CUMAS (Cabled Underwater Module for Acquisition of Seismological data): a new seafloor module for geohazard monitoring of the Campi Flegrei volcanic area

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Introduction

CUMAS (Cabled Underwater Module for Acquisition of Seismological data) is an underwater module that is equipped with different types of sensors that have been developed for the acquisition of geophysical signals on the shallow seafloor, for geohazard monitoring in volcanic areas. It was conceived for the specific application in the Campi Flegrei caldera (southern Italy), where the main features of the present volcanic activity consist of slow soil movements (bradyseism) accompanied by intense and shallow seismic activity.
The aim of CUMAS is to:

- continuously acquire geophysical and oceanographic data on the seafloor according to a single time reference, and to store them on hard disk;
- transmit the acquired data in real time to an acquisition centre on land;
- receive commands from the land centre and modify its acquisition configuration accordingly.

The sensors installed in the module comprise: a broad-band seismometer and hydrophone to record local earthquakes related to volcanic activity and artificial explosions; and physical oceanographic sensors for the long-term monitoring of the water current system, which are also useful for seafloor seismic microtremor studies. A further task consists of testing the feasibility of the use of water pressure measurements at the seafloor to detect changes in the water column pressure that are potentially related to bradyseismic activity.
The module is connected via an electromechanical cable to a previously deployed buoy (elastic beacon) equipped with an electrical supply and a Wi-Fi communication system to ensure the transfer of the seafloor data to the land acquisition centre in Naples.

CUMAS has been developed for the system to be installed within the sea sector of the Campi Flegrei caldera, at 97 m depth, from 2 to 3 km from shore and about 4 km from the land acquisition centre (Figure 1).

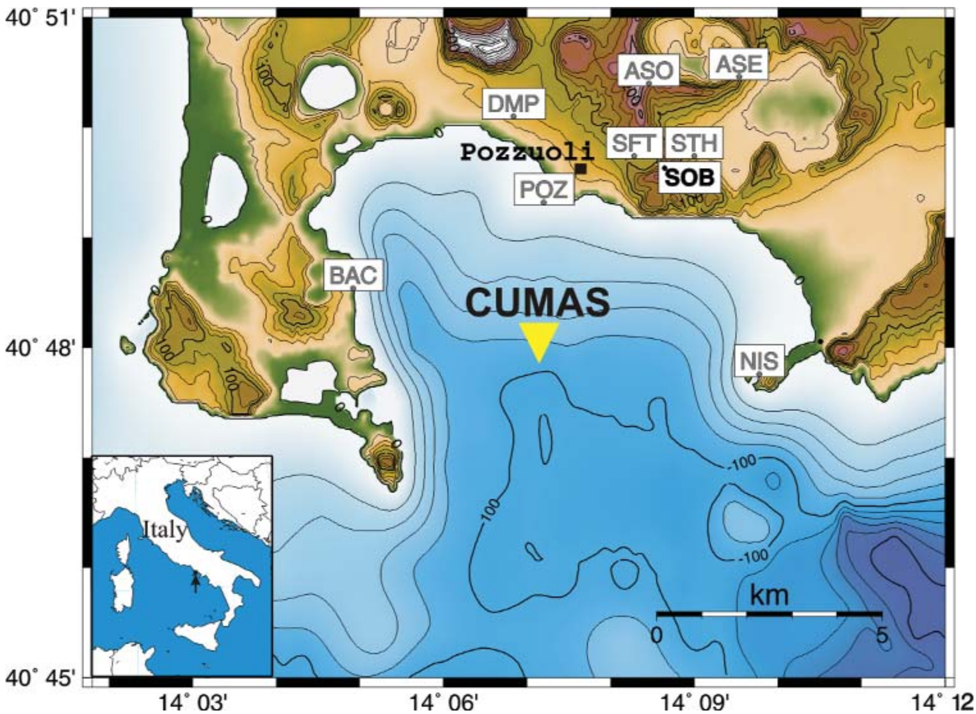

Fig. 1. The Gulf of Pozzuoli area and the site (yellow triangle) selected for the deployment of CUMAS. White rectangles represent seismic stations of the monitoring system managed by Osservatorio Vesuviano.

