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CLEARANCE OPERATION OF TEULADA SITE (ITALY): A NOVEL APPROACH FOR SHORT TERM MCM MISSIONS IN SEAFLOOR HARD CONDITIONS

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ABSTRACT

In May 2007, following a request by Italian Navy (ITN), NURC agreed to provide the technology, developed during the port protection studies and 2006 MCM ops. in Baltic sea for Estonian Navy, to survey part of the Capo Teulada firing range (Sardinia Island, Italy), used by NATO Armed Forces.

The goal of the service, fully funded by ITN, was to survey part of the firing range with acoustic, magnetic and optical instruments in order to detect and classify the ordnance laying on the seafloor.

The team operated from CRV Leonardo to produce a detailed acoustic and magnetic map of the area. The positions of the targets of interest have been provided to Italian Navy for further identification and disposal. The activities have demonstrated that the NURC Autonomous Underwater Vehicles (AUVs) Remus type equipped with high frequency side scan sonar can detect and classify targets of the dimensions of unexploded ordnance laying proud on the sea floor. A multiple sonar images technique has also been used to improve the classification performances. However, in some areas, targets that were completely buried or concealed in Posidonia fields wouldn't have been detectable with AUV sonar. To overcome this limitation, INGV supported the NURC team by using a new high definition magnetometer technique to detect and classify buried metal targets. A

proton Overhauser sensor was towed from Leonardo vessel and a magnetometer reference station was set ashore in an appropriate site.

A subset of interesting contacts (acoustic and magnetic) have been identified optically by means of the video camera installed on the ROV (Pluto Plus type by Gaymarine) operated from Leonardo. The positioning accuracy achieved was fully compatible with the reacquisition by ROV and then by divers or mine hunters for future disposal ops. The survey has also produced an accurate map of the Posidonia fields and a detailed bathymetry of the area.

More than 300 contacts have been acquired and more than 200 were classified in less than 15 days.

The success of Teulada operation has convinced ITN to ask NURC for a common development programme with the aim to validate at sea a fully integrated multi-sensor approach (sonar, magnetic and optical) in MCM short term ops. using USV/AUV platforms.

INTRODUCTION

The goal of the service led by NURC was to survey part of the Capo Teulada NATO firing range (see fig. 1). The ITN commissioned this mission in the mainframe of a general agreement between Italian Ministry of Defence and Autonomous Region of Sardinia with the aim to reuse demilitarized territories and waters.

The output was to provide ITN:

- detection, classification and identification of the targets of interest for further removal or disposal;
- a detailed acoustic and magnetic map of the area of interest;
- an accurate map of the Posidonia fields and a detailed bathymetry of the area.

The operation was planned to be conducted within 15 days.

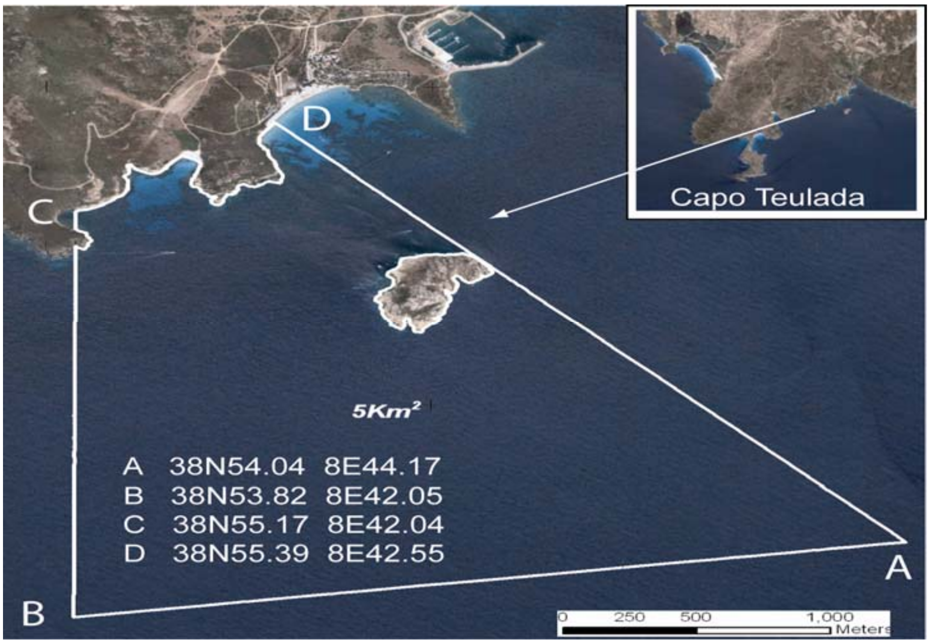


Figure 1 – Area of operation.

The area (4.86 Km²) is characterized by a steep bathymetry near the shore line, Posidonia fields from 10 to 35 m. depth, and sandy sea floor mixed with small rocks from 35 to 60 m.

The expected targets were artillery shells and projectiles. Other type of ordnance that could have been present in the area were naval mines (WWII or exercise type) and high clutter density due to the presence of fishery activities.

To survey that wide area in such a short time, ITN has chosen an integrated team, led by NURC, with the highest capability at sea available at the moment.

