THE DGA "ALMA" PROJECT: AN OVERVIEW OF THE RECENT IMPROVEMENTS OF THE SYSTEM CAPABILITIES AND OF THE AT-SEA CAMPAIGN ALMA-2016

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Abstract:

ALMA (Acoustic Laboratory for Marine Applications) is a deployable and autonomous acoustic system, with passive and active sub-systems, designed in 2012 by DGA Naval Systems in order to address future problems in underwater acoustics, especially in shallow waters and coastal waters.
The ALMA project has two main objectives: 1) to increase the scientific knowledge of the impact of the environment and of its variability at different temporal and spatial scales, on the acoustic propagation and on the signal processing in the sonar domain, and 2) to collect and share high quality real data (both acoustical and environmental data) with scientists of the underwater acoustics domain, in order to increase the scientific knowledge needed for improving the mastering of sonar performance in such highly variable and fluctuating environments.
In this paper, we present an overview of the evolutions of the system and of the improvements in its capabilities realized since 2015. These evolutions address in particular the mechanical structure for the passive array, mainly allowing new array geometry configurations and increasing the number of hydrophones and their spacing range capability.
We also present an overview of the at-sea campaign (ALMA-2016) conducted on the continental shelf of the island of Corsica in November 2016. Details are given on all the acoustic and environmental aspects of this one-week at-sea trial mainly dedicated to the impact of the environmental variability and fluctuations on acoustic propagation in shallow and coastal waters.

Keywords: *acoustic systems, shallow waters, coastal waters, underwater acoustics*

1. INTRODUCTION

The interest in shallow and coastal waters is in a continuous increasing since many years, either in the defence community than in the civilian community.

In the defence community, the mastering of sonar performance is a constant objective of the underwater warfare domain. This mastering implies the mastering of the acoustical impact on the sonar systems of all environmental typologies, from deep waters to shallow and coastal waters. The evolution of sonar systems, combined with the complexity of shallow and coastal environments and the high variability and fluctuation of their environmental parameters, at different temporal and spatial scales, lead to the necessity to continuously increase the scientific knowledge of the impact of the environment on the acoustic propagation and on the sonar signal processing.

In the civilian domain, the interest in underwater acoustics in shallow and coastal waters is continuously increasing, mainly due to environmental preoccupations linked with, for example, the monitoring of ambient noise and the quantification of effects of the anthropogenic noise on marine life, species counting and, more generally with ecological objectives.

For both the defence and the civilian communities of underwater acoustics, the current knowledge of the preponderant physical and acoustical processes in such harsh environments is incomplete, mainly due to the lack of environmental and acoustical data available for the scientific community allowing to quantifying the impact of the environment and of its variability at different temporal and spatial scales on spatial and temporal processing dedicated to the detection, localisation and classification processes.

In 2012, DGA Naval Systems conducted the design studies of an acoustical system, named ALMA (Acoustic Laboratory for Marine Applications) in order to address the main topics of the underwater acoustics domain for shallow and coastal waters. The ALMA system was realized in 2013-2014 by the ALSEAMAR and CESIGMA companies, with the COMEX company for at-sea deployment of the system and for marine operations. The first version of the ALMA system was qualified at sea on October 2014 [1].

Evolutions and improvements of the ALMA system have been continuously realized since the first at-sea campaign in 2014, mainly concerning the mechanical structure for the passive array: improvements of the rigidity and of the weight, increase in the capability of array geometry configurations, increase in the capability of the hydrophones spacing range, increase in the number of hydrophones (64 hydrophones in 2014 and 2015, 128 hydrophones in 2016).

2. ALMA : MAIN OBJECTIVES AND TECHNICAL CHARACTERISTICS

The philosophy chosen for the ALMA project is the following one:

- to design an acoustical system able to address the spatial and temporal decoherence effects on acoustic propagation and on array processing, decoherence due to the environmental fluctuations (in the water column, on the interfaces), in a large frequency range.
- to gather environmental and acoustical data for developing and validating advanced signal processing algorithms and acoustic models, linked with the

current and future main topics of the underwater acoustics domain for shallow and coastal waters.
- to share these data with the technical and scientific community, in order to contribute to the improvement of the scientific knowledge and of the state-of-the-art of the underwater acoustic domain.
- to design a fixed acoustical system, deployable in shallow and coastal waters (water depth less than 200 meters for the system anchoring), energetically autonomous, able to gather, store and transmit acoustical and environmental data.
- to design a system with a high level of modularity and capability of evolution (array geometry, hydrophones number and spacing,…).
- to ensure a high quality level for the acoustic components and for acoustical measurements.
- to minimize specific technological developments, use of COTS.
- to minimize the impact of the ALMA system on the environment: no anchoring left on the sea-floor at the end of the at-sea measurements campaign.

From the philosophy previously presented, the ALMA system is composed of two separated components with their dedicated anchoring and acoustic systems: a passive sub-system and an active sub-system (cf. Fig. 2.1 for an "artist view" of the system).