All these features ensure that CUMAS is fully integrated into the centralised monitoring system of the Neapolitan volcanic areas (Vesuvio, Campi Flegrei and Ischia Island) that are managed by the Osservatorio Vesuviano-INGV. It also represents the first step towards the extension of the present land-based Campi Flegrei monitoring networks that operate in the marine sector of the caldera, and which cover something over one third of the volcanic area.

The features of CUMAS

The CUMAS set-up consists of a steel frame in the shape of a truncated pyramid of about 1 m in height and with a square base of 1 m per side. The total weight including the equipment is about 430 kg in air (320 kg in water) (Figure 2). The structure, which is made from welded open profiles, has a lower section with vertical mountings, surmounted by an upper section in the form of

Fig. 2. The fully equipped CUMAS set-up in the laboratory during tests; the acquisition system was kept out of its frame temporarily to check on its operation.

a truncated pyramid. In the middle section (between the vertical section and the pyramidal section), there are four ballast plates have the double function of stabilizing the structure during its release and to provide controlled sinking into the superficial sediment of the seabed, on the basis of our knowledge of the mechanical characteristics of the seabed itself.

The seismometer and the cylinder containing the electronics are located in the lower section of the structure, while the rest of the instrumentation is installed in the upper section. The container for the electronics is made of aluminium, type 6082 T6. Moreover, the structure is protected by 8 sacrificial anodes in zinc positioned on each horizontal element. The number of anodes needed was determined according to the DNV RP B401 “Cathodic Protection Design” Normative.

Sensors

The following sensors have been installed within the CUMAS' structure:
a) seismic sensor;
b) hydrophone;
c) current meter;
d) pressure gauge;
e) status and control sensors.

Seismic sensor

This comprises a three-component, broad-band seismometer, model Güralp CMG-40T OBS (30 s, 50 Hz), housed in a 16 cm glass sphere with an auto-leveling platform.
It is equipped with a ±30° microprocessor-controlled leveling system, with an internal three-axis magnetometer for orientation measurements and the automatic calibration and tilt compensation system.

Hydrophone

A broad-band hydrophone, model SQ03 Sensor Technology (1 Hz ÷ 65 kHz), equipped with an integrated pre-amplifier with 40-dB gain.
Our interest is concentrated around the acquisition of signals of very low frequencies (1-10 Hz) detected by the hydrophone.
The hydrophone has a nominal voltage sensitivity of 162.0 ±1 dBV, 1 μPa at 20 °C and an operating depth down to 650 m. Its typical horizontal-vertical directivity is of ±2 dB.

Current meter

A single-point, three-component acoustic wave/current meter, model 3D-ACM Falmouth Scientific, Inc.
The current meter ensures the acoustic measurement of vector-averaged current speeds and directions. It is also capable of high-accuracy temperature measurements (resolution, 0.01 °C), with an ASCII serial data output via an RS-232 interface.
The specifications of these sensors include:
– velocity range from 0 to 600 cm/s (resolution, 0.01 cm/s);
– direction and 0° to 30° two-axis tilt measurement (resolution, 0.01°);
– vector averaging period from 15 s to 1 h;
– MEMS pressure transducer (resolution, 0.01% FS).

Pressure gauge

The pressure gauge is a Series 8000 Paroscientific, Inc., 8CDP200-I model, characterised by:
– an accuracy better than 0.01% FS;
– 10-8 resolution (resolution/sample time depends on the integration time);
– low power.

Status and control sensors

These include tilt and heading sensors, for the measurement of the real module attitude on the seafloor, and status sensors for the monitoring of the internal status of the vessel (e.g., internal temperature, power absorption, water intrusion).

