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GEOSTAR: a technical overview of the first European seafloor observatory

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Abstract - Between 2000 and 2001, the multidisciplinary seafloor observatory GEOSTAR, developed in the framework of a European project, successfully carried out the first long-term deep-sea mission in the Southern Tyrrhenian Sea at the depth of 2000 m offshore Ustica Island. During the mission, scientists and engineers could get real-time continuous access to the deep-water environment. Around seven months of scientific data were collected, opening the road to the development of submarine networks of seafloor observatories. The scope of this paper is to give a technical overview of GEOSTAR, describing, in particular, the system architecture, the main features of its components and the peculiarities of the concept with respect to the experiences so far developed worldwide.

1. Introduction

The need for long-term seafloor observatories for solid Earth studies (as well as for oceanographic, climatic and environmental investigations) has been widely recognised for many years, leading to the definition of a “Seafloor Observatory Science”, complementary to the traditional “Expeditionary Science”. Several national and international efforts are underway to solve the challenging technological issues associated with such developments; recent international workshops like “Multidisciplinary Observatories on the deep seafloor” (Montagner and Lancelot, 1995), “Illuminating the Hidden Planet. The future of seafloor observatory science” (NRC, 2000) and in “Science-Technology Synergy for Research in Marine Environment: Challenges for the XXI century” (Beranzoli et al., 2002) have contributed in defining the scientific needs and technological requirements, as well as to keeping the state of the art updated.

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According to a commonly recognised definition, a seafloor observatory may be defined as an “unmanned system at a fixed site in the ocean providing power, control and communications to sensors located on or below the seafloor, in the overlying water column or at the air-sea interface”. Its purpose is therefore to carry out long-term scientific investigations in a fully automated way, ensuring, at the same time, a high level of interaction with the operator on shore.

2. Technical description

GEOSTAR (GEophysical and Oceanographic STation for Abyssal Research) is one of the few experiments on deep-sea scientific observatories currently being carried out around the world, fully qualified in real operational conditions; it is the result of the joint efforts of Italian, German and French scientific organizations and industrial companies, supported by EU in the framework of MAST-3 programme. The GEOSTAR concept is shown in Fig. 1.

Designed for missions of up to 1 year at 4000 mwd, GEOSTAR is composed of four main subsystems:
- the Bottom Station,
- the Scientific Payload,
- the Communication System,
- the Deployment and Recovery Vehicle (Mobile Docker).