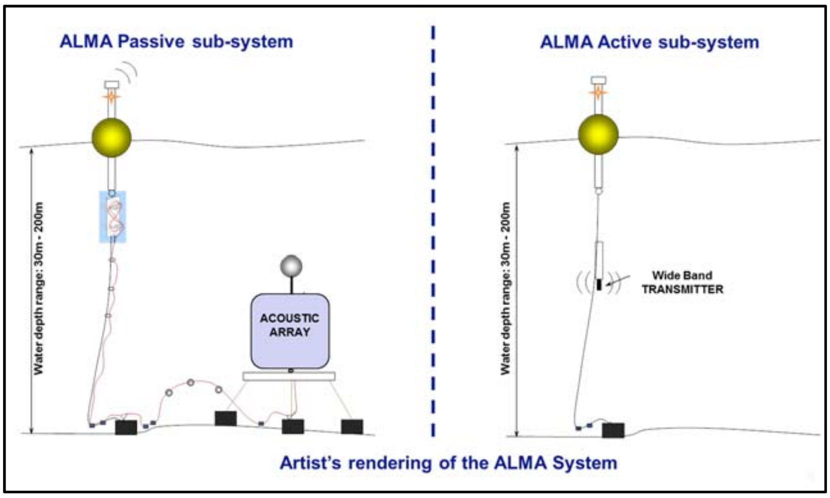

Fig. 2.1: "Artist view" of the ALMA system composed of passive and active sub-systems.

- <u>Technical characteristics of the ALMA Passive sub-system:</u>

    - 8 rigid acoustic "arms", each composed of 16 hydrophones with an adjustable spacing between 3 cm and 15 cm (cf. Fig. 2.2). Arm length: 2.70 m. Total number of hydrophones: 128.
    - Capability of several array geometries: linear, plane, volume (cf. Fig. 2.3).
    - Adjustable sampling frequency from 7.5 kHz to 48 kHz.
    - Noise level less than sea state 0 for the hydrophonic chain.
    - 32 temperature sensors (4 sensors per arm).
    - Adjustable array depth.
    - 3 anchoring in order to minimize the array disorientation.

- 3D orientation sensors for the monitoring of the array orientation.

- Energy and data storage in the surface buoy (cf. Fig. 2.4).
- Electric energy: 9.6 kWh. Rechargeable electric battery.
- Autonomy: more than 100 hours in continuous measurements.
- Programming of the measurements sequences via wired connection or WIFI.
- Data storage on extractible 2 TB hard drive
- Data transmission via long range WIFI.
- Link to Acoustic Array via electro-optical cable (energy + data) (550 m long).
- Height: 3.5 m – Diameter: 2.1 m – Weight: 550 kg.
- Anchoring: reinforced concrete "cube" (1000 kg in water)

- <u>Technical characteristics of the ALMA Active sub-system:</u>

  - Omnidirectional wideband transmitter, from 1 kHz to 14 kHz (cf. Fig. 2.4), designed and realized by the ALSEAMAR company.
  - Adjustable source level up to 160 dB ref µPa@1m.
  - Transmitted signal programming through .wav files
  - Autonomy larger than 20 hours for a continuous transmission with source level of 160 dB ref µPa@1m.

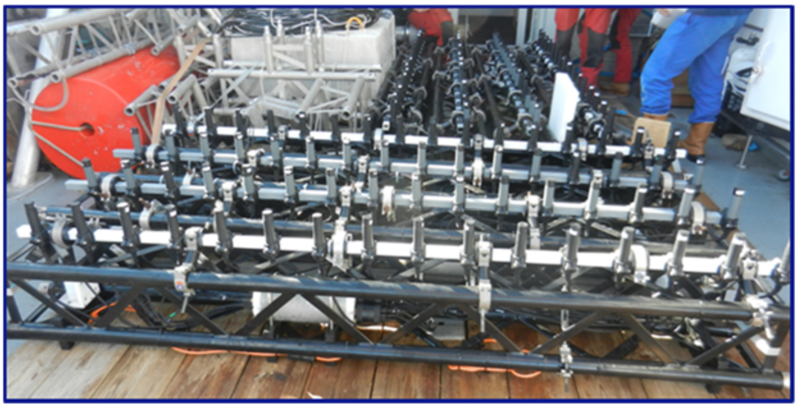

Fig. 2.2: ALMA modular acoustic arms: 8 rigid acoustic "arms", each composed with 16 hydrophones with an adjustable spacing between 3 cm and 15 cm.

