



## CERTIFICATION PAGE

### Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the Authorized Organizational Representative or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, lobbying activities (see below), responsible conduct of research, nondiscrimination, and flood hazard insurance (when applicable) as set forth in the NSF Proposal & Award Policies & Procedures Guide, Part I: the Grant Proposal Guide (GPG) (NSF 11-1). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

### Conflict of Interest Certification

In addition, if the applicant institution employs more than fifty persons, by electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.A; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

### Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

### Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency?

Yes

No

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Exhibit II-4 of the Grant Proposal Guide.

### Certification Regarding Lobbying

The following certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding \$100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding \$150,000.

### Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

- (1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.
- (2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure of Lobbying Activities," in accordance with its instructions.
- (3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than \$10,000 and not more than \$100,000 for each such failure.

### Certification Regarding Nondiscrimination

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative is providing the Certification Regarding Nondiscrimination contained in Exhibit II-6 of the Grant Proposal Guide.

### Certification Regarding Flood Hazard Insurance

Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:

- (1) community in which that area is located participates in the national flood insurance program; and
- (2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:

- (1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
- (2) for other NSF Grants when more than \$25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

### Certification Regarding Responsible Conduct of Research (RCR)

**(This certification is not applicable to proposals for conferences, symposia, and workshops.)**

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative of the applicant institution is certifying that, in accordance with the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.B., the institution has a plan in place to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduates, graduate students and postdoctoral researchers who will be supported by NSF to conduct research.

The undersigned shall require that the language of this certification be included in any award documents for all subawards at all tiers.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE		SIGNATURE		DATE	
NAME					
TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS			FAX NUMBER	

\* EAGER - EARly-concept Grants for Exploratory Research

\*\* RAPID - Grants for Rapid Response Research



## CERTIFICATION PAGE

### Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the Authorized Organizational Representative or Individual Applicant is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, lobbying activities (see below), responsible conduct of research, nondiscrimination, and flood hazard insurance (when applicable) as set forth in the NSF Proposal & Award Policies & Procedures Guide, Part I: the Grant Proposal Guide (GPG) (NSF 11-1). Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

### Conflict of Interest Certification

In addition, if the applicant institution employs more than fifty persons, by electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.A; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

### Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Exhibit II-3 of the Grant Proposal Guide.

### Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency?

Yes

No

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Exhibit II-4 of the Grant Proposal Guide.

### Certification Regarding Lobbying

The following certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding \$100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding \$150,000.

### Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

- (1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.
- (2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, "Disclosure of Lobbying Activities," in accordance with its instructions.
- (3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than \$10,000 and not more than \$100,000 for each such failure.

### Certification Regarding Nondiscrimination

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative is providing the Certification Regarding Nondiscrimination contained in Exhibit II-6 of the Grant Proposal Guide.

### Certification Regarding Flood Hazard Insurance

Two sections of the National Flood Insurance Act of 1968 (42 USC §4012a and §4106) bar Federal agencies from giving financial assistance for acquisition or construction purposes in any area identified by the Federal Emergency Management Agency (FEMA) as having special flood hazards unless the:

- (1) community in which that area is located participates in the national flood insurance program; and
- (2) building (and any related equipment) is covered by adequate flood insurance.

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant located in FEMA-designated special flood hazard areas is certifying that adequate flood insurance has been or will be obtained in the following situations:

- (1) for NSF grants for the construction of a building or facility, regardless of the dollar amount of the grant; and
- (2) for other NSF Grants when more than \$25,000 has been budgeted in the proposal for repair, alteration or improvement (construction) of a building or facility.

### Certification Regarding Responsible Conduct of Research (RCR)

**(This certification is not applicable to proposals for conferences, symposia, and workshops.)**

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative of the applicant institution is certifying that, in accordance with the NSF Proposal & Award Policies & Procedures Guide, Part II, Award & Administration Guide (AAG) Chapter IV.B., the institution has a plan in place to provide appropriate training and oversight in the responsible and ethical conduct of research to undergraduates, graduate students and postdoctoral researchers who will be supported by NSF to conduct research.

The undersigned shall require that the language of this certification be included in any award documents for all subawards at all tiers.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE		SIGNATURE	DATE
NAME <b>Maribel Respo</b>			<b>02/13/12</b>
TELEPHONE NUMBER <b>845-365-8829</b>	ELECTRONIC MAIL ADDRESS <b>mrespo@admin.ldeo.columbia.edu</b>	FAX NUMBER <b>845-365-8112</b>	

\* EAGER - EARly-concept Grants for Exploratory Research

\*\* RAPID - Grants for Rapid Response Research

## **PROJECT SUMMARY**

This collaborative proposal from MBARI and L-DEO seeks renewed five-year support for the development and maintenance of MB-System, an open source, freely available software package for the processing and display of swath mapping sonar data. Over the past 19 years, and four grants, NSF-OCE support has allowed us to develop software that is widely used in the international marine geology and geophysics (MG&G) community. We propose to continue to develop MB-System capabilities to meet the needs of the NSF-funded MG&G community, to improve and update documentation, hold training workshops, and provide general software support.

### **Intellectual Merit:**

The MB-System project benefits NSF-supported MG&G research by providing open source software that:

- Includes the tools required to process swath mapping sonar data.
- Supports all relevant swath mapping sonar data formats, allowing researchers to work simultaneously with all available data in their field areas, including old data from systems that are no longer operated.
- Ensures that all archived swath data will be usable in the future through the joint archiving of MB-System source code that reads, writes, and works with the data.
- Continues to include new processing and display tools that meet the evolving needs of the MG&G community.
- Allows researchers to easily implement new ideas for the processing and use of seafloor mapping data.
- Is supported in a timely fashion with fixes and updates in response to user queries.

This project is cost-effective for NSF because the software is designed specifically to meet the needs of the research community, because the software support is timely and therefore increases the efficiency of shipboard operations and onshore processing, and because the free availability of the package allows all MG&G researchers and students access to needed tools without having to purchase commercial software.

### **Broader Impacts**

Since seafloor mapping is a fundamental activity in Oceanography, MB-System also has relevance and impact in oceanographic disciplines other than MG&G. For instance, MB-System is used for habitat mapping as part of fisheries projects, for preparing site basemaps for ROV and submersible dives, for providing bathymetric models for tsunami predication, and for marine archeological projects. The software is used in teaching marine geophysics and seafloor mapping at many universities.

MB-System also has a significant impact beyond the U.S. academic community. Download statistics and online discussion demonstrate that the software is used by researchers and students from at least 68 non-U.S. universities and 40 non-U.S. government agencies worldwide, in addition to 41 universities and 11 governmental agencies within the U.S. At least 37 commercial organizations also use MB-System.

## TABLE OF CONTENTS

---

For font size and page formatting specifications, see GPG section II.B.2.

	Total No. of Pages	Page No.* (Optional)*
Cover Sheet for Proposal to the National Science Foundation		
Project Summary (not to exceed 1 page)	1	_____
Table of Contents	1	_____
Project Description (Including Results from Prior NSF Support) (not to exceed 15 pages) <b>(Exceed only if allowed by a specific program announcement/solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)</b>	15	_____
References Cited	1	_____
Biographical Sketches (Not to exceed 2 pages each)	2	_____
Budget (Plus up to 3 pages of budget justification)	7	_____
Current and Pending Support	1	_____
Facilities, Equipment and Other Resources	1	_____
Special Information/Supplementary Documents (Data Management Plan, Mentoring Plan and Other Supplementary Documents)	25	_____
Appendix (List below.) <b>(Include only if allowed by a specific program announcement/ solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)</b>	_____	_____
Appendix Items:		

\*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

---

## TABLE OF CONTENTS

For font size and page formatting specifications, see GPG section II.B.2.

	Total No. of Pages	Page No.* (Optional)*
Cover Sheet for Proposal to the National Science Foundation		
Project Summary (not to exceed 1 page)	_____	_____
Table of Contents	1	_____
Project Description (Including Results from Prior NSF Support) (not to exceed 15 pages) <b>(Exceed only if allowed by a specific program announcement/solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)</b>	0	_____
References Cited	_____	_____
Biographical Sketches (Not to exceed 2 pages each)	2	_____
Budget (Plus up to 3 pages of budget justification)	8	_____
Current and Pending Support	2	_____
Facilities, Equipment and Other Resources	1	_____
Special Information/Supplementary Documents (Data Management Plan, Mentoring Plan and Other Supplementary Documents)	25	_____
Appendix (List below.) <b>(Include only if allowed by a specific program announcement/ solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)</b>	_____	_____
Appendix Items:		

\*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

## INTRODUCTION

MB-System [Chayes and Caress, 1993, 1994-2000, 1995, 1996, 2000-2012; Caress et al., 2008; Schmidt et al., 2006] is an open source software package consisting of programs that manipulate, list, analyze, process, display, or visualize swath mapping sonar bathymetry and sidescan data. Over the past nineteen years, continuous NSF support has allowed us to develop MB-System into a package that is widely used in the US and international marine geology and geophysics (MG&G) community.

Although MB-System is currently a reliable and powerful set of tools for working with swath mapping data, long term software development, support, and maintenance effort remains necessary for MB-System to continue to be relevant to the MG&G community. Rapid advances in sonar technology are requiring (and will continue to require) support for data from new systems and updated file formats. Simultaneously, innovation in the use of these new sonars for science is requiring new processing and display capabilities, and enabling new kinds of science (e.g multibeam “water column” data). MB-System users frequently have questions or problems that we (or other users connected through our discussion list) can resolve quickly. Relentless changes in computer operating systems and compilers will also continue to require software maintenance to ensure portability and to take advantage of new performance options.

In order to further develop and maintain the MB-System software while providing general support to the NSF-funded MB-System user community, we propose a five-year project. This is a collaborative proposal submitted jointly by the Monterey Bay Aquarium Research Institute (MBARI) and the Lamont-Doherty Earth Observatory of Columbia University (LDEO). MBARI is the lead institution.

Seafloor mapping, at any scale, is one of the most fundamental activities in Oceanography. The intellectual merits of this project derive both from the development of software that enables researchers to easily and inexpensively work with mapping data and from the utility of this software as a platform for innovation in seafloor mapping. For instance, the capabilities highlighted in Figures 1-4 now allow geologists to process multibeam data collected on autonomous underwater vehicles (AUVs) so as to map seafloor topography at lateral resolutions of one meter or less, and, in the case of repeated surveys, to detect and map changes in seafloor topography as small as 0.2 m. Many of the software tools needed to achieve these results have been developed since we last requested NSF support in 2006. Although the lava flow mapping example of Figure 4 involves an MBARI AUV, the National Deep Submergence Facility (NDSF) at the Woods Hole Oceanographic Institution (WHOI) uses MB-System to process multibeam data, and so the exact same capability is available to NSF-supported researchers through use of AUV *Sentry*. Figure 5 demonstrates the use of MB-System by NSF-MG&G-funded scientists to process shipboard multibeam data collected using the state-of-the-art sonars now installed on many UNOLS vessels.

The broader impacts of MB-System are substantial. During 2011 and 2012, MB-System was used by at least 197 universities, research institutions, agencies, and

companies worldwide (see Results From Prior Support below, and the download statistics at <http://www.mbari.org/data/mbsystem/2012NSFProposal/ProposalSupplement.pdf> ). As a successful open source project, MB-System also has an active community of users and developers. At present, the MB-System online discussion forum has about 245 members. During the previous five-year NSF grant, users at several institutions made substantial contributions to the software (most notably NDSF/WHOI, CCOM (University of New Hampshire), CSIRO (Australia), MARUM (University of Bremen, Germany), and Tekmap Consulting (Canada)).

In addition to the NSF support, the Packard Foundation has funded considerable MB-System software development related to seafloor mapping with autonomous underwater vehicles (AUVs) for the past decade. We expect continued support from the Packard Foundation for development related to MBARI seafloor mapping projects. We also anticipate that groups outside MBARI and LDEO will contribute significantly to MB-System, albeit to address their own needs, which are not necessarily not the same as the needs of NSF-funded scientists. Since MB-System derives from a considerable NSF investment and since the software has an established user base in the academic community, we think that long-term NSF support continues to be both prudent and appropriate.