In particular:

- ITN Commands (CSSN, Comfordrag, Istituto Idrografico della Marina) providing data from MCM/hydrografic databases and supervision on site during the operation (to support decision about target classification and investigation);
- NURC, providing its recognized capability in MCM studies, research and experiments at sea;
- INGV La Spezia (an Italian Governmental Institute), providing the recent and encouraging results in the field of magnetometric high definition detection technique;
- GAYMARINE (an Italian industry), providing its portable ROV Pluto Plus type, used by ITN MCM Ships (Lerici and Gaeta Class) with great satisfaction.

MISSION

The operation has been concluded in time, from 14 may to 3 june 2007, with only 3 stop days in harbour, due to logistic needs and rough sea condition (one day). The activities at sea has been run in daylight conditions (8-9 hours).

The integrated team, composed by 10 people (6 NURC scientists/engineers, 2 INGV researchers, one Gaymarine technician and an Officer of ITN) operated on board the Coastal Research Vessel (CRV) Leonardo (the NURC Italian flagged ship) equipped with the HiPap ultra short base line and a Dynamic Positioning System.

CRV Leonardo, even if without any MCM sonar system on board for this operation, has confirmed to be one of the most suitable platform for coastal experiments at sea.

The "key mission" equipment for the operation was composed by:

- two AUVs equipped with dual frequency side scan sonar (900 and 1800 kHz) and operated by two workboats;
- two Gateway buoys;
- one towed magnetometer and one reference station (with sensibility at least of 2 nT);
- one ROV equipped with high definition sonar and video camera;
- one Kinematic GPS (KGPS) reference station.

SONAR SURVEY

The acoustic survey was conducted using two AUVs Remus 100 type (in service at NURC) using MarineSonics sidescan sonar. The autonomous vehicles were controlled from CRV Leonardo by means of a Gateway buoy and equipped with dual frequency 900/1800 KHz. Navigation was accomplished by a long-baseline (LBL) underwater transponder system. A KGPS base station was deployed in the area for accurate positioning of LBL transponders and precise navigation of Leonardo. The AUVs were launched from the Leonardo workboat by the NURC team. After each mission the AUVs and buoys were recovered by the workboat and brought onboard Leonardo for data analysis. Two vehicles operated simultaneously in adjacent areas and perform missions of typically 4-5 hours duration. Initially the area was surveyed with the 900 kHz sonar that provides images up to 30 m on each side of the vehicle. To cover the blind spot under the vehicle, the tracks were alternatively spaced at 15 and 45 m. To improve the probability of detection and classification of cylindrical targets two sets of perpendicular tracks have been utilized to cover twice the area (i.e. 200% coverage). The vehicles followed the sea floor at 3 m. altitude. The sonar survey was limited to areas deeper than 5 m. The location of the LBL transponders and the exact shape of each mission were determined on site after examination of the propagation conditions.

After the initial survey, the detected targets have been inspected with a multi aspect survey at 900 or 1800 kHz to improve the classification performance. The choice of the frequency depended on the size of the object to be classified. Larger targets (bigger than 1 m.) were classified by the 900 kHz sonar and smaller targets (less than a meter) at 1800 kHz. The accuracy of target localization (CEP 95%) achievable with the AUV was better than 10 m.

Classification of detected target has been improved by a novel NURC algorithm during off line data analysis. This processing tools available on site have allowed to get data with high confident level of classification, most of them by using 900 kHz side scan sonar images. Data at 1800 kHz have been gathered only in a few samples for very small targets.

A total of 306 objects have been detected and classified acoustically.

MAGNETIC SURVEY

Teulada area is characterized by the presence of Posidonia in proximity to the coast, and by sandy sea bottom in off-shore area. This environmental conditions makes very high the probability of presence of hidden targets, expected very small (also quasi dot-like objects) but with a high magnetic mark. For these reasons, the magnetic exploration method was the best option to integrate optical and acoustical exploration techniques. The effectiveness of magnetic survey to detect microsources is related to three metrological conditions: high density in the magnetic field measurements, sensor nearness to the sea bottom, and high precision in the time reduction of the survey data. On the other hand, INGV projected a typical HD (high definition) geomagnetic survey to environmental purpose. As well known, the gradiometric system effectiveness in microsources targets in a little area is very low, because weighting devices (e.g. gradiometric apparatus) have not nautical characteristics to produce the necessary precision in their underwater navigation. INGV used a single device and the “base station” time reduction procedure (Hill & Mason, 1962). Of course, to have the HD time reduction, it is strictly necessary having a good verify of the space coherency of observatory time variations over the entire survey area.