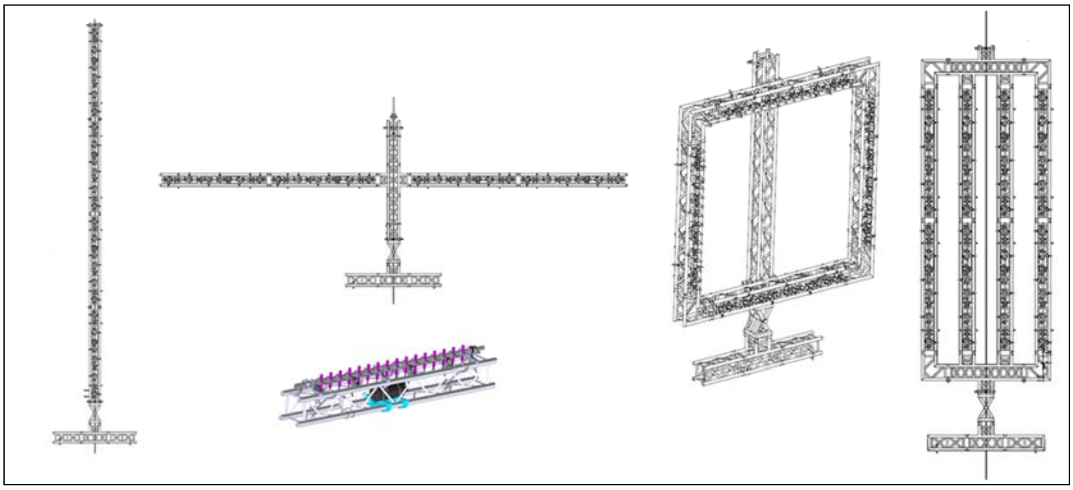

Fig. 2.3: some examples of array geometries allowed by the modular structure of the ALMA passive array.

Fig. 2.4: surface buoy for the ALMA passive component: energy and data storage, link to Acoustic Array via electro-optical cable communication link by long range WIFI.

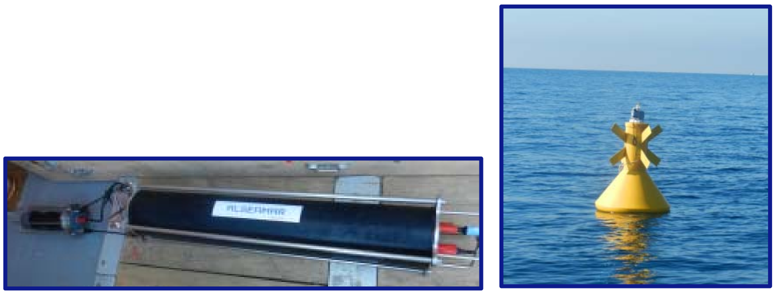

Fig. 2.5: omnidirectional wideband transmitter (realized by ALSEAMAR) and its mooring surface buoy.

3. ALMA AT-SEA TRIALS WITH A FOCUS ON ALMA 2016 CAMPAIGN

Since the qualification of the first version of the system in 2014, three at-sea campaigns have been conducted with the ALMA system, on the continental shelves of Corsica (Alistro 2014, Campoloro 2015) and of Provence (La Ciotat 2015) (cf. Fig. 3.1).

Fig. 3.1: Mediterranean Sea areas for the 2014, 2015 and 2016 ALMA at-sea campaigns.

Each of these three campaigns allowed: (1) to validate the evolutions of the system, and (2) to gather high quality data, acoustical and environmental, in various environmental conditions and for different geometries and capabilities of the passive array (cf. Fig. 3.2).

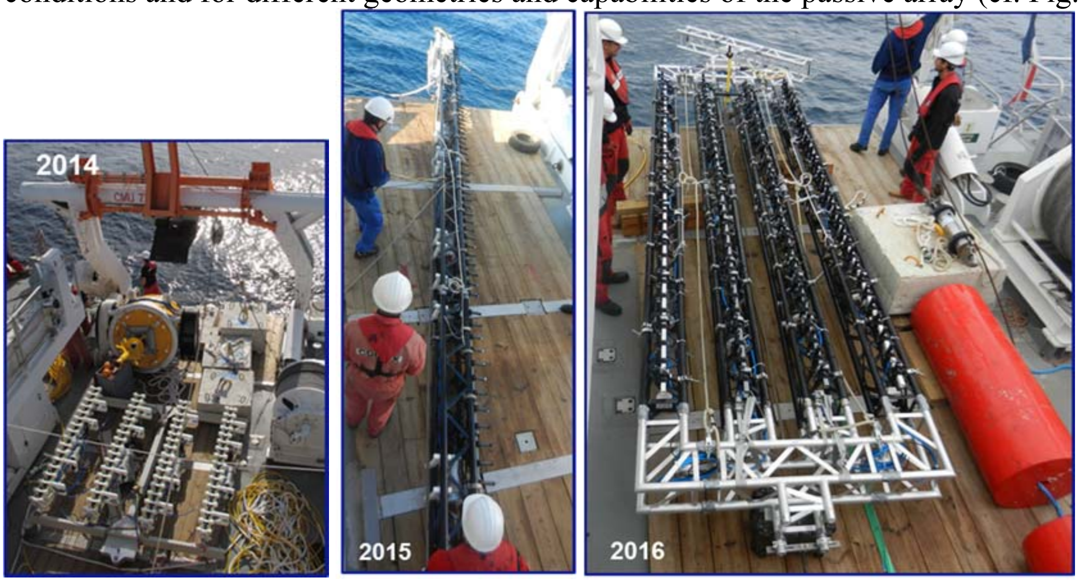

Fig. 3.2: ALMA Passive Array configurations for the 2014, 2015 and 2016 at-sea campaigns.

