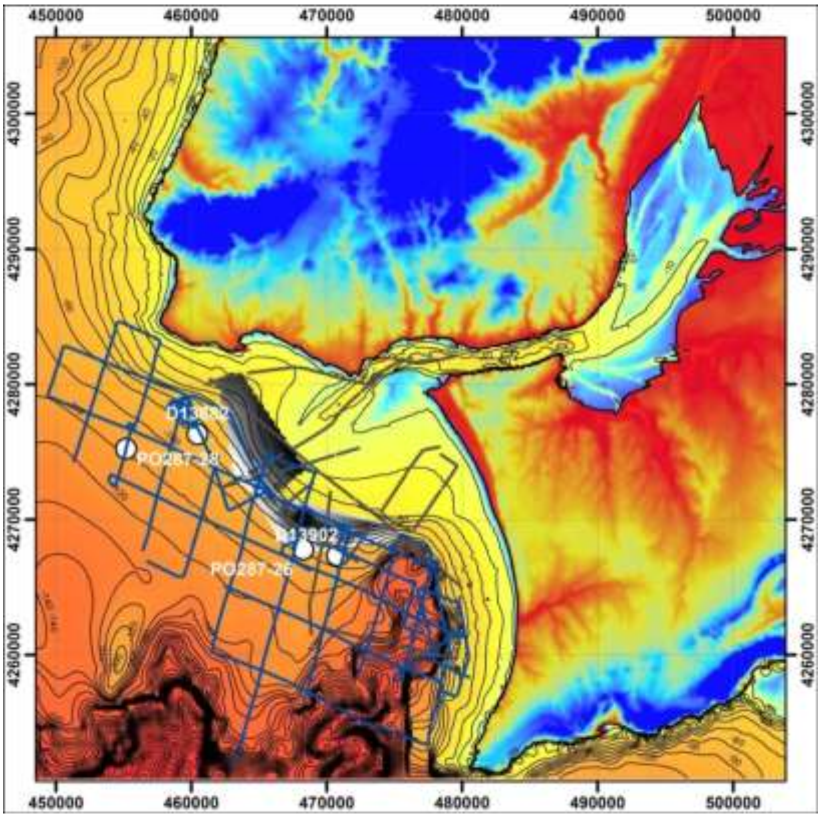



**Figure 2 - Previous work done in the study area. The grey lines are boomer single channel profiles from Lisboa 98 cruise, the blue lines are sparker single channel profiles from Pacemaker cruise and the white dots symbolizes the sampling cores from Poseidon 287 and Discovery 249 cruises (Abrantes et al., 2005, 2008). The gray grids represent isobaths of a gas layer and of the Lisbon prodelta main slide originated by the 1975 Lisbon earthquake and tsunami.**

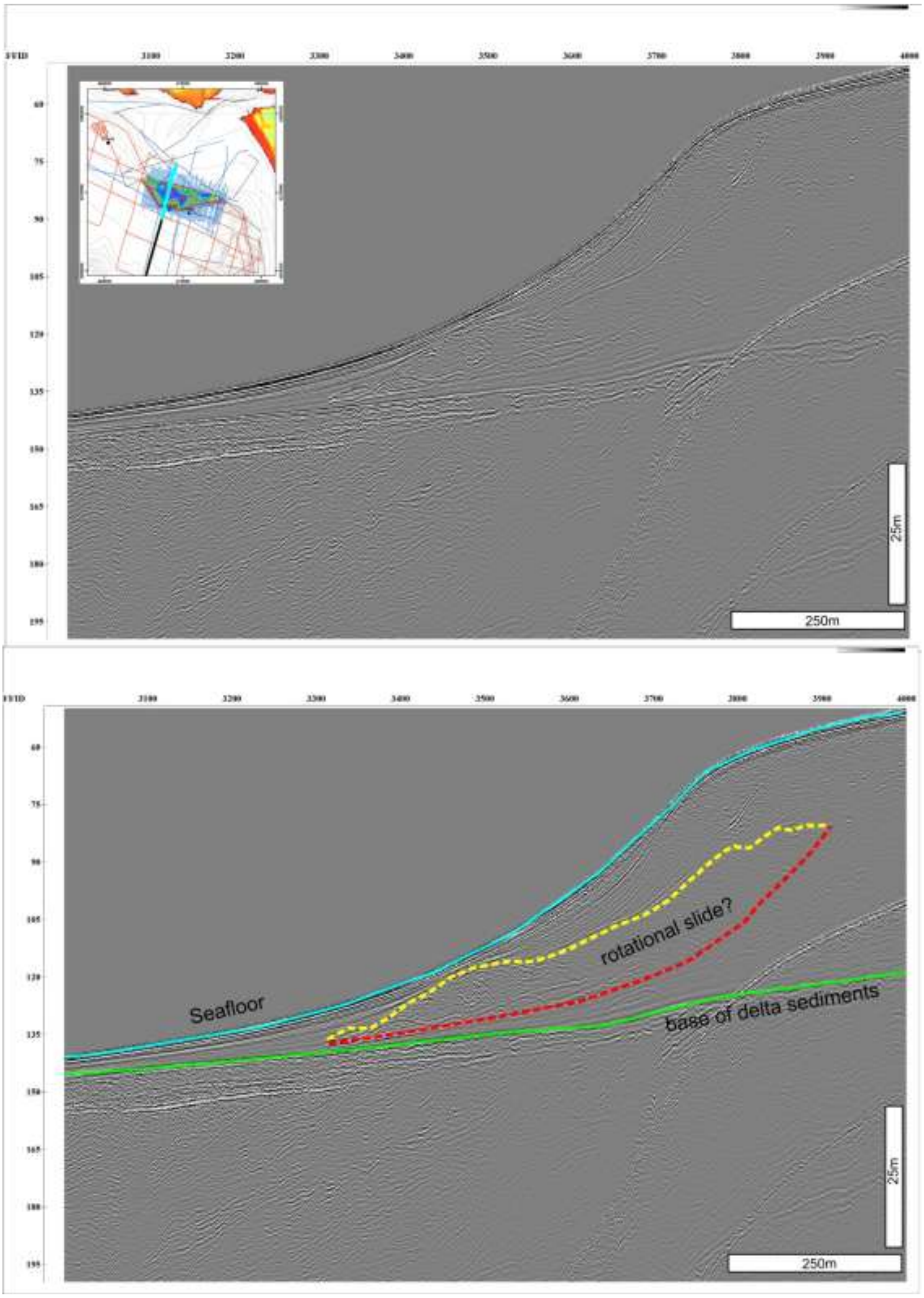



**Figure 3 – Extract of the Pacemaker cruise seismic line PM-D01 across the Tagus river ebb-tide delta frontal lobe, showing the scar and associated deposit of a possible rotational slide. Upper panel, seismic data and inset with the line location. Lower panel, reflections interpreted as the delta base, and limits of a possible rotational slide.**

## 1.4 Planned work

### 1.4.1 Initial plan

The initial plan prepared for the TAGUSDELTA 2013 campaign was divided into two stages, the 2D and the 3D data acquisition. In the first stage it was planned to acquire the six 2D profiles showed in Figure 4, to: i) better constrain the target area for the 3D survey, ii) obtain an accurate velocity model of the study area for the time migration of the 3D seismic data, iii) cross the sampling sites of the existent cores, to allow an accurate chrono-stratigraphic calibration of the study area. The second stage consisted in the acquisition of the 3D data. To produce the high resolution 3D seismic reflection volume of the study area it was planned to acquire about four hundred seismic profiles with 16 meters of line spacing and a length of 4 kilometers each, as shown in Figure 5.

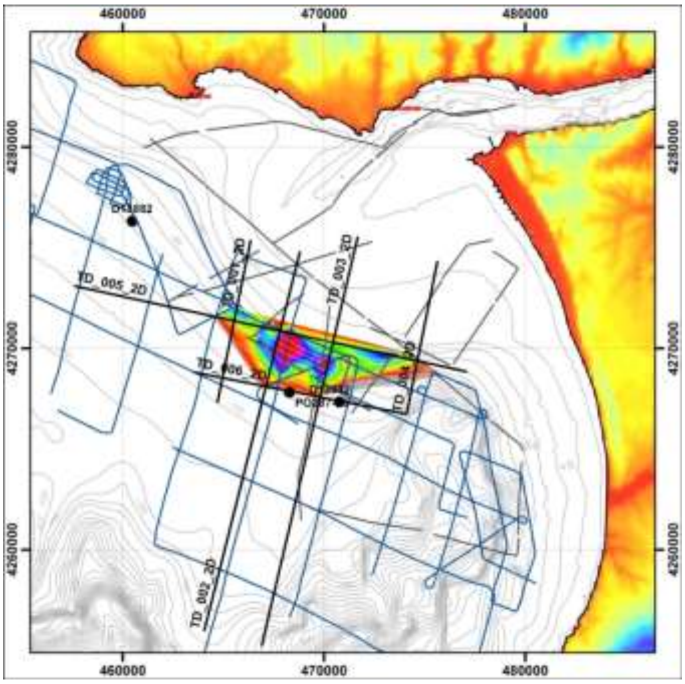



**Figure 4 - The labeled black line represents the initial 2D survey line plan. The grey lines are existent boomer single channel profiles from Lisboa 98 cruise, the blue lines are existent sparker single channel profiles from Pacemaker cruise and the black dots symbolizes the sampling cores from Poseidon 287 and Discovery 249 cruises (Abrantes et al., 2005, 2008). The color grid represents an isopach map of the Lisbon prodelta main slide.**

### 1.4.2 New plan

Due to delays on the mobilization works and to an incident during the initial phase of acquisition that cut off the starboard outrigger during the initial phase of 2D data acquisition, it was necessary to reevaluate the initial 2D/3D survey plan. The cause of the incident was that the starboard streamer got caught on a fishing net whose weight broke the steal outrigger arm.

The mending of the broken outrigger took two days since that it was a complex operation that could only be done during the day time and in sheltered areas. During that time, with only one operational outrigger, only 2D data could be acquired. Because of that it was necessary to decrease the 3D surveyed area, and increase de 2D surveyed area.

A new 2D survey plan was designed to cover both, the entire area where the main landslide was identified in the previously interpreted seismic data and the entire area initially planned for the 3D survey. This new 2D line grid has 4 km long lines, oriented perpendicular to the delta frontal lobe and with a line spacing of 200m (Figure 6). The new 3D survey line plan kept the same design as previously, but with this new situation, the lines were sequentially surveyed in order to complete the survey in an area as large as possible.

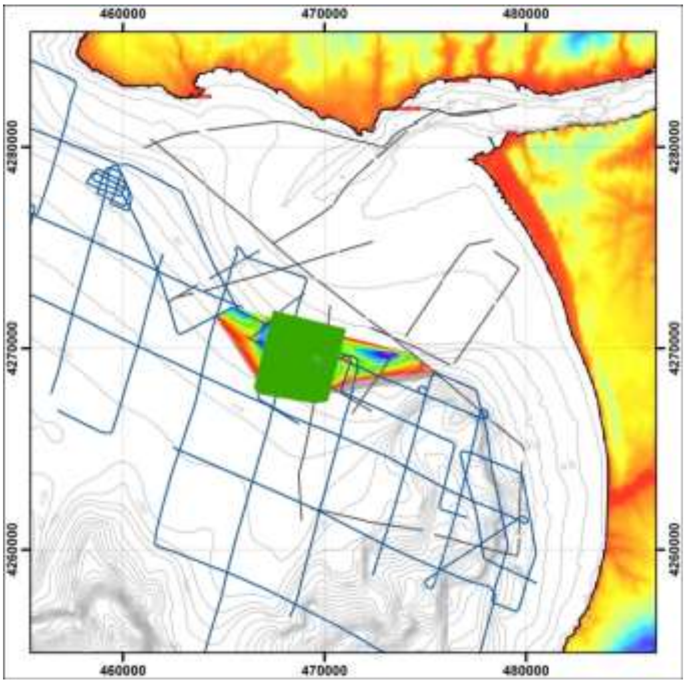



Figure 5 - In green the area planned for the 3D survey plotted on top of isopach map of the Lisbon prodelta main slide originated by the 1975 Lisbon earthquake and tsunami. The grey lines are previous boomer single channel profiles from Lisboa 98 cruise, the blue lines are previous sparker single channel profiles from Pacemaker cruise.