## DESCRIPTION OF THE MB-SYSTEM SOFTWARE PACKAGE

MB-System (<http://www.mbari.org/data/mbsystem/>) is an open source software package consisting of programs which manipulate, process, list, or display swath sonar bathymetry, amplitude, and sidescan data. The swath mapping sonar data may derive from multibeam sonars, interferometry sonars, or sidescan sonars. This software is distributed freely (and for free) in the form of source code for Unix-based platforms using the GNU Public License (GPL) version 3. MB-System can also be built on Windows computers in conjunction with freely available Unix extensions.

A complete list of the current MB-System programs and macros can be found at [http://www.mbari.org/data/mbsystem/html/mbsystem\\_man\\_list.html](http://www.mbari.org/data/mbsystem/html/mbsystem_man_list.html). MB-System programs allow users to do things like:

- Find out what is in a swath data file (*mbinfo*).
- Extract arbitrarily constructed text tables of navigation and per-beam data (*mblast*).
- Copy swath data from one format to another (*mbscopy*).
- Generate GMT-compatible Postscript maps of bathymetry and sidescan directly from the swath data (*mbcontour* and *mbswath*).
- Interactively identify and fix errors in navigation (*mbnavedit* – Figure 1).
- Visualize bathymetry and sidescan with 2D and 3D views (*mbgrdviz* – Figure 2).
- Interactive survey planning (*mbgrdviz*– Figure 2).
- Automatically identify and flag obvious artifacts in bathymetry data (*mbclean*).
- Interactively identify and flag artifacts in bathymetry data in a waterfall view (*mbedit* – Figure 1) and in a 3D point cloud view (*mbeditviz* – Figure 3).
- Interactively identify and measure bias parameters in a 2D/3D visualization context with 3D point cloud view of soundings (*mbeditviz* – Figure 3).

- Interactively model the effect of changes in a water sound speed profile (“SVP”) on bathymetry calculations (*mbvelocitytool* – Figure 1).
- Recalculate swath bathymetry from travel time information using a user-specified sound speed profile (SVP) (*mbprocess*).
- Adjust navigation of surveys conducted from ROVS or AUVs (or from old, poorly navigated ship surveys) so that features match in overlapping/crossing swaths to the resolution of the bathymetry (*mbnavadjust* – Figure 4).
- Correct amplitude and sidescan data (*mbackangle*, *mbprocess*).
- Apply corrections and edits to generate processed swath files (*mbprocess*).
- Grid bathymetry data using a variety of algorithms (*mbgrid*).
- Create mosaics from sidescan data (*mbmosaic* – Figure 5).
- Export grids, mosaics, and images in georeferenced formats for use in other (GIS) packages such as ArcView (*mbm\_grd2arc*, *mbgrdtiff*, *mbm\_grdtiff*).

In developing MB-System, we have been strongly influenced by GMT, the “Generic Mapping Tools” package developed by Paul Wessel and Walter Smith for the generation of Postscript based maps and graphics [Wessel and Smith, 1991, 1998]. Like GMT, most MB-System programs depend on command line arguments rather than interactive questions to control the operation of the programs. The advantages to this Unix-style approach include flexibility of use and reliability. Several script “macros” make common operations easier (e.g., a first cut plot of the bathymetry and navigation in a swath file).

In addition to the command-line tools, there are four interactive graphical editing and analysis tools (bathymetry editor *mbedit*, navigation editor *mbnavedit*, navigation adjustment tool *mbnavadjust*, and *mbvelocitytool* for water sound speed model analysis), and two tools that provide 3D visualization (data analysis and survey planning tool *mbgrdviz* and bathymetry editor and patch test tool *mbeditviz*). The results from the interactive tools are integrated with the command line utilities.

The heart of the system is an input/output library called MBIO which allows programs to work transparently with any of the 72 supported swath sonar data formats (see [http://www.mbari.org/data/mbsystem/html/mbsystem\\_formats.html](http://www.mbari.org/data/mbsystem/html/mbsystem_formats.html) for a list of the supported data formats). This approach allows the development of "generic" utilities that can be applied in a uniform manner to sonar data from a variety of sources. MBIO and its associated programs are capable of dealing with bathymetry, beam intensity, and sidescan data in a single data stream (as produced by the current generations of multibeam and interferometry sonars).

We distribute the MB-System source code and documentation through the anonymous ftp site at LDEO, which can be directly accessed from the MB-System web pages hosted at the MBARI and LDEO web sites (<http://www.mbari.org/data/mbsystem/> or <http://www.ldeo.columbia.edu/res/pi/MB-System/>). MB-System is licensed using the GNU General Public License (GPL) version 3, ensuring that this freely available software cannot be modified and redistributed without including the modified source code. The MB-System web pages comprise the primary documentation detailing the available programs, their options, and the supported data formats. Complete copies of

these web pages are included in the distribution along with traditional Unix manual pages. The MB-System Cookbook [Schmidt et al., 2006] provides additional background and examples to supplement the manual pages.

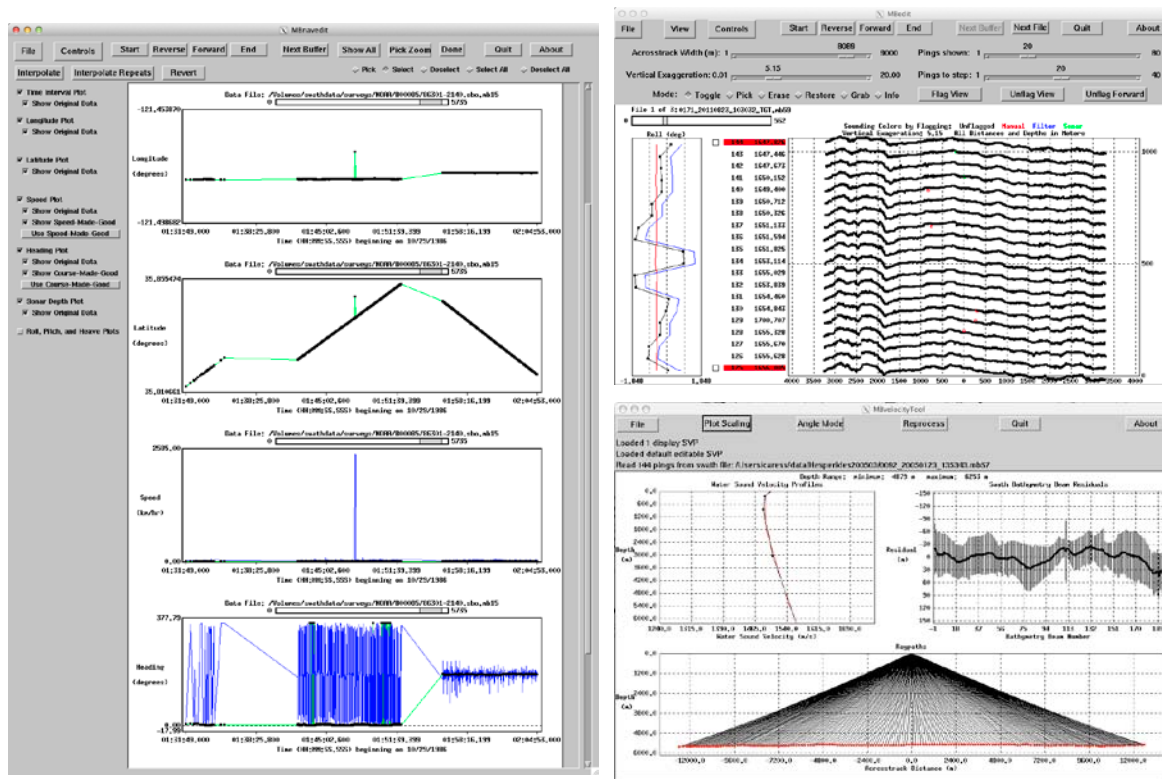


Figure 1. Screen captures of three interactive MB-System programs. (Left) Program *mbnavedit*, a tool used to correct navigation data. Several time-series style data plots are stacked for a selected time interval; this plot of SeaBeam Classic data from NOAA shows longitude, latitude, speed, and heading. A navigation outlier produces a spike in the apparent ship speed. Data in any plot may be selected and changed by interpolation or by substitution with an alternative measure (e.g. heading may be replaced by course made good). (Top Right) Program *mbedit*. This interactive MB-System tool is used to edit swath bathymetry data. The data here were collected in 2011 using the R/V *Thompson's* Kongsberg EM302, a 30 kHz multibeam sonar whose data are supported as MB-System formats 58 and 59. The across-track profiles are shown stacked in a waterfall style plot. The black dots show unflagged soundings, and the red dots show soundings that have been flagged as bad data. Automated filters may be applied in *mbedit* or in the command line program *mbclean*. The optional panel on the left can plot several types of information, here it shows roll at ping time. (Bottom Right) Program *mbvelocitytool*. This tool allows users to assess the effect of changing the water sound velocity profile (SVP) on bathymetry calculations using raytracing. The user can display several reference SVP's and interactively edit the active SVP. Average bathymetry residuals are calculated using the active SVP. If the SVP is incorrect, typically across-track profiles will tend to either “smile” (shoal toward the edges of the swath) or “frown” (deepen toward the edges of the swath). The SVP can be interactively altered until the residuals are “flat” across the swath. With this tool, the user can attempt to correct after-the-fact for inadequate at-sea calibrations.