- 2014: Corsica (Alistro), 64 hydrophones, 2,5m x 2,5m comblike passive array, 4x16 hydrophones, 0.15m hydrophones spacing on each acoustic arm.
- 2015: Provence (La Ciotat), 64 hydrophones, 10 m vertical passive array, 0.15m hydrophones spacing.

- 2016: Corsica (Campoloro), 128 hydrophones, H 5 m x L 1,5 m comblike passive array, 4x32 hydrophones, 0.15m hydrophones spacing on each acoustic arm.

Focus on the ALMA 2016 at-sea campaign:

The ALMA 2016 at-sea campaign was conducted (from November 7th to 17th, 2016) on the continental shelve and slope of the eastern coast of the island of Corsica, off the coast of Campoloro (cf. Fig. 3.3).

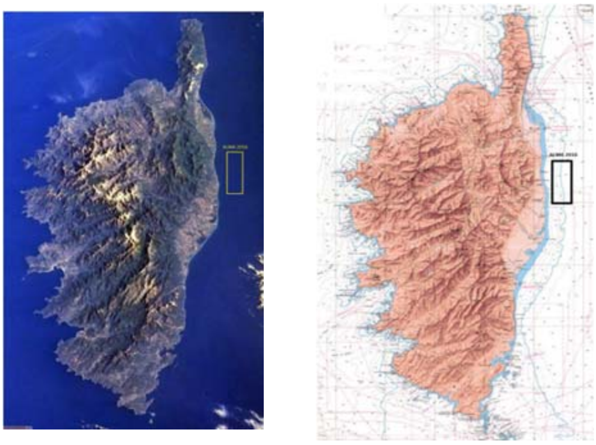

Fig. 3.3: ALMA 2016 at-sea campaign area, on the continental shelf and slope of the eastern coast of the island of Corsica.

<u>Instrumentation deployed</u>

- <u>Passive array</u>: 128 hydrophones, H 5 m x L 1,5 m comblike configuration, 4x32 hydrophones, 0.15m hydrophones spacing on each acoustic arm. Total recording time: 34h30mn.

- <u>Two active sources</u>:

    - One moored active source (ALSEAMAR pinger, from 1 kHz to 14 kHz, at low acoustic level) (cf. §2).
    - One towed active source (DGA source "SYSMAS", from 20 Hz to 20 kHz, at low acoustic level). This active source was towed at 2-3 knots speed by the COMEX "JANUS II' ship along acoustic propagation legs centered on the passive array.

- One <u>thermistor string</u> (RBR Concerto T24), deployed vertically and moored near the passive array: 150m long, 24 temperature sensors with 6.25m depth spacing, sampling the entire water depth, recording every 3s the temperature fluctuations throughout the entire duration of the campaign.
- One <u>glider</u> (ALSEAMAR "SEA EXPLORER", cf. Fig. 3.4), equipped with a CTD payload. The glider was deployed in a devoted area in the east of the acoustic trial area, allowing CTD measurements in space and time up to 300m in depth.

- One Valeport SVP 500 Profiler, for CTD casts from the JANUS ship during the campaign.

Fig. 3.4: ALSEAMAR "SEA EXPLORER" glider, with CTD payload, deployed on the area during the ALMA 2016 campaign.

Figure 3.5 resumes the main geographical elements of the ALMA 2016 campaign: bathymetry, locations for all the acoustical and environmental devices deployed, acoustic propagation legs, glider deployment area. On the Figures 3.6a, 3.6b and 3.6C are respectively shown the bottom profile measured by the JANUS depth sounder: (a) between the passive arrays ans the moored active source, (b) along Leg 1, and (c) along Leg 2. Fig. 3.5d shows the map for the bottom type on the ALMA 2016 area.