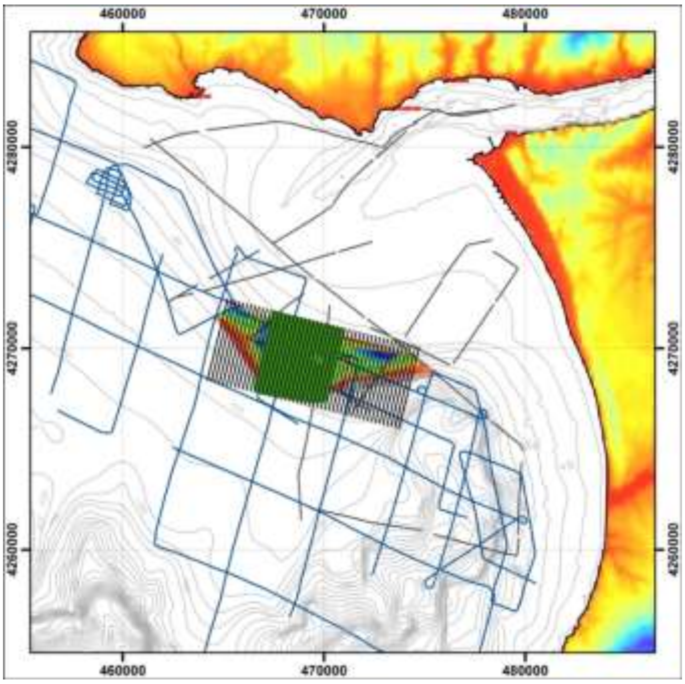



Figure 6 - In black the new 2D survey plan plotted on top of isopach map of the Lisbon prodelta main slide originated by the 1975 Lisbon earthquake and tsunami. In green the area planned for the 3D survey. The grey lines are previous boomer single channel profiles from Lisboa 98 cruise, the blue lines are previous sparker single channel profiles from Pacemaker cruise.

# 2 PARTICIPANTS

## 2.1 Scientific team and mission participant's chronogram

The total duration of the mission was 12 days. Three days were spent in the mobilization and software setup, eight days in the 2D/3D seismic data acquisition and one day for the demobilization. The scientific team included members of various institutions and changed along the several campaign days as shown in Table 1.

Pedro Terrinha that is the Principal Investigator (PI) of the Tagusdelta project was the Chief of Mission. The operational activities were coordinated by João Noiva and the technical activities were led firstly (until Wednesday 4th of December morning) by Henrique Duarte and secondly by his release Miguel Mouga, both from Geosurveys.

**Table 1 - List of participants. The orange filling symbolizes the mobilization and demobilization days whilst the green filling represents the seismic acquisition work days.**

| Name | Position | Institution | 29 Nov | 30 Nov | 1 Dec | 2 Dec | 3 Dec | 4 Dec | 5 Dec | 6 Dec | 7 Dec | 8 Dec | 9 Dec | 10 Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pedro Terrinha | Chief of mission | IPMA | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| João Noiva | Chief of operations | IPMA | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Henrique Duarte | Senior Geophysicist | Geosurveys | Yes | Yes | Yes | Yes | Yes | Yes* | - | - | - | - | - | - |
| Miguel Mouga | Senior Geophysicist | Geosurveys | - | - | - | - | - | Yes* | Yes | Yes | Yes | Yes | Yes | Yes |
| Vitor Vajão | Operations | IPMA | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Vitor Magalhães | Scientist | IPMA | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes* | - | - | - | - |
| Pedro Brito | Scientist | LNEG | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Paulo Alves | Scientist | IPMA | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Marcos Rosa | Scientist | IPMA | - | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | - |
| Eduardo Rolim | Geophysicist | Geosurveys | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Francisco Curado | Scientist | Univ. Aveiro | - | - | - | - | - | Yes | Yes | Yes | Yes | Yes | Yes | - |

During the 2D/3D seismic reflection data acquisition two teams that worked ensuring continuity in 12 hour shifts were formed. At every shift there was 3 main tasks to accomplish: i) operation of seismic acquisition software (Geophysics), ii) operation of navigation software and recording positioning (Surveying) and iii) quality control of signal and geology (Q/C). In addition to the acquisition tasks there was a shift chief that was responsible for the operation of placing the equipment in the water and for the operation of the PPS source.

The team of each 12-hour shift was composed by the elements described in Table 2 and Table 3. The chief of the 0-12 hours shift was Vitor Magalhães and the 12-24 hours shift chief was Pedro Brito. At each shift change was made a brief meeting for report and handover of the operations. The Chief of Mission Pedro Terrinha, simultaneously ensured signal and geology quality control tasks of the 12-24 shift until the departure of Vitor Magalhães on December 6th. After this date Pedro Terrinha also assumed the leadership of the 0-12 hours shift, assisted by João Noiva, until the end of the survey. Francisco Curado arrived on Wednesday 4th December morning took the 12-24 hours shift working without a fixed task helping with is expertise in hydrodynamics on the 3D system setup and deploy. Vitor Vajão was in charge of the link between the scientific crew and the vessel crew and, with is seamanship expertise, to lead the outriggers setup and also the 2D and 3D system setup and deploy/withdraw in/out of the water. Miguel Mouga, a senior geophysicist from Geosurveys Company, who embarked on

Wednesday, 4th December, was in charge of the signal quality control management and technical advice. He had a fixed shift from 08-16 hours and was always available to coordinate all technical operations with seismic acquisition material.

**Table 2 - Initial shifts list. In bold are assigned the chief of each turn.**

| 0-12 hours shift | Task | 12-24 hours shift |
|---|---|---|
| **Vitor Magalhães** | **Seismic multichannel acquisition** | **Pedro Brito** |
| Marcos Rosa | **Surveying** | Paulo Alves |
| Pedro Terrinha | **Signal Quality control** | Eduardo Rolim |
| Pedro Terrinha | **Geology Quality control** | Eduardo Rolim |

**Table 3 - Shifts list after Vítor Magalhães departure. In bold are assigned the chief of each turn. *João Noiva helped Pedro Terrinha on seismic multichannel acquisition task.**

| 0-12 hours shift | Task | 12-24 hours shift |
|---|---|---|
| **Pedro Terrinha*** | **Seismic multichannel acquisition** | **Pedro Brito** |
| Marcos Rosa | **Surveying** | Paulo Alves |
| Pedro Terrinha | **Signal Quality control** | Eduardo Rolim |
| Pedro Terrinha | **Geology Quality control** | Eduardo Rolim |

# 3 Log of activities

The time log with the several performed activities is presented in the Table 4. The distribution of the operation time for each type of activity is shown in the Table 5 and the Figure 77. The tracks plots of the surveyed lines are shown in the Figure 8 to Figure 10.

During the Tagusdelta 2013 campaign a total of 1031 km were navigated. Of these, 410 km correspond to 2D MCS acquisition (59 profiles of which the longest and shortest profiles were 23km and 1.8km, respectively) and 182km correspond to 3D MCS acquisition (5 profiles of which the longest and shortest are 81 km and 6km, respectively). Thus, 57% of the navigation was dedicated to actual acquisition.

**Table 4 - Time log of activities during field investigations. See table 5 for activity codes.**

| Date | From | To | Duration | Code | Activity |
|---|---|---|---|---|---|
| 29-11-2013 | 09:00 | 24:00 | 15:00 | Mob | Mobilization in Lisbon |
| 30-11-2013 | 00:00 | 24:00 | 24:00 | Mob | Mobilization in Lisbon |
| 01-12-2013 | 00:00 | 24:00 | 00:00 | Mob | Mobilization in Lisbon |
| 02-12-2013 | 00:00 | 23:30 | 23:30 | Mob | Mobilization in Lisbon |
| 02-12-2013 | 23:30 | 24:00 | 00:30 | Op | Transit to survey area |
| 03-12-2013 | 00:00 | 01:45 | 01:45 | Op | Transit to survey area |
| 03-12-2013 | 01:45 | 08:30 | 06:45 | Op | Deployment of equipment |
| 03-12-2013 | 08:30 | 18:30 | 10:00 | Survey | 2D Survey |
| 03-12-2013 | 18:30 | 22:30 | 04:00 | Op | Equipment repair |
| 03-12-2013 | 22:30 | 23:30 | 01:00 | Survey | 2D Survey |
| 03-12-2013 | 23:30 | 24:00 | 00:30 | Op | Starboard outrigger damage, equipment recovery |
| 04-12-2013 | 00:00 | 02:00 | 02:00 | Op | Equipment recovery |
| 04-12-2013 | 02:00 | 03:00 | 01:00 | Op | Deployment of equipment |
| 04-12-2013 | 03:00 | 04:00 | 01:00 | Op | Equipment repair |
| 04-12-2013 | 04:00 | 05:30 | 01:30 | Survey | 2D Survey |
| 04-12-2013 | 05:30 | 08:15 | 02:45 | Survey | 2D Survey, Transit to Cascais |
| 04-12-2013 | 08:15 | 14:00 | 05:45 | Crew | Crew change and handover |
| 04-12-2013 | 14:00 | 15:30 | 01:30 | Op | Transit to survey area and deployment of equipment |
| 04-12-2013 | 15:30 | 24:00 | 08:30 | Survey | 2D Survey |
| 05-12-2013 | 00:00 | 24:00 | 24:00 | Survey | 2D Survey |
| 06-12-2013 | 00:00 | 14:00 | 14:00 | Survey | 2D Survey |
| 06-12-2013 | 14:00 | 14:30 | 00:30 | Op | Equipment recovery |
| 06-12-2013 | 14:30 | 17:00 | 02:30 | Op | Starboard outrigger mount during transit to Cascais |
| 06-12-2013 | 17:00 | 20:30 | 03:30 | Op | Crew change and starboard outrigger mount |
| 06-12-2013 | 20:30 | 24:00 | 03:30 | Op | Transit to survey area and deployment of 3D equipment |
| 07-12-2013 | 00:00 | 01:00 | 01:00 | Op | Deployment of 3D equipment |
| 07-12-2013 | 01:00 | 08:30 | 07:30 | Survey | 3D Survey |
| 07-12-2013 | 08:30 | 09:30 | 01:00 | Op | Equipment recovery |
| 07-12-2013 | 09:30 | 12:00 | 02:30 | Crew | Transit to Cascais to take GMSS technician |
| 07-12-2013 | 12:00 | 13:30 | 01:30 | Crew | Transit to survey area and deployment of equipment |
| 07-12-2013 | 13:30 | 16:30 | 03:00 | Op | 2D Survey |
| 07-12-2013 | 16:30 | 17:00 | 00:30 | Op | Equipment recovery |
| 07-12-2013 | 17:00 | 19:00 | 02:00 | Crew | Transit to Cascais to leave GMSS technician |
| 07-12-2013 | 19:00 | 20:30 | 01:30 | Op | Transit to survey area and deployment of equipment |

| Date | From | To | Duration | Code | Activity |
|---|---|---|---|---|---|
| 07-12-2013 | 20:30 | 24:00 | 03:30 | Survey | 2D Survey |
| 08-12-2013 | 00:00 | 12:30 | 12:30 | Survey | 2D Survey |
| 08-12-2013 | 12:30 | 13:00 | 00:30 | Op | Equipment recovery |
| 08-12-2013 | 13:00 | 16:00 | 03:00 | Op | Deployment of 3D equipment |
| 08-12-2013 | 16:00 | 24:00 | 08:00 | Survey | 3D Survey |
| 09-12-2013 | 00:00 | 16:00 | 16:00 | Survey | 3D Survey |
| 09-12-2013 | 16:00 | 17:00 | 01:00 | Op | Equipment recovery |
| 09-12-2013 | 17:00 | 18:00 | 01:00 | Op | End of survey. Transit to Lisbon |
| 09-12-2013 | 18:00 | 24:00 | 06:00 | Mob | Begin of demobilization in Lisbon |
| 10-12-2013 | 00:00 | 17:00 | 17:00 | Mob | End of demobilization in Lisbon. |

Table 5 – Distribution of the operational time for each task category.

| Task Category | Code | Hours |
|---|---|---|
| Mobilisation/Demob | Mob | 109.5 |
| Operational Setup | Op | 41.5 |
| Survey | Survey | 109.25 |
| Crew Change | Crew | 11.75 |
| **Total** | | 272 |

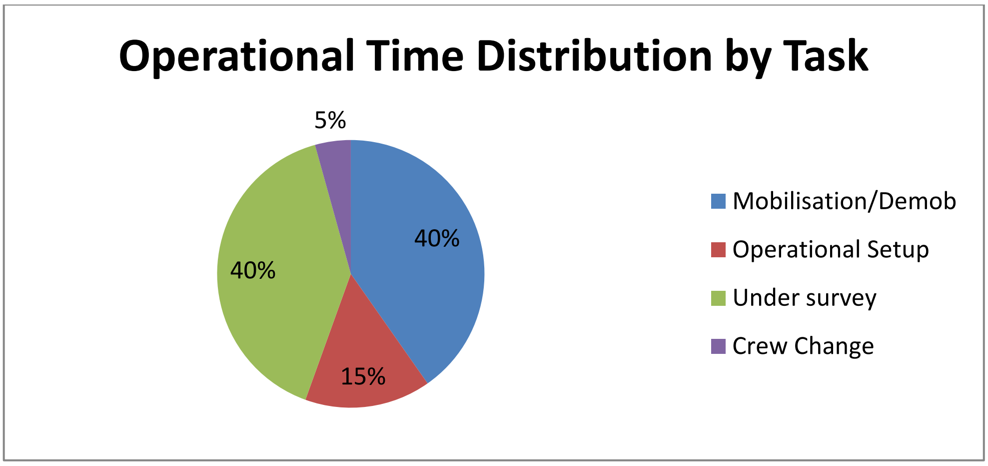



Figure 7 – Graphic of the operational time distribution for each task category.