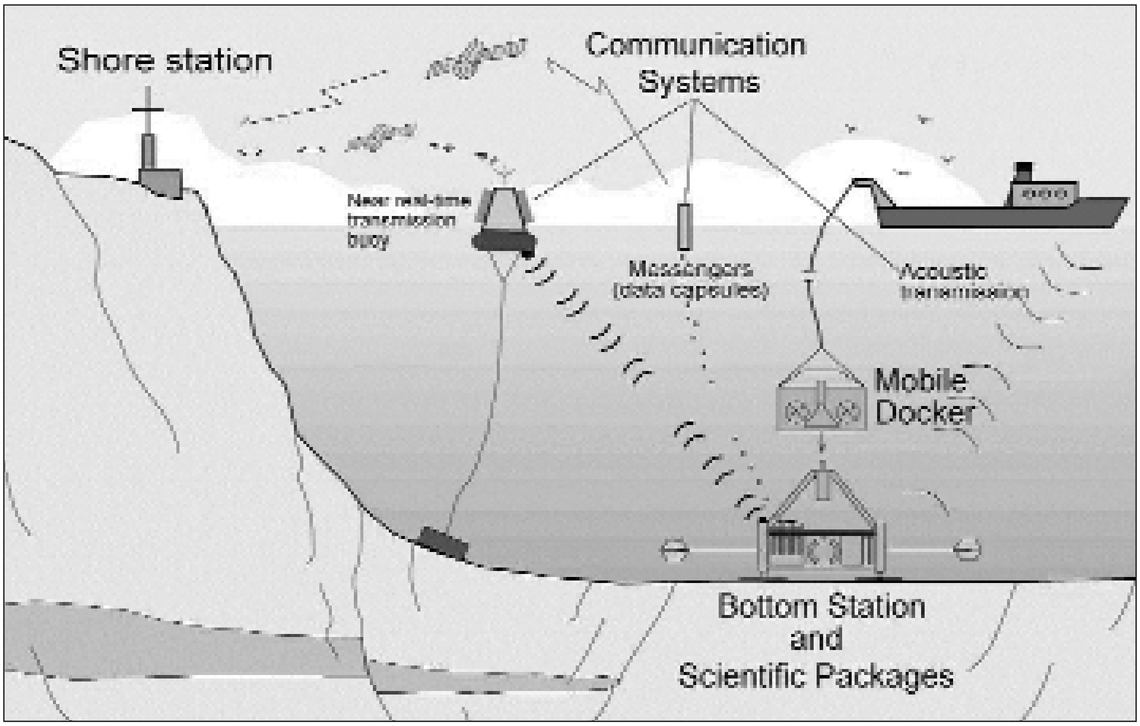

Fig. 1 - GEOSTAR concept.

A basic technical description of these subsystems is given here; readers interested in more technical details can refer to papers like Gasparoni et al. (2002a) for the Bottom Station, Clauss et al. (2002) for the Mobile Docker and Marvaldi et al. (2002) for the Communication Systems.

2.1. Bottom Station

GEOSTAR seafloor observatory (hereafter referred as to Bottom Station) is a stand-alone unit based on a four-legged frame supporting the scientific payload, the vessels housing the control system and the battery pack, the communication systems, the auxiliary sensors and transducers. The Bottom Station is positioned at seabed (and recovered at the end of the mission) by the Mobile Docker.

The Bottom Station (see Fig. 2) is characterised by specific technological solutions such as:

- an open frame (3500x3500x2900 mm, 25 kN in air, 14 kN in water) made in aluminum alloy, with titanium pressure vessels;
- active devices for the deployment of specific packages from the Bottom Station (like the seismometer and the magnetometers);
- a dedicated data acquisition, storage and mission management hardware, based on custom-built low power electronic boards, capable of managing a data flow in the order of 2.5 Mbyte/hour with a power consumption ranging between 180 mA (IDLE mode, only data acquisition