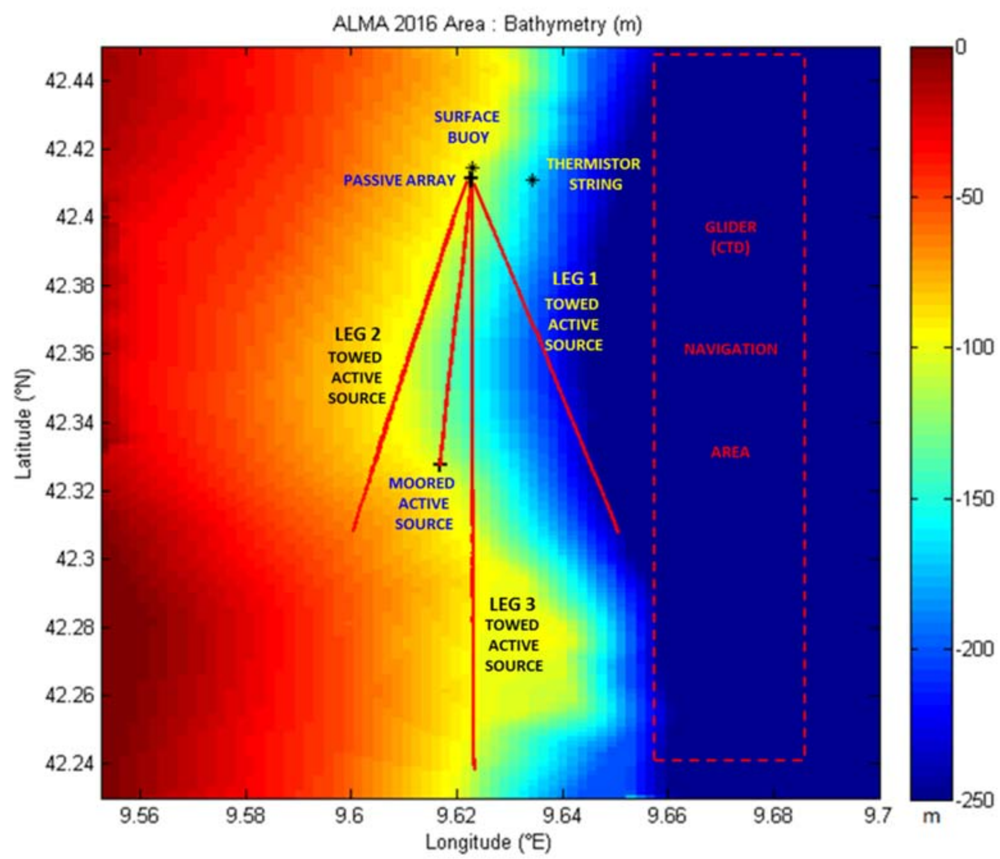

Fig. 3.5: Main geographical elements of the ALMA 2016 campaign.

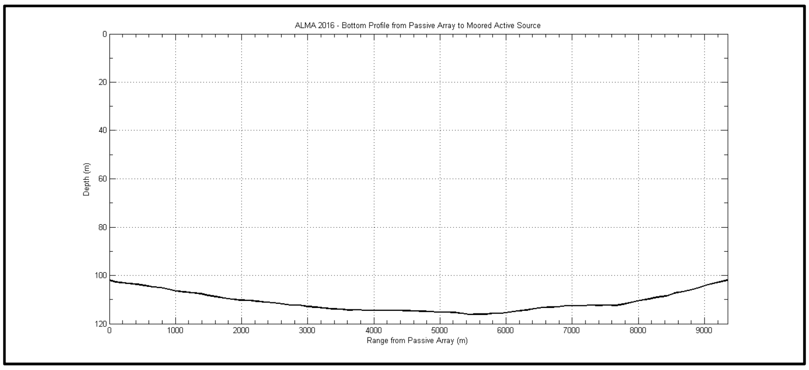

Fig. 3.5a: Bottom profile from the passive array to the moored active source.

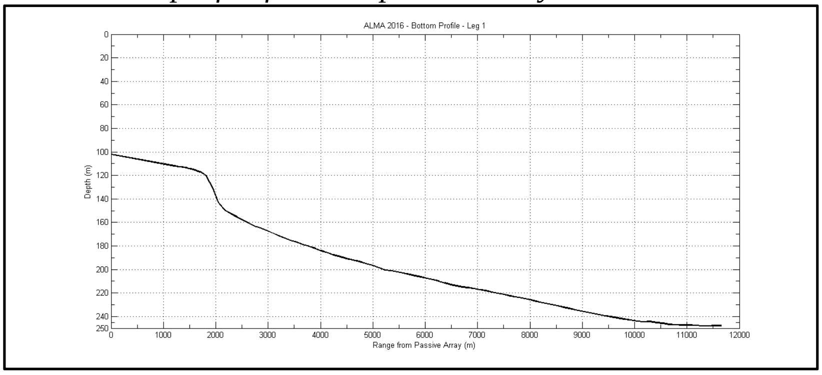

Fig. 3.5b: Bottom profile along Leg1.

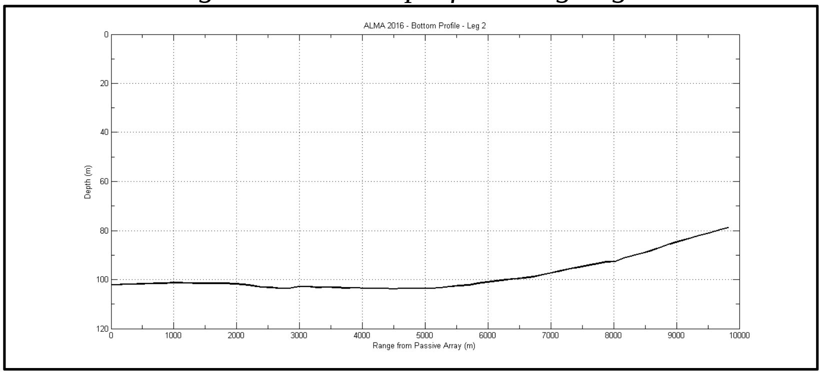

Fig. 3.5c: Bottom profile along Leg 2.