# 4 NAVIGATION DATA

The maps of the total navigation, the 2D seismic reflection survey and the 3D survey are shown below.

## 4.1 Total navigation map

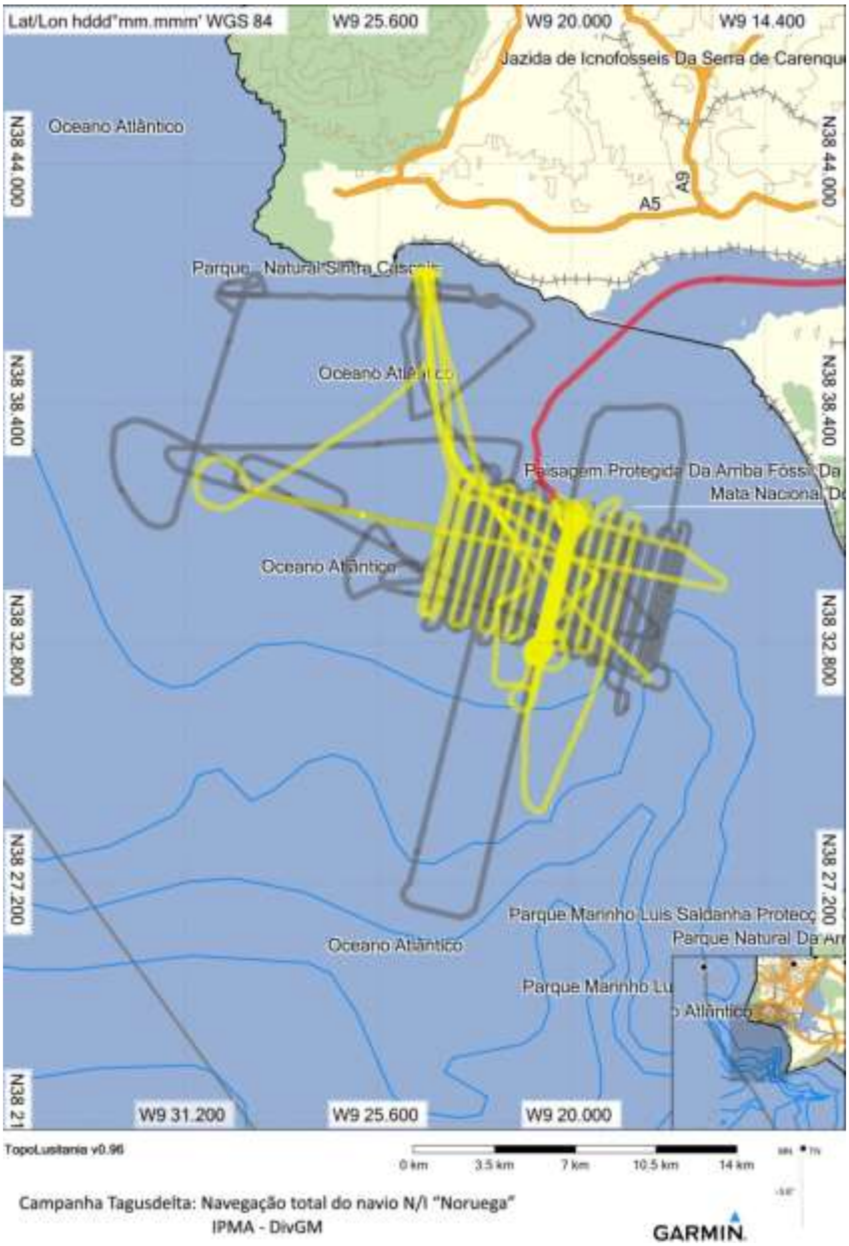



Figure 8 - Total navigation map covered by the R/V Noruega during the TAGUSDELTA 2013 cruise.

## 4.2 2D seismic reflection navigation maps

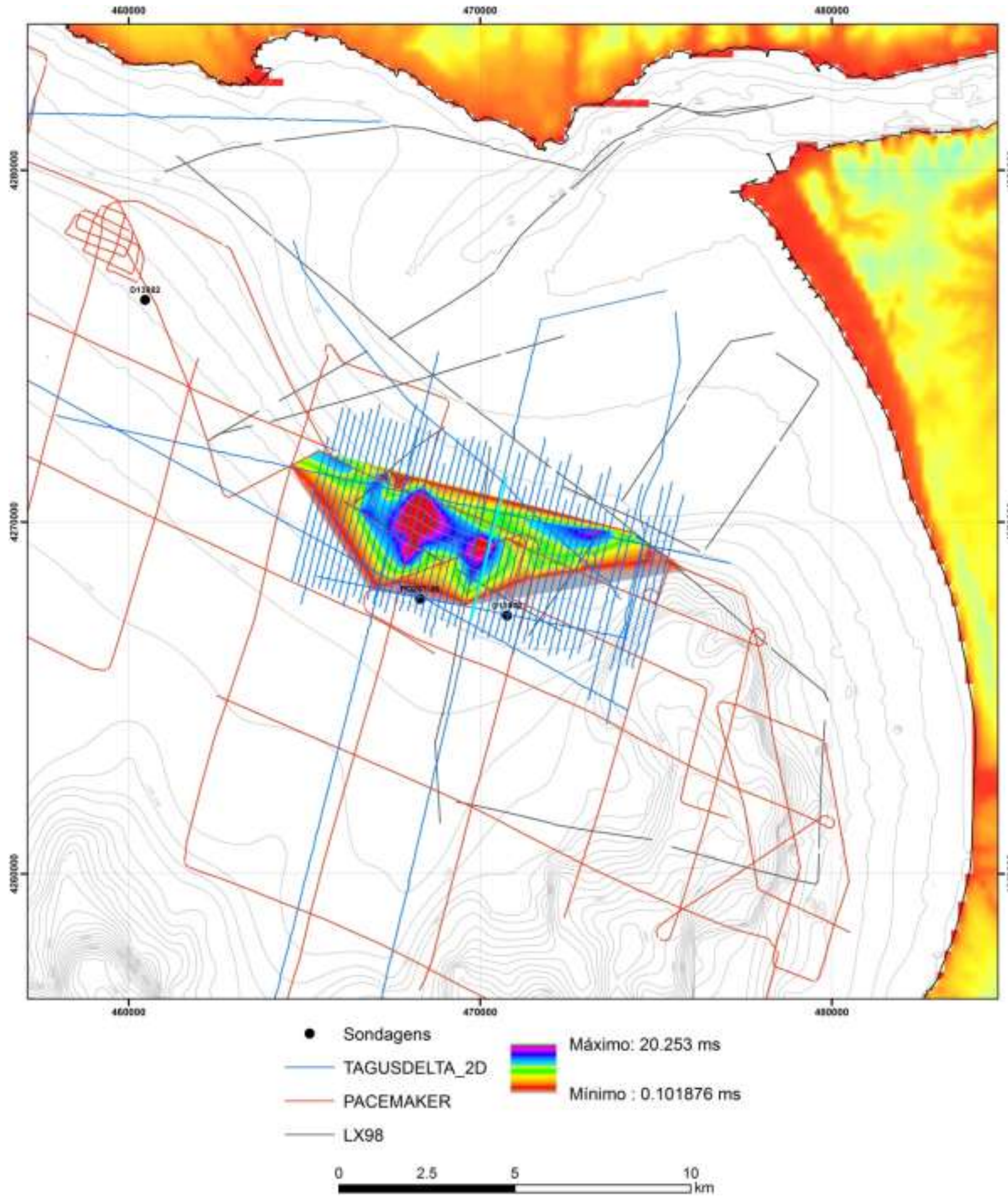



Figure 9 - Map of the total 2D multichannel seismic lines acquired during the TAGUSDELTA 2013 cruise. Isobaths show the Tagus landslide area interpreted from previous data.

## 4.3 3D seismic reflection navigation map

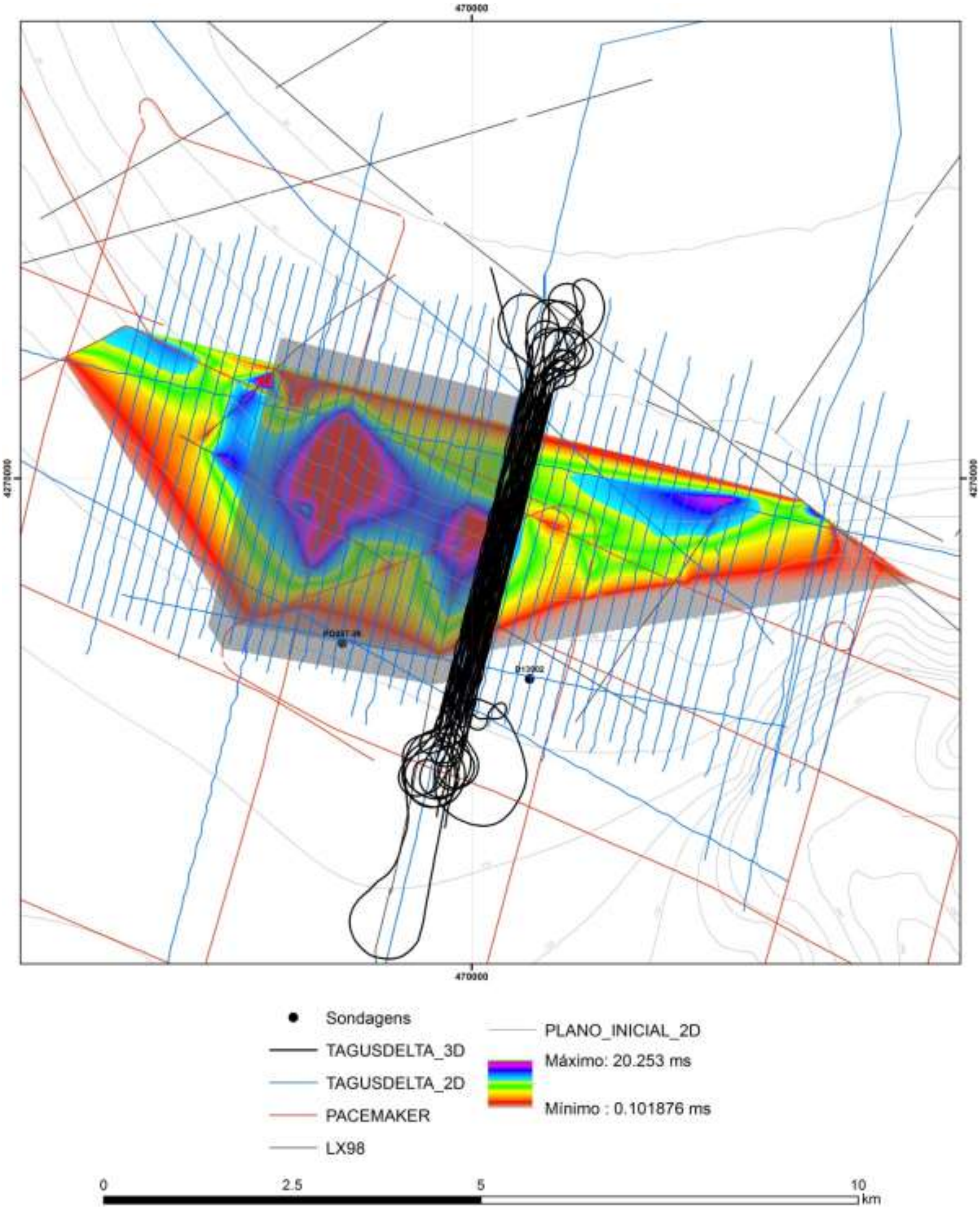



Figure 10 - Map of the acquired 3D seismic during the TAGUSDELTA 2013 cruise.