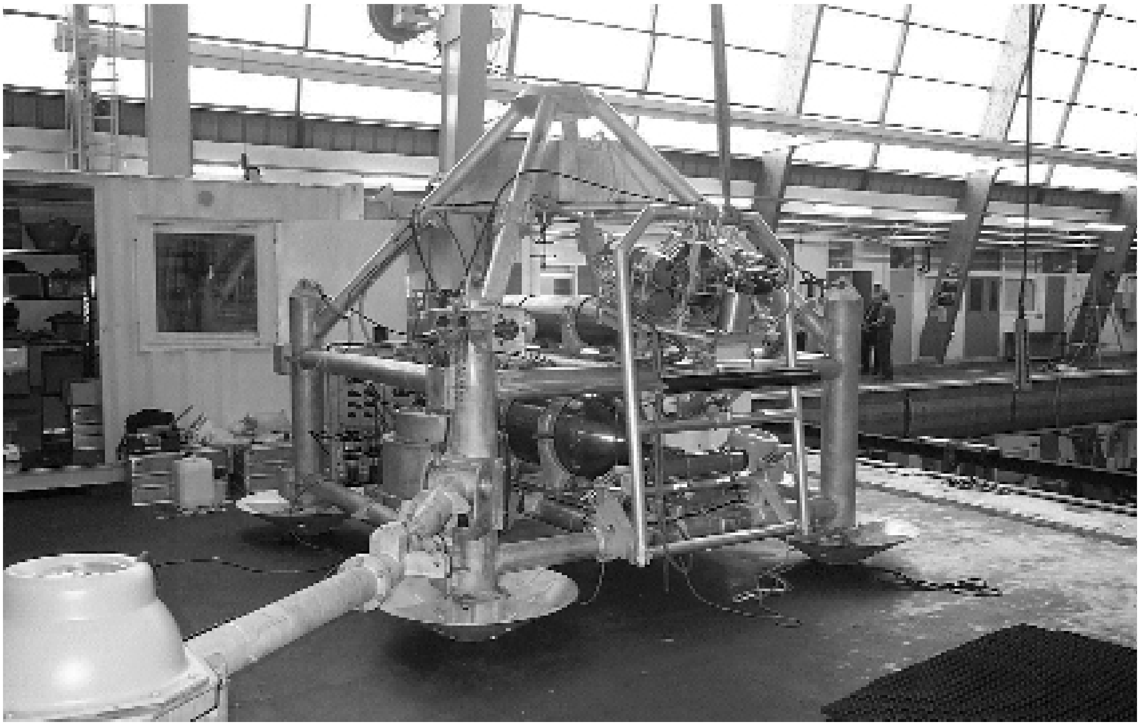

Fig. 2 - GEOSTAR Bottom Station during final tests in IFREMER deep water basin.

and control electronics powered on) and 450 mA (MISSION mode, all scientific packages powered on);

- autonomous mission control capabilities, including power management and self-diagnostics;
- possibility of being reconfigured according to different mission requirements and sites;
- multiple possibility of interfacing with external devices (communication systems, deployment system) for continuous control of system status both during the deployment phase and during the mission.

The mass memory available is in the order of tens of Gbyte, while the energy supply is based on a 24 V, 3000 Ah battery pack.

2.2. Scientific Payload

GEOSTAR Bottom Station has been designed around a multidisciplinary Scientific Payload, covering the needs of geophysicists and oceanographers, but at the same time is open to supporting new payload, pertaining to other disciplines.

Table 1 shows the scientific packages hosted during the first two missions.

Table 1 - GEOSTAR Scientific Payload. Packages indicated with asterisk have been custom-built and qualified inside the project.

Scientific Package	Mfr. and model	Geostar 1	Geostar 2
triaxial broad-band seismometer	Guralp CMG-1T	✔	✔
scalar magnetometer	GEM Systems GSM-19L	✔	✔
fluxgate magnetometer	(*)	✔	✔
300 kHz Acoustic Doppler Current Profiler	RDI Workhorse Monitor	✔	✔
CTD	SeaBird SBE-16 + SBE-5	✔	✔
transmissometer	Chelsea Alphatracka Mk.II	✔	✔
electrochemical package (pH, H2S)	(*)		✔
water sampler (48 × 500 ml samples)	MacLane RAS-48-500		✔
hydrophone	Geomar		✔
gravity meter	(*)		✔
single point current meter (incl. tilt, H, T, P)	FSI 3D-ACM		✔

Tests with a seismometer, derived from a space-qualified prototype, have also been carried out, demonstrating the capability of the Bottom Station to operate as support platform for technological activities (like the qualification of new instrumented systems).

2.3. Mobile Docker

GEOSTAR does not depend on traditional deep-sea Remotely Operated Vehicles (ROV) for its operation, especially for the deployment and recovery. Although ROVs can presently be considered as the standard tool to carry out underwater activities both for scientific and industrial purposes, in order to meet the specific requirements of the Seafloor Observatory

Science, they suffer form some basic limitations. First of all, availability of deep-rated ROVs is limited to very few nations (USA, Japan, France); more important, ROVs have a very small capability in carrying external payload (100-150 kg max in air); for this reason the existing Seafloor Observatories based on this concept (like the Japanese VENUS, or the American H2O) are in fact made of a multiplicity of modules, each characterised by a weight and volume compatible with the support vehicle used. These modules require separate deployments at the seabed; this has obvious consequences in terms of the ship time required for a single mission.