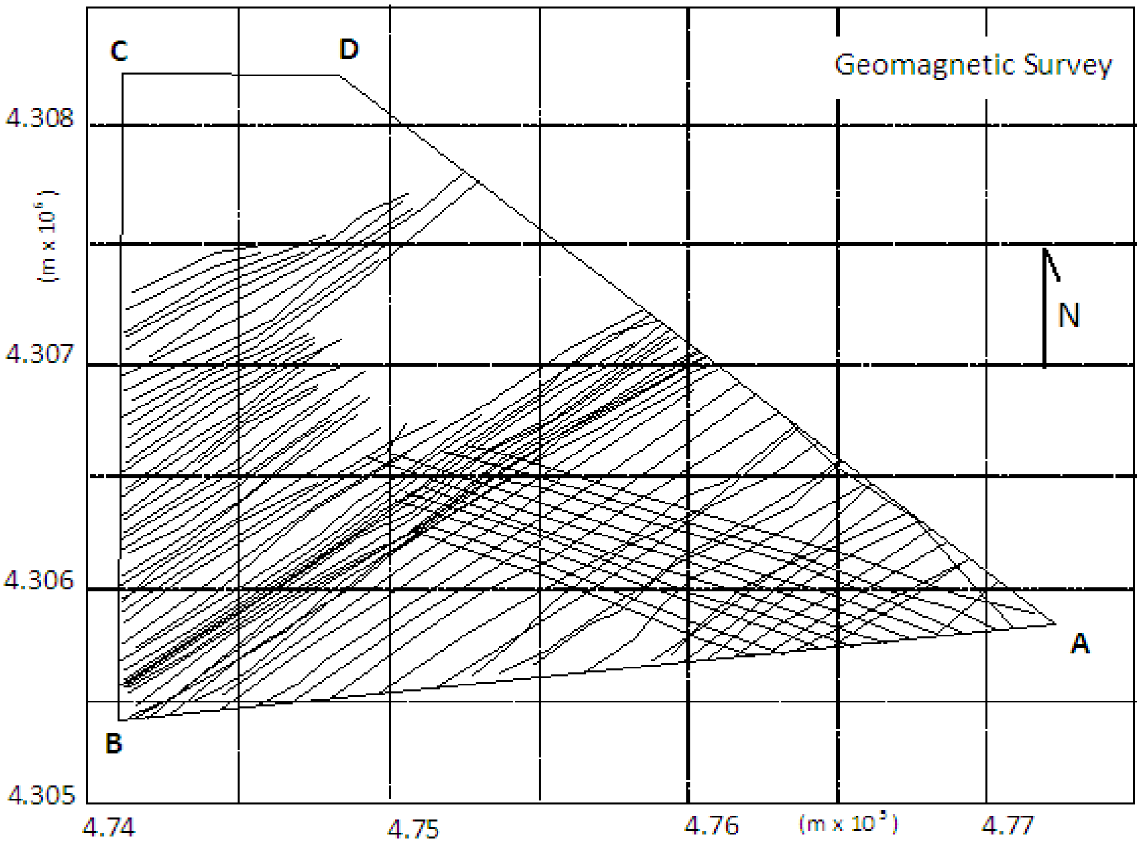


Figure 2 – Geomagnetic survey of Capo Teulada (South Sardinia - Italy), standard tracks.

The area was covered by a proton magnetometer measures over 75 standard tracks (see figure 2) and 19 special tracks performed to have more definition over specific targets. The standard tracks survey had a sampling rate of 1 [s]; the transversal distance between tracks was related to the local density of targets: its range was 10 [m] - 70 [m]. The use of a single magnetometer allowed a very low survey navigation speed (standard 2-3 knots) and a good control of distance between the magnetometer and sea bottom, controlled by a length variation of the magnetometer traction cable. In the standard condition this distance “h” was 1 [m] < h < 2 [m]; over the Posidonia area the survey height h was more or less 3 [m] from the sea bottom to prevent biological damages. The spatial position of the magnetometer was obtained by the HI-PaP system, that was based on a transponder towed near the magnetometer by the magnetometric system traction cable and on a master station locked to the GPSof the ship: the transponder measurements Δx, Δy, Δz were corrected by the satellite position and the bathymetry (by the ship echo-sounder system) to have the absolute position of the magnetometer.

About measurements sensibility, we considered that a device sensibility of 1 [nT] was sufficient for our purpose, because we decided a magnetic signal with amplitude lower than 5 [nT] had not informative capability about our targets (much more if it has not a well defined dipolar form). In fact, the signals with amplitude lower than 3-5 [nT] can be produced by a lot of kind of sources, as little device shaken, magnetic induced signals (not ferromagnetic), etc...

During the mission at sea, the reference geomagnetic observatory was located in Isola Rossa, near to the northern border of the surveyed area. To control its spatial coherence, we used the Timer Tracks (TT) techniques, based on the time correction of the geomagnetic profiles and on the correlation between the corrected profiles. In fact, the spatial coherence defines the spatial stability of the geomagnetic time variations measured in an observatory (Faggioni & Caratori Tontini, 2002; Faggioni et Al., 1997). If the same profiles are performed in two different times, the two geomagnetic surveys have not the same results, because they have the same geomagnetic spatial contribution but also have different geomagnetic time contributions. If the profiles have the same values after the time correction, and then the time variations measured in the observatory are stable over all distance surveyed, then the observatory geomagnetic is named "in spatial coherency".