# 5 Examples of the seismic lines

Examples of brute stacks produced on board with the software RadEx Pro Plus during the TAGUSDELTA 2013 survey are shown in the Figure 11, Figure 12 and Figure 13.

A signal penetration of around 250 m below the seabed was achieved in the investigated area. Horizontal and vertical resolution was approximately 2 m and 0.3 m respectively. The accuracy of reflector depths is expected to be valid within 1 meter.

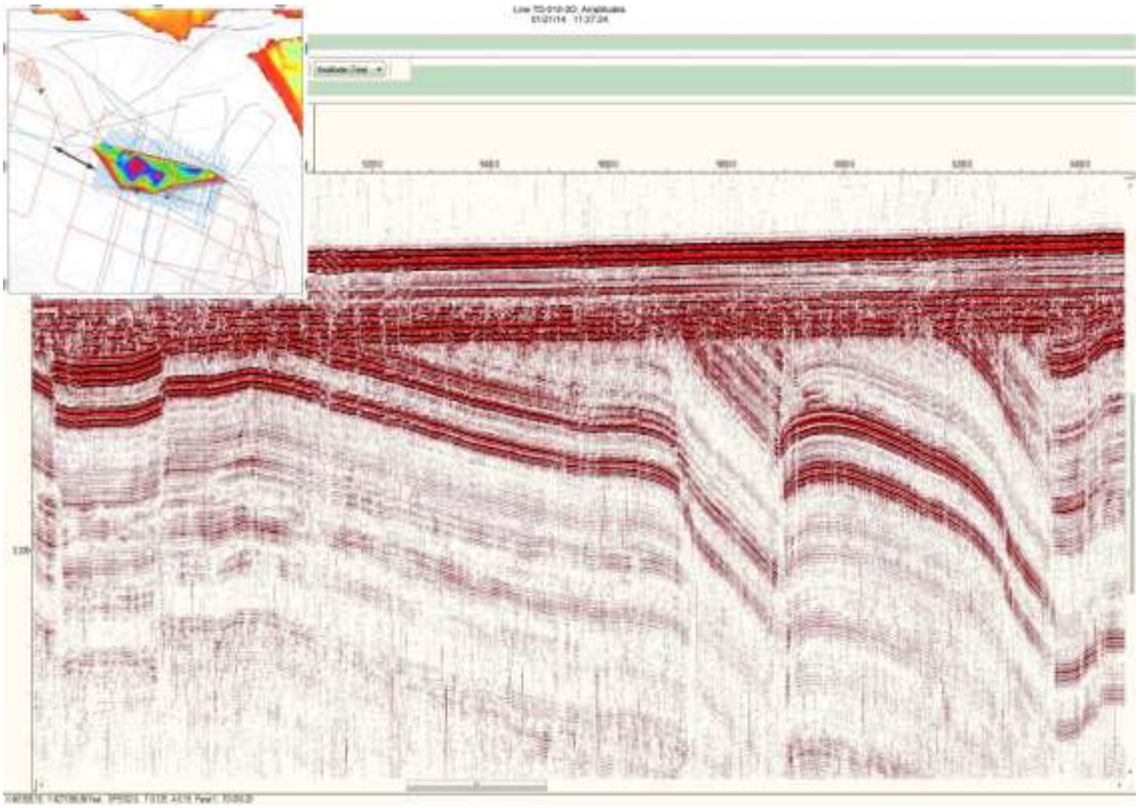


**Figure 11 - TAGUSDELTA 2013 multichannel seismic line showing faulting on possible Mesozoic strata and Miocene unconformity.**

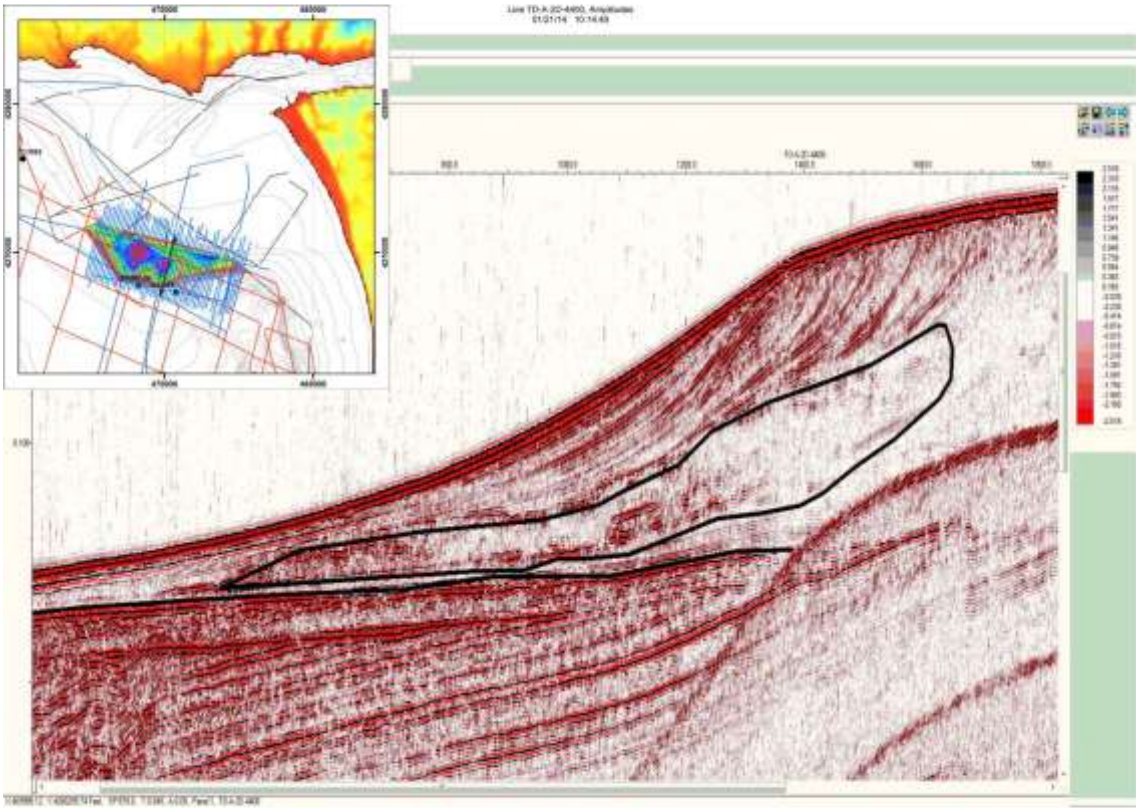


**Figure 12 - TAGUSDELTA 2013 multichannel seismic line showing the main Tagus landslide.**

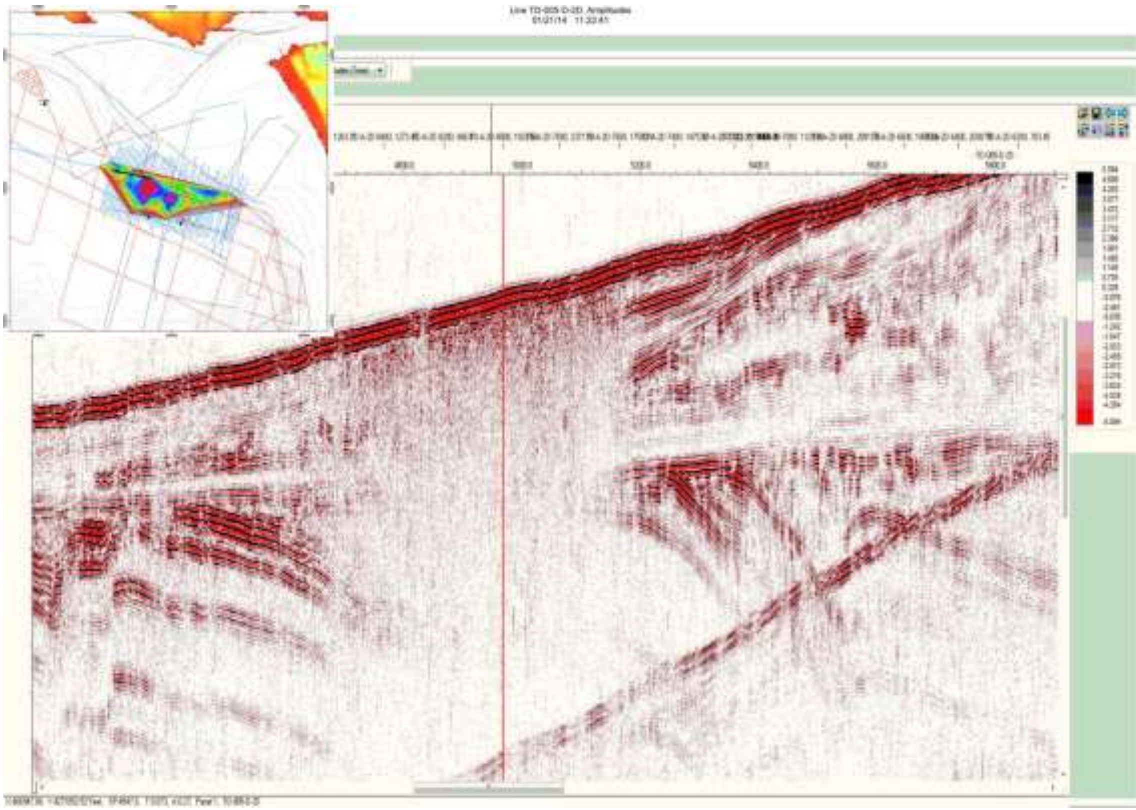


**Figure 13 - TAGUSDELTA 2013 multichannel seismic line showing the superficial gas accumulation.**

# 6 Vessel

The fishery research vessel Noruega (Figure 14 and Table 6) from IPMA was used to carry out the TAGUSDELTA 2013 survey cruise. Mobilization of the vessel was performed at Rocha Conde de Óbidos wharf. 2 Outriggers of 12m specifically done for this purpose were mounted on each side of the vessel to tow the streamers further apart from the vessel wake


Figure 14 - R/V Noruega vessel with outriggers mounted.

Table 6 – R/V Noruega vessel main technical details.

| | |
|---|---|
| Vessel type | Fishery research |
| Length | 47 m |
| Draught | 4.5 m |
| Gross tonnage | 950 tons |
| Beam | 10 m |
| Service speed | 9 knots |
| Endurance | 15 days |
| Accommodation | 21 |
| IMO | 7704992 |
| MMSI | 263601000 |
| Callsign | CSDJ |

# 7 Acquisition methods

## 7.1 Datum and co-ordinate system

Co-ordinates for locations are given according to WGS84, UTM Zone 29N.

All depths are given in relation to the hydrographic zero that locally is placed 2.08m below the cartographic mean sea level.

Ellipsoid : WGS84

Projection : UTM (north)

Zone : 29

Central meridian (C.M.) : 9° W

## 7.2 Navigation and positioning

The principal elements of the aquisition system set up for this campaign are enumerated in the Table 7 and their respective connection scheme is illustrated in Figure 15.