Data acquisition

Data from the broad-band seismic sensor and from the hydrophone are acquired by a Q330 Kinemetrics Quanterra digitiser at a rate of 100 sps, which is equipped with an external hard disk (Baler PB14F, 20GB) as the local mass storage. The digitiser is installed inside the electronics container. The Q330 consists of a six-channel, ultra-low-power $\Delta\Sigma$ 24-bit A/D resolution with DSP, 8 Mb of RAM memory, a GPS receiver, and a telemetry application for real-time data transmission. The Q330 datalogger has an integrated GPS receiver, for correct synchronization of the internal clock, and an external GPS antenna with a 5-m cable. With our system configuration, due to the more than 100-m distance between the GPS antenna installed on the buoy and the Q330 positioned in the vessel on the seabed, this set-up could not be used. Therefore, it was necessary to design two electronic boards (Guardato and Iannaccone, 2007) that allow the external use of the same remotely mounted GPS antenna-receiver combination of the Q330 datalogger (unplugged from this), via an RS-485 interface, allowing a much greater distance between the antenna and the recorder. The data from the external GPS transmission are sent over a 120-Ω-impedance, twisted-pair cable (length up to 3 km, at 9600 bps) via different transmitting-receiving lines, in addition to a 1 PPS marker from the GPS receiver and the power control line for the RS-485 interface.
The digital output from the sensors (current meter, pressure gauge, and status and control sensors) are acquired by an embedded computer (MOXA UC-7408) equipped with Linux OS, via an RS-232 port. This embedded CPU features eight RS-232/422/485 serial ports, an eight-channel digital input, an eight-channel digital output, dual 10/100 Mbps ethernet ports, and USB, PCMCIA and CompactFlash interfaces.

Cable

The electromechanical cable connecting CUMAS to the buoy has a diameter of 23 mm and weighs 630 g/m; its length is 140 m. It is dedicated to the transportation of the overall signals (ethernet 10/100 Mbps, four differential pairs of RS-485 ports for the GPS) and the power distribution (48 V DC). The cable was designed also to be used for the installation and later recovery of the system. To simplify these operations, the cable was divided into two sections with underwater electrical connectors: 16-pin, wet-mateable, MCIL16M and MCIL16F connectors.

Technical characteristics of the buoy

The elastic beacon is a semi-rigid structure with a metallic pole of 20 m in height (diameter, 0.25 m) that is fixed to the sea bottom by an antitorsion steel cable (diameter, 40 mm), to a ballast of 17 tons. The pole is kept vertical by a plastic submerged float (diameter, 2.1 m; length 3.2 m) that can be adjusted to a pear shape, according to the local sea conditions. The buoy is equipped with a two square platforms mounted at 2 and 4 m above the level of the sea, which are equipped with ten batteries that are recharged by six solar panels (110 W each). For the charging of the solar panels, the reduced possibility of torsional movement around the vertical axis of the elastic beacon still allows a precise placing of the equipment on the tower where it is best exposed to the sun at a precise angle, therefore ensuring a powerful supply. On the space (1.5 m2) of the square tower, there is a 400-W aeolic generator (Air-X Marine). A meteorological station is also mounted on the tower, providing local meteorological measurements (e.g., barometric pressure, wind velocity and direction, rain-meter, thermometer), to allow the correlation of the air and seafloor data. A 19-inch enclosure for the rack-mountable electronic equipment contains an 802.11g wireless WLAN bridge (Cisco Aironet 1300 series) equipped with an omni-directional antenna, for the data transmission to the land, and other added equipment, including the RS-485 interface with the Q330 GPS receiver and antenna, an embedded CPU, an interface board connected to the CPU with electronic switches used to enable/ disable the power to the overall set-up and to the instrumentation, an Ethernet 10/100 Mbps hub, and a DC/DC power converter (12 V to 48 V, 50 W).

Power requirements

The power requirements of CUMAS

The power requirements for the devices (voltage range specifications included) embedded in the vessel and for the sea bottom sensors are shown in Table 1.

Tab. 1. Sea-bottom power requirements.