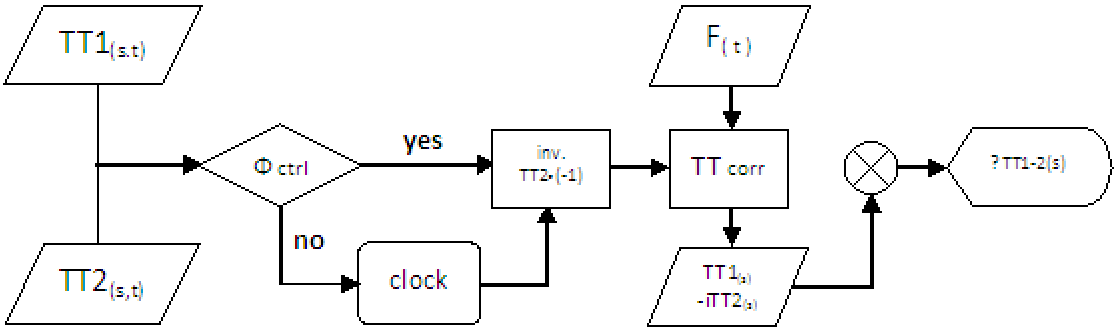


Figure 3 – Procedure of the reference geomagnetic time variations space stability.

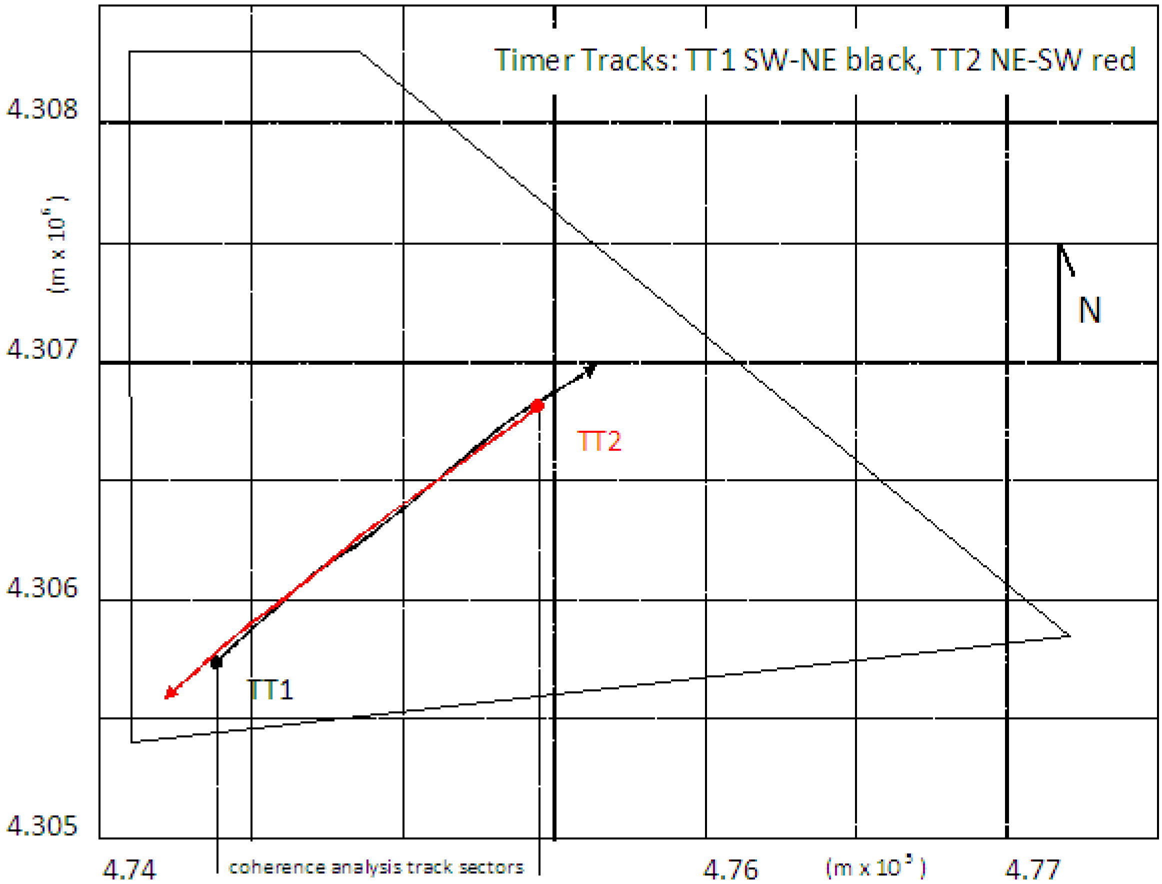


Figure 4 – Timer Tracks for the geomagnetic time variations spatial coherence computation, Isola Rossa geomagnetic reference station.

So, to test the Isola Rossa observatory spatial coherency, we used a profile sampled in two different times (go and back), then we verified the sampling phase and reverse the second survey (back run), and lastly we subtracted the second survey to the first one (Fig. 3). The level of Isola Rossa observatory spatial coherence was defined by the the difference between the corrected TT1 track (black marked, from SW to NE) and the corrected and reversed TT2 Track (red marked, before elaboration oriented from NE to SW); this difference was nearly zero (Fig 4). In the Teulada operation, the effective analysis of coherence was executed in the sector of tracks superimposition. Figure 4 shows the coherence survey (without the ship evolution courses) and the sectors of tracks superimposition. The TTs analysis shows that the 70 % of the samples have, after the correction, a geomagnetic amplitude residual of $0 < \Delta F <= 2$ [nT], the 25 % 2 [nT] $< \Delta F <=$ 3 [nT] and lastly 5% 3 [nT] $< \Delta F <=$ 5 [nT]. We could consider the geomagnetic observatory of Isola Rossa was in spatial coherence with the area of Capo Teulada survey.