**Table 7 - Main elements of the navigation system**

| Equipment / Function | Model, Manufacturer | Observations |
|---|---|---|
| GPS, primary vessel positioning | Starpack, Furgro | Types of coordinates received: HP/XP, G2 and GNSS. Recorded coordinates: XP and GNSS |
| GPS, , pulse per second (PPS) for data synchronization | Ublocks box | --- |
| ATTU, Accurate Time Tagging Unit | Eiva | --- |
| Ship gyro | --- | It was used the cable that carries the gyro signal to the ship meteorological station |
| Navigation software | Navipac, Eiva | Running on a desktop PC |
| AIS GPS, positioning of the streamer buoys | --- | 4 units, 3 used at the same time |

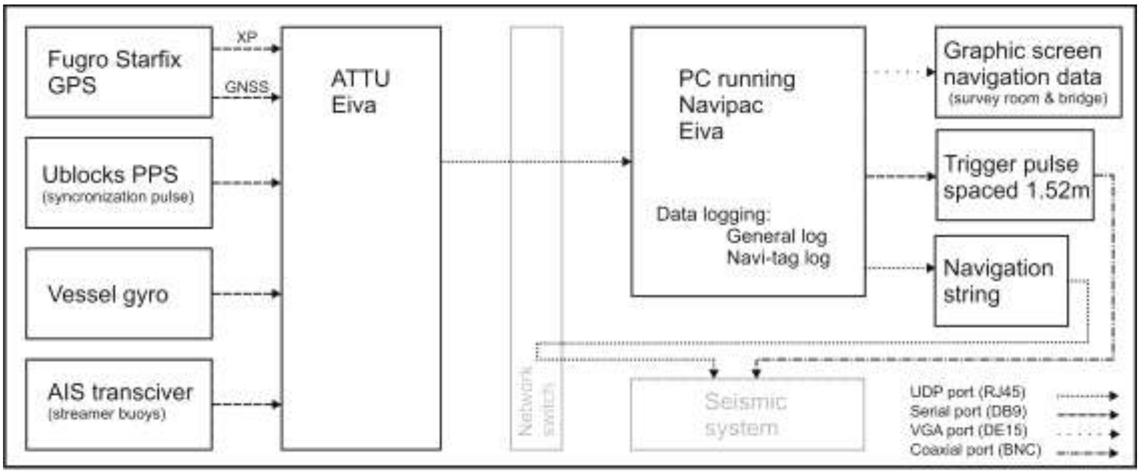



Figure 15 - Implemented navigation interconnection scheme.

The primary vessel surface positioning was centered on Fugro Starfix using XP/HP & G2 service based on ESAT satellite. SkyFix-XP is a GPS positioning system that is based on clock and orbit corrections supplied by NASA's Jet Propulsion Laboratory (JPL). SkyFix-XP is a Precise Point Positioning (PPP) technology, which distinguishes itself from the traditional differential approach as satellite errors are not lumped together but estimated per source, per satellite; it is also known as a 'State Space solution'. The GPS clock and orbit corrections are computed independently, free of ionospheric and tropospheric effects. The performance of Fugro Starfix is 10 cm accuracy in horizontal and 20 cm in vertical domain. Two sets of coordinates were recorded, the ones from the XP servide and the autonomous uncorrected (GNSS) ones.

The Fugro GPS antenna was mounted above the survey room at a position shifted 2.82 m to the port side relative to the longitudinal axis of the vessel, 16.83 m from the stern rail (sparker tow point) and at 10.47 m (estimated) above the waterline. The corrections in the 3 axes (offsets) introduced in the navigation program (Navipac) to transport the coordinates from the GPS antenna to the Sparker tow point (Navipac) were:-2.82 m in X, 16.83 m in Y and 0 m in Z.

The navigation computation was done by EIVA Navipac software and the system considered 4 input sources, namely: 1) Positioning of the vessel with GPS Starfix Fugro, 2) Pulse per Second (PPS) box of the Ublocks for GPS data time synchronization, 3) Gyro data from vessel and 4) positioning during the 3D data acquisition of the streamers buoys with GPS Automatic Identification System (AIS) (Figure 15 and Figure 15). All these data sources were connected by serial ports to an Accurate Time Tagging Unit (ATTU) from EIVA where the data are marked with a time identifier and exported by an User Datagram Protocol (UDP) port to Navipac navigation software.

The navigation data was recorded using the 3 formats of the Navipac logging tool (general, XYZ ASCII and the custom format) and also the Navi-tag log. Through Navipac was also exported information from 3 sources, namely: 1) A costumed navigation phrase (string ascii) with the essential navigation information for positioning the seismic data, sent by UDP to the seismic acquisition recording software (Geometrix Turbo-Marine)., 2) a trigger pulse spaced in time (1.52 m) and 3) Navigation information (through Navipac Helmsmans display) used to control the ship navigation in the bridge and in the survey room.

Figure 16 - Navigation hardware setup.

### 7.2.1 Main navigation problems and implemented or proposed solutions

The main navigation problems encountered were related with Navipac event generation both in time and space and with the AIS data frequency, stability and integration into the Navipac system. This problems lead to 1) Missing coordinates within the seismic positioning files, 2) Inconsistent event numbering, 3) The use of a trigger signal spaced in time, instead of being in space, 4) A lower frequency than the expect of the streamer buoys (AIS) positioning information, 5) Lost of many AIS data to instability of the AIS antennas and 6) Additional error in the time synchronization between the AIS data and the other navigation data.

#### *7.2.1.1 Frequency of the AIS data transmission*

It was expected a 2 seconds (0.5 Hz) transmission rate of the GPS signal in the AIS used for positioning the towed buoys. However, due to unexpected hardware limitations of the used AIS antennas only a 30 seconds transmission rate was possible.

#### *7.2.1.2 Integration of the AIS data in the navigation system*

The used version of Navipac does not decode AIS messages of type 18 (type used by our AIS's) and only writes into the logs the decrypted messages. We tried to solve this problem by connecting the AIS transceiver to laptop PC. The PC decoded and filtered the relevant AIS messages, that were them sent as a NMEA sentence to the Navipac through de ATTU. The Navipac was configured to receive and record this information as if they were data from a GPS. However, although it was possible to visualize the data received on the port configured for this purpose in Navipac, the data was not written to the logs. As a contingency solution, the AIS data were recorded on the PC that was being used for its decoding. The relationship between these data and other navigation data can be done through the date/time info.

#### *7.2.1.3 Stability of the AIS transponder signal*

Sometimes shortly after deployment of the streamer buoys equipped with AIS's some of the 3 AIS signals failed. It was found that to obviate this problem it was necessary to turn on the transponders about 10 or 15 minutes before its deployment. During this period and the following deployment the equipment the equipment should be stable and with a clear view of the sky.

#### *7.2.1.4 Regularity of the navigation string generated by the Navipac*

The Navipac was supposedly configured to generate events at each second, with the event generation starting and ending with the beginning and ending of the seismic lines. For each event the navigation string generated by the Navipac to positioning the seismic data should be sent to the seismic acquisition software. However, it happen systematical faults In the generation of that navigation string. Typically groups of 2 or 3 messages were lost at more or less regular intervals. Moreover, the number of generated events was not regular, and in some cases the event numbering was made in a decreasing order. This problem was not solved, so all the seismic data positioning files have groups of traces without the corresponding coordinates pairs.

The coordinate pairs missing in the seismic positioning files, were subsequently generated by linear interpolation. For this purpose it was developed by Marcos Rosa computer program that starting from the navigation files generated by the seismic system interpolates the missing coordinate pairs and produces a new navigation file. Note that while this program solve the problem of lack of coordinates does not solve the inconsistencies detected in the numbering of the events.

#### *7.2.1.5 Regularity and signal characteristics of the trigger in space generated by the Navipac*

Several problems were found during the attempt to use the Navipac to generate a trigger signal with a regular spacing of 1.52m. Namely, problems with the signal voltage level, its duration and its irregularity.

It was found that the trigger signal generated by the Navipac had a voltage substantially higher than the typical 5V. To avoid exposing the geodes and the PPS to what could be an overvoltage trigger signal, it was decided to make the signal pass through the trigger box that would work as a filter to such an overvoltage signal.

The voltage peak generated by the Navipac trigger signal was very short in time (it was really a peak and not a square wave has expected). Although apparently the signal duration could be configured, the interface to do it was not working has expected.

The more serious problem of the trigger signal was its irregularity. Similarly to what append with the time generated events associate with the exporting of the navigation message, once more the events in space (trigger in space) were not regularly generated. Once more we had alternating periods when the trigger signal in space seemed to be well generated and other periods when the signal was not generated. Since that this problem was not solved, the trigger in space was never used. Alternatively it was used a trigger in time with a period of 900ms, generated by the trigger box.

## 7.3 Multichannel Seismics Reflection Acquisition system

The principal elements of the very high resolution multichannel seismic acquisition system set up for this campaign are enumerated in the Table 8 and their respective connection scheme is illustrated in Figure 17.

Table 8 – Main elements of the very high resolution multichannel seismic acquisition system

| Equipment / Function | Model, Manufacturer | Observations |
|---|---|---|
| High voltage pulsed power supply (PPS) | Geo Spark 16kJ PPS; Geo Marine Survey Systems | Operated at 2000J |
| Seismic source, Sparker | Geo-Source 800, Marine Multi-Tip Sparker System; Geo Marine Survey Systems | Operated with the 800 tips active, at 2,5J per tip |
| Seismic receiver, Streamer | Geo-Sense Ultra hi-res multi-channel streamers, Geo Marine Survey Systems | 2 streamers with 24 channels each, 3 AQ 2000 per group, group spacing of 3,125m |
| Analogue to digital signal conversion (ADC ) | Geodes, Geometrics | 2 units |
| Seismic acquisition software (ADC controle and data saving) | Seismodule controller, Geometrix TurboMarine Acquisition software | Beta release |
| Trigger signal generation | Triggerbox, Geo Marine Survey Systems | Trigger spaced in time, 900ms |

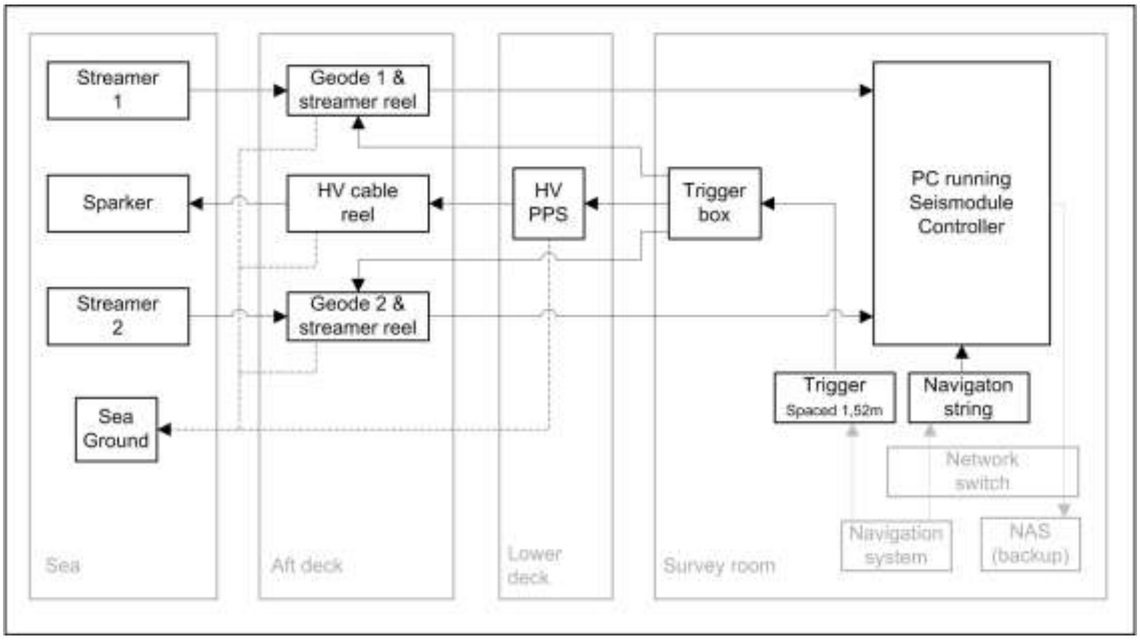



Figure 17 - Implemented seismic acquisition system interconnection scheme.

The seismic source used for the acquisition of the multichannel seismic was the GEO-SPARKER 800 (Figure 18). This seismic source creates a sound pulse by discharging an electric charge close to the water surface and has a core frequency between 1200-1500 Hz. The sparker was operated at an output of 2000 Joules per shot at a shot rate of 0.9 shot per second (with exception of the 2D lines 5 and 5A were a trigger rate of 3s was used).