To get the connection to external facilities (like a central data acquisition and control system, a power source, a communication cable) these modules have to be connected one to the other to a submarine junction box; this operation implies further complexity for the task involved (manipulation, electrical underwater connections) as well as the adoption of critical and expensive components like ROV-mateable underwater connectors.

To overcome these limitations, the GEOSTAR vehicle has been designed according to a "shuttle" concept, capable of handling loads of up to 30 kN with accurate positioning at seafloor as well as easy and cost-effective management.

Basically the Mobile Docker is a special underwater vehicle dedicated to the Bottom Station deployment and recovery. Suspended to an electro-mechanical umbilical cable (see Fig. 3), the vehicle is equipped with electrical thrusters ensuring mobility on the horizontal plane, while the winch onboard the support vessel regulates its ascent/descent.

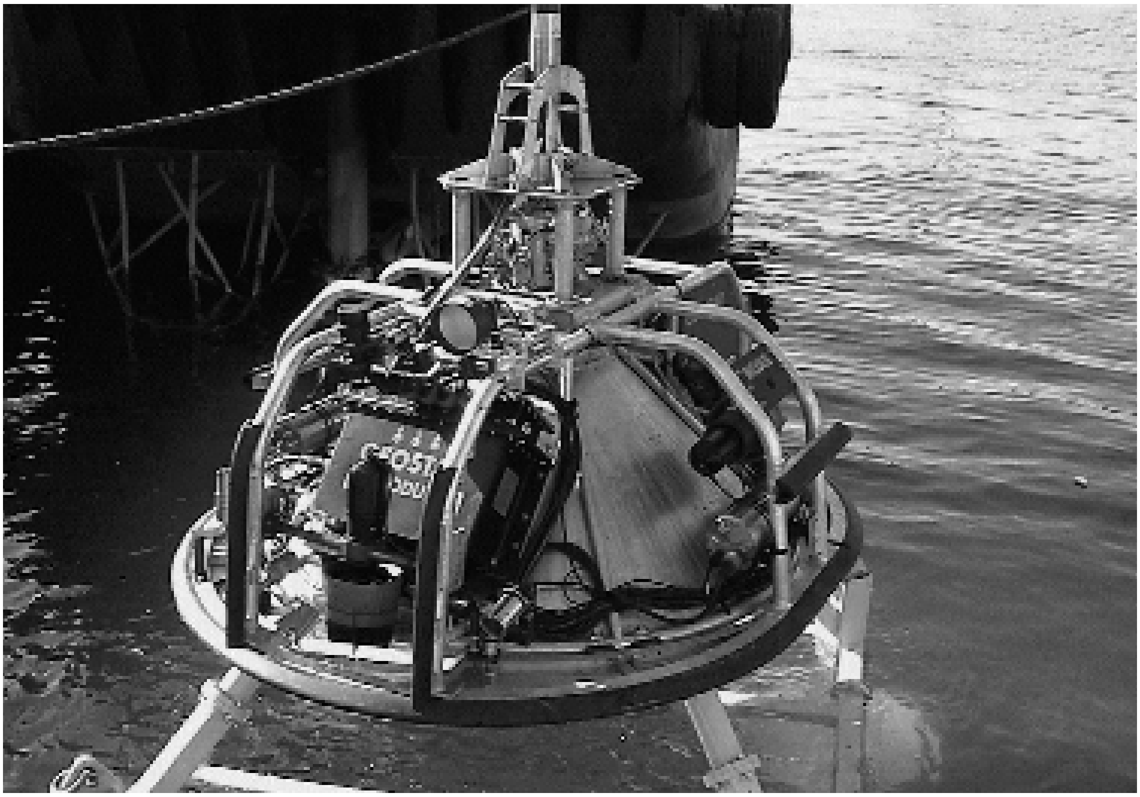

Fig. 3 - Mobile Docker.

By means of instrumented (a 360°sonar, LF transponder; see Fig. 4 left) and visual systems (4 TV cameras + lights; see Fig. 4 right), the Mobile Docker is guided from surface to reach the deployment area, or find the Bottom Station for recovery.