The length of coherence calculation sectors was more or less 1500 [m] and its circular surface centred in the Isola Rossa geomagnetic observatory covered more or less the 80% of survey surface; furthermore, in the external area (corner of SE) there was not sources of local noise able to change the high frequency band of the geomagnetic field. This class of noise sources are typical of the coast and urbanized area.

The HD geomagnetic survey of Capo Teulada and the cleaning of its data set permitted to detect and localize 258 magnetic target signals; 134 impulses positive (52%), 93 dipoles (37%), 28 impulses negative (11%). The maximum of amplitude detected was 574 [nT] and the minimum was 6 [nT]; the statistic of amplitude distribution was 127 signals with 5 [nT] < A <= 20 [nT] (49%), 21[nT] <= A < 100 [nT], 101 <= A < 574 [nT]. In the survey of very high definition, where the targets are very little, the 2D and 3D maps have not very high effectiveness because it is no possible to have topographic scale fit to localize the targets with sufficient precision; a lot of dipoles or impulses have wavelength of few meters. It is standard procedure defining the targets position by the 1D products (profile) corresponding to the survey tracks. In the present case we showed two maps (2D and 3D) to indicate an artificial anomaly crossing the entire survey area . Figures 5 and 6 show a magnetic anomaly corresponding to the magnetic field associated to two electrical cables laying on Teulada sea bottom. These “targets” looked like an inductive type where the Est cable (A external) was the active component (inductor) and the W cable (B internal) the passive one.

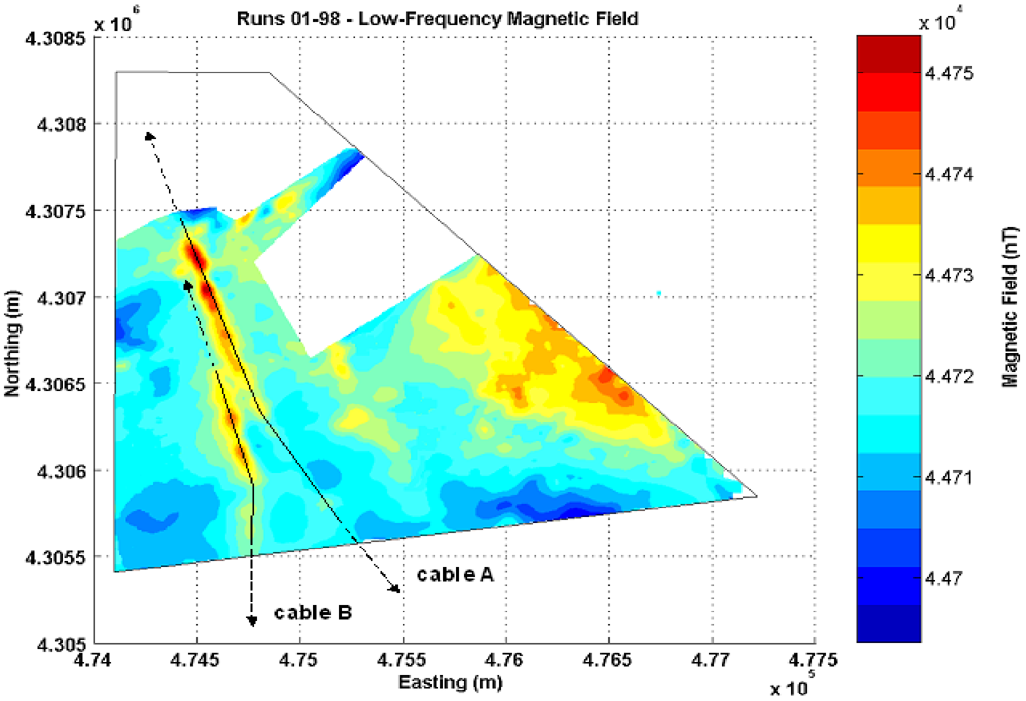


Figure 5 – Cables 1D magnetic anomaly.