The sparker was always operated with its 800 tips active (2.5 Joules per tip). The deployment in the water and recovery was made via the ship stern access ramp. The sparker source was towed in alignment with the longitudinal axis of the ship spaced about 30 meters from the stern line. A sea anchor (drogue) was fixed to the sparker stern to allow an easier release from the vortices created by the vessel propulsion.

**Figure 18 - GEO-SPARKER 800 seismic source.**

The Geo-Source 800 (Figure 18) was used with the Geo-Spark 16 kJ pulsed power supply (PPS) using the patented 'Preserving Electrode Mode'. This mode uses a negative electric discharge pulse instead of a positive pulse. Please note that this negative pulse is not the same as the simple reversal of the positive polarity of a 'standard' power supply.

Two 24 channels Geo-Sense multi-channel streamer (GMSS) with 3,125 m group spacing with 3 AQ 2000 per group were used as receivers. The streamers were towed from a 12m long outriggers mounted on each side of the vessel (Figure 19). For the 2D acquisition the streamers were used one at each time, with exception of the lines 5 and 5A were both streamers were used at the same time. Initially it was used the starboard side streamer for the 2D acquisition and from the line 5A onward (03:12:2013, 22:10) it was used the port side streamer. The streamers were towed at 32 m from the vessel stern by 12 m long arms (outriggers) mounted to starboard and port sides near the ship stern (Figure 19). Although the two streamers had a different number of calibration weights, it was considered that both passed the calibration tests. So it was decided not to change the number and position of the streamers calibration weights. Given the good performance of the streamers in water during the 2D acquisition the head buoys were not necessary and only a tail buoy was used. In the 2D seismic acquisition the two streamers were used but usually one at a time, with the exception of the 2D lines 5 and 5A were it was tested the use of the 2 streamers at the same time.

The seismic signal digitalization and recording was made using 1 (or 2 for the 3D acquisition) Geodes of 24 channel integrated in the streamer reels and connected through a LAN deck lead to the Geometrix TurboMarine Acquisition software (Beta realease) running in a Lenovo Thinkpad T530 laptop (Figure 17).

**Figure 19 - The 2D streamer setup.**

### 7.3.1 2D Multichannel seismics acquisition geometry

The seismic system geometry adopted during the 2D data acquisition is schematized in the Figure 20. The indicated across-track separation (along the X axis) between the source and receiver was estimated from the analysis of the time of arrival of the direct wave

The relevant distances considered to process the seismic 2D lines according with the Promax axis convention are: Sou-Rec X = +2m; Sou-RecPORT Y = +13.5m and Sou-RecSTBD =-13.5m.

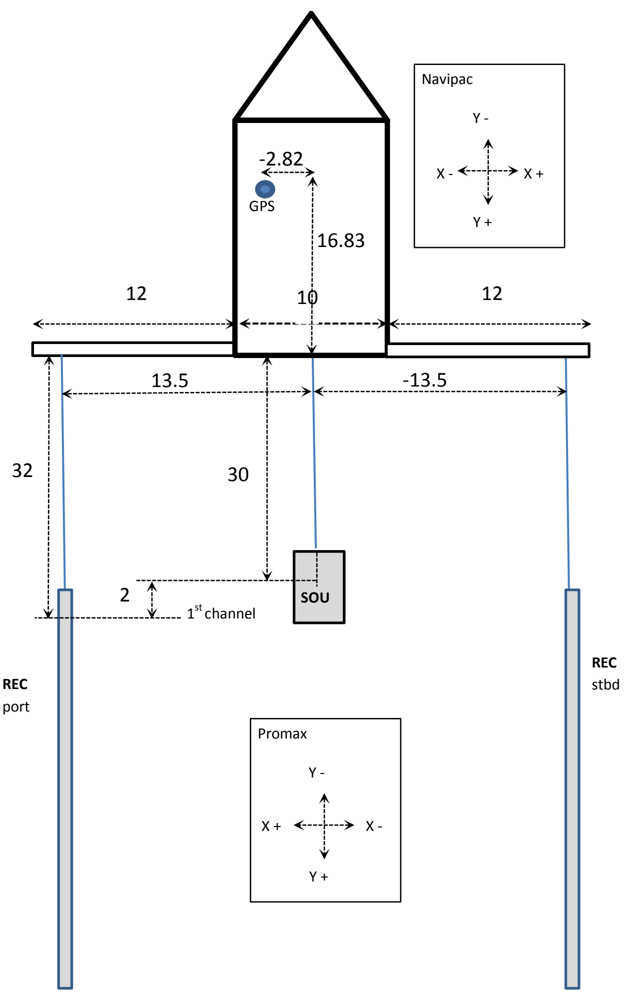



**Figure 20 – Scheme of the geometry set up used during the 2D acquisition. Distances in meters.**

### 7.3.2 3D Multichannel seismic acquisition geometry

Some of the equipment used in the implemented 3D acquisition system didn't have the same technical and operational characteristics of the ones considered in the conceptual set up describe in the Tagusdelta project (Figure 21). Due to those differences the implemented set up geometry (Figure 22) is somewhat different from the initial conceptual one.

In the implemented geometry for 3D data acquisition the two streamers were set up in a "V" shape. The "V" shape geometry was achieved by linking the two streamers at the same tail buoy by a weak link which defines the vertex of the "V" (Figure 24) and using in each streamer front a floating buoy port type (Figure 25).

The weak link was implemented for safety reasons. If the structure was exposed to an unexpected pulling force, caused for example by a fishing gear (as occurred in the first deployment test), the weak link breaks first safeguarding the outriggers.

The port buoys differ from normal ones by having a pannel (stainless steel plate) welded to a submerged structure and are mounted at an angle of about 45º (variable 0-90º) with the streamer (Figure 25). The force applied by the water displacement on the buoy panels tends to hold the gates open and allows the maintenance of the "V" shape geometry of the streamer's, as the ports used in fishing nets that tend to keep their net mouth open. To control the angle of aperture of the port buoys it was used a cable attached to buoy frontal eyelet and running through the eyelet of the streamer Kellum grip to the ship stern. Adjusting the tension on this cable, the buoy angle of aperture could be managed (Figure 26).

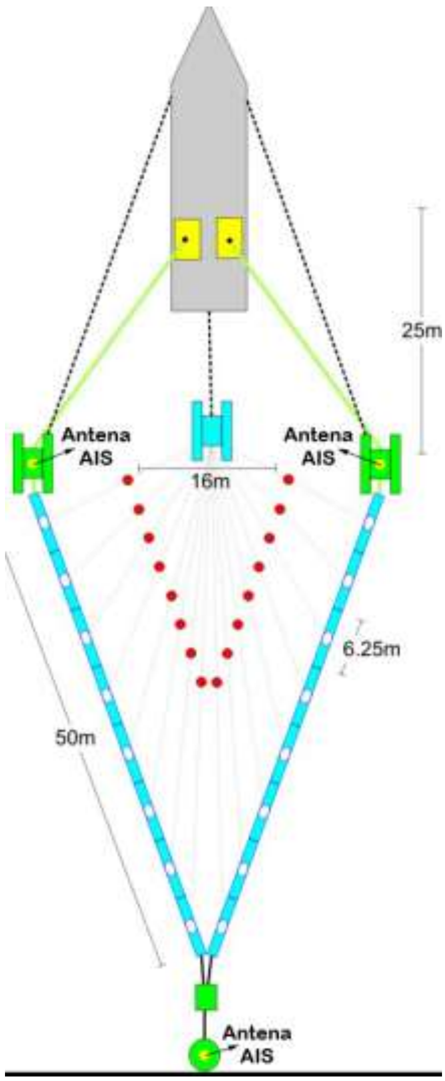



Figure 21 - The conceptual 3D setup.

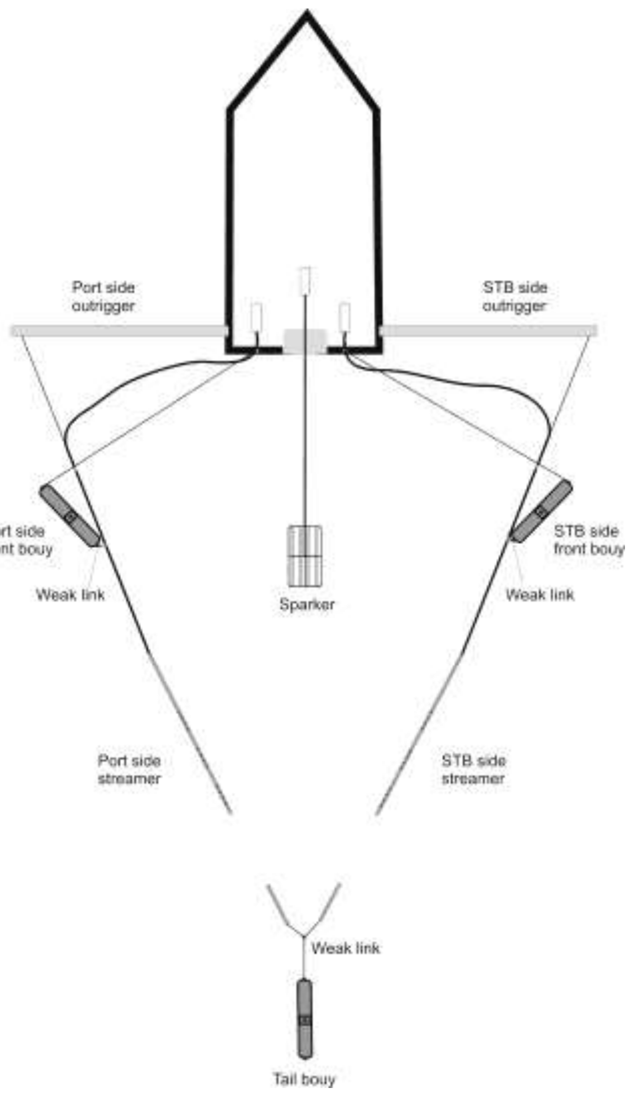



**Figure 22 - Schema of implemented 3D geometry data acquisition setup.**

**Figure 23 - The 3D towed setup. In the foreground we can see the two streamers towing buoys, which are also used to control the geometry opening. In background we can see the tail buoy where the two streamers are connected. At middle is placed the sparker source.**

Figure 24 - The weak link joining the 2 streamers.

Figure 25 - Deploy of a floating port buoy with AIS antenna at top.

Figure 26 - Example of the management of the streamer and the port buoy opening angle.

### 7.3.3 Main seismic acquisition problems and implemented or proposed solutions

In general the implemented set up for the acquisition of both the 2D and the 3D seismic data worked properly. The main problems encountered were related with the entanglement of fishing gear into the seismic equipment, the control of the streamer port buoys and with the positioning of the brutestacks produced on board. The problems encountered lead to: 1) Inconsistencies in the positioning of the on board produced brutestacks, 2) Difficulties in controlling the angle of aperture of the gate buoys, 3) Breaking of the starboard outrigger and 4) loss of one streamer buoy.

#### *7.3.3.1 Georeferencing of the on board produced brutestacks for the 2D data*

Because of the already described navigation problems that lead to a systematic periodical missing of coordinate pairs for some seismic traces, it was decided to produce the on board brutestacks considering only a nominal geometry, without taking into account any real coordinates. The corrected navigation files, already including the interpolated initially missing coordinates, were matched with the seismic data only during the importation of the brutestacks SEG-Y files into the seismic interpretation software. Therefore, the CMP stack during the brutestack processing should have been done assuming full fold. Since that the triggering was done in time, each 900ms (and not in space), the real fold varied according with the vessel speed. Consequently, the full fold assumption lead to an error in the number of seismic traces generated during the CMP stack. Moreover the errors in the positioning of the seismic traces correspondent to the CMP are cumulative along the line. Thus if the data acquisition is done with a vessel velocity significantly different from the ideal velocity for the full fold coverage, a long seismic line processed assuming full fold can easily end up with a position error of several hundreds of meters. Because of this inappropriate methodology the final brutestack files have important positioning inconsistencies that result in large misties that difficult the join interpretation of the dataset.

#### *7.3.3.2 Sparker avoidance of floating fishing gear during 2D data acquisition*

The square form of the sparker structure makes of its front side of the frame (tow point side) an easy point for catching any obstacles that arise, including fishing gear. In an attempt to minimize this issue a rope structure was built up to deflect the potential upcoming obstacles. This triangular structure is made with two cables stretched between each ends of the front side of the sparker frame and the point of attachment of the safety cables into the tow cable. This setup was tested during the cruise and yield good results.