During these operations the vehicle control is ensured by fibre optic telemetry.

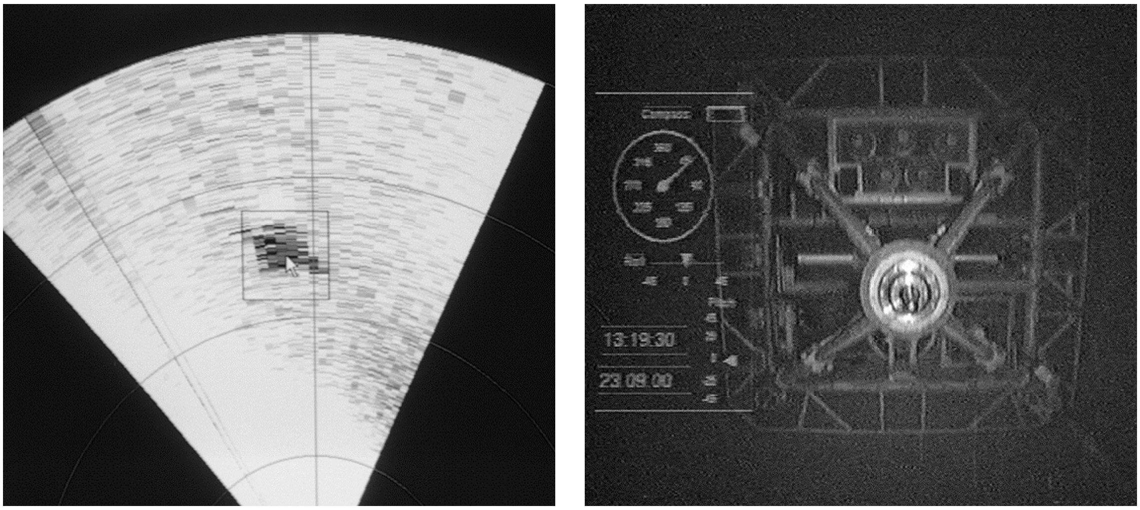

Fig. 4 - GEOSTAR Mobile Docker approaching the Bottom Station: (left) screen shot of sonar image during recovery and (right) video image of the Bottom Station (view from above).

2.4. Communication System

Communication is another aspect in which the GEOSTAR project has developed solutions in many aspects original and cost-effective.

GEOSTAR is provided with two Communication Systems, intended to transfer data from the Bottom Station to the final scientific users and to ensure full control of the mission. The first one (the so-called Messenger Communication System) consists of a set of buoyant data capsules (the Messengers), which are capable of carrying a small but significant percentage (presently up to 40 Mbyte) of the data collected by the Observatory up to the surface. Data are transmitted to shore via the ARGOS satellite system, or may be downloaded directly from the Messenger itself (once recovered by a ship of opportunity). Messengers are kept stored on the Bottom Station and released periodically or on external request; typical periodicity is one-two months. Up to 5 Messengers can be presently managed by GEOSTAR Bottom Station (see Fig. 5a).

The second one is a bi-directional Near-Real-Time Communication System, based on an acoustic telemetry link between the Bottom Station and a moored buoy (see Fig. 5b), and then a satellite (or radio) link from the buoy to shore. This system allows scientists and technicians to get daily communications with the Bottom Station, simply connecting their office PC to the telephone line.

The Acoustic Link is based on a Multi-modulation Acoustic Modem operating at 24 kHz (up to 2400 bit/s).