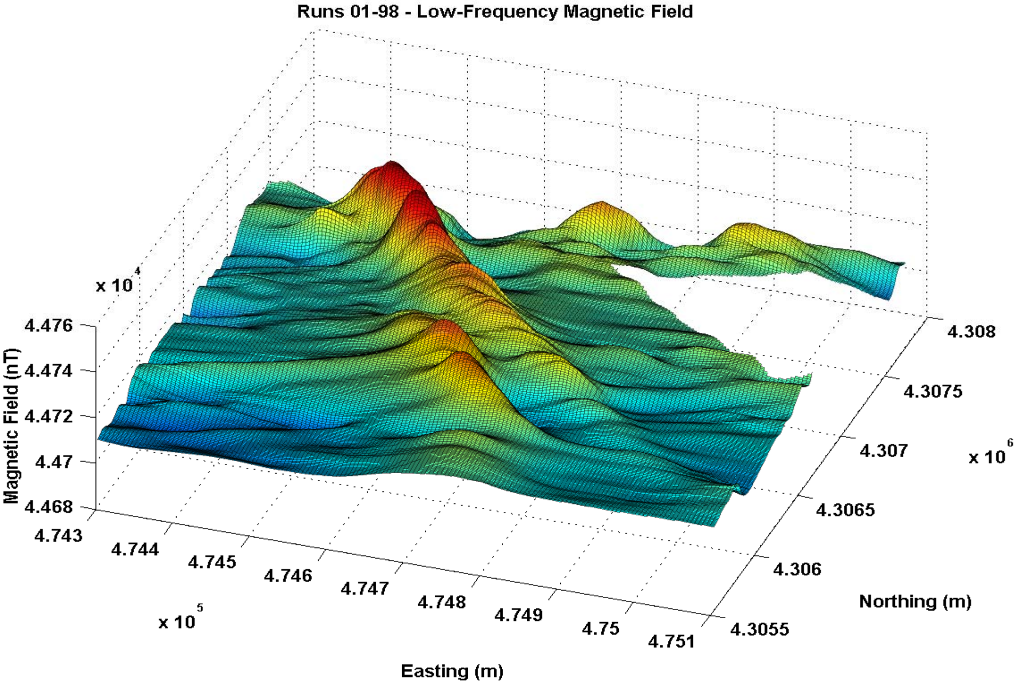
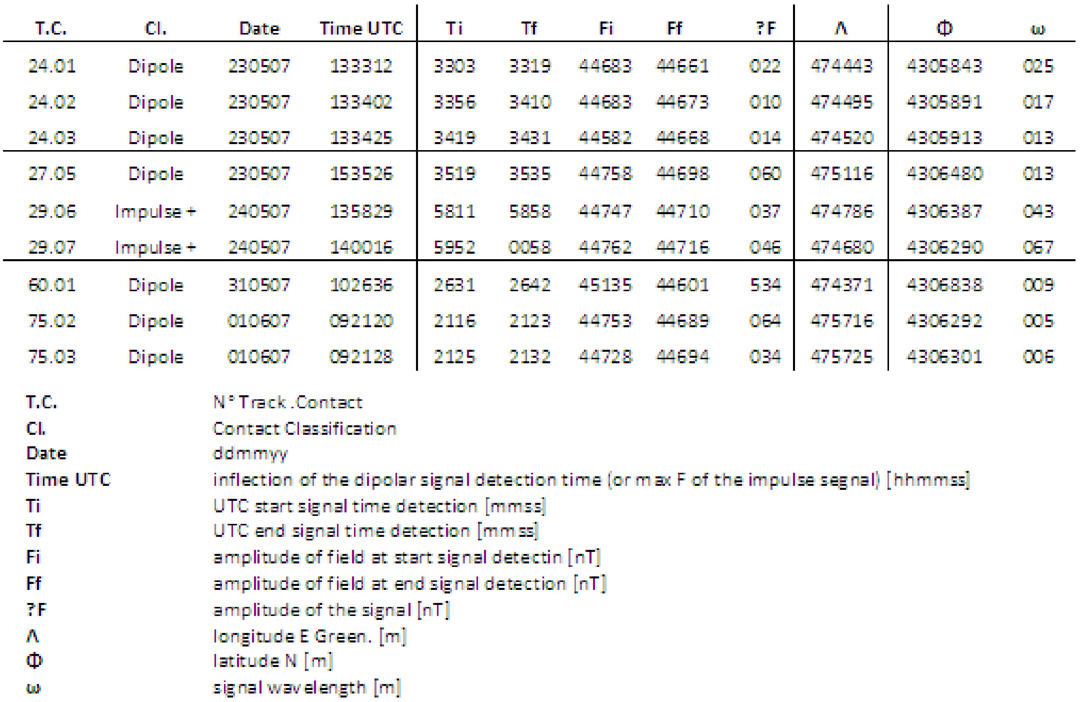


Figure 6 – Total intensity field of "Capo Teulada" investigated area 2D;
B, 3D picture.

In figure 7 are listed a sample of targets, after magnetic processing. Figure 8 shows a sequence of dipolar anomalies due to a series of targets.



T.C.	Cl.	Date	Time UTC	Ti	Tf	Fi	Ff	?F	Λ	Φ	ω
24.01	Dipole	230507	133312	3303	3319	44683	44661	022	474443	4305843	025
24.02	Dipole	230507	133402	3356	3410	44683	44673	010	474495	4305891	017
24.03	Dipole	230507	133425	3419	3431	44582	44668	014	474520	4305913	013
27.05	Dipole	230507	153526	3519	3535	44758	44698	060	475116	4306480	013
29.06	Impulse +	240507	135829	5811	5858	44747	44710	037	474786	4306387	043
29.07	Impulse +	240507	140016	5952	0058	44762	44716	046	474680	4306290	067
60.01	Dipole	310507	102636	2631	2642	45135	44601	534	474371	4306838	009
75.02	Dipole	010607	092120	2116	2123	44753	44689	064	475716	4306292	005
75.03	Dipole	010607	092128	2125	2132	44728	44694	034	475725	4306301	006

T.C.	N° Track .Contact
Cl.	Contact Classification
Date	ddmmyy
Time UTC	inflection of the dipolar signal detection time (or max F of the impulse segnal) [hhmmss]
Ti	UTC start signal time detection [mmss]
Tf	UTC end signal time detection [mmss]
Fi	amplitude of field at start signal detectin [nT]
Ff	amplitude of field at end signal detection [nT]
?F	amplitude of the signal [nT]
Λ	longitude E Green. [m]
Φ	latitude N [m]
ω	signal wavelength [m]

Figure 7 – Examples of detection magnetic signals after processing.

