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MBARI Mapping AUV: A High-Resolution Deep-Ocean Seafloor Mapping Capability

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Please see Poster OS33C-1490 for System Results

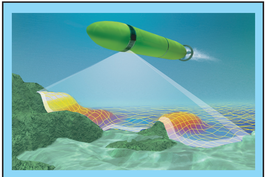
ABSTRACT

The Monterey Bay Aquarium Research Institute (MBARI) has developed an autonomous seafloor mapping capability for deep ocean science applications. The MBARI Mapping AUV is a 0.53 m (21 in) diameter, 5.1 m (16.7 ft) long, Dorado-class vehicle designed to carry four mapping sonars. The primary sensor is a 200 kHz multibeam sonar producing swath bathymetry and sidescan. In addition, the vehicle carries 100 kHz and 410 kHz chirp sidescan sonars, and a 2-16 kHz sweep chirp subbottom profiler. Navigation and attitude data are obtained from an inertial navigation system (INS) incorporating a ring laser gyro and a 300 kHz Doppler velocity log (DVL). The vehicle also includes acoustic modem, ultra-short baseline navigation, and long-baseline navigation systems. The Mapping AUV is powered by 6 kWhr of Li-polymer batteries, providing a mission duration of 12 hours at a typical speed of 1.5 m/s. All components of the vehicle are rated to 6000 m depth, allowing MBARI to conduct high-resolution mapping of the deep-ocean seafloor. The sonar package can also be mounted on ROV Ventana, allowing surveys at altitudes less than 10 m at topographically challenging sites. The vehicle was assembled and underwent initial tests during 2004. During 2005 we have commenced science survey operations while completing the integration and testing of the complete suite of sensors and systems. MBARI is now using this capability in both autonomous and ROV-mounted surveys to

PROGRESS

The Mapping AUV system has been in testing through the year using a phased approach while bring the numerous sub-systems on line. Closing out 2004 the Sub-bottom Profiler was fully operational and the Multibeam Sonar had accomplished several engineering tests. The Sub-bottom sonar was used to perform a series of dives for science in 2004 and the first peer reviewed paper from the MBAUV system was published (*Paull, C.K., Greene, H.G., Ussler, W. III., and Mitts, P.J., Pesticides as tracers of sediment transport through Monterey Canyon: Geo-Marine Letters, v. 22, p. 121- 126, 2002*). Early this year the multibeam development continued with software upgrades in preparation for the scheduled 2005 science missions. Interlaced with the Multibeam and Side Scan science missions the engineering team continued development of the dual frequency Side Scan sub-system. The low frequency elements were designated a priority with the high frequency tuning slated for later in the year. This approach has proven necessary since the complexity for running all sonars simultaneously must be carefully managed. As of this writing the all the sonars are operational with some further gain adjustments and possible baffling for the high frequency side scan required. The entire system has completed a series of repeat multibeam missions for science in the Monterey Canyon. A key missions serires was accomplished for the Monterey Accelerated Research Site cable which resultsed in modifying the planned route ofthe cable installation.

For 2006 the system is considered fully operational for science. A few sub-system elements still requiring further development which will be completed during normal at sea operations with engineering testing allocated when time is available. The two key elements to be completed are the acoustic modem and testing of the integrated Long Baseline navigation which is part of the modem hardware. Although obstacle avoidance and vehicle controls are already in place and functional, further the development of the two components is believed to be worthwhile for maxmizing topographic results. Better obstacle avoidance will provide for better terrain following and reduce the current ly very conservative approach to protect the system. Better timing and control will increase the resolution and multibeam data quality. Navigation results are showing tremendous promise with performance exceeeding the vendor specifications on a regular basis. Improving the other inputs of the data stream should allow for better correlation and overall topographic accuracy.



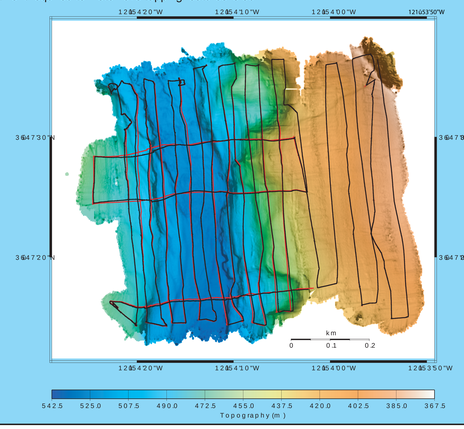
Original Vehicle Concept

Team Members from Previous Years:
F. Shane, A. Hamilton, D. Thompson, K. Salamy
M. Sibenac (now at Carnegie Mellon University)

Acknowledgements:
The David Lucille Packard Foundation
and the crew of R/V Zephyr

NAVIGATION PERFORMANCE

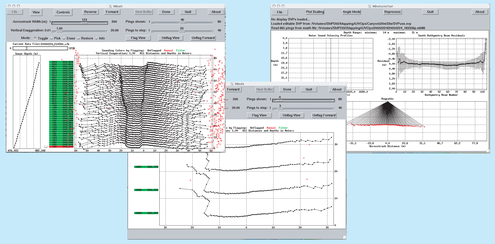
The navigation requirment for MBARI seafloor mapping operations is that the raw navigation error at the end of the survey must be no worse than half a swath width. This allows navigation adjustment software to reliably locate overlapping and crossing swathes, in turn enabling bathymetric features to be matched and navigation adjusted with a precision equalent to the lateral resolution of the bathymetry data. The MBnavadjust screen dump above shows how a misfit (or cross-correlation) function is used to adjust crossing swathes. Once all crossings are analyzed, the relative offsets and other contraints are inverted for an optimal navigation model that fits the observed offsets while minimizing perturbations to vehicle speed and acceleration. The bathymetry map below shows the original INS navigation in red overlain by the final adjusted navigation in black. As can be seen, the navigation adjustments required for this survey are modest. The largest relative adjustment required to match overlapping features is 30 m.



Multibeam Performance

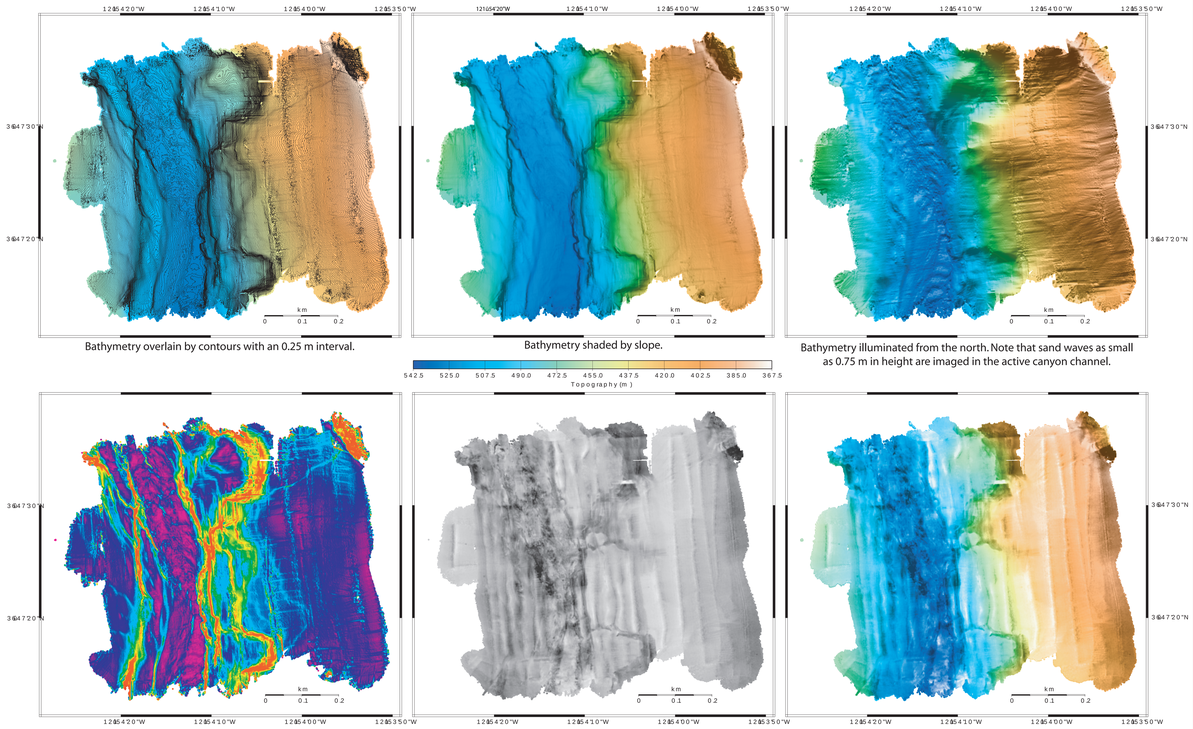
The MBARI Mapping AUV is presently, and temporarily, equipped with a Reson 7125 200 kHz multibeam sonar. This sonar includes flat project and receive transducer arrays installed within the AUV hull that allow a 0.94 degree X 0.4 degree beam resolution at nadir (the center of the swath), with resolution degrading towards the outer swath. The current multibeam uses simple FFT-based beamforming and a crude (maximum amplitude) bottom pick algorithm, contributing to a high noise level in the multibeam bathymetry and a large number of egregious artifacts requiring manual data editing.

The next update to the sonar control software will includetime-domain beamforming with near-field focusing, more sophisticated bottom detection algorithms (center of energy amplitude for vertical incidence and phase detect for shallow grazing returns), and automated flagging of bad soundings. Ultimately, the flat receive array will be replaced by a circular array conformal to the AUV faring, upgrading the multibeam to the Reson 7100 model. The 7100 will achieve 0.94 degree X 0.4 degree beams across the entire degree swath.



The survey belowwas conducted using a 35 m line spacing and an ROV and sonar altitude of roughly 20 m. Despite the shortcomings of the present system, once the bathymetry is edited the sonar performance is adequate for the task of detecting fine-scale changes in canyon axis morphology through repeated surveys of selected sites. The MBedit screen dumps at right show acrosstrack bathymetric profiles with no vertical exageration; each profile represents the return from a single sonar ping. The top view shows forty profiles mapping a small gully incised into the canyon wall. The middle screen dump presents four profiles showing undercutting of the east canyon wall by the active canyon channel. The lower screen dump is of an MBvelocitytool session showing bathymetry standard deviation as a function of beam number. The sonar achieves a 30 cm standard deviation over a 100 degree swath, with higher noise levels in the outermost swath.

Multibeam Bathymetry and Backscatter Maps



Bathymetry overlain by contours with an 0.25 m interval.

Bathymetry shaded by slope.

Bathymetry illuminated from the north. Note that sand waves as small as 0.75 m in height are imaged in the active canyon channel.

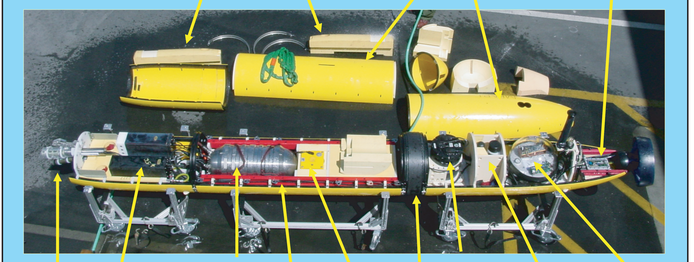
Bathymetry slope map, with slopes greater 0.5 shown in red.

Multibeam backscatter amplitude map, with high amplitudes shown as dark.

Bathymetry shaded by backscatter amplitudes, with high amplitudes shown as dark.

The bathymetry beam footprints are as small as 0.5 m across. The bathymetry grid and amplitude mosaic displayed here have a lateral resolution of 1 m, and were generated using 6,770,883 soundings.

Interior of the Mapping AUV



Specifications:

General
- 21 inch diameter Dorado class AUV
- Depth rated to 6000 m
- Operable from the Zephyr and from blue water UNOLS vessels

Instrumentation
- Reson 7100 Multibeam Sonar
  - 200 kHz
  - 1 degree by 1 degree beams
  - 213 beams reported across a maximum 150 degree swath
  - Swath width 5 times altitude at 150m altitude
- Edgetech FS-AU chirp Sidescan and Subbottom Profiler Sonar
  - 2 kHz Ð 16 kHz chirp Subbottom Profiler
  - 110 kHz low frequency sidescan
  - 410 kHz high frequency sidescan
- Paroscientific UCB7000-I-005 Pressure sensor 0.005% precision for vehicle depth
- Sea-Bird SBE-49 FastCat CTD
- Datasonics PSA-916D 225 kHz Sonar Altimeter

Navigation
- Kearfott SeaDeVil inertial navigation system
  - Integrated with RDI 300 kHz DVL
  - Integrated with GPS at surface

Power
- Bluefin Lithium-Polymer rechargeable batteries or Eagle-Picher Lithium Secondary cells in a 1 atmosphere glass housing.
- Initial configuration carries three 2 kWhr batteries
- The 6 kWhr configuration should allow 12-14 hour missions.

Propulsion
- MBARI articulated tailcone (licensed to and manufactured by Bluefin Robotics)

Acoustic Communications
- Benthos acoustic modems
- 7-15 kHz omnidirectional transducers at surface and on vehicle
- Integrated functions for long baseline navigation and acoustic abort

Safety
- Single vertical lift point
- Front tow hook
- Emergency drop weight with internal and remote acoustic trigger
- Homerpro acoustic beacon, RDF, strobe light
- RF modem for communications at surface

ROV Mode of Operations

First intended for system development, this mode has proven very useful for working in areas to steep and narrow for normal autonomous flight. Hovering sections are under development which would enable this capability in fully autonomous operations.

Autonomous Mode of Operations

The standard mode for most surveys allowing for large araes to be covered in the shortest amount of time. Area coverage and resolution are a function of altitude and available battery power.

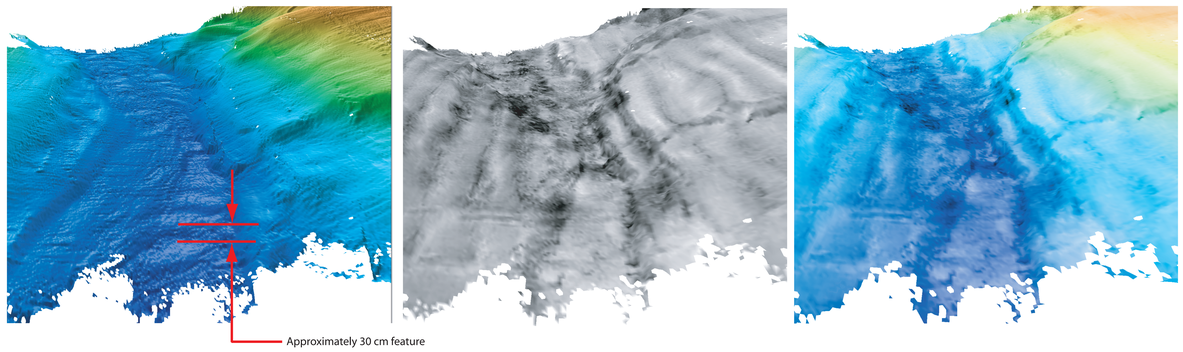
SCHEDULED SURVEYS for 2006

Barkley Canyon, Vancover Island B.C. - Hydrate Research / Cable Route Mapping

Axial Sea Mount - Explosive Volcanism Research

Santa Monica Basin - Sub Surface Fault Relationships to Exposed Features

Monterey Canyon - Repeat Surveys of Dynamically Active Sites

Monterey Accelerated Research Site - Post Cable Laying Route Survey

Perspective Views from the South