Victor 6000: New High Resolution Tools for Deep Sea Research. « Module de Mesures en Route »

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***Abstract*— This paper describes the new survey module (called *"Module de Mesures en Route")*, of the Remotely Operated Vehicle (ROV) *Victor 6000* and presents the first results obtained during two scientific cruises held during the summer of 2006 (Viking and Momareto).**

I. INTRODUCTION

Victor 6000 is a French ROV entirely dedicated to deep sea scientific studies. Owned by Ifremer, Victor 6000 has achieved ten oceanographic cruises in the Atlantic, Arctic and Pacific oceans. More than 300 dives have been carried out from L'Atalante, Thalassa, Pourquoi pas? and Polarstern research vessels. *Victor 6000* is a modular submersible made up of two sub-systems:

– The vehicle itself includes specialised servicing equipments dedicated to propulsion, video surveying, lighting, remote control, navigation and tele-manipulation. The positioning is carried out by an ultra short baseline system "POSIDONIA" ®.
– The scientific module is composed of a frame located under the vehicle where most of the scientific instruments are installed.

Today, *Victor 6000* is proposed to scientists with a "basic sampling" module, which includes a retractable drawer, sampling tools and temperature probes. Specific instrumentation can be connected to the tool sled using power connectors and serial links. With such a configuration, the system is well adapted to sample, observe and manipulate within constrained areas.

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II. NEW SURVEY MODULE "MODULE DE MESURES EN ROUTE"

To increase the ability of the vehicle to explore and work on larger areas (km scales), a new survey module has been designed. This new module, called ***"Module de Mesures en Route",*** is unique in Europe. It complements oceanographic vessels for high resolution bathymetric mapping. It can cover surfaces of up to 1,5 km^2 per day.

The new ***Module de Mesures en Route***, is able to gather real time bathymetric, chemical, acoustic and visual data over large areas using different sensors:

– A RESON 7125® multi-beam echo sounder for high resolution mapping.
– An "OTUS" black and white camera for long range optical imaging.
– Flashes for the camera (1200 joules).
– A Seabird® SBE 25 CTD, a water sampler, a magnetometer.
– A EK60 SIMRAD® vertical echo sounder.
– In 2008, a new sub-bottom profiler will be installed.

A. Reson Seabat 7125® on *Victor 6000*

The SeaBat 7125 multi-beam echo-sounder system operates at 400 kHz and offers up to 120° swath coverage to an altitude of at least 100 meters with a maximum slant range in excess of 200m. The maximum depth is 6000m.
The system is composed of:

– On the surface, a processor (7P).
– On the vehicle, a titanium housing and two arrays (one projector and one receiver).
– Data is transmitted in full duplex between surface/vehicle with an optical telemetry.

1) 7P processor

The 7P processor unit consists of an industrial PC running an embedded version of windows XP® operating system.
The PDS2000® data acquisition software suite also runs on the 7P machine.

The purpose of the 7-P sonar processor unit is to receive data from the sonar arrays, beam-form acoustic data, time stamp data, interfacing with external survey sensors, georeferencing bathy, sidescan and snippet data, generating 7K data records with georeferenced data, export over the Ethernet connection, display the sonar image and also, to allow user interface.

2) Bathymetry

256 equally spaced, fully corrected bathymetry soundings are generated per ping and broadcast from the 7P processor over a standard 10/100 using UDP protocol. Each sounding may be corrected for: refraction, mechanical offsets between the projector and hydrophone, sensor offsets, attitude, heading, depth and tide.

3) Input auxiliary sensors

For corrected and time stamped data, the 7P processor receives sensors from the MMR and from the surface. Serial link or Ethernet link are used.

- From Octans (IXSEA®) the vehicle attitude (heave, pitch, roll & heading).
- From Paroscientific digiquartz ® the vehicle depth.
- From clock ACEB® the time reference which is a combination of 1PPS and ZDA message.
- Vehicle position: dead-reckoning navigation over the Ethernet network.
- Sound velocity (Operator input).

4) Export Ethernet data

The 7P exports data over a 10/100 ethernet using UDP protocol Output data from the 7P:

- Bathymetric, sidescan and snippet data and, sensor vehicle.
- Sound velocity profile. Run time installation parameters. Status and alert messages.

5) The LCU

The LCU is installed inside a cylindrical titanium pressure housing that has electrical connectors at one end.

Data from the hydrophone is digitised in the LCU, formatted and transmitted with an optical telemetry to the sonar processor on surface. Power distribution is also located in the LCU.

6) The projector

The TC 2160 projector unit generates an acoustic signal in the water column below the vehicle. The TC2160 is a 70-ring ceramic projector operating at 400 KHz.

Along-Track Beam 1° width and the swath coverage is 130°.

7) The Receiver

The EM7200 Receiver Unit receives acoustic signals from the water below the transducer. It filters, amplifies, and digitizes the signals; then sends them to the LCU.

8) The telemetry

Data is transmitted between LCU (vehicle) and 7P (surface) in full duplex with an optical telemetry. Two ways communication, on one single mode fibre are available, one downlink at 1300 nm, and one uplink at 1500 nm.

Serial data rate is 1Gbyte/s and the optical budget is 25 db at 1550 nm and 1300nm.

9) Operation principles

The transmission signal is a CW pulse of operator selectable length between 33 and 200 µsec. The system operates on a single frequency of 400 kHz with a transmission bandwidth of 30 kHz. The transmission source level is operator controllable between OFF (0dB) and maximum (220dB).

In reception, the EM7200 uses 256 receiver channels

10) Performances

Depth	6000m
Frequency	400 kHz
Beams	512 equidistant
Bathymetric accuracy	0.2% altitude ROV
Resolution	5% altitude ROV
Swath width	3.4 altitude ROV (200m max)

B. Camera OTUS and Flashes

For high altitude observation at 8 m to 12 m, a new generation of black and white still camera associated with flashes (1200 joules) is now available on the MMR.

In real time, the scientist could have a large view of each picture of the bottom (100m²). In post processing mosaics can be done.

1) Still camera

- Still camera with a CCD THOMSON MPP,
- 1 M pixel. Size: 19x19um,
- Rate of picture: 1 image x 5 seconds,
- Software: DIGIPHOT® For control and loading the pictures in real time,
- Ethernet link: 10/100Mb.
- Pictures tiff: format 2Mbits pixel on 14 bits.

2) 4 Flashes

- 300 joules each, one shot every 3 seconds
- Automatic Light Feedback
- Real time control/command

C. Software on MMR

Software package have been developed for real time and post process data on MMR.

TECHSAS® is run by Linux RedHat® Operating System and installed on an industrial PC with multiport serial boards. It provides the following functionalities: sensor measurements acquisition, measure time-stamping, measure recording, technical display for control and real-time broadcast on the local IP network.

SUMATRA® provides oceanographic or hydrographic users real-time cartographic monitoring of the main scientific sensors of the remote-operated devices.

CARAIBES® and ADELIE® software are dedicated to data post processing.

CARAIBES provides scientific tools to:

– Evaluate the performances of the Reson Seabat 7125® (accuracy, lengthwise,…),
– Process multi-beams echo data (i.e. bathymetry, backscatter) to get mosaic or DTM maps,
– Improve the ROV acoustic navigation with specific tools.

D. Navigation, equipment and method

Navigation on *Victor* is POSIDONIA system (ultra-short baseline). Accuracy is about 1% of depth. *Victor* also uses a dead-reckoning navigation (shift about 10m/2h).

Navigation is very important for survey. One of the main problems in post processing data is bad positioning.

1) Navigation Equipment

The onboard navigation system consists of: an RDI Doppler velocity log Workhorse Navigator® at 600 KHz, an iXSEA® fibre-optic gyrocompass OCTANS, which provides geographical heading (to true North), roll/pitch angles and rate, a Paroscientific depth sensor®; an iXSEA® long-range ultra-short baseline acoustic positioning system POSIDONIA®.

2) Navigation method

The navigation method is based on dead-reckoning in the horizontal plane. The horizontal velocities from the WH600 are compensated for known offsets with respect to the OCTANS (mounting angle and calibration offsets). The velocities are then projected onto the North and East axes and numerically integrated from an initial reference point. Only bottom-lock velocities are used.

The initial reference positions can be geographical coordinates given by the user, e.g. known sea-bottom features, or USBL positions validated by the operator.

The update of the dead-reckoning navigation by reference positions can be done at any moment. Dead-reckoning has proven very robust, a reboot or start-up during a dive can be done without loss in subsequent navigation, if a reference position for update is available.

3) Methods for multibeam survey

The deep sea survey acoustical system is not accurate enough to make a survey with good coverage. The shift with dead reckoning is about 10m/2h. After 4 hours of dive the distance between profiles could be great and it would be impossible to make a profile survey without blanks on the “map”.

For *Victor 6000*, the method consists of coming back every 2 hours to the same marker and resetting the dead reckoning on this point. The drift on the survey will be less than 10m/2h. The main inconvenients of this method are:

– The absolute position of the marker is localised with the Posidonia system with an accuracy of 1% of depth (so absolute position on the map too).
– The distance and the time on the bottom increase (time + distance spent to come back to marker every 2 hours).

III. Scientific Cruises

The new ***“Module de Mesures en Route”*** was used for the first time during two scientific cruises during the summer of 2006 on the Pourquoi pas? French Research vessel.

A. Scientific cruise “VIKING”

The VIKING cruise was a multidisciplinary (geology, geophysics, geotechnics, geochemistry, biology and microbiology) study of focused fluid escape features (pockmarks and mud volcanoes) off Norway. The objectives of the cruise were to assess the impact of these fluid escape features on methane release to the atmosphere, to determine their relevance to slope stability and their importance for the development of benthic ecosystems. The ROV *Victor 6000* and a set of specific tools were used to study in detail two sites. The first site, on the northern flank of the Storegga slides, is characterized by the occurrence of gas hydrates in the slope sediments, large slides and numerous fluid escape structures, mainly pockmarks. At present, active mud expulsions are observed at the second site, the Hakon Mosby Mud Volcano. The cruise focussed on trying to specify: 1/ the small scale structure, the formation and evolution models, the activity level (continuous or episodic) of the seep sites, 2/ the relationships between fluid escape structures and gas hydrates; 3/ the relationships between fluids and slides; 4/ models for the development of benthic microbial communities and associated ecosystems, as a function of biogeochemical gradients at the study sites.

During the cruise, the new “Module de Mesures en Route” (MMR) was mounted on *Victor* during three dives. In the Storegga area, two detailed micro-bathymetric maps of two large gas chimneys were produced. The study sites were selected in particular because of their morphological expression at the seafloor. In contrast to the Nyegga pockmarks, the two gas chimneys mapped form mud domes. These maps were used to plan further seismic investigations, using seafloor instruments which needed to be precisely deployed during the R/V Logatchev TTR16 – Leg 3 cruise.

On the Hakon Mosby Mud Volcano, in order to document the activity level of the structure, one of the specific objectives of the VIKING cruise was to collect observations to compare to previous existing data, especially those of the Ark XIX3/b cruise in 2003 on the R/V Polarstern. A MMR dive was thus dedicated to obtain a new bathymetric map of the central part of the volcano. When compared to the data obtained in 2003, this map shows significant changes in the topography that suggest fresh mud flows (Figure 4).

Another success of this dive was the use, for the first time, of the vertical-echo-sounder ER60. The echo-sounder could detect locations of individual gas flares (see §IV).

Furthermore, a dense coverage of photos over an area of 400 m by 400 m, from the grey mud central part of the volcano to outer pogonophoran fields, was carried out with the large aperture OTUS black and white still camera. OTUS-type surveys appear to be promising to monitor temporal changes in the faunal and microbial distributions on the seafloor.

B. Scientific cruise "MoMARETO"

The MoMARETO cruise (Sarrazin et al. 2006) took place from August 6 to September 6, 2006 on three hydrothermal fields of the mid-Atlantic ridge. The main objective of the cruise was to study the spatial and temporal dynamics of hydrothermal communities colonizing the MoMAR zone, located on the Azores Triple Junction. The first leg of the cruise was dedicated to the final integration and validation phase of 13 equipment prototypes developed during the European EXOCET/D project. The proposed approach for the second leg was to study the response of different hydrothermal species to their environment at different spatial and temporal scales. Although most of the dives were centred on Lucky Strike, two other vent fields, Menez Gwen and Rainbow, were also visited.

1) The Lucky Strike vent field

Lucky Strike is one of the largest known active vent fields (>1 km^2). The vent sites are distributed around a large lava lake at depths varying from 1650 to 1750m (Fouquet et al., 1995; Ondréas et al., 1997). Well-defined hydrothermal edifices such as Tour Eiffel, Elisabeth and Bairro Alto, as well as diffuse flow areas, are scattered throughout the vent field. The composition of hydrothermal fluids varies significantly from site to site, suggesting the presence of two fluid sources (Charlou et al. 2000). Faunal communities are dominated by extensive mussel beds of *Bathymodiolus. azoricus* partially covered by visible microbial mats. The vicinity of active high-temperature chimneys, flanges and cracks are colonized by *Chorocaris chacei*/*Mirocaris. fortunata* shrimp assemblages (Desbruyères et al. 2001).

2) Micro-bathymetric survey

The first two dives of the cruise were used to gather microbathymetric data of the Lucky Strike vent field with the new MMR module. The challenge was the acquisition of high-quality bathymetric data on a terrain characterized by a chaotic relief. Tall active hydrothermal edifices, fields of pillow lava, typical lava lake structures, fissures and cracks are found in the area. Altitude variations can reach 200m. A first survey surrounding the lava lake was done at 30m altitude (1000m x 800m). Seven transects of 1000m long were done over the entire vent field, at a speed of 0.3-0.4m/sec. The range at this altitude was 90m. To insure the quality of the data, transects were separated by 70m. To improve navigation data, a calibration of both navigation systems (BUC and dead-reckoning) was done once every two transects on a know calibration point: the Tour Eiffel hydrothermal edifice. A raw 50-cm resolution map was obtained with the CARAÏBES® software (Figure 1-2). For comparison, the previous map of the area had a resolution of 20 m. The overall survey requested 30 hours of bottom time.

This fine-scale resolution permitted, for the first time, fine analyses of geological features such as faults, fissures, lineaments and comparison with geological maps deduced from numerous in situ observations made previously on this area. Future studies will be conducted in order to analyse direction and nature of local structuration and their relation to the distribution of hydrothermal vents.

A second passage was done at 8m to couple the micro-bathymetric survey with OTUS. The data acquired give important insights on bottom texture and structure and permitted mapping of vent faunal habitats in the vicinity of active sites. A complete coverage of the Tour Eiffel edifice was done (80m x 120m). The survey around this 10-m high structure was particularly tedious and several additional passages were needed to complete the data set. A first image mosaic mapped the distribution of faunal assemblages around the structure. This small-scale survey took 4 hours of bottom time (Figure 3).

With the SIMRAD ER 60, a zigzag strategy was promoted in order to cover active and inactive areas around high- and low-temperature vent emissions (see §IV).

IV. VERTICAL ECHO SOUNDER ON MMR

A SIMRAD ER-60 vertical echo-sounder was installed on the survey module to evaluate its potential for mapping high- and low-temperature vent emissions (Momareto survey) and to acquire high resolution acoustic data of individual gas flares (Viking survey). Acoustic signals were provided by a split-beam deep water 200 kHz transducer with a –3dB beam angle of 6.3° (SIMRAD ES200-7CD). For both surveys the ping interval was 0.5s with 256µs pulse length.

For Viking survey dive, an exploratory strategy was promoted to localise bubble flows which could be detected by the echo-sounder surveying at an altitude of 40m at depths of 1260m in the Hakon Mosby Mud Volcano area. Four individual gas flares were observed corresponding to different crossings over the bubble source (Figure 5). This was helpful to guide Victor to the gas bubbling site at the origin of a gas flare (Figure 6). Mean volume backscattering strength of gas flares were estimated by Movies+ software and values spread between –49 and –41 dB re 1 $m^{-}1$. The reduced sensor-to-target distance allows measurements of target strength (TS) from bubbles taken as individual targets by ER-60 algorithm. Target strength measured values varied from –60 to –42 dB using standard ER-60 detection parameters and a minimum threshold of –60 dB. Higher TS values correspond to echoes surrounding the upper part of the bubble plumes. The use of ROV mounted echo-sounders reduces the sensor-to-target distance, in comparison to hull mounted echo-sounder data, allowing to explore direct measurements of bubble target strengths and gas flare volume backscattering strengths. These measurements could then be used to estimate gas release of deep sea bubbling sources.

For Momareto survey dive, a zigzag strategy was promoted in order to cover active and inactive areas around high- and low-temperature vent emissions and to obtain contrasted profiles at an altitude of 30m over bottom and a depth of 1700m. The signal acquired over the Tour Eiffel active structure was astonishing. The plume of high-temperature fluids escaping the vent was detected with a great resolution showing acoustic density variations according to distance from the source. A lower signal was observed on surrounding surfaces. Whether this signal is due to low-temperature emissions, to faunal coverage or simply to an acoustic artefact resulting from a sharp bottom topography detection still has to be defined. The reduced sensor-to-target distance allows the detection of individual fish around vent areas. Positive results from this feasibility test show the potential use of a vertical echo-sounder to detect and map vent emissions as well as to estimate fish abundance in the surrounding environment.

V. Conclusion

During these two scientific cruises, the ***"Module de Mesures en Route"*** was deployed during five dives between 1000 and 1700m depth for a total of 90 hours of bottom time. The two targets presented different topographic reliefs: a 1 km^2 mud volcano mound and a high relief terrain, with hydrothermal structures reaching 10m in height. The MMR tools have provided very fine-scale maps which will be used to constrain the geology and the biology of these unusual areas.

An important gap in the acquisition of bathymetric data was present between vessel mapping with resolution of 50 to 100m, and ROV optical high resolution mapping at 3m of altitude.

The new module ***"Module de Mesures en Route",*** proposes an intermediary view (altitude of 10 to 50m) with high resolution bathymetric mapping (10cm to 1m) and high resolution of plumes or gas flare detection in water column. (Figure 1-2)

Associated with this high resolution mapping, the MMR proposes an optical view at 10m with the new black and white camera OTUS (Figure 3).

The combination of these 3 equipment constitutes a very important "leap" in the methodology of mapping during a scientific cruise. It permits a new strategy with:

- An area overview with ship: bathymetric mapping (resolution 100m). An area of 100 km x 10 km can be covered in 3 days.
- A ROV **"MMR" survey:** high resolution bathymetric mapping on an area of special interest (resolution 10cm /1m) with plume detection with vertical echo sounder. An area of 3 km by 2 km can be mapped in 3 days.
- A ROV dive for visual observation and sampling on a very small area, selected from previous maps.

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R/V Pourquoipas?: Captain P. Guillemet and his team.

The team of *Victor 6000*.

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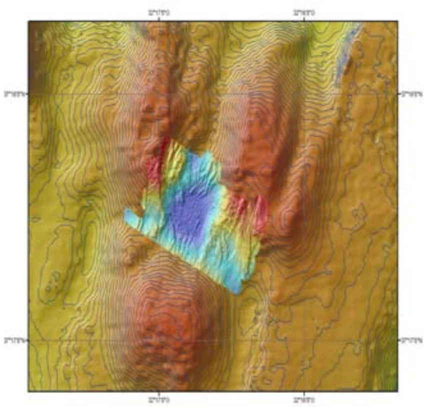
Note

Part of MoMARETO was funded by the EXOCET/D European project, contract # GOCE-CT-2003-505342.



Ballade on Lucky Strike vent field

Fig. 1. The center of the map is occupied by a MMR "Reson SMF 7125" map. The area covered is 1000m x 500m for a resolution of 1m. The lava lake is visible in blue and is surrounded by several active hydrothermal structures. In contrast, the background shows the previous up-to-date map of the area, obtained from the ship. The area covered was 4000m x 4000m for a resolution of 50m.

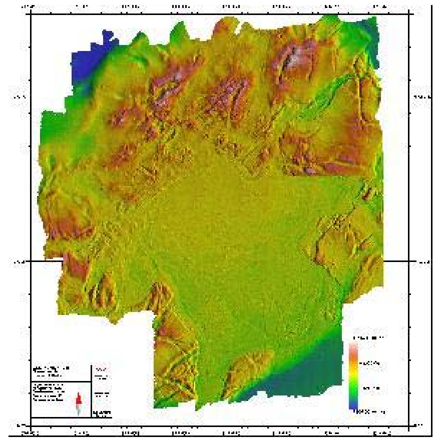


Fig. 4. Hakon Mosby Mud Volcano This active mud volcano has a 1 km diameter.

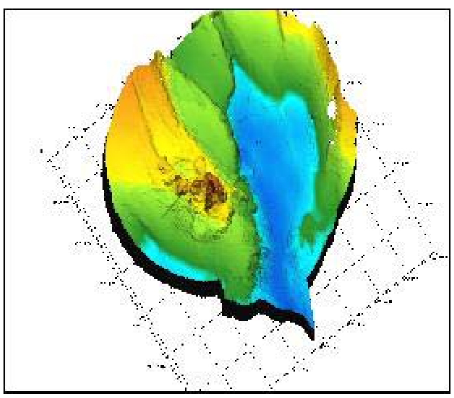


Fig. 2. A zoom on Tour Eiffel hydrothermal structure with MMR "Reson SMF 7125". Area 150m by 100m, DTM = 0.25m. The sulfide edifice is 11m high.

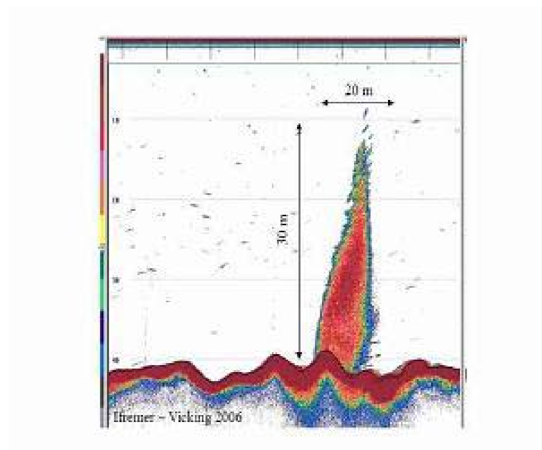


Fig.5. Bubbles gas on Hakon Musby Mud Volcano

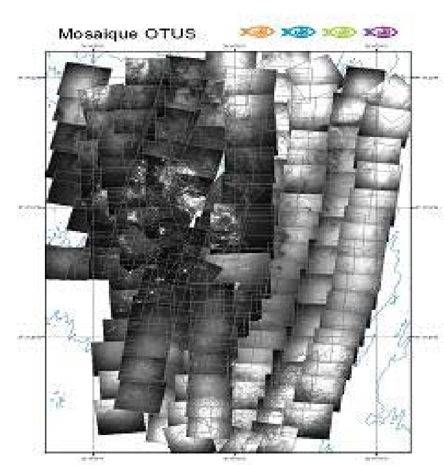


Fig. 3. Raw mosaic of black and white OTUS images giving an optical view of Tour Eiffel .

Fig. 6. Bubble plume detected by ER-60 on MMR. And picture during the same dive.