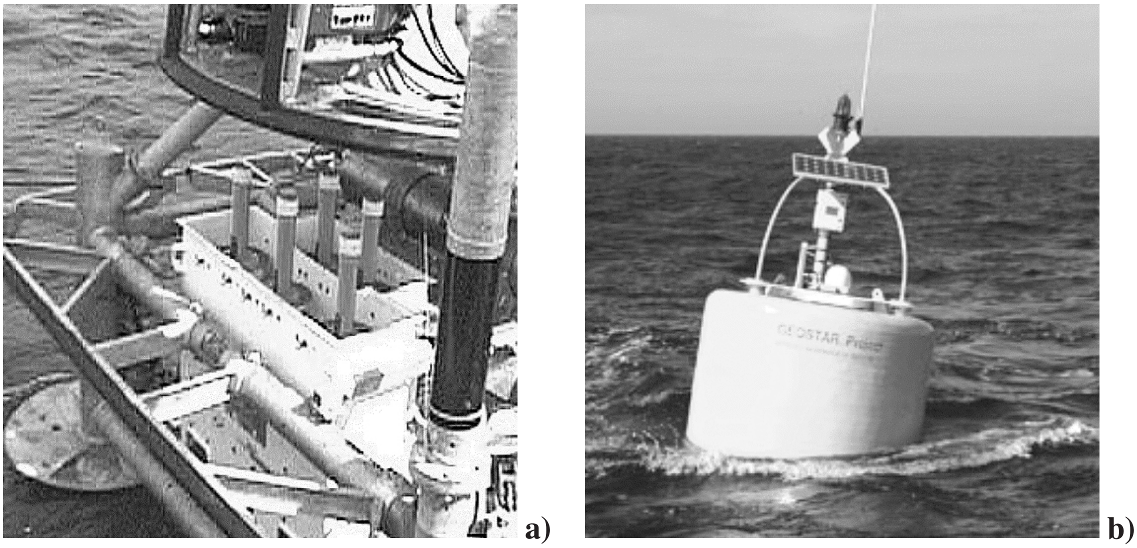

Fig. 5 - Communication System: a) five ARGOS Messengers onboard GEOSTAR Bottom Station; b) the Near-Real-Time Communication buoy.

3. Main results

In August 1998, GEOSTAR was deployed for the first time in Adriatic Sea at 42 mwd, and operated continuously for 450 hours. The mission served to demonstrate, in real conditions, all system capabilities and marine operations. At the same time, significant data regarding seismic events, magnetic field variations, water circulation and characteristics of the area were collected. Details on this mission can be found in Beranzoli et al. (2000).

The long-term scientific mission started on September 23, 2000 and was concluded on April 16, 2001 with the system recovery (Fig. 6). 4159 hours of continuous data were collected with an acquisition efficiency of 99.6% (Favali et al., 2002; Gasparoni et al., 2002b). Significant details on the research work till now performed on the basis of the scientific data collected with GEOSTAR can be found in Fuda et al. (2002), Beranzoli et al. (2003a, 2003b), Iafolla et al. (2003).

During the mission, a significant selection of scientific and status data was transmitted to shore in two ways: by data capsules (Messengers) automatically released by the observatory and transmitting via ARGOS satellite once at surface; via acoustic link to a surface buoy and then via radio and/or satellite (INMARSAT) connection to shore. In this way, first data were available while the observatory was still at the seafloor. The complete data set was downloaded from the observatory hard disks just after its recovery. The acquired data are presently undergoing quality check procedures, elaboration and interpretation.

This mission represents so far the longest experience of a deep-sea observatory, equipped with a central data acquisition and control system managing a multidisciplinary scientific payload as well as a near-real time communication system to shore.