#### *7.3.3.3 Difficulty in controlling the opening angle of the gates buoys*

The pulling force exerted by the port buoys, even at low speeds, makes it difficult to control its aperture angle (angle between the port buoys and the streamer). This operation was even more complicated when given the high tension on the cable the angle exceeds the 90˚. In this situation the port acts in a reverse way, tending to close to the opposite direction, and its difficult to bring it to its normal position again. To avoid this inversion, it is proposed the use of a fixed cable between the gate buoy head eyelet and the streamer Kellum grip. This cable should have a length shorter than the one required to the angle between the streamer and the port exceeds 90˚. The safety rope that allows controlling the port aperture from the ship should go thru the streamer kellum grip eyelet and attach to a loophole in this fixed rope (e.g.

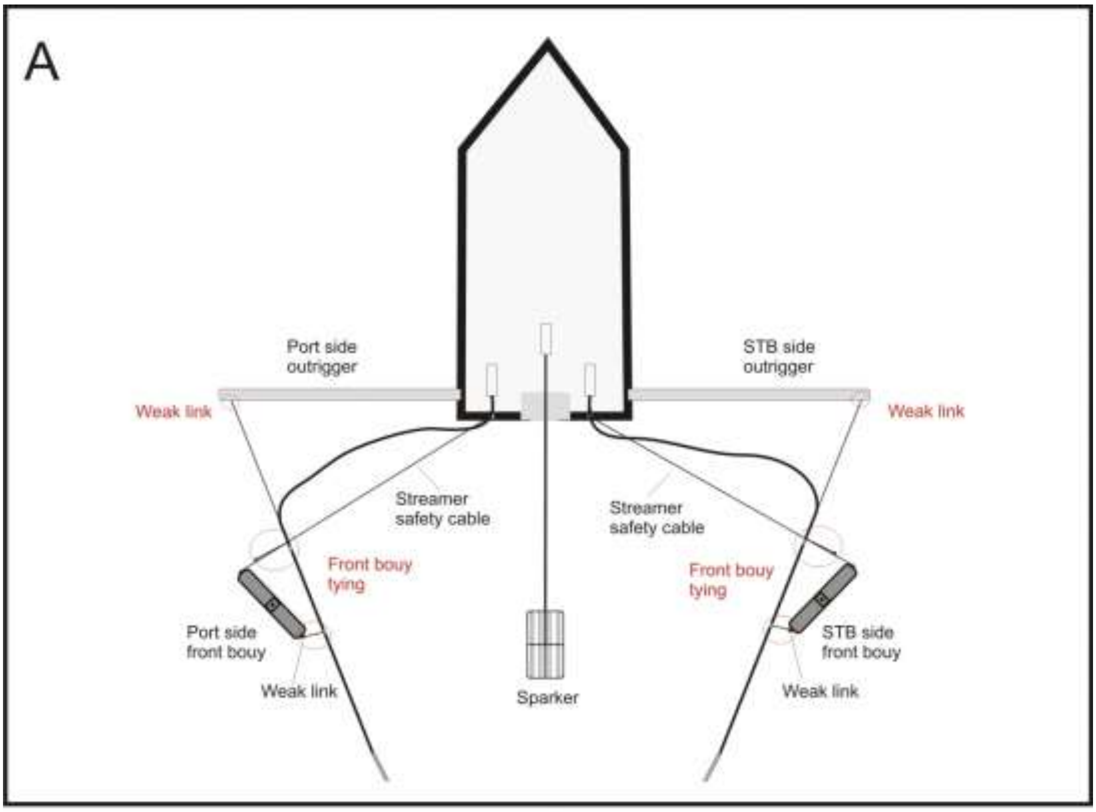
use the alpine butterfly knot to make the loophole) (Figure 27B). This proposed set up was not tested.

#### *7.3.3.4 Minimization of losses and damage to equipment caused by fishing gear*

It was known that the planed operation area for the cruise was an area usually used by fishermen for the installation of fishing gear. So the risk of having problems with fishing gear entangled into the seismic equipment was considerable. Since that the streamer buoys are the ones more exposed to this risk, it was decided that to minimize the risk the connection between the streamer and the buoys should be made using swivels that would act as weak link, breaking off wen subjected to a strong tension. However, the used swivels were too strong, and when a fishing gear get couth by a streamer buoy the starboard outrigger start to bend and its hinges breakdown before the swivel disruption. After the outrigger breaking on it was decided to use a different type of weak link.

After the starboard outrigger breaking on 03-12-2013, the new type of weak link that started to be used was hand-made using several turns of fishing net string (Figure 24). This new type of weak link prove to work properly, since that when the equipment was once more entangled with fishing gear, the weak link broke leading to the loss of one streamer buoy but the outrigger was preserved intact.

To prevent future losses of buoys when the weak link is broken it is proposed the used off a weak link in the connection of the streamer to the outrigger, instead of the connection between the buoy and the streamer (although this may also keep the weak link). If the weak link is broken the streamer and the buoys can be both recovered using the safety rope, which is also the rope used to regulate the opening of the gate buoys (Figure 27). This proposed set up was not tested.



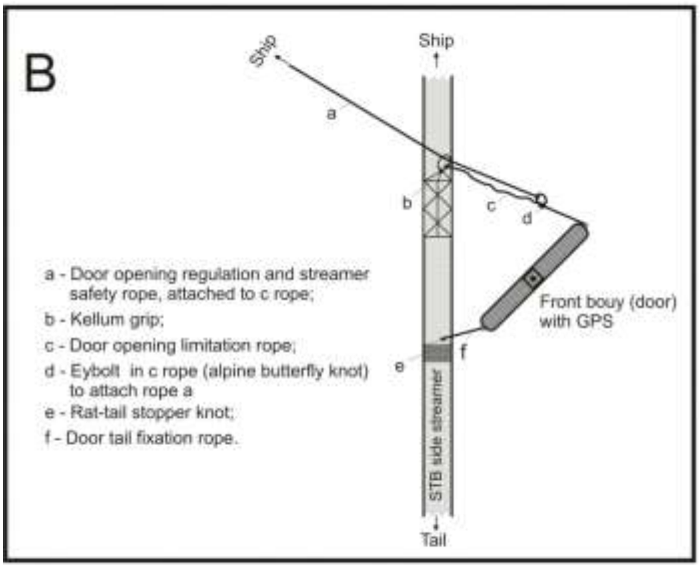




**Figure 27 - A- Schematic configuration of the seismic system geometry set up for the acquisition of 3D data with the proposed changes identified in red. B-Detail scheme of the proposed set up for fixing the port buoys to the streamer.**

**APENDIX 1**

TAGUSDELTA 2013 cruise seismic profiles notes

| Survey<br>Location<br>System | TAGUSDELTA<br>Inner cont Shelf – Tagus prodelta<br>Geo-sense 24 MCS+6kJ PPS | Client<br>Vessel<br>Operator | IPMA<br>RV Noruega<br>H Duarte, P Brito, M. Mouga | Start date<br>End date<br>Site nr. |
|---|---|---|---|---|