OPTICAL SURVEY

To confirm and validate the acoustic and magnetic contacts, a selected number of classified objects have been visually investigated by the video camera mounted on the ROV Pluto Plus Type operated from Leonardo. In order to maximize the output, a list of target to investigate were decided jointly by the ITN observer and the NURC team. During the investigations CRV Leonardo used its dynamic positioning system. The ROV was guided by means of the HiPap transponder to the geographical location of the contacts. The ROV operator reacquired all the previously detected targets (acoustic and magnetic) thanks to high repeatability of HiPap navigation system (see same transponders used on AUVs, magnetometer and ROV) and by means of the VHF Reson type sonar installed on the Pluto Plus.

At the end of operation, up to 211 video data have been stored (see fig. 8-9), most of them used to match and validate acoustic and magnetic data, gathered in independent way.

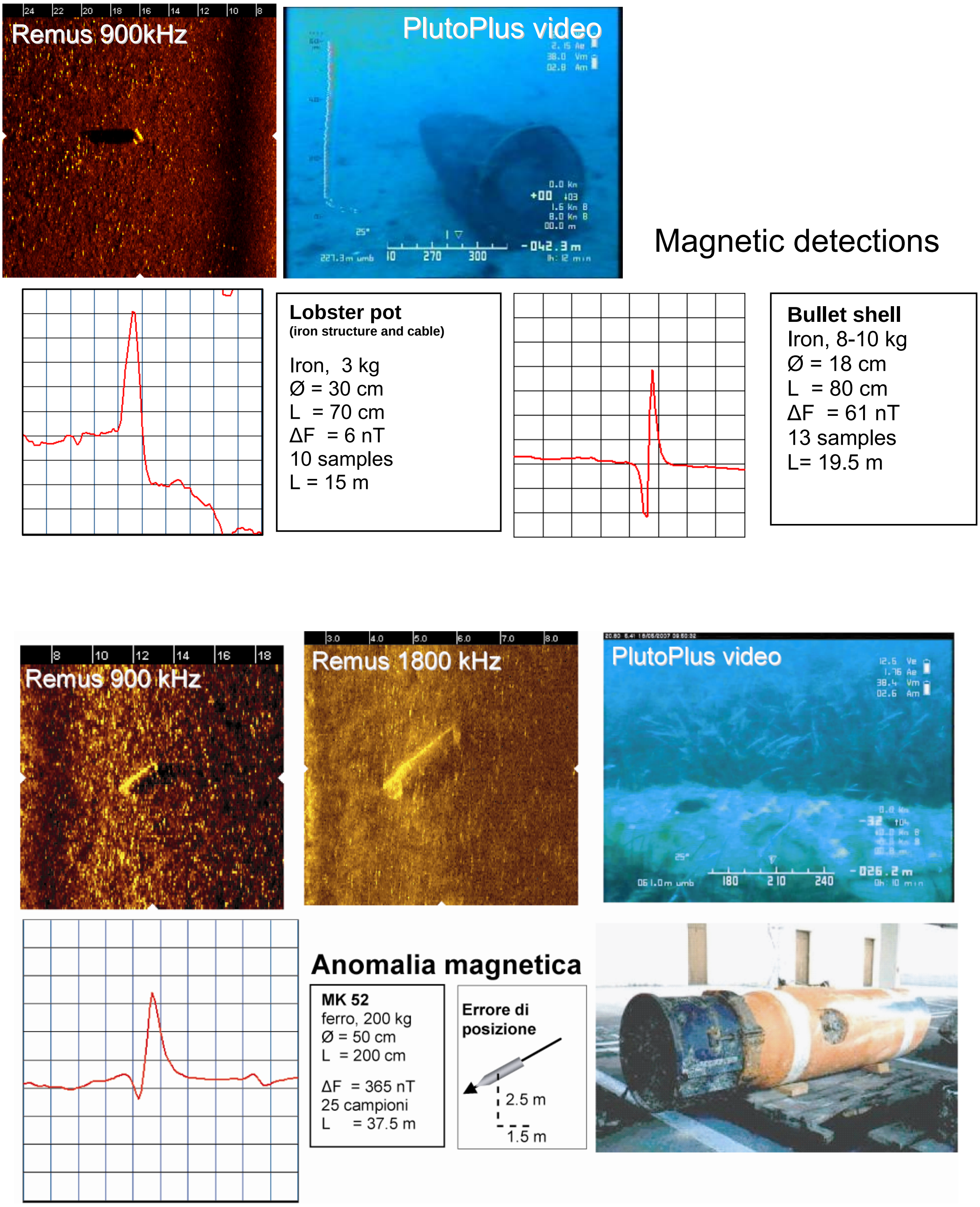


Figure 8: Examples of acoustic, magnetic and optical targets.