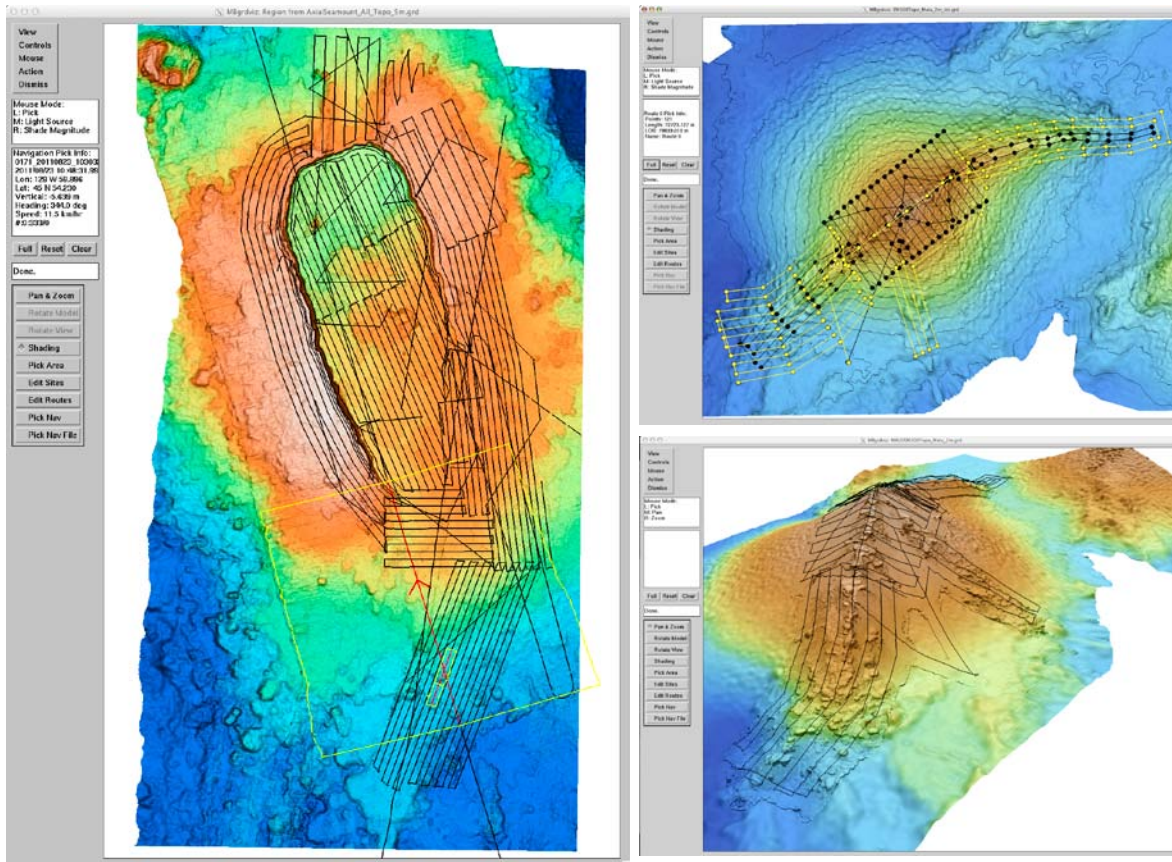


Figure 2. Screen captures of program *mbgrdviz*, which is used to visualize bathymetry grids, plan survey routes, and launch editing applications on selected data. (Left) Map (2D) view of a bathymetry grid of the summit of Axial Seamount overlain with ship and AUV survey tracklines. Here the map combines hull-mounted multibeam EM300 data collected on R/V *Ocean Alert* in 1998 and EM302 data collected on R/V *Thompson* in 2011 with higher resolution bathymetry collected using the MBARI Mapping AUV on 13 missions during 2006-2009. The bathymetry was gridded using the “weighted footprint” algorithm of *mbgrid*, which uses the actual beam footprints to properly mix data with different resolutions. When sections of navigation are selected (shown in red) the associated swath coverage is shown with a yellow outline. Editing tools such as *mbedit* or *mbeditviz* can be launched on the selected data. (Upper Right) Map (2D) view of West Mata Volcano bathymetry in the Lau Basin, shown with 100 m contours. Here the route planning feature of *mbgrdviz* has been used to plan two AUV missions. The mission over the summit (black) was created by dragging a box, automatically laying out a regular grid of equally spaced lines to cover the area, and then interactively adjusting the result. The more complicated mission to survey the lower flanks (yellow) was laid out interactively. This feature can also be used to plan ship surveys, cable routes, or other multi-point constructs. (Lower Right) 3D perspective view, with no vertical exaggeration, of the West Mata bathymetry [Clague et al., 2011]. The AUV tracklines (black) are draped on the bathymetry grid, which combines the high resolution AUV multibeam data with the lower resolution hull-mounted multibeam data.

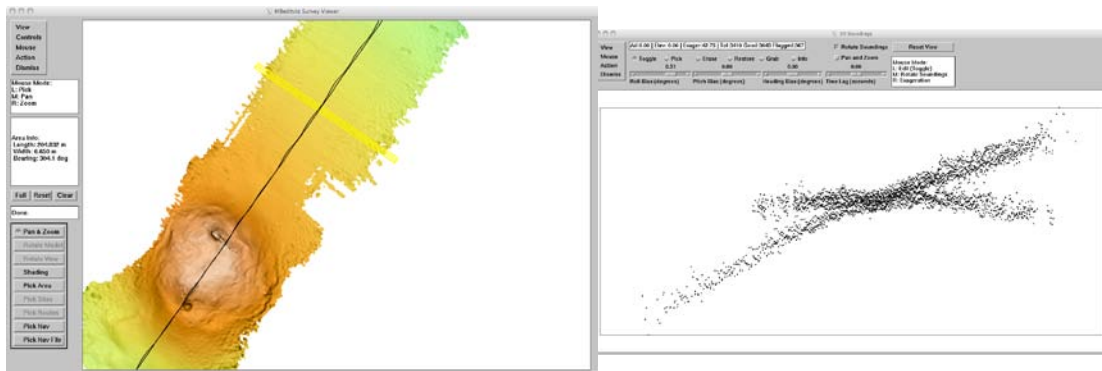
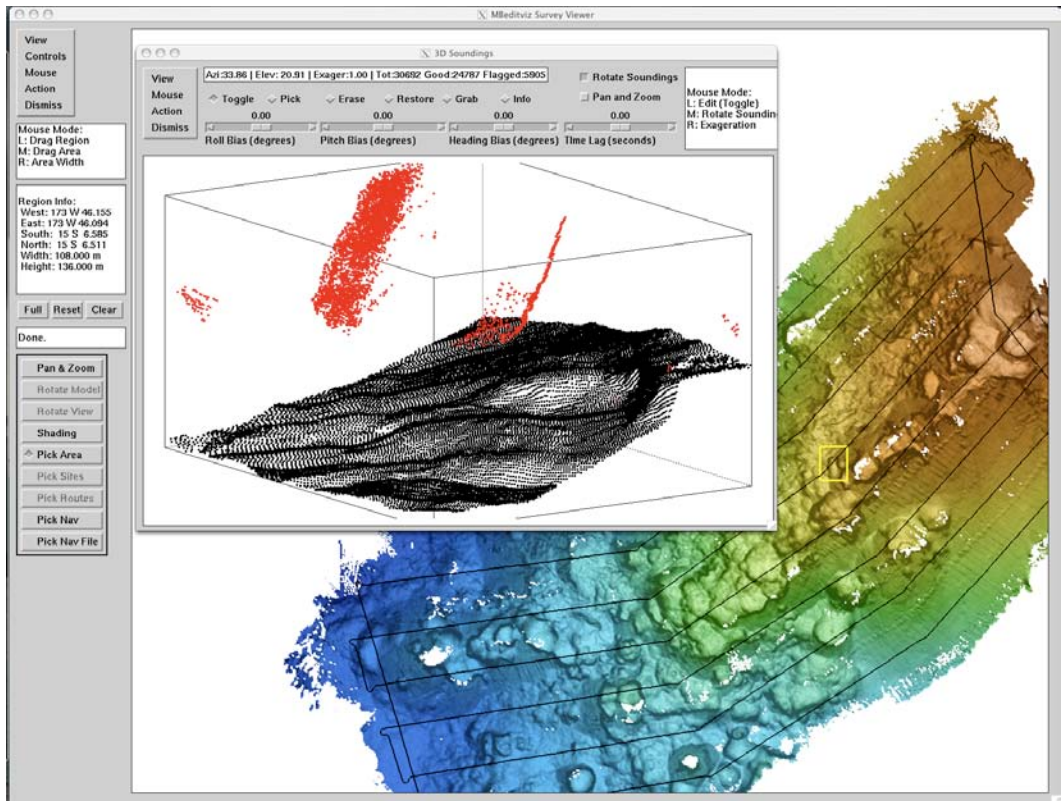


Figure 3. Screen captures of program *mbeditviz*, which reads in swath data from multiple files, constructs a bathymetry grid and displays it using the *mbrdviz* interface, allows users to select arbitrary areas or sections of navigation, and displays the associated soundings in a 3D box that can be rotated or scaled as desired. This 3D “sounding cloud” can be used for bathymetry editing, data analysis, or measurement of attitude bias and time lag. (Top) An example of editing bathymetry using *mbeditviz*. In this case a small area has been selected (yellow box), and the soundings inside displayed as a rotatable 3D cloud. Soundings that have been flagged as bad are displayed in red. (Bottom) Example of measuring roll bias using *mbeditviz*. The map view on the left shows bathymetry from two AUV tracks running in opposite directions. A narrow strip perpendicular to the AUV tracks has been selected. The sounding cloud window on the right allows users to interactively apply roll, pitch, or heading biases and observe the consequent changes to the data. This example shows the mismatch in bathymetry produces when a large, incorrect roll bias is applied.



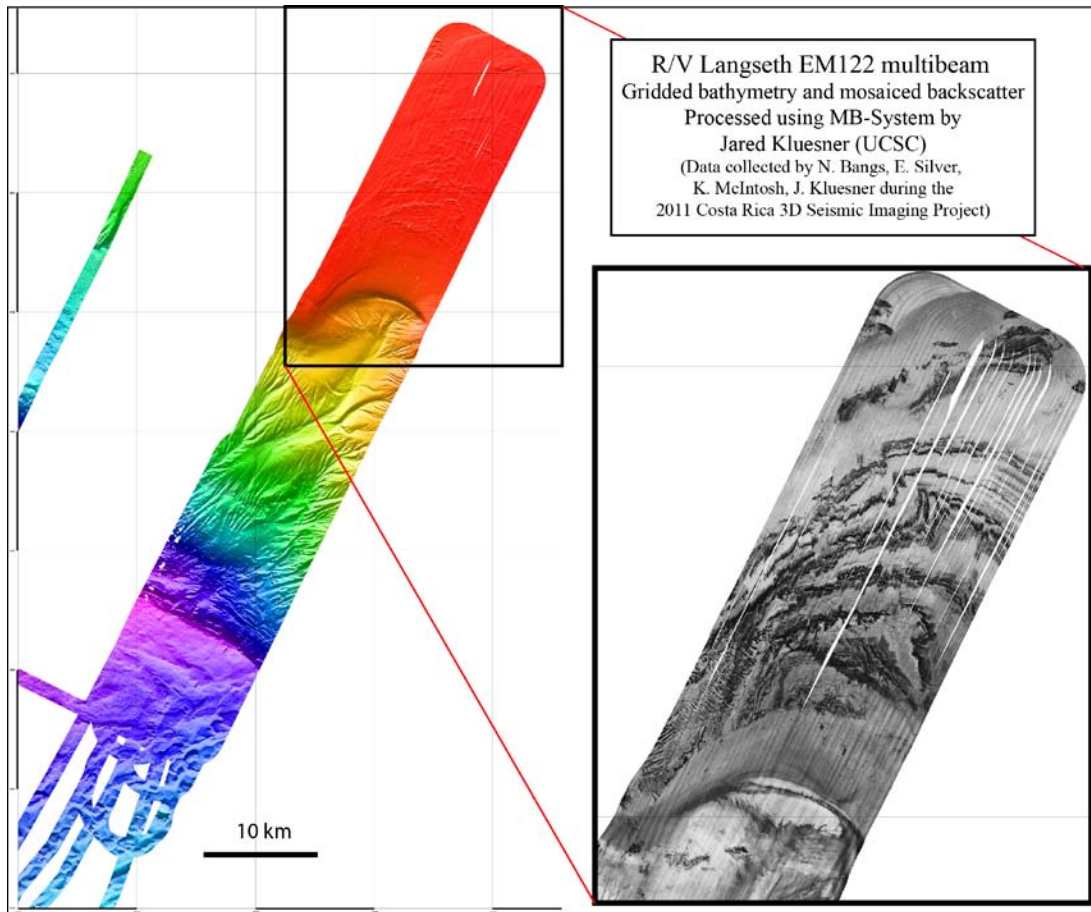


Figure 5. Example of multibeam backscatter correction and mosaicking by an MB-System user working with Kongsberg EM122 data collected on an UNOLS vessel with NSF funding. This survey was collected during a 3D multichannel seismic reflection cruise, and benefited from closely spaced lines and unusual sonar settings – the PI’s chose to operate the EM122 with all beams focused in a narrow 1.4 km wide swath. (left) Bathymetry gridded at 10 m resolution (red=150 m, purple=2500 m depth) using the weighted footprint algorithm of mbgrid. (right) Multibeam backscatter mosaicked at 3 m resolution revealing bedding planes and fault traces exposed on the seafloor. These images provided by Jared Kluesner [Kluesner et al., 2011].

### WHY OPEN SOURCE?

In contrast to 1993, when we began the MB-System project, a number of commercial software packages now exist for processing swath sonar data (e.g. Caris: <http://www.caris.com>; Hypack: <http://www.hypack.com>; Fledermaus <http://www.qps.nl/>; OIC GeoDAS: <http://www.oicinc.com>). We must therefore justify our request for NSF software development support by discussing how the seafloor mapping needs of the ocean science community can be better met by continued development of our open source software than by the adoption of commercial software.

There are several aspects in which scientific seafloor mapping differs from other uses of seafloor mapping technology and data. Commercial and hydrographic seafloor surveys tend to be self-contained projects with well-defined deliverables and a focus on achieving

a contractually acceptable result for the least cost. Consequently, the commercial processing packages are oriented towards efficiently taking individual surveys through to a set of standard data products. In all cases, swath data are imported into an internal representation, and then processed using proprietary tools. The capabilities for exporting processed results in a swath form (as opposed to grids, xyz sounding sets, etc.) are limited or nonexistent.