| TYPE | Ex. Ord. | File Name | Date | Start | End | Trig. Int. (ms) | En.(J) | tip ar. | n. tips | J / tip | Rec len (ms) | Spl. Int. (ms) | FFIDs Min | FFIDs Max | FFIDs Total | Line lgth (m) | speed (knots) | Wave hght – kn | Nav log QC | Nav log Missed shots(%) | QC MT F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Test | 1 | TD-Test01 | 03-12-13 | 08:13 | 08:20 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 25001 | 25497 | 497 | 798.4305 | 3.5 | 1 | | | |
| Survey | 2 | TD-004-2D | 03-12-13 | 09:07 | 10:41 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 16301 | 6301 | 10122.56 | 3.5 | 0.5 | | *10 | |
| Survey | 3 | TD-003-2D | 03-12-13 | 11:31 | 14:19 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 21182 | 11182 | 17450.63 | 3.4 | 0.5 | | 2 | |
| Survey | 4 | TD-002-2D | 03-12-13 | 14:50 | | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 21065 | 11065 | 17268.04 | 3.4 | 0.5 | | | |
| Test | 5 | Test02 | 03-12-13 | 20:45 | | 3s | 2000 | all | 800 | 2.5 | 200 | 0.25 | 10001 | - | | 0 | 3.4 | 0.5 | | | |
| Survey | 6 | TD-005-2D | 03-12-13 | 21:00 | | 3s | 2000 | all | 800 | 2.5 | 200 | 0.25 | 10001 | - | | 0 | 3.4 | 0.5 | | | |
| Survey | 7 | TD-005A-2D | 03-12-13 | 22:10 | 23:29 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 16557 | 6557 | 10232.85 | 3.4 | 0.5 | | | |
| Survey | 8 | TD-006-2D | 04-12-13 | 03:47 | 04:00 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 16617 | 6617 | 10630.21 | 3.5 | 0.5 | | 1 | |
| Survey | 9 | TD-006B-2D | 04-12-13 | 04:08 | 05:31 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 15589 | 5589 | 8978.729 | 3.5 | 0.5 | | 1 | |
| Survey | 10 | TD-007-2D | 04-12-13 | 05:45 | 07:42 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 17751 | 7751 | 14230.84 | 4 | 0.5 | | 3 | |
| Survey | 11 | TD-008-2D | 04-12-13 | 15:27 | 17:02 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 16414 | 6414 | 10304.09 | 3.5 | 0.5 | | | |
| Survey | 12 | TD-009-2D | 04-12-13 | 17:40 | - | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | - | - | 0 | 3.5 | 0.5 | | | |
| Survey | 13 | TD-009A-2D | 04-12-13 | 18:07 | - | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | - | - | 0 | 3.5 | 0.5 | | | |
| Survey | 14 | TD-009A-2D | 04-12-13 | 18:39 | 20:04 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 15656 | 5656 | 9086.364 | 3.5 | 0.5 | | | |
| Survey | 15 | TD-010-2D | 04-12-13 | 21:26 | 00:53 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 23782 | 13782 | 22140.78 | 3.5 | 0.5 | | | |
| Survey | 16 | TD-A-2D+400 | 05-12-13 | 01:17 | 02:00 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 12882 | 2882 | 4629.933 | 3.5 | 0.5 | | | |
| Survey | 17 | TD-A-2D-200 | 05-12-13 | 02:16 | 02:54 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 12560 | 2560 | 4112.64 | 3.5 | 0.5 | | 3 | |
| Survey | 18 | TD-A-2D-800 | 05-12-13 | 03:08 | 03:55 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13119 | 3119 | 5010.674 | 3.5 | 0.5 | | 2 | |
| Survey | 19 | TD-A-2D-1400 | 05-12-13 | 04:12 | 04:28 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 11102 | 1102 | 1770.363 | 3.5 | 0.5 | | | |
| Survey | 20 | TD-A-2D-1400B | 05-12-13 | 04:49 | 04:16 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 11821 | 1821 | 2925.437 | 3.5 | 0.5 | | | |
| Survey | 21 | TD-A-2D-2000 | 05-12-13 | 05:30 | 06:18 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13191 | 3191 | 5126.342 | 3.5 | 0.5 | | 1 | |
| Survey | 22 | TD-A-2D-2600 | 05-12-13 | 06:50 | 07:31 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 12722 | 2722 | 4372.893 | 3.5 | 0.5 | | 2 | |
| Survey | 23 | TD-A-2D-3200 | 05-12-13 | 07:48 | 08:29 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 12763 | 2763 | 4438.76 | 3.5 | 0.5 | | 1 | |
| Survey | 24 | TD-A-2D-3800 | 05-12-13 | 08:42 | 09:21 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 12597 | 2597 | 4172.081 | 3.5 | 0.5 | | | |
| Survey | 25 | TD-A-2D-4400 | 05-12-13 | 09:36 | 10:13 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 12432 | 2432 | 3907.008 | 3.5 | 0.5 | | 3 | |
| Survey | 26 | TD-A-2D-5000 | 05-12-13 | 10:26 | 11:06 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 12643 | 2643 | 4245.98 | 3.5 | 0.5 | | 6 | |
| Survey | 27 | TD-A-2D-5600 | 05-12-13 | 11:16 | 12:07 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13410 | 3410 | 5478.165 | 3.5 | 0.5 | | 6 | |
| Survey | 28 | TD-A-2D-6200 | 05-12-13 | 12:41 | 01:24 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 12805 | 2805 | 4506.233 | 3.5 | 0.5 | | | |
| Survey | 29 | TD-A-2D-6800 | 05-12-13 | 13:46 | 02:32 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13105 | 3105 | 4988.183 | 3.5 | 0.5 | | | |
| Survey | 30 | TD-A-2D-7400 | 05-12-13 | 14:46 | 15:35 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13254 | 3254 | 5227.551 | 3.5 | 0.5 | | | |
| Survey | 31 | TD-A-2D-8000 | 05-12-13 | 15:47 | 16:32 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13002 | 3002 | 4822.713 | 3.5 | 0.5 | | | |
| Survey | 32 | TD-A-2D-8600 | 05-12-13 | 16:59 | 17:46 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13105 | 3105 | 4988.183 | 3.5 | 0.5 | | | |
| Survey | 33 | TD-A-2D-9200 | 05-12-13 | 18:04 | 18:54 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13339 | 3339 | 5364.104 | 3.5 | 0.5 | | | |
| Survey | 34 | TD-A-2D-8400 | 05-12-13 | 19:12 | 20:00 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13106 | 3106 | 4989.789 | 3.5 | 0.5 | | | |
| Survey | 35 | TD-A-2D-7800 | 05-12-13 | 20:19 | 21:14 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13558 | 3558 | 5715.927 | 3.5 | 0.5 | | | |
| Survey | 36 | TD-a-2D-7200 | 05-12-13 | 21:27 | 22:13 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13195 | 3195 | 5132.768 | 3.5 | 0.5 | | | |
| Survey | 37 | TD-A-2D-6600 | 05-12-13 | 22:26 | 11:11 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 12950 | 2950 | 4739.175 | 3.5 | 0.5 | | | |
| Survey | 38 | TD-A-2D-6000 | 05-12-13 | 23:25 | 00:10 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13034 | 3034 | 4874.121 | 3.5 | 0.5 | | | |
| Survey | 39 | TD-A-2D-5400 | 06-12-13 | 12:25 | 01:22 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13773 | 3773 | 6061.325 | 3.5 | 0.5 | | | |
| Survey | 40 | TD-A-2D-4800 | 06-12-13 | 01:33 | 02:24 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13414 | 3414 | 5484.591 | 3.5 | 0.5 | | | |
| Survey | 41 | TD-A-2D-4200 | 06-12-13 | 02:39 | 03:27 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13182 | 3182 | 5111.883 | 3.5 | 0.5 | | | |
| Survey | 42 | TD-A-2D-3600 | 06-12-13 | 03:40 | 04:36 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13731 | 3731 | 5993.852 | 3.5 | 0.5 | | 1 | |
| Survey | 43 | TD-A-2D-3000 | 06-12-13 | 04:50 | 05:45 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13693 | 3693 | 5932.805 | 3.5 | 0.5 | | 1 | |
| Survey | 44 | TD-A-2D_-2400 | 06-12-13 | 06:01 | 06:51 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13298 | 3298 | 5298.237 | 3.5 | 0.5 | | | |
| Survey | 45 | TD-A-2D_-1800 | 06-12-13 | 07:08 | 07:59 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13401 | 3401 | 5463.707 | 3.5 | 0.5 | | | |
| Survey | 46 | TD-A-2D_-1200 | 06-12-13 | 08:09 | 08:56 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13097 | 3097 | 4975.331 | 3.5 | 0.5 | | | |
| Survey | 47 | TD-A-2D_-600 | 06-12-13 | 09:58 | 10:52 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13648 | 3648 | 5860.512 | 3.5 | 0.5 | | | |
| Survey | 48 | TD-A-2D_0 | 06-12-13 | 11:02 | 11:50 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13195 | 3195 | 5132.768 | 3.5 | 0.5 | | | |
| Survey | 49 | TD-A-2D_+600 | 06-12-13 | 12:02 | 12:50 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13027 | 3027 | 4862.876 | 3.5 | 0.5 | | | |
| Survey | 50 | TD-A-2D_+200 | 06-12-13 | 13:07 | 13:55 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13223 | 3223 | 5177.75 | 3.5 | 0.5 | | | |
| Survey | 51 | Teste_3D | 07-12-13 | 00:47 | 00:49 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | - | | 0 | 3.5 | 0.5 | | | |
| Survey | 52 | TD_3D+3680 | 07-12-13 | 00:52 | 01:30 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13442 | 3442 | 5529.573 | 3.5 | 0.5 | | | |
| Survey | 53 | TD-3D+3616 | 07-12-13 | 01:31 | 01:44 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 12963 | 2963 | 4760.06 | 3.5 | 0.5 | | | |
| Survey | 55 | TD-3D+3664 | 07-12-13 | 02:31 | 03:31 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 12964 | 16951 | 3988 | 6406.722 | 3.5 | 0.5 | | | |
| Survey | 56 | TD-3D+3600 | 07-12-13 | 03:31 | 04:25 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 16952 | 20566 | 3615 | 5807.498 | 3.5 | 0.5 | | | |
| Survey | 57 | TD-3D+3648 | 07-12-13 | 04:40 | 05:30 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 20567 | 26222 | 5656 | 9086.364 | 3.5 | 0.5 | | | |
| Survey | 58 | TD-3D+3584 | 07-12-13 | 05:37 | 06:18 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 26223 | 28075 | 1853 | 2976.845 | 3.5 | 0.5 | | | |
| Survey | 59 | TD-3D+3632 | 07-12-13 | 06:23 | 07:20 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 28076 | 32220 | 4145 | 6658.943 | 3.5 | 0.5 | | | |
| Survey | 60 | TD-3D+3568 | 07-12-13 | 07:21 | 08:11 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 32221 | 35659 | 3439 | 5524.754 | 3.5 | 0.5 | | | |
| Survey | 61 | TD-2D-008-D | 07-12-13 | 13:40 | 16:32 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 21400 | 11400 | 18314.1 | 3.5 | 0.5 | | | |
| Survey | 62 | TD-A-2D_-9600 | 07-12-13 | 20:53 | 21:32 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 12557 | 2557 | 4107.821 | 3.5 | 0.5 | | | |
| Survey | 63 | TD-A-2D_-9000 | 07-12-13 | 21:43 | 22:30 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13083 | 3083 | 4952.84 | 3.5 | 0.5 | | | |
| Survey | 64 | TD-A-2D_-9400 | 07-12-13 | 22:47 | 23:34 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13021 | 3021 | 4853.237 | 3.5 | 0.5 | | | |
| Survey | 65 | TD-A-2D_-8800 | 07-12-13 | 23:45 | 00:34 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13254 | 3254 | 5227.551 | 3.5 | 0.5 | | | |
| Survey | 66 | TD-A-2D_-8200 | 08-12-13 | 00:46 | 01:36 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13078 | 3078 | 4944.807 | 3.5 | 0.5 | | | |
| Survey | 67 | TD-A-2D_-7600 | 08-12-13 | 01:48 | 02:38 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13093 | 3093 | 4968.905 | 3.5 | 0.5 | | | |
| Survey | 68 | TD-A-2D_-7000 | 08-12-13 | 02:48 | 03:38 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13292 | 3292 | 5288.598 | 3.5 | 0.5 | | | |
| Survey | 69 | TD-A-2D_-6400 | 08-12-13 | 03:53 | 04:46 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13511 | 3511 | 5640.422 | 3.5 | 0.5 | | | |
| Survey | 70 | TD-A-2D_-5800 | 08-12-13 | 04:57 | 05:43 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13075 | 3075 | 4939.988 | 3.5 | 0.5 | | | |
| Survey | 71 | TD-A-2D_-5200 | 08-12-13 | 05:58 | 06:46 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13200 | 3200 | 5140.8 | 3.5 | 0.5 | | | |
| Survey | 72 | TD-A-2D_-4000 | 08-12-13 | 07:04 | 07:51 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13104 | 3104 | 4986.576 | 3.5 | 0.5 | | | |
| Survey | 73 | TD-A2-D_-3400 | 08-12-13 | 08:03 | 08:52 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13264 | 3264 | 5243.616 | 3.5 | 0.5 | | | |
| Survey | 74 | TD-A2-D_-2800 | 08-12-13 | 09:20 | 10:10 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13328 | 3328 | 5346.432 | 3.5 | 0.5 | | | |
| Survey | 75 | TD-A2-D_-2200 | 08-12-13 | 10:20 | 10:59 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 12531 | 2531 | 4066.052 | 3.5 | 0.5 | | | |
| Survey | 77 | TD-3D+3552 | 08-12-13 | 15:47 | 16:24 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 12416 | 2416 | 3881.304 | 3.5 | 0.5 | | | |
| Survey | 78 | TD-3D+3312 | 08-12-13 | 16:49 | 17:30 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 12417 | 16820 | 4404 | 7075.026 | 3.5 | 0.5 | | | |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Survey | 79 | TD-3D-3536 | 08-12-13 | 17:50 | 18:29 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 16821 | 20754 | 3934 | 6319.971 | 3.5 | 0.5 | | | |
| Survey | 80 | TD-3D-3296 | 08-12-13 | 18:54 | 19:52 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 20755 | 26269 | 5515 | 8859.848 | 3.5 | 0.5 | | | |
| Survey | 81 | TD-3D-3520 | 08-12-13 | 21:17 | 21:57 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 12536 | 2536 | 4074.084 | 3.5 | 0.5 | | | |
| Survey | 82 | TD-3D-3504 | 08-12-13 | 22:22 | 23:01 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 12537 | 16798 | 4262 | 6846.903 | 3.5 | 0.5 | | | |
| Survey | 83 | TD-3D-3488 | 08-12-13 | 23:27 | 00:04 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 16799 | 21010 | 4212 | 6766.578 | 3.5 | 0.5 | | | |
| Survey | 84 | TD-3D-3440 | 09-12-13 | 00:30 | 01:10 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 21011 | 27917 | 6907 | 11096.1 | 3.5 | 0.5 | | | |
| Survey | 85 | TD-3D-3472 | 09-12-13 | 01:10 | 02:20 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | | | | 0 | 0 | 0 | | | |
| Survey | 86 | TD-3D-3472 | 09-12-13 | 02:52 | 03:45 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 10001 | 13487 | 3487 | 5601.866 | 3.5 | 0.5 | | | |
| Survey | 87 | TD-3D-3456 | 09-12-13 | 03:46 | 05:12 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 13488 | 19280 | 10776 | 17311.64 | 3.5 | 0.5 | | | |
| Survey | 88 | TD-3D-3424 | 09-12-13 | 05:13 | 06:27 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 19281 | 24263 | 10169 | 16336.5 | 3.5 | 0.5 | | | |
| Survey | 89 | TD-3D-3408 | 09-12-13 | 06:46 | 07:45 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 24264 | 29449 | 10096 | 16219.22 | 3.5 | 0.5 | | | |
| Survey | 90 | TD-3D-3392 | 09-12-13 | 07:46 | 08:59 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 29450 | 34359 | 8637 | 13875.34 | 3.5 | 0.5 | | | |
| Survey | 91 | TD-3D-3376 | 09-12-13 | 08:59 | 09:55 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 34360 | 38086 | 8076 | 12974.09 | 3.5 | 0.5 | | | |
| Survey | 92 | TD-3D-3360 | 09-12-13 | 10:23 | 11:00 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 38087 | 42435 | 8918 | 14326.77 | 3.5 | 0.5 | | | |
| Survey | 93 | TD-3D-3344 | 09-12-13 | 11:29 | 12:09 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 42436 | 47004 | 9509 | 15276.21 | 3.5 | 0.5 | | | |
| Survey | 94 | TD-3D-3328 | 09-12-13 | 12:45 | 13:24 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 47005 | 51944 | 9617 | 15449.71 | 3.5 | 0.5 | | | |
| Survey | 95 | TD-3D-3280 | 09-12-13 | 13:53 | 14:33 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 51945 | 56621 | 9515 | 15285.85 | 3.5 | 0.5 | | | |
| Survey | 96 | TD-3D-3264 | 09-12-13 | 15:06 | 15:46 | 0.9s | 2000 | all | 800 | 2.5 | 350 | 0.25 | 56622 | 61450 | -56621 | 00961.6 | 3.5 | 0.5 | | | |

# 8 References

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