Device	Voltage (V)	Power (W)
Q330 datalogger	10÷18	1.0
PB14F Baler	10÷18	6.0 max.
RS-485 GPS interface	10÷18	0.3
CPU Moxa UC-7408	12÷48	6.0 max.
10/100 Mbps hub	10÷18	2.0
Tilt & heading Ostar-Compass	6÷16	0.5
Status card	12	0.2
CMG-40T-OBS seismometer	10÷18	1.7
Pressure gauge transducer	6÷16	0.2
SQ03 hydrophone	10÷18	0.1
3DACM current-meter	7÷24	0.4
Total		**18.4 max.**

The total consumption of the system is therefore around 12 W, with peaks to 18.4 W due to the disc unit of the PB14F Baler.
To minimize the drop in resistance along the electromechanical cable, the whole length of the cable has a continuous tension of 48 V, which satisfies the basic security criteria. In the electrical panel at the surface on the tower of the buoy, a DC/DC step-up converter is installed with 12 V in and a nominal 48 V out. Considering an additional peak power margin of 20%, which corresponds to about 4 W, the DC/DC step-down in the underwater module should have a nominal power of around 23 W; on this basis, a DC/DC converter with a nominal power of 50 W was chosen (model PS50-48S12 PowerSolve).

Power requirements of the buoy

The power requirements for the various loads included on the 19-inch rack enclosure on the tower of the buoy are shown in Table 2.
All of the power supplies pass through the switching board and are protected by a 2-A rapid fuse, while a 1.5-A fuse has been inserted on the main power line of 48 V. The minimum entry tension of the underwater module instrumentation was obtained considering the maximal fall in tension along the cable that can be generated by the maximum current, which must be able to guarantee a transfer of 20 W. Considering this peak power that is needed to run the cable and the underwater module, and the ca. 20 W that is needed for the DC/DC power supply of the control panel on the platform of the buoy, the maximum output power needed by the main power supply system comprising the battery rechargers with charge regulators and by the ten back-up batteries is a little over 40 W.

Tab. 2. Surface power requirements.

Device	Voltage (V)	Power (W)
CR200 meteorological datalogger	7÷16	0.03
Pressure transducer	9÷33	0.01
Wind direction & speed sensor	10÷15	0.1
Rain meter	n/a	none
Temperature sensor	10÷16	0.01
RS-485 GPS interface (including GPS receiver and active antenna)	10÷18	1.5
UC-7408CPU Moxa	12÷48	6.0 max.
10/100 Mbps hub	10÷18	2.0
Tilt & heading Ostar compass	6÷16	0.5
Status card	12	0.2
Bridge Cisco WLAN	10÷18	10.0
Total		20.4 max.

The electrical power supply chain of the system was designed according to the expected consumption by the various users, and comprises:
– 11 Haze-Sonnenshein back-up batteries of 12 V, 110 Ah (one of which is for the exclusive use of the sea light as a visual warning);
– electromechanical cable with its resistance fall (about 4 Ω);
– step-down DC/DC converter for the power supply to the underwater module.

Under these conditions, it is possible to guarantee continuous autonomous functioning for more than 48 h in the case of a total absence of solar or wind energy; indeed, the continuous consumption that needs to be supplied corresponds to a current of around 600 mA at 48 V DC. The nominal capacity of 110 Ah of each of the batteries (when fully charged) allows the continuous functioning in the absence of sunlight for at least three days. To all of this, there should also be added the energy provided by the wind generator, meaning that it is possible to guarantee about a week of autonomy of the system under all atmospheric conditions.

Expected results

CUMAS represents the first marine node of an integrated land-sea network for geo-hazard monitoring in the Campi Flegrei volcanic area. The CUMAS data, which is continuously sent to the land acquisition center, will be integrated with those from to the whole of the surveillance system. In particular, the seismological data will be used jointly with the land seismic network and will contribute towards improvements to the localization of earthquakes occurring in the sea sector of the caldera. Furthermore, and as demonstrated by Vassallo et al. (2007) this use will enhance the seismic detection capabilities for low energy earthquakes that are usually masked by the high level of anthropic seismic noise seen in this area. The pressure gauge measurements, which are corrected for tidal effects and complemented with coastal tide gauge network data, can for the first time estimate the vertical seafloor bradyseismic movement, which until now has only been measured on land.