In contrast, Marine Geology and Geophysics (MG&G) scientists' goals are to maximize new insights into geological processes, structure and history. Some common features of MG&G research survey work include:

- A desire to work with all available swath data, including data from different sonars in different formats, often collected over a span of years to decades.
- A need to simultaneously work with both old and modern data. Much of the seafloor is poorly surveyed, if at all, and so many 25-year-old SeaBeam classic surveys are still vitally important to science. We fully expect today's surveys to be equally important 25 (or more) years from now.
- A desire to extract all possible information from the data.
- A desire to apply new processing techniques or to use the data in innovative ways.
- A requirement that the data be archived and permanently available for further use.
- Occasionally, the need to support very new data file formats, or recently released data in new file formats.

All of these science needs are best satisfied by the existing open source solution. Of the available software, only MB-System transparently supports (nearly) all of the relevant data formats (and is committed to supporting all) and maintains the processed data in a native swath format with all pertinent information. Also, in order for archived data to be useful for the long term, software capable of reading and writing those data must be available. We can have no assurance that proprietary software sold now will still be available, or work, on computers and data files years from now. Archiving the source code with the data is the only way to ensure that yesterday's data will still be fully accessible in the future, and only open source code can be publicly archived. Scientists frequently conceive, develop, and wish to apply new ideas for data processing and use. Only open source software allows any researcher to easily incorporate innovations into the processing code. The open source approach also allows a community of users to work with the primary development team in improving the software. Six of the MB-System tools have been written entirely by users, and several other programs have benefited from substantial contributed improvements. Users can also write i/o modules for any desired swath data format. For all these reasons, we think that the oceanographic research community will be best served by continuing MB-System development.

Because MB-System is freely available (for free), installation and use is within the resources of nearly any potential user of multibeam data. This low barrier allows exploration of multibeam processing in a much broader range of situations including the teaching environment.

There is, of course, also the question of cost to NSF. Our download statistics (at <http://www.mbari.org/data/mbsystem/2012NSFProposal/ProposalSupplement.pdf>) show that at least 41 U.S. universities and 11 U.S. government agency offices use MB-System, and we know there are multiple users at many of these groups. Put simply, the expense of supporting this project to maintain and develop MB-System so that it can be used freely by anyone will be much smaller than the cost of purchasing and maintaining commercial software licenses for all NSF-supported researchers and students working with seafloor mapping data. In addition to routine maintenance fees, commercial vendors would require additional payment to undertake many of the improvements and format support work we have been, and propose here to continue, handling routinely.

## PROPOSED WORK

The proposed project includes considerable software development effort, as well as general software maintenance, documentation, and support. Our priorities reflect discussions and rankings at an MB-System planning meeting held at LDEO on January 17-18, 2012. The twelve participants in this meeting included the core MB-System developers, users that have substantially contributed to the project over the past few years, and representatives of organizations that have expressed interest in parallel development efforts contributing to MB-System (participants and summary at: <http://www.mbari.org/data/mbsystem/2012NSFProposal/20120117MBPlanning.pdf>).

The focus of our software development efforts in this project will be:

- **Re-architect underlying MBIO library**  
The scope of requested new capabilities require substantially recasting the MBIO application programming interface (API) and the associated functions:
  - Store and pass beam quality information needed for determining if soundings meet IHO (International Hydrographic Organization) quality standards.
  - Recast the internal coordinate systems consistently through the code.
  - Handle corrections to sensor offsets and biases for all sensors.
- **Support new and important data formats**
  - Keep up to date with data from Kongsberg multibeam installations on UNOLS vessels
  - Keep up to date with data from Reson multibeam installations on WHOI NSDF platforms (Sentry, Jason, Alvin)
  - Support input from Bathymetry Attributed Grid (BAG) files
  - Support other data formats associated with NSF-supported projects as they become relevant.
- **Improve performance of common tasks**  
Several straightforward improvements have been identified that can substantially reduce the time required for analysis and processing:
  - Augmenting the datalist scheme so that surveys as well as individual files have .inf metadata files, and thus data trees outside bounds of interest can be skipped.
  - Recasting ancillary files (esp. fbt) for improved read performance.

- Allow raw files and processed files to be located on different filesystems to improve processing performance.
- **Fix existing problems with support of current generation Kongsberg data**  
The beam angles for current generation Kongsberg multibeam sonar data are not calculated correctly, and an iterative method used to estimate these angles in an optional pre-processing stage is slow. Fixing this issue is high priority.
- **Improve *mbeditviz***  
Improve patch test calibration capability of *mbeditviz* by allowing the soundings to be colored according to a variety of parameters.
- **Add capability to generate additional data products:**
  - Shapefiles for ESRI and other GIS
  - KML file for Google Earth
  - Bathymetry Attributed Grid (BAG) files
- **Support reading from compressed files in gzip format.**  
This will reduce data storage requirements, and is a priority of NGDC, MGDS, and R2R.
- **Rewrite the graphical utilities to use Qt graphics**  
The interactive programs currently use obsolete Motif/X11 graphics. In addition to improving performance and moving MB to a modern graphics context, switching to Qt will enable true cross-platform portability, including to Windows computers.
- **Develop tools for working with multibeam water column data**  
The use of recorded beamformed time series data from multibeam sonars to image biological and other water column targets is of great interest to many users. This issue was the highest ranked desired capability at the MB-System planning meeting. Water column data are also an asset in troubleshooting interference in multibeam sonar systems. We will develop a new MB-System tool to display water column data and to identify and display targets.
- **Implement the CHRT algorithm as an MB-System tool.**  
CUBE is an algorithm developed by Brian Calder [Calder and Mayer, 2003] that automatically processes swath bathymetry soundings and provides depth estimates and uncertainties at defined points and identifies soundings inconsistent with the best estimates. Thus, CUBE can be used both to identify bad (or suspect) soundings and to generate gridded bathymetry models. This is a particularly useful feature in shallow water data sets with very large numbers of tracks and soundings. The CUBE source code is held proprietary by the University of New Hampshire, and cannot be distributed as open source. During the previous grant period we enabled the CUBE function of the commercial software Fledermaus to integrate with an MB-System development environment. Calder is now developing a new version of his algorithm called CHRT, and he plans to disseminate this proprietary software in a server-client structure, where the standard CHRT server is distributed freely in compiled form. We will thus be able to develop an open source CHRT client tool within MB-System, enabling MB-System users to use Calder's algorithm without having to buy Fledermaus.

- **Develop real-time display tool**  
We will implement a display tool that reads swath data from real-time streams, updates a gridded representation of the bathymetry, and displays the current grid and tracklines in a 2D/3D view using the new, Qt-based *mbview* visualization library.
- **Develop a “test suite” to allow automatic determination that an MB-System installation is successful.**  
As MB-System has become more complex it has become clear that we need an automated method to verify new builds. Using our existing example data set, we will develop a test procedure implemented in a script that will exercise a new build of MB-System and compare the results against a pre-defined set of results.

The participants of the MB-System planning meeting also identified updating documentation and improving training resources for both users and developers as significant priorities. We plan to:

- **Rewrite the MB-System Cookbook to reflect the current software.**  
We will rewrite the cookbook to reflect the current state of the software.
- **Create an MB-System Wiki to store and disseminate user-created documentation and training materials.**  
A number of users have created their own MB-System presentations, how-to documents, and even some quite good how-to videos.
- **Hold MB-System workshops to assist groups that want to develop data format modules and applications and for user training.**  
We propose to hold annual workshops intended for 10-20 participants each. During years 1, 3, and 5 we will hold developer workshops at MBARI. During years 2 and 4 we will hold user workshops at LDEO.

Our software maintenance and support effort includes fixing bugs in the programs, answering user questions, helping users to install the software, and generally solving user problems. Questions and problems arise all the time; we have and we will continue to try to be as responsive to users as possible. The MB-System Discussion Forum hosted at MBARI (<http://listserver.mbari.org/sympa/arc/mbsystem>) greatly facilitates this effort by involving the user community in responding to queries and improving the software. We will also continue to freely distribute the MB-System source code through the web and the LDEO ftp site.

Several groups intend to develop MB-System capabilities to meet needs beyond those addressed in this project, or to collaborate with us in augmenting MB-System. These efforts are documented by supplemental letters of collaboration, and include:

- **MBARI:** Over the next few years MBARI seafloor mapping will be focusing on autonomous cm-scale mapping from altitudes of 1-2 m. This is part of the “Ocean Visualization” research theme outlined in the current MBARI Strategic Plan, and is embodied in the multi-year “Ocean Imaging” project led by David Caress. The associated data processing capabilities will be developed as part of MB-System.

- **MARUM/GEOMAR/BSH:** MARUM (Center for Marine Environmental Sciences at University of Bremen), GEOMAR (Kiel), and BSH (German Hydrographic Agency) will be jointly proposing a MARUM-led software development project in late 2012 that will seek to support data from a number of sonars not used in the NSF-supported community, allow identification of soundings as compliant (or not) with IHO standards, and augment our efforts to work with water column data.
- **CCOM/JHC (UNH):** As described above, Brian Calder will work with us to integrate his new CHRT algorithm into an MB-System tool.
- **IEDA (LDEO):** The Integrated Earth Data Applications (IEDA) group at LDEO will continue to contribute improvements associated with data archiving.
- **Tekmap Consulting:** Tekmap Consulting will continue to contribute bug-fixes, program enhancements, and format support. Bob Covill at Tekmap is currently working to improve the package-building scheme for MB-System.
- **NDSF/WHOI:** The National Deep Submergence Facility (NDSF) at the Woods Hole Oceanographic Institution uses MB-System for processing multibeam data collected on AUV Sentry, ROV Jason, and DSRV Alvin. NDSF is working to improve their shipboard processing scheme, and will continue to contribute their improvements to MB-System.

### THE MB-SYSTEM TEAM

MB-System has been primarily developed and supported by two people: David Caress of MBARI and Dale Chayes of L-DEO. David Caress and Dale Chayes will continue to be primarily responsible for the MB-System project. As in the past, Caress will lead the software development effort, with Chayes assisting. Caress and Chayes will both provide user support and code maintenance. Chayes will lead the documentation effort, including a new MB-System Cookbook. Bob Arko of LDEO will support the Subversion source code archive, the LDEO MB-System website, and a new MB-System user wiki. Krystle Anderson, an MBARI research assistant, will assist Chayes in writing documentation. Anderson is currently responsible for processing MBARI Mapping AUV surveys using MB-System, and she has previous survey experience with hull-mounted multibeam data processed using commercial software tools.

### RESULTS FROM PRIOR NSF SUPPORT

1. Hardware and Software Upgrade for Shipboard Processing of Hydrosweep Multibeam Bathymetry Data on the R/V *Maurice Ewing*
  - a. LDEO: OCE92-17724      \$267,960      2/15/1993–1/31/1995
2. Development and Support of the MB-System Software Package for Processing and Display of Multibeam Sonar Data
  - a. LDEO: OCE95-05188      \$237,837      7/1/1995 – 6/30/2000
3. Collaborative Research: Development and Support of the MB-System Software Package for Processing and Display of Swath Mapping Sonar Data
  - a. MBARI: OCE00-83082      \$118,928      6/15/2001 – 6/14/2006
  - b. LDEO: OCE00-83120      \$250,616      6/15/2001 – 6/14/2006

4. Collaborative Research: Development and Support of the MB-System Software Package for Processing and Display of Swath Mapping Sonar Data
  - a. MBARI: OCE06-23687      \$155,133      9/1/2006 – 8/31/2011
  - b. LDEO: OCE06-83120      \$368,965      9/1/2006 – 8/31/2011

MB-System formally began as part of grant (1) in 1993, which primarily supported enhancements to the operation of the Hydrosweep DS multibeam sonar on the R/V *Ewing*. Although the focus of the initial software development was processing of Hydrosweep data, the long-term intent was to develop a set of generic software tools that could be used to process multibeam data from a number of different sonars. Major MB-System releases began in June 1993. Interest in MB-System developed rapidly, and by the end of grant (1) at least 25 oceanographic institutions worldwide used the software. Grants (2), (3), and (4) supported continued development and support of the MB-System software package for five years each. We have released dozens of versions of MB-System over the years, with 48 updates during the most recent five-year project.