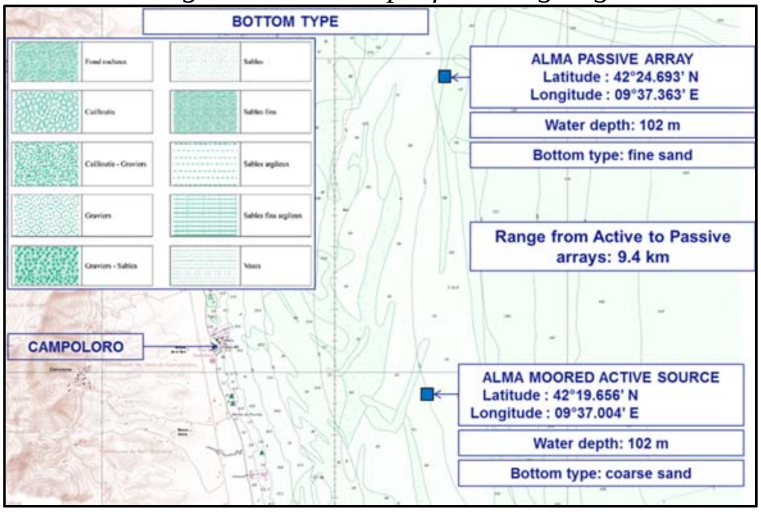

Fig. 3.5d: Map of the bottom type on the ALMA 2016 area.

Transmitted acoustic signals:

- Transmitted signals by the moored acoustic source (ALMA pinger):

The transmitted signal was a sequence consisting of broadband pulses (Ricker type), linear frequency modulated signals (LFM), continuous waves (CW) and white noise, in the frequency range 1-13 kHz. This sequence of 59s duration (cf. Fig. 3.6) was repeated every 2mn during the transmission phases of the trial.

- Transmitted signals by the towed acoustic source (SYSMAS):

Two complex sequences of 30mn each, continuously repeated during the the transmission phases, respectively composed with 70 and 75 different signals of variable duration (from 2s to 100s). Among these complex sequences, the following signals are transmitted:

- the same sequence than for the ALMA pinger (frequency range 1-13 kHz)
- the sequence of the ALMA pinger, with frequencies divided by 100 (frequency range 10 Hz -130 Hz)
- underwater acoustics communication signals
- environmental signals: biologics, geophysics
- real and synthetic signals of ships radiated noise

During the acoustic Legs with the active source towed by the JANUS, the depth of this source was continuously monitored (5 measurements per second: 5 Hz) (cf. Fig. 3.7).

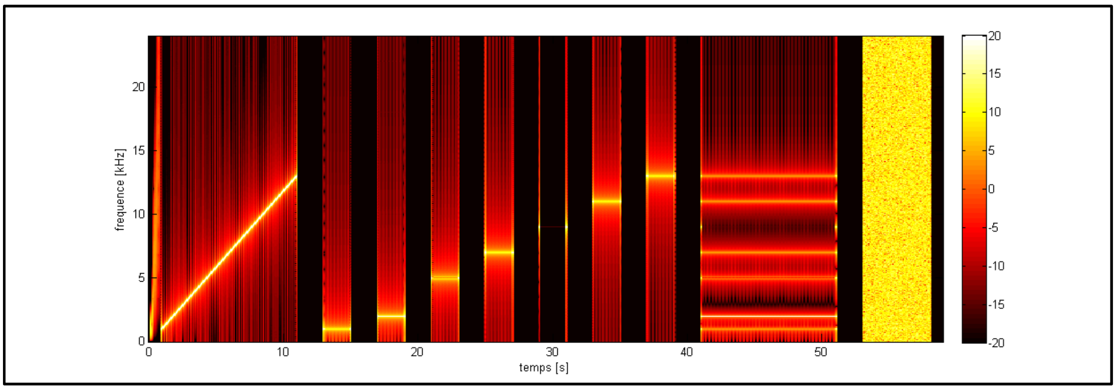

Fig. 3.6: Spectrogram of the transmitted Sequence by the moored acoustic source.

Sound Velocity Profiles measurements:

A very important effort was made during the ALMA 2016 campaign in terms of environmental data gathering, especially in terms of Sound Velocity Profiles measurements. High quality data were collected in order to ensure the required level of knowledge required for the studies we conducted on the impact of the environmental fluctuations on acoustic propagation and on sonar signal processing and on sonar performance.

Fig. 3.8 shows the Temperature profile versus time measured by the moored thermistor string during 3.5 days (with 3s resolution).

From the data shown on Fig. 3.8, we present on Fig. 3.9 the deviation from the first temperature profile versus time, measured by the thermistor string during 3.5 days.

Fig. 3.10 shows the 6 of Sound Velocity Profiles recorded by the profiler deployed from the JANUS ship, at different locations during the campaign.

Fig. 3.11 shows the temperature versus depth over 34 km and during 1 day, measured by the CTD payload on the glider deployed on the ALMA 2016 area.