DATA FUSION AND OVERALL RESULTS

All data (acoustic, magnetic, optical) have been stored in a GIS multilayered database, provided to ITN (see fig. 9).
The survey has also produced an accurate map of the Posidonia fields and a detailed bathymetry of the area (see fig. 10).
The results of survey allowed to declare the area free of ordnance.
The mission has been fully accomplished in time with a sustainable amount of money (about 300 K€), compared to what ITN would have faced for the same operation (at least 2 MHCVs for 3 weeks).

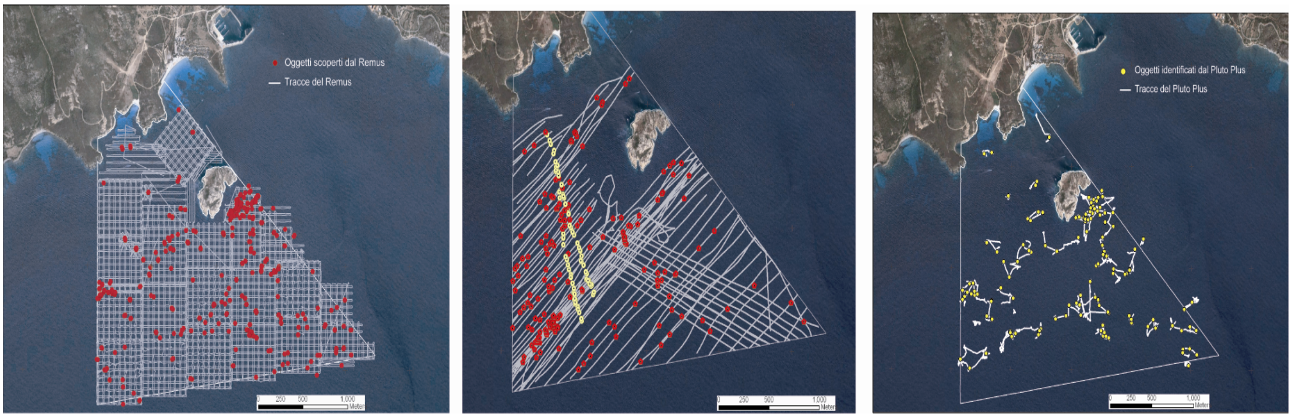


Figure 9 : Acoustic, magnetic and optical targets

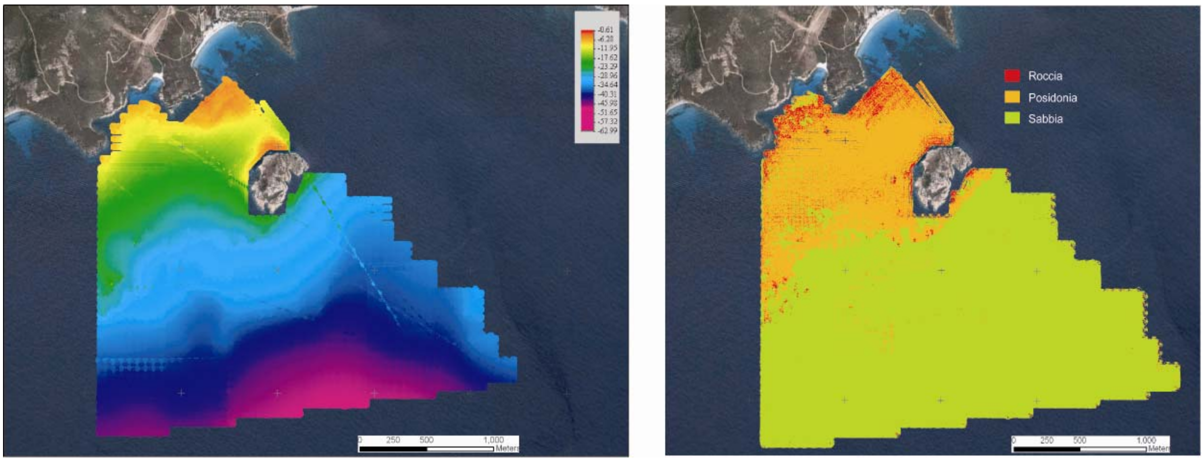


Figure 10 : Bathymetry and sea floor characterization of the area

CONCLUSIONS

AUVs are ready to provide a level of operational capability to MCM operations, in particular among covert short term , reconnaissance and survey missions. Many of the problems which held back AUV performance in early years have been overcome with current systems delivering ever more robust levels of capability. Developments are still required to improve the automation of the processing chain in order to allow AUVs to deliver their full potential and operate effectively as part of a networked MCM force.

Anyway, the most performing autonomous platforms are not sufficient without the right sensors and processing packages, depending from environmental conditions at sea.

Beside new MCM sonar developments still in progress (e.g. Synthetic Aperture Sonar), ITN is investigating non acoustic techniques for concealed (e.g. in Posidonia) and buried naval mine detection and classification.

NURC and INGV La Spezia are going to be key partners for ITN to develop integrated HD magnetic sensor on AUVs.

The success of Teulada operation has convinced ITN to ask NURC for a common development programme with the aim to validate at sea a fully integrated multi-sensor approach (sonar, magnetic and optical) in MCM short term ops. using USV/AUV platforms.

The project is going to be run in the framework of the recent bilateral cooperation agreement signed 8th feb. 2008 between CSSN (ITN) and NURC, with the aim to strengthen applied research capability in maritime contest among NATO transformation Naval Forces process.

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