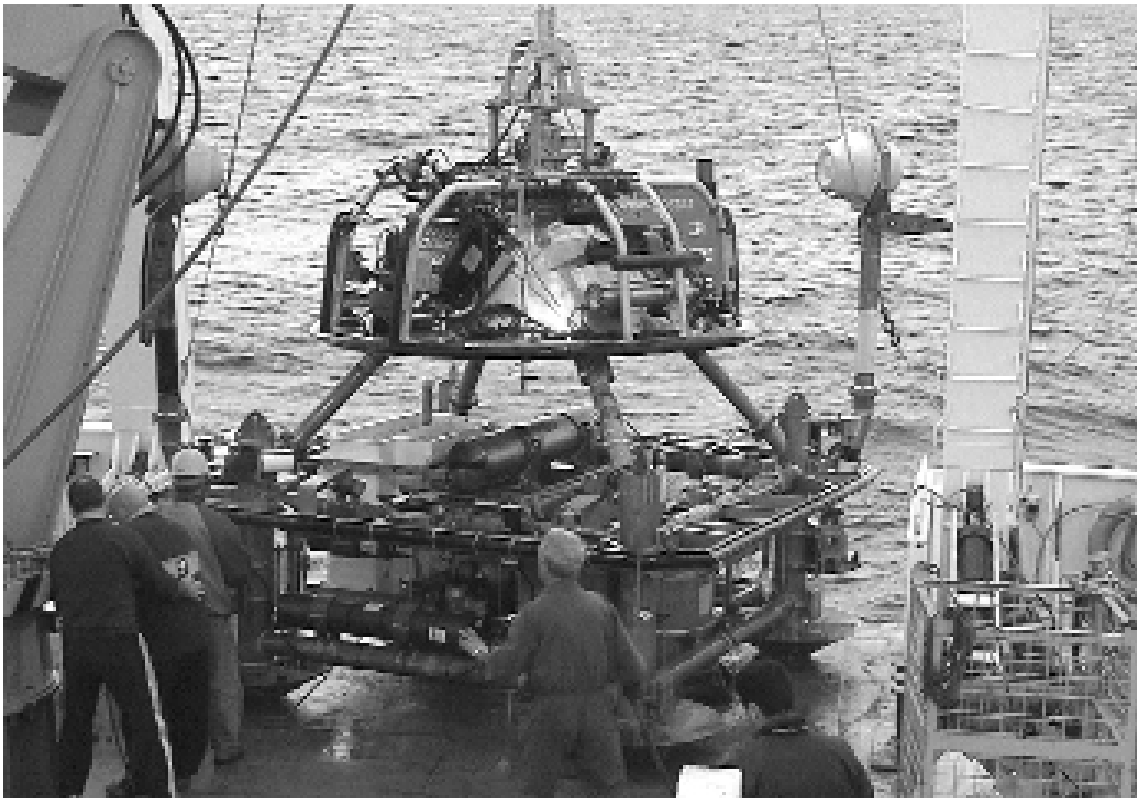

Fig. 6 - GEOSTAR immediately after recovery from the deep-sea mission (April 16, 2001).

4. Conclusions

Through the uninterrupted acquisition of around 180 days of a multidisciplinary payload, GEOSTAR demonstrated the feasibility of the operation of seafloor observatories technically conceived in an alternative way with respect to other ongoing experiences (USA, Japan). GEOSTAR concept is not dependent on deep-sea ROVs or manned submersibles, and can be managed by a medium-size ship (like the Italian R/V Urania) with consequent associated low cost. The scientific payload is managed by the same data acquisition and mission control system; this ensures that measurements are referred to the same clock.

Analysis of data collected demonstrated the correct operation of the system.

At the same time, with minimum modifications, the concept of Bottom Station developed in GEOSTAR is fully compatible with the connection to external cables (where they exist), allowing the conversion of GEOSTAR from a moored-buoy based observatory to a cable-based observatory.

The success of GEOSTAR is also demonstrated by the fact that through the same concept, other seafloor observatories are being developed under national initiatives. We refer, in particular, to SN-1, the first node of the Italian submarine network, that was successfully deployed on October 9, 2002 in a site of primary scientific interest (eastern Sicily, 20 km offshore Catania, 2105 mwd).

The technological development is also progressing in the framework of other ongoing initiatives at European and national level: ORION (GEOSTAR-3) project, started in 2002, will make solutions available for two critical aspects, enabling the future operation of submarine networks of seafloor observatories: the networking and the burial of seismometers; with the MABEL project a seafloor observatory will be operating in Antarctic waters for the first time.

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