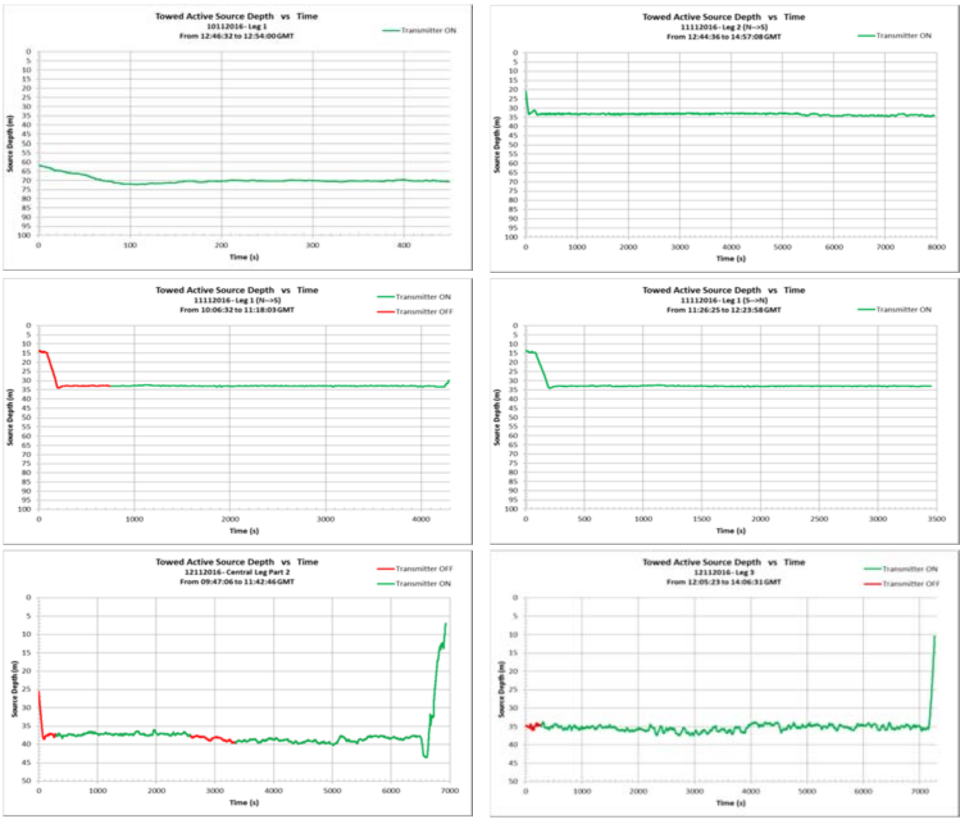

Fig. 3.7: Continuous depth monitoring (5 Hz) of the towed active source

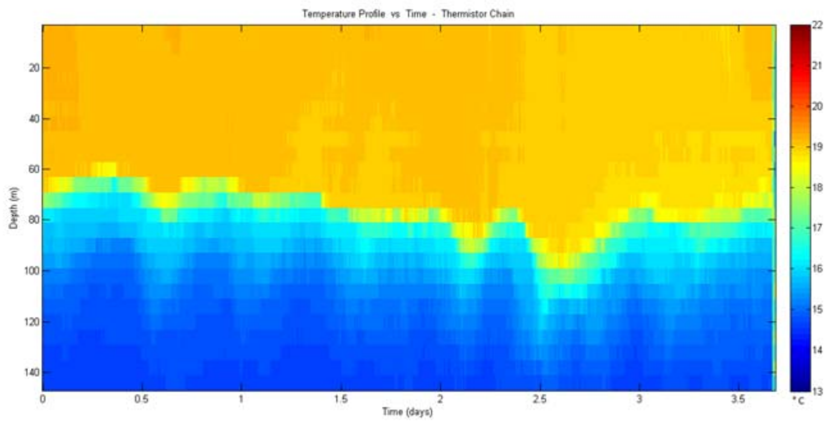

Fig. 3.8: Temperature profile versus time measured by the thermistor string during 3.5 days (with 3s resolution).

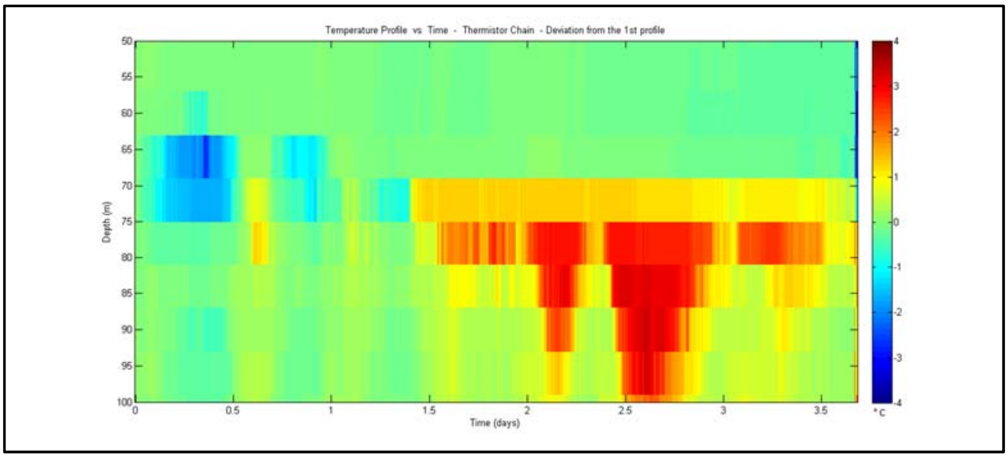

Fig. 3.9: Deviation from the first temperature profile versus time, measured by the thermistor string during 3.5 days(with 3s resolution).

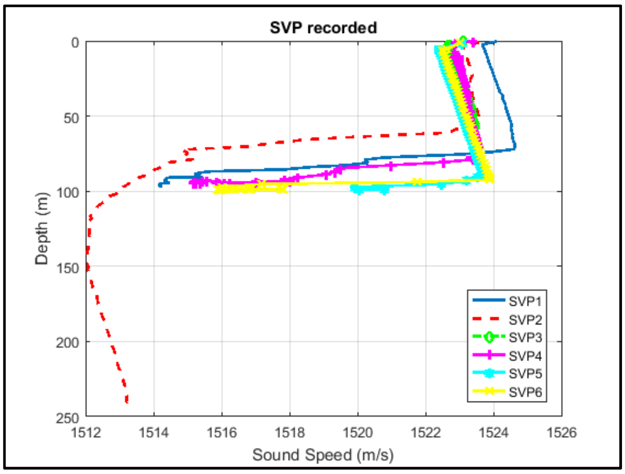

Fig. 3.10: SVP recorded by the profiler deployed from the JANUS ship

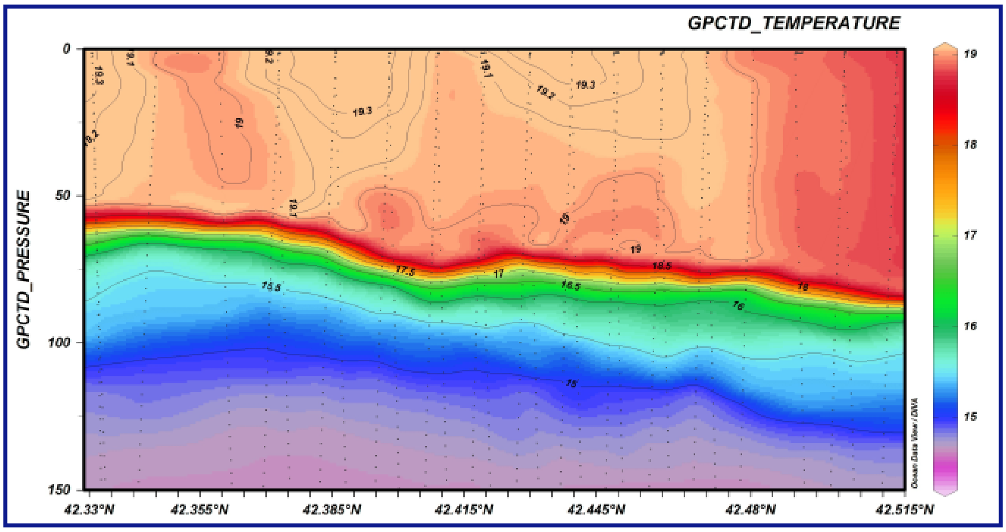

Fig. 3.11: Temperature versus depth over 34 km and during 1 day, measured by the CTD payload on the glider deployed on the ALMA 2016 area.

4. CONCLUSION

Since the qualification of the first version of the system in 2014, and after three at-sea campaigns conducted with the successive evolutions of the system, the ALMA system demonstrated its capabilities to reach the technical and scientific objectives dedicated to ALMA:

- a high level of modularity, capability of evolution and of acoustical measurements
- an "environment-friendly" system.
- a scientific acoustic system able to address the main current and future issues of operational sonar systems (in particular the de-coherence effects).
- a very useful tool for sharing real data and "real life sonar issues" with the scientific community, contributing to the improvement of the scientific knowledge in underwater acoustics for coastal and shallow waters.
- an "embryo" of an underwater acoustic observatory, federating Underwater Acoustics community (laboratories, companies).

Since 2014, ALMA data fed and still feed numerous scientific projects within the framework of research projects funded by DGA, in particular for the studies on acoustic decoherence and its effects on sonar signal processing (see the companion paper [2] "Acoustic coherence in a fluctuating ocean: analysis of the 2016 ALMA campaign", Real & al.). Several French academic laboratories and companies are involved in the valorisation of the ALMA data, demonstrating the usefulness of this system as a tool for federating Underwater Acoustics community (laboratories, companies).

The ALMA research program, led by DGA Naval Systems, can be opened to international cooperation, through data sharing and scientific exchanges between French and foreign laboratories.

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[2] **Real G., Fattaccioli D.**, "Acoustic coherence in a fluctuating ocean: analysis of the 2016 ALMA campaign", *UACE 2017 Proceedings*, 2017.