The current suite of MB-System tools and their capabilities (version 5.3.1980) are listed in the MB-System web pages (<http://www.mbari.org/data/mbsystem/>) at [http://www.mbari.org/data/mbsystem/html/mbsystem\\_man\\_list.html](http://www.mbari.org/data/mbsystem/html/mbsystem_man_list.html). The significant additions to MB-System during these grants are too numerous to list here. However, the most notable improvements over the past few years have included:

- The *mbnavadjust* tool for adjusting navigation of AUV/ROV-based surveys.
- The *mbeditviz* tool for interactive 3D visualization based bathymetry editing and bias parameter (patch test) estimation.
- Supporting data from current Kongsberg, Reson, and R2Sonics sonars.

The popularity of MB-System has continued to grow during this project. Our download and forum post statistics (available at <http://www.mbari.org/data/mbsystem/2012NSFProposal/ProposalSupplement.pdf>) indicate that the software is used by researchers at most of the major oceanographic centers in the US, at many other universities worldwide, by several groups within NOAA, the Navy, and the USGS, and at many universities and government agencies in other countries. The 197 organizations known to use MB-System include:

- 41 U.S. Academic Institutions
- 11 U.S. Government Agencies
- 68 Non-U.S. Academic Institutions
- 40 Non-U.S. Government Agencies
- 37 Companies

Some additional indications of the software's broad acceptance include:

- The National Geophysical Data Center (NGDC) requests that multibeam data be submitted to its archive in a data format supported by MB-System.
- NGDC uses MB-System extensively in managing its archives.
- The NSF-supported Rolling Deck to Repository (R2R) program and the Integrated Earth Data Applications (IEDA) facility at Lamont at also uses MB-System extensively in the operations of its archive and data portals.

- The NSF-Supported National Deep Submergence Facility (NDSF) at the Woods Hole Oceanographic Institution uses MB-System to process multibeam data collected on AUV Sentry, ROV Jason, and DSRV Alvin.
- The MB-System Discussion email list has approximately 245 registered members, and had more than 400 posts during 2011.  
(<http://listserver.mbari.org/sympa/arc/mbsystem> )
- A large but unknown number of publications have involved mapping data processed using MB-System. A list of 112 publications explicitly citing MB-System is available at:  
<http://www.mbari.org/data/mbsystem/2012NSFProposal/ProposalSupplement.pdf>

The MB-System software has been distributed as source code releases since 1993, and a “cookbook” manual was completed in 2006:

Caress, D.W., and D.N. Chayes (1993-2012), MB-System, Open source software distributed from the MBARI and L-DEO web sites,  
<http://www.mbari.org/data/mbsystem/> , <http://www.ldeo.columbia.edu/res/pi/MB-System/>.

Schmidt, V., D. Chayes, and D. Caress (2006), *The MB-System Cookbook*,  
<http://www.mbari.org/data/mbsystem/mbcookbook.pdf> .

These peer-reviewed papers have explicitly presented MB-System capabilities:

Manley, Patricia L. and David W. Caress (1994), Mudwaves on the Gardar Sediment Drift, NE Atlantic, *Paleoceanography*, **9**, 973-988,  
<http://dx.doi.org/10.1029/94PA01755> .

Caress, David.W., and Dale N. Chayes (1996), Improved processing of Hydrosweep DS Multibeam Data on the R/V Maurice Ewing, *Marine Geophysical Researches*, **18**, 631-650, <http://dx.doi.org/10.1007/BF00313878> .

Caress, D.W., H. Thomas, W. J. Kirkwood, R. McEwen, R. Henthorn, E. A. Clague, C. K. Paull, J. Paduan, and K. L. Maier (2008), "[High-Resolution Multibeam, Sidescan, and Subbottom Surveys Using the MBARI AUV D. Allan B.](#)", *Marine Habitat Mapping Technology for Alaska*, J.R. Reynolds and H.G. Greene (eds.) Alaska Sea Grant College Program, University of Alaska Fairbanks.  
<http://dx.doi.org/10.4027/mhmta.2008.04>

Clague, D.A., J.B. Paduan, D.W. Caress, H. Thomas, W.W. Chadwick, S. Merle (2011), Volcanic morphology based on high-resolution bathymetry and depth changes at West Mata Volcano, NE Lau Basin, *Geochemistry, Geophysics, Geosystems*, **12**,  
<http://dx.doi.org/10.1029/2011GC003791>.

Caress, D.W., D.A. Clague, J.B. Paduan, J.F. Martin, B.M. Dreyer, W.W. Chadwick, A. Denny, D.S. Kelley (2012), “Repeat bathymetric surveys at 1-metre resolution of lava flows erupted at Axial Seamount in April 2011 ”, *Nature Geoscience*, **5**, pp. 483-488, <http://dx.doi.org/10.1038/NCEO1496>.

## REFERENCES

- Calder, B. R., and L. A. Mayer (2003), Automatic processing of high-rate, high-density multibeam echosounder data, *Geochemistry Geophysics Geosystems*, 4(6), 1048, <http://dx.doi.org/10.1029/2002GC000486>.
- Caress, D.W., and D.N. Chayes (1993), MB-System Version 3, Open source software distributed from the L-DEO ftp site.
- Caress, D.W., and D.N. Chayes (1994-2000), MB-System Version 4, Open source software distributed from the MBARI and L-DEO web sites, 9 major releases.
- Caress, D. W. and Chayes, D. N. (1995), New software for processing sidescan data from sidescan-capable multibeam sonars, Proc. IEEE Oceans 95 Conf., 997-1000, <http://dx.doi.org/10.1109/OCEANS.1995.528558>.
- Caress, David.W., and Dale N. Chayes (1996), Improved processing of Hydrosweep DS Multibeam Data on the R/V Maurice Ewing, *Marine Geophysical Researches*, 18, 631-650, <http://dx.doi.org/10.1007/BF00313878>.
- Caress, D.W., and D.N. Chayes (2000-2012), MB-System Version 5, Open source software distributed from the MBARI and L-DEO web sites.
- Caress, D.W., H. Thomas, W. J. Kirkwood, R. McEwen, R. Henthorn, E. A. Clague, C. K. Paull, J. Paduan, and K. L. Maier (2008), "High-Resolution Multibeam, Sidescan, and Subbottom Surveys Using the MBARI AUV D. Allan B.", *Marine Habitat Mapping Technology for Alaska*, J.R. Reynolds and H.G. Greene (eds.) Alaska Sea Grant College Program, University of Alaska Fairbanks. <http://dx.doi.org/10.4027/mhmta.2008.04>.
- Caress, D.W., D.A. Clague, J.B. Paduan, J.F. Martin, B.M. Dreyer, W.W. Chadwick, A. Denny, D.S. Kelley (2012), "Repeat bathymetric surveys at 1-metre resolution of lava flows erupted at Axial Seamount in April 2011 ", *Nature Geoscience*, 5, pp. 483-488, <http://dx.doi.org/10.1038/NGEO1496>.
- Clague, D.A., J.B. Paduan, D.W. Caress, H. Thomas, W.W. Chadwick, S. Merle (2011), Volcanic morphology based on high-resolution bathymetry and depth changes at West Mata Volcano, NE Lau Basin, *Geochemistry, Geophysics, Geosystems*, 12, <http://dx.doi.org/10.1029/2011GC003791>.
- Kluesner, J., E. Silver, R. von Huene, N. Bangs, K. McIntosh, C. Ranero, D. Orange, S. Cavanaugh, S. Graf, A. Baracco, A. Lago (2011), Detailed surface structure in high-resolution bathymetry and backscatter from the CRISP 3D seismic experiment, offshore Costa Rica, 2011 AGU National Meeting.
- Manley, Patricia L. and David W. Caress (1994), Mudwaves on the Gardar Sediment Drift, NE Atlantic, *Paleoceanography*, 9, 973-988, <http://dx.doi.org/10.1029/94PA01755>.
- Schmidt, V., D. Chayes, and D. Caress (2006), The MB-System Cookbook, distributed from MBARI and L-DEO web sites.
- Wessel, P. and W. H. F. Smith (1991), Free software helps map and display data, *EOS Trans. AGU*, 72, 441, <http://dx.doi.org/10.1029/90EO00319>.
- Wessel, P. and W. H. F. Smith (1998), New, improved version of the Generic Mapping Tools released, *EOS Trans. AGU*, 79, 579, <http://dx.doi.org/10.1029/98EO00426>.

DAVID W. CARESS  
Monterey Bay Aquarium Research Institute  
7700 Sandholdt Road, Moss Landing, CA 95039  
831-775-1775 [caress@mbari.org](mailto:caress@mbari.org)

**Professional Preparation:**

1984 B.S., Physics, Harvey Mudd College, Claremont, CA  
1989 Ph.D., Geophysics, Scripps Institution of Oceanography, La Jolla, CA

**Appointments:**

2011-Present Software Engineer IV, MBARI, Moss Landing, CA  
2009-2011 Software Engineer III, MBARI, Moss Landing, CA  
1998-2009 Senior Research Specialist, MBARI, Moss Landing, CA  
1997-1998 Geophysicist, SAIC, Newport, RI  
1994-1997 Geophysicist, SeaBeam Instruments, East Walpole, MA  
1994-2004 Adjunct Associate Research Scientist, L-DEO  
1989-1994 Associate Research Scientist, Lamont-Doherty Earth Observatory of  
Columbia University, Palisades, NY  
1985-1989 Graduate Research Assistant  
Scripps Institution of Oceanography (SIO), La Jolla, CA  
1984-1985 Regents Fellow, SIO

**Five Most Relevant Publications**

Caress, D.W., D.A. Clague, J.B. Paduan, J.F. Martin, B.M. Dreyer, W.W. Chadwick, A. Denny, D.S. Kelley, "Repeat bathymetric surveys at 1-metre resolution of lava flows erupted at Axial Seamount in April 2011", *Nature Geoscience*, 5, pp. 483-488, <http://dx.doi.org/10.1038/NGEO1496>, 2012.

Clague, D.A., J.B. Paduan, D.W. Caress, H. Thomas, W.W. Chadwick, S. Merle, Volcanic morphology based on high-resolution bathymetry and depth changes at West Mata Volcano, NE Lau Basin, *Geochemistry, Geophysics, Geosystems*, 12, <http://dx.doi.org/10.1029/2011GC003791>, 2011.

Paull, C.K., D.W. Caress, W. Ussler III, E. Lundsten, M. Meiner-Johnson, High-resolution bathymetry of the axial channels within Monterey and Soquel submarine canyons, offshore central California, *Geosphere*, 7, 1077-1101, <http://dx.doi.org/10.1130/GES00636.1>, 2011.

Caress, D.W., H. Thomas, W. J. Kirkwood, R. McEwen, R. Henthorn, E. A. Clague, C. K. Paull, J. Paduan, and K. L. Maier, "High-Resolution Multibeam, Sidescan, and Subbottom Surveys Using the MBARI AUV D. Allan B.", *Marine Habitat Mapping Technology for Alaska*, J.R. Reynolds and H.G. Greene (eds.) Alaska Sea Grant College Program, University of Alaska Fairbanks. <http://dx.doi.org/10.4027/mhmta.2008.04>, 2008.

Caress, David.W., and Dale N. Chayes, Improved processing of Hydrosweep DS Multibeam Data on the R/V Maurice Ewing, *Marine Geophysical Researches*, 18, 631-650, <http://dx.doi.org/10.1007/BF00313878>, 1996.

**Five Other Significant Publications**

Caress, D. W., M. K. McNutt, R.S. Detrick, and J.C.Mutter, Seismic imaging of hotspot-related crustal underplating beneath the Marquesas Islands, *Nature*, 373, 600-603, <http://dx.doi.org/10.1038/373600a0>, 1995.

- Caress, David W., Mark S. Burnett, and John A. Orcutt, Tomographic image of the axial low velocity zone at 12°50'N on the East Pacific Rise, *J. Geophys. Res.*, **97**, 9243-9263, <http://dx.doi.org/10.1029/92JB00287>, 1992.
- Caress, David W., Structural trends and back-arc extension in the Havre Trough, *Geophys. Res. Lett.*, **18**, 853-856, <http://dx.doi.org/10.1029/91GL01060>, 1991.
- Caress, David W. and Robert L. Parker, Spectral interpolation and downward continuation of marine magnetic anomaly data, *J. Geophys. Res.*, **94**, 17393-17408, <http://dx.doi.org/10.1029/JB094iB12p17393>, 1989.
- Caress, David W., H. W. Menard, and R. N. Hey, Eocene reorganization of the Pacific-Farallon spreading center north of the Mendocino fracture zone, *J. Geophys. Res.*, **93**, 2813-2838, <http://dx.doi.org/10.1029/JB093iB04p02813>, 1988.

**Synergistic Activities:**

**Open Source Software:** MB-System, NSF-supported software for processing and display of swath mapping sonar data (with D. N. Chayes).

**Membership in Professional Societies:** American Geophysical Union

**Memberships on Boards, Committees; Activities:**

- |                  |  |
|------------------|--|
| 2000 - 2003      | Member, ODP/iODP Site Survey Panel                       |
| 1994, 1999, 2009 | NSF Proposal Review Panels                               |
| 1994             | Lecturer, Multibeam Course, US/Canada Hydrographic Comm. |
| 1993 -1996       | Member, ODP Lithosphere Panel                            |

**Consulting:**

- |                 |  |
|-----------------|--|
| 2012            | Ocean Floor Geophysics, MB-System training.  |
| 2002, 2005-2006 | Raytheon Polar Services Company, MB-System training and RVIB Palmer multibeam acceptance trials. |
| 1999 - 2000     | SeaBeam Instruments, software development  |

**Outreach:**

- |                |  |
|----------------|--|
| 2002 – present | Mentor for middle and high school teams in MATE ROV Competitions |
|----------------|--|

**Field Programs:** participated in over 37 oceanographic expeditions, 14 as chief or co-chief scientist, as well as dozens of single day operations since 1984. Operations have included acoustic seafloor mapping from ships, AUVs, and ROVs. Experienced also in single and multi-channel seismic reflection, active source seismic refraction using ocean bottom seismometers, magnetics, gravity, dredging, and coring.

**Non-MBARI Collaborators within last 48 months:**

S. Augenstein (Stanford), E. T. Baker (NOAA-PMEL), T. Baumberger (ETH Zurich), N. J. Buck (UW/PMEL), D. A. Butterfield (UW/PMEL), W. W. Chadwick (OSU/NOAA PMEL), D. N. Chayes (LDEO), J. P. Cohen (U. Hawaii), J. A. Covault (Stanford), R. Davis (Oregon Health and Science U.), A. Denny (UW), B. M. Dreyer (UC Santa Cruz), R. P. Dziak (OSU/NOAA-PMEL), R. W. Embley (NOAA PMEL), A. Fildani (Chevron), S. A. Graham (Stanford), J. A. Huber (MBL), N. S. Keller (WHOI), D. S. Kelley (U. Washington), M. D. Lilley (U. Washington), J. E. Lupton (NOAA-PMEL), K. L. Maier (Stanford), M. McGann (USGS), T. R. McHargue (Stanford), S. G. Merle (OSU/NOAA-PMEL), P. J. Michael (U. Tulsa), J. A. Resing (U. Washington/PMEL), A.-L. Reysenbach (Portland State University), K. H. Rubin (U. Hawaii), T. M. Shank (WHOI), R. Sliter (USGS), A. Soule (WHOI), S. L. Walker (NOAA-PMEL), J. Xu (USGS)

**Graduate Advisors:** John A. Orcutt (SIO) and Richard N. Hey (U. Hawaii)

## Biographical Sketch

Dale N. Chayes

Lamont Research Engineer (Columbia University Senior Staff Associate)  
Lamont-Doherty Earth Observatory of Columbia University  
61 Route 9W, Palisades, NY 10964,  
Phone: (845) 365-8434, Fax: (845) 359-6940  
Email: dale@ldeo.columbia.edu  
Web: www.ldeo.columbia.edu/~dale

### **Education:**

1973: B.S. (Geology) St. Lawrence University, Canton, NY.

2009: Honorary Doctor of Science, St. Lawrence University, Canton, NY.

### **Professional Experience:**

2002 – Present Lamont Research Engineer, Lamont-Doherty Earth Observatory  
of Columbia University  
1988 to 2002 Senior Staff Associate, Lamont-Doherty Earth Observatory of  
Columbia University  
1980 to 1988 Staff associate, Lamont–Doherty Geological Observatory  
(LDGO)  
1977 to 1980 Research Staff Engineer, LDGO  
1973 to 1976 Research Assistant, LDGO

### **Professional Activities:**

Ex-Chair, UNOLS Research Vessel Technical Enhancement Committee and Member,  
UNOLS Council (2000-2004)

Member, Institute of Electrical and Electronic Engineers (Oceanic Engineering and  
Communications Societies)

Life Member, American Geophysical Union

### ***Oceanographic Cruises:***

Participation well over a one hundred fifty oceanographic cruises in support of scientific  
research programs on ships and submarines operated by U.S. and foreign academic,  
private, government, and military organizations in a broad range of roles from technician  
to chief scientist. In the Arctic, Antarctic and all latitudes in between.

### **Related Publications:**

Chayes, D. N., Roberts, S. D., Perron, P.J., Beaudoin, J, Arko, R.A., Perry, R.S., (2010),  
A new multibeam swath mapping echosounder for USCGC Healy: Eos Trans. AGU.

Brumley, K., L. A. Mayer, E. L. Miller, S. Roberts, B. Coakely, and D. Chayes, 2010, 3D  
Visualization of Arctic Ocean Multibeam Bathymetric Data and the Constraints it Offers  
to Tectonic Reconstruction Models, GSA, 2010 Meeting Paper 172-3.

Caress, D. W., Chayes, D.N (2001). Improved Management of Large Swath Mapping Datasets in MB-System Version 5, Abstract OS11B-0373, Eos Trans. Fall Meet. Suppl. 82(47).

Caress, D. W. and D. N. Chayes (1995), New Software for Processing Sidescan Data from Sidescan-Capable Multibeam Sonars, IEEE Oceans '95, San Diego, CA., IEEE.

Caress, D. W., and D. N. Chayes, 1996, Improved Processing of Hydrosweep Multibeam Data on the R/V Maurice Ewing, Marine Geophysical Researches, v. 18, p. 631-650.

### **Other significant publications:**

Chayes, D. N., A. D. Chave, et al. (2006). Concept Design for a Cabled Seafloor Observatory at Barrow, Alaska, Scientific Seafloor Cables 2006, IEEE Oceanic Engineering Soc. Dublin, Ireland.

Anderson, R. M., D. Chayes, et al. (2003). "Seafloor Sounding in Polar and Remote Regions, Abstract OS42A-0831." Eos Trans. AGU, Fall Meet. Suppl. 84(47).

Chayes, D. N., R. M. Anderson, et al. (1999). Seafloor Characterization and Mapping Pods (SCAMP): submarine-mounted geophysical mapping. OCEANS '99, DOI: 10.1109/OCEANS.1999.800224

Chayes, D. N., N. Tervalon, et al. (2001). Ice Profiling Sonars: a Comparison of Error Budgets. Oceans 2001, Honolulu, HI, IEEE Ocean. Eng.

W. M. Smethie, P. Schlosser, D. N. Chayes, and R. S. Perry, A Lightweight Vertical Rosette for Deployment in Ice Covered Waters, Deep Sea Research, vol. 58 pp. 460-467, 2011.

### **Synergistic Activities:**

Design, upgrade, management and operational support of science systems on the US Coast Guard Icebreaker Healy (WAGB20) including a new multibeam and integration of UHDAS.

System engineering for the Seafloor Sounding in Polar And Remote Regions (SSPARR) autonomous bathymetric sounding system.

Development of MB-System, an open source swath bathymetry software system with Dave Caress at MBARI and the MB-System Cookbook with Val Schmidt at LDEO.

Installation and integration of POS/MV inertially aided GNSS attitude, heading and position systems on research vessels Knorr, Thompson, Ewing and Healy and development of enhanced real-time navigation on the R/V Knorr to support dynamic positioning while drilling in shallow water.

System engineering for development of database and software in support of community review system of Digital Library for Earth System Education (DLESE), the RIDGE2000 and Margins Data Management Systems, underway metadata capture for Healy.

### **Collaborators (last 48 months):**

R.M. Anderson (SAIC), S. Carbotte (LDEO), D. Caress (MBARI), B.J. Coakley (UAF), K. A. Kastens (LDEO), C. Lee (UW) , L. Mayer (UNH/CCOM), W.B.F. Ryan (LDEO), P. Schlosser (LDEO), W. Smethie (LDEO), M. Steele (UW)

## **MBARI Budget Justification**

This five-year project involves collaborative proposals from David Caress at the Monterey Bay Aquarium Research Institute (MBARI) and Dale Chayes at the Lamont-Doherty Earth Observatory (L-DEO). MBARI is the lead institution.

### **A. Senior Personnel**

In each year we request 1.5 months/year of MBARI salary for David Caress. MBARI will match the NSF support for Caress, resulting in a total of 3-months/year effort. Caress will lead the software development effort, and help to provide user support and code maintenance.

### **B. 2. Other Professionals**

We request 4-months/year support for Krystle Anderson, an MBARI research assistant, to assist Chayes in writing documentation. Anderson is currently responsible for processing MBARI Mapping AUV surveys using MB-System, and she has previous survey experience with hull-mounted multibeam data processed using commercial software tools.

### **C. Fringe Benefits:**

Fringe benefits are calculated based on MBARI's established rates. The rate for full-time regular employees is 57%.

### **E. Domestic Travel:**

We request 1 round trip to LDEO in years 2 and 4 for Caress to help Chayes lead MB-System user workshops.

### **G.6 Other Direct Costs: Workshop:**

In years 1, 3, and 5, Caress will host developer workshops at MBARI. We request modest support to cover on-site costs of these events at MBARI.

### **I. Indirect Cost Rate:**

The institutional IDC rate is 51% MTDC. The base excludes capital items, participant support costs, and subcontract costs exceeding the first 25K of each subcontract.

Collaborative Research: Development and support of the MB-System software package for processing and display of swath mapping sonar data

#### Budget Justification

##### **Personnel**

PI Dale Chayes will coordinate with Caress at MBARI on system architecture and prioritization, contribute to the support effort, contribute to the MB-System Cookbook, supervise the efforts of the other Lamont personnel and lead the development of the test suite described in the proposed work section. One month per year of time is budgeted for his participation in this project.

Bob Arko will assist with support of our Subversion source code control system, our ftp repository and the establishment of a Wiki to facilitate user-contributed documentation as well as provide technical assistance with porting issues. For his participation in this project we request .50 per year.

One month per year of salary is requested for a TBD software engineer/programmer. This person will contribute to improvements to MB-System.

Three months of salary per year are requested to support a TBD summer undergraduate student to work with PI Chayes on MB-System user documentation and/or the test suite.

##### **Fringe benefits**

Fringe benefits are assessed at Columbia's government-negotiated rate of 33.3%, effective July 1, 2012 through June, 30, 2013 and estimated beyond that. Undergraduate fringe is assessed at 8.15%.

##### **Travel**

One round trip per year is budgeted to participate in the fall AGU meeting in San Francisco. We have budgeted \$530 for airfare, \$545 for Registration/Abstract Fees, \$226/day for Subsistence and \$200 each year for transportation. One roundtrip to Monterey, CA is budgeted in each of Years 1, 3 and 5 for the PI to participate in an MB-System developer's workshop which will be hosted by Caress at MBARI. We have budgeted \$593 for airfare, \$205/day for subsistence and \$200 each year for transportation.

##### **Equipment**

The budget includes \$5,884 in the first year for a server. This server will be used by the PI and other personnel listed as necessary to perform the quantitative tasks that are central to this project. The cost for this server is based on a quote obtained with Columbia's discounted rate.

##### **Other Direct Costs**

*Materials and supplies:* We request a modest amount each year, \$300, for office consumables such as data storage and toner.

*Communications* is budgeted at \$150 each year for teleconferences, Web conferencing, phones and faxes.

*Services:* In years 2 and 4, PI Chayes will host a user's group workshop at Lamont. We request \$470 in Year 2 and \$492 in Year 4 for services to supply on-site catering of refreshments.

**Indirect costs**

Indirect costs for the Lamont campus are assessed at Columbia's government-negotiated rate of 53% on modified total direct costs.

David Caress, Co-PI

## Current and Pending Support

### Pending

Title: Collaborative Research: Development and Support of the MB-System Software Package for Processing and Display of Swath Mapping Sonar Data (this proposal)

Amount: \$407,912

Project Period: 04/01/13-03/31/18

Effort: 3 mo

**CURRENT AND PENDING SUPPORT**

8/9/2012

**DALE CHAYES**

A Supporting Agency	B Project Title	C Award Amount	D Period Covered Award	E Man-Month Acad. Sum. Cal.	F Location
<b><u>A. Current Support</u></b>					
*UNIV. ALASKA UALASKA FP01306	EVALUATION OF METHODS AND PLATFORMS FOR THE ACQUISITION OF MULTI- CHANNEL SEISMIC REFLECTION DATA IN THE ARCTIC OCEAN (CHAYES, D., PI; DIEBOLD, J., CO- PI)	132,624	9/1/09 8/31/12	.75/1.25/.50	LDEO
NSF OCE 06-23584	COLLABORATIVE RESEARCH: DEVELOPMENT AND SUPPORT OF THE MB-SYSTEM SOFTWARE PACKAGE FOR PROCESSING AND DISPLAY OF SWATH MAPPING SONAR DATA. (CHAYES, D.;PI w/ARKO, B.)	368,965	9/1/06 8/31/12	1/1/1/1/ NC	LDEO
NSF ARC 10-23529	COLLABORATIVE RESEARCH: LONG-TERM OBSERVATIONS IN THE SWITCHYARD REGION OF THE ARCTIC OCEAN AS PART OF THE ARCTIC OBSERVING NETWORK (AON) (SCHLOSSER, P., PI; SMETHIE, W., CHAYES, D., TAKAHASHI, T., CO-PIS w/NEWTON, R., FRIEDRICH, R., GORMAN, E.)	1,326,358	9/1/10 8/31/12	1/1	LDEO
<b><u>B. Pending Support</u></b>					
NSF #13935	COLLABORATIVE RESEARCH: DEVELOPMENT AND SUPPORT OF THE MB-SYSTEM SOFTWARE PACKAGE FOR PROCESSING AND DISPLAY OF SWATH MAPPING SONAR DATA (CHAYES, D., PI; w/ARKO, R.)	316,168	4/1/13 3/31/18	1/YR	LDEO

**DALE CHAYES**

<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>	<b>E</b>	<b>F</b>
<b>Supporting Agency</b>	<b>Project Title</b>	<b>Award Amount</b>	<b>Period Covered Award</b>	<b>Man-Month Acad. Sum. Cal.</b>	<b>Location</b>

*UNIV.NEW HAMP. #13900	SUPPORT FOR ECS SURVEY ON USCGC HEALY (CHAYES, D., PI)	69,558	7/1/12 12/31/12	1.8	LDEO
---------------------------	---	--------	--------------------	-----	------

**C. Outstanding Increments**

NSF ARC 10-23529	YEAR 3: COLLABORATIVE RESEARCH: LONG-TERM OBSERVATIONS IN THE SWITCHYARD REGION OF THE ARCTIC OCEAN AS PART OF THE ARCTIC OBSERVING NETWORK (AON) (SCHLOSSER, P., PI; SMETHIE, W., CHAYES, D., TAKAHASHI, T., CO-PIS w/NEWTON, R., FRIEDRICH, R., GORMAN, E.)	656,883	9/1/12 8/31/13	1	LDEO
---------------------	---	---------	-------------------	---	------

**D. Proposals Planned to be Submitted in Near Future:**

NONE

**E. Transfer of Support:**

NONE

**F. Other Agencies to Which Proposal Has Been/Will be Submitted:**

NONE

## **MBARI FACILITIES STATEMENT**

The MBARI component of the project is software development, and as such primarily depends upon computer and data storage facilities. MBARI maintains a diverse network including MacOs X, Linux, and Windows computers and large data storage servers. The MBARI PI (Caress) has access to all hardware and software computing resources required for the project tasks.

## **Facilities Statement**

The LDEO personnel who will work on this proposal have suitable workstations (desktops and laptops) to perform the work proposed here. The requested server will be installed in an existing server room and managed as part of the Marine Geology & Geophysics (MG&G) server/storage cluster. A laptop is available for the summer intern and for potential work-study students during the academic year.

The Lamont network has redundant, independent connections to the Internet: one is an OC3 connection through the local telephone provider (Verizon) that terminates on the Columbia campus and provides direct connection to Internet 2; the other is a 54 megabit per second microwave link across the Hudson River to a different Columbia satellite campus (Nevis Labs) where it connects to an independent (Qwest) ISP.

Lamont's campus has meeting rooms, each with an Internet connection and projector which will be available to Chayes to host the user's workshop. This space along with any copies or handouts will be provided by Lamont for the user's group workshop.

## Data Management Plan

MB-System is an open source software package. We do not collect any scientific data, nor do we track users.

By definition, all of the products (software and documentation) have been and will continue to be publicly available via the Internet as web pages, by anonymous read-only access to our version control system, and via anonymous ftp. We also provide a publicly available set of example multibeam data for test and to support our documentation.

Our source code and documentation are released under the terms of the GNU Public License 3.0 and we plan to continue to use a widely accepted open source public license.

The MB-System web pages are mirrored from servers maintained at MBARI (<http://www.mbari.org/data/mbsystem/>) and at Lamont (<http://www.ldeo.columbia.edu/MB-System>)

MB-System uses a low-volume list server for announcements that is maintained at Lamont and a public list-server for user discussion and support that is maintained at MBARI.

Subversion (an open-source version control package) and FTP access to MB-System resources is provided by well maintained servers at the Lamont-Doherty Earth Observatory that are partially supported by the institution and that shared with other projects.

As part of this proposal, we expect to add a public "wiki" for user-contributed documentation and a password-controlled "wiki" to facilitate support for developers. Both of these services will be supported on servers at Lamont.

**Supplementary Information for the  
MB-System NSF Proposal**

**Collaborative Research: Development and Support of the MB-System Software  
Package for Processing and Display of Swath-Mapping Sonar Data**

Submitted to NSF-OCE-MG&G August 15, 2012 by:

David W. Caress (Monterey Bay Aquarium Research Institute)  
Dale N. Chayes (Lamont-Doherty Earth Observatory of Columbia University)

The purpose of this renewal proposal is to fund five years of continued development and support of the MB-System software package. MB-System is used for the processing and display of swath mapping sonar data, and has been supported since 1993 by four successive OCE-MG&G grants. The software is distributed and licensed as open source, and is widely used in both the U.S. and international MG&G communities.

The five-year work plan presented in our proposal involves software development efforts by several other groups. Supplement 1 includes letters of collaboration from seven of our separately funded MB-System development partners.

Also, in order to justify our request for software development support from NSF, we need to document the user base and community support for MB-System. Two additional supplements include (2) a listing of the groups that are known to be currently using MB-System, and (3) a listing of peer-reviewed publications that explicitly cite MB-System and therefore demonstrate long-term use of the software.

## Supplement 1: Collaboration Letters

We include here letters of intent to collaborate with our MB-System project from our MB-System development partners.

---

### UNIVERSITY OF NEW HAMPSHIRE

Center for Coastal and Ocean Mapping / Joint Hydrographic Center  
Chase Ocean Engineering Lab  
24 Colovos Road  
Durham, New Hampshire 03824-3525  
PHONE: (603) 862-3433  
FAX: (603) 862-0839  
www.ccom.unh.edu

Dr. D. W. Caress  
Monterey Bay Aquarium Research Institute  
7700 Sandholdt Road  
Moss Landing, CA 95039

2012-01-31

Dear Dave,

**Re.: CHRT integration in MB-System future development**

Thanks for inviting me to the MB-System development meeting at the start of the year. I was very enthusiastic about the developments that you're suggesting, which should really help in supporting current users and making it easier to port the code into many new environments. This is a very good thing for the whole community.

As we discussed, I think it would be a very interesting project to get a version of our CHRT (CUBE with Hierarchical Resolution Techniques) algorithm for computer-assisted processing of dense MBES data into MB-System. Our previous generation of the CUBE (Combined Uncertainty and Bathymetry Estimator) algorithm would have been difficult to integrate due to the licensing agreements that we had arranged with CCOM's Industrial Associates; the new model that we're working on for CHRT should make it possible, however, and that's something that we're (corporately) enthusiastic about seeing happen.

We intend CHRT's distribution to be implemented through a co-development model. That is, each co-developer will sign a license agreement with UNH that provides them access to the code base for the algorithm. They will have the right to modify and use the code in their own software, so long as it passes the validation test suite provided at the project's website. We will also encourage, and expect, all of the co-developers to contribute fixes back to the code base; the validation test suite will only ever be defined with respect to the reference version of the code base managed by CCOM, which should be a big incentive to have it as the 'usual' model. Source code redistribution, except for the public header files, will not be allowed. Typically, for-profit organizations are required to become CCOM Industrial Associates before they can negotiate a license, providing aide-in-kind to CCOM as part of the arrangement. For non-profits, research organizations, etc., these terms are difficult to support, but for CHRT we intend that non-profits could sign licenses and contribute their "sweat equity" to the development of the project as their aide-in-kind to CCOM. That's the mechanism under which I see MB-System taking part in the project.

CHRT is implemented as a client-server model, so that the user interface (in this case MB-System) only has to link with a small library in order to take advantage of any server instances running on the local network. This means that MB-System would be able to be released with just the client interface files (to allow compilation) and binary versions of the client and server libraries. We intend to host at CCOM any binary versions of the libraries that are provided to us by the co-developers, and allow all co-developers to download them for distribution (although the co-developers will of course be responsible for supporting what they distribute). I don't know in advance how many different versions we'll have contributed, but we will at least support Mac OS X and Windows (in 64-bit mode) and possibly some variant of Linux (likely Ubuntu) ourselves from our internal requirements. We may get others from the co-developers.

Details of the agreement and final license terms are still developing as we negotiate with our current Industrial Associates, but I will keep you apprised of the developments. I would hope that a version of CHRT should be available for integration sometime in the second quarter of 2012. I look forward to working with Dale and you on the MB-System integration!

Regards,



Brian Calder, M.Eng(Merit), Ph.D., MIEE, MIEEE  
Associate Research Professor  
Associate Director, CCOM

Universität Bremen Fachbereich 5 · Postfach 33 04 40 · 28334 Bremen

To  
**David Caress**  
Monterey Bay Aquarium Research Institute  
7700 Sandholdt Road  
Moss Landing, CA 95039, and  
**Dale Chayes**  
Lamont-Doherty Earth Observatory  
Columbia University, 61 Route 9W  
Palisades, NY 10964-1000 USA



**DFG-Research Center |  
Cluster of Excellence  
-Vice Director**

Prof. Dr.  
**Gerhard Bohrmann**  
Marine Geologie

Ihre Zeichen:

Ihre Nachricht vom:

Unser Zeichen:

Datum: 10.02.12

Telefon 00 49 (421) 218 -65050  
Fax 00 49 (421) 218 -65099  
eMail [gbohrmann@marum.de](mailto:gbohrmann@marum.de)

**Dear colleagues**

MARUM, the Center for Marine Environmental Sciences at the University of Bremen is strongly supporting your initiative to continue further developments of the software MB-System. MB-System is becoming increasingly important within the marine community in Germany. This open source software has been used since its origin (in the 90's) at GEOMAR as well as at other places, and slowly increasing its use at the BSH (the German Hydrographic Agency). At MARUM several groups have used MB-System besides other software packages like CARIS HIPS&SIPS, CARAIBES, PDS2000, FLEDERMAUS etc. The Seafloor Imaging Group at MARUM has now adopted MB-System as the primary software for processing both, shipboard and AUV survey data.

We are very supportive of the priorities for future development of MB-System that were identified at the planning meeting at Lamont in January, where Christian dos Santos Ferreira represented the MARUM group. Now we are excited about your plans to add water column data display and processing capabilities to the package. We also noted that some issues that are high priority for MARUM, are unlikely to be addressed within your NSF and Packard Foundation funded projects. These include support for data from sonars that are not used in the U.S. academic community, like Kongsberg GeoAcoustics Geoswath+, Benthos C3D, SEA Swath+, and multibeam data logged using EIVA-Naviscan, Hypack Hysweep and QPS Qinsy. We are also very interested in adding capabilities to MB-System that allow identification of soundings as compliant or non-compliant with IHO standards. Such features can only be added after some of your proposed modifications, specifically those enabling the software to store and use a variety of quality values. The BSH will use MB-System also for educational purposes within their internal training courses for hydrographers.

We would like to confirm that it is our intention to lead a MARUM/GEOMAR proposal for a software development project that will add the capabilities mentioned above to MB-System. This proposal in collaboration with the BSH has submission planned for the end of 2012 or the beginning of 2013.

Sincerely Yours,

Prof. Dr. Gerhard Bohrmann (Vice director of MARUM)

**Sekretariat**

Angelika Rinkel  
Greta Ohling

Telefon 00 49 (421) 218 -65051  
Fax 00 49 (421) 218 -65099  
E-Mail [arinkel@marum.de](mailto:arinkel@marum.de)  
[gohling@marum.de](mailto:gohling@marum.de)

**Postanschrift:**  
Universität Bremen  
GEO-Gebäude, Raum 1080  
FB 5, Klagenfurter Str.  
28359 Bremen

**LAMONT-DOHERTY**  
**EARTH OBSERVATORY**  
OF COLUMBIA UNIVERSITY  
P.O. Box 1000 61 ROUTE 9W Palisades, NY 10964-8000 USA

February 10, 2012.

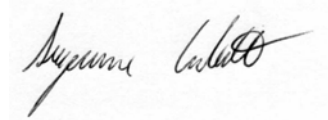
Dear Dave,

I'm writing to confirm our intent to collaborate with you on your proposal for ongoing development and support of MB-System. MB-System tools are an integral part of the data management activities of both the MGDS and the Rolling Deck to Repository (R2R) programs that I manage here at Lamont. For our MGDS activities, MB-System tools are used to extract data set metadata needed for registration of multibeam datasets and for submission to NGDC. We also make extensive use of your tools in our workflow for adding new multibeam datasets to our gridded Global Multi-Resolution Topography (GMRT) Synthesis (for scripted first-pass evaluation of new multibeam data sets, for sound velocity corrections, ping editing, and editing of embedded navigation prior to gridding into the GMRT).

An important component of our R2R program is to develop procedures for and conduct automated quality assessment (QA) of underway data types collected with the UNOLS fleet. For multibeam data, our automated QA procedures are built around existing MB-System tools with extensions we have built for additional QA functionality. As we complete this work, these extensions will be provided to the MB-System code archive so as to become part of the regular distributions available to the broader community.

It would be very difficult for us to perform the swath processing work for MGDS and R2R without the tools available in the MB-System package. In the coming years, we expect to continue to make new modifications and enhancements to support our ongoing data archiving and dissemination activities and we look forward to working with you to include any functionality of use to the broader community in future MB-System distributions.

Best Regards.



Suzanne Carbotte  
Heezen Lamont Research Professor  
Carbotte@ldeo.columbia.edu

GEOMAR | Wischhofstraße 1-3 | 24148 Kiel | Germany

**David Caress**  
Monterey Bay Aquarium Research Institute  
7700 Sandholt Road  
MossLanding, CA 95039, and

**Dale Chayes**  
Lamont-Doherty Earth Observatory  
Columbia University, 61 Route 9W  
Palisades, NY 10964-1000  
U. S. A.

**Dr. Wilhelm Weinrebe**  
Senior Staff Scientist

Tel +49 431 600-2281  
Fax +49 431 600-2922  
wweinrebe@geomar.de

13. Februar 2012

Dear colleagues,

GEOMAR, the Helmholtz Centre for Ocean Research Kiel is strongly supporting your initiative to continue further developments of the software MB-System. MB-System is our basic software for the processing of all our multibeam echosounder data since 1994. We have processed multibeam data of more than 100 major cruises of German research vessels using MB-System. MB-System will definitely remain the standard processing software for multibeam data at GEOMAR in the future because of its broad functionality, high performance, streamlined workflow and its open software architecture.

Though we were not able to participate personally in the planning meeting at Lamont in January 2012, we fully agree with the conclusions of that meeting, in particular with the list of future developments and extensions of MB-System. We realize that some topics of the list are unlikely to be addressed within your NSF and Packard Foundation funded projects. These include support for data formats from sonar systems that are not used in the U. S. academic community, e. g. Benthos C3D, Geoacoustics Geoswath+, multibeam data logged using Hysweep or water column data of Seabeam 3050 systems.

We confirm that we are preparing a proposal for software development to add the capabilities mentioned above to MB-System jointly with MARUM at the University of Bremen and in collaboration with BSH, the German Hydrographic Service. This proposal will be submitted to German funding agencies at the end of 2012 or the beginning of 2013.

Sincerely Yours,



Prof. Dr. Peter Herzig, Direktor | Ursula Frank-Scholz, Verwaltungsdirektorin (m.d.W.b.)  
MinDir Dr. Karl Eugen Huthmacher, Vorsitzender des Kuratoriums

**GEOMAR**  
Helmholtz-Zentrum für  
Ozeanforschung Kiel  
Wischhofstraße 1-3  
24148 Kiel | Germany  
Tel +49 431 600-0  
Fax +49 431 600-2805  
www.geomar.de  
Deutsche Bank AG Kiel  
BLZ 210 700 24  
Kto. 144 8000  
SWIFT/BIC DEUTDEDB210  
IBAN DE 69210700240144800000  
Steuernummer 1929400468  
USt.-IdNr. DE232115773

**February 13, 2012**

**Subject: Letter of Collaboration for MB-System**

Attention: MB-System Development Team

Tekmap Consulting is a Canadian Company working in the field of Ocean Science since 1994. Tekmap uses the MB-System suite of multibeam processing tools on an almost daily basis.

Because the software is Open Source (GPL), Tekmap is able to modify existing programs and to develop new programs that meet the specific needs of our clients. In addition, Tekmap contributes back to MB-System in the form of bug-fixes, program enhancements, and format support.

MB-System is an essential part of the multibeam processing services offered by Tekmap. Therefore, Tekmap will continue to actively use and contribute to MB-System.

MB-System provides a valuable set of tools to the Ocean Science sector. The features outlined in the 2012 NSF Proposal ensure that MB-System will continue to be a valuable tool to the Marine industry.

Sincerely,



Robert Covill  
President



## WOODS HOLE OCEANOGRAPHIC INSTITUTION

---

Feb 14, 2012

David Caress  
Monterey Bay Aquarium Research Institute  
7700 Sandholdt Road  
Moss Landing, CA 95039,

Dale Chayes  
Lamont-Doherty Earth Observatory Columbia University  
61 Route 9W  
Palisades, NY 10964-1000 USA

Dear Dave and Dale,

It's my pleasure to outline our current and planned collaboration with you with regards to MB-System development and its continued use for multibeam processing for data from our autonomous, remotely-operated vehicles and the human-occupied vehicle Alvin. MB-System is the main processing software we use to generate our multibeam maps, and it's also the platform used by our collaborators (University of South Carolina, University of Hawaii).

We are both users of MB-System as well as contributors. In addition to providing feedback to other MB-system developers, we've made additions and improvements to source code for the automated editing program (mbedit). These include a revised "rail" filter, filters for min/max height, and a filter to eliminate data in turns. We now can provide well-edited data to our users with no manual editing. We've added features to mb7kpreprocess that let us repair small sound speed errors that create incorrect beamforming. Additionally, we have also developed some bug fixes in the sidescan processing.

We've also developed a Matlab input/output capability for the generic MB-system fbt data format. This has been useful for importing MB-system data into Matlab for algorithm testing and refinement. For example our improvements to mbedit were developed first in Matlab, then ported to the mbedit program where they can be executed very efficiently on large files. We have also used the Matlab import capability to diagnose problems in real-time acquisition code supplied by our vendor. Recently our vendor inadvertently "discontinued" support for the mechanism we had been using to synchronize our main system clock with the clock in the sonar. We were able to track down this problem by examining the data carefully in Matlab, which then allowed us to convince our vendor they had a problem, then engineer a solution.

In the future, we anticipate continued participation in MB-System development. Our contributions will include improved automated editing, improved ability to correct sound speed beamforming errors, and

we will update the Matlab import/export capability to reflect the improved fbt format. We are also starting an effort to extract geological changes from multibeam data sets made at different times. Separating geological change from mapping artifacts will be a real challenge. We will develop these methods by importing the data into Matlab, but we will also add our resulting algorithms to the MB-System base.

regards

A handwritten signature in black ink, appearing to read "Dana R. Yoerger", with a long horizontal flourish extending to the right.

Dana R. Yoerger  
Senior Scientist



BUNDESAMT FÜR  
SEESCHIFFFAHRT  
UND  
HYDROGRAPHIE

BSH · Neptunallee 5 · 18057 Rostock · Germany

**Dr. David Caress**  
Monterey Bay Aquarium Research Institute  
7700 Sandholdt Road  
Moss Landing,  
CA 95039, USA

**Mr Dale Chayes**  
Lamont-Doherty Earth Observatory  
Columbia University, 61 Route 9W  
Palisades,  
NY 10964-1000 USA

Rostock Office

Date 20.02.2012

Extension:  
+ 49 (0) 381 4563 - 719  
Reference:  
N1317

**Letter of Intend for the support of the NSF proposal for further activities of the MB-System**

Dear Dr. Caress, dear Mr. Chayes,

the Federal Maritime and Hydrographic Agency (BSH) as the NHO of Germany, is happy to support your initiative of a NSF funding for further developments of the MB-System software package. MB-System is used intensively as a tool for processing multibeam data, which was acquired by German Research Vessels worldwide for further use within the German Bathymetric Database. At BSH the MB-System is also used for educational purposes especially in training courses for hydrographic surveyors.

With respect to the lack of time, no representative of the Hydrographic Office was able to attend the MB-System workshop at Lamont in January 2012, but the results of this workshop are being supported. The further development of MB-System, mainly the integration of additional proprietary data formats of sonars and of third party processing software would be appreciated by the BSH. The MB-System software is one of the few independent and perhaps Open Source software packages for processing multibeam sonar data. With respect to the proposed enhancements, the BSH could imagine that MB-System offers the possibility to compare processing results with the results of commercial multibeam sonar software.

The BSH will also support the funding initiative of MARUM, University of Bremen and GEOMAR, Centre of the Helmholtz Community for Oceanographic Research, Kiel to realize several contributions for MB-System enhancements, especially the S-44 compliance.

Best regards  
Dr. Mathias Jonas

Neptunallee 5  
18057 Rostock  
Tel.: + 49 (0) 381 4563 716  
-Fax: + 49 (0) 381 4563 - 948  
posteingang.rostock@bsh.de  
www.bsh.de

## Supplement 2: MB-System User Community Estimate

We all periodically need to justify our existence (at least with respect to funding), and a key way to justify the resources devoted to MB-System by MBARI and NSF is to document a significant user community. Since we don't sell MB-System, and we don't ask users to register in any way, usefully estimating the scale of the MB-System user community is a difficult endeavor. We do have three sources of information: membership in the MB-System Discussion List (<http://listserver.mbari.org/sympa/info/mbsystem>), emails to us not routed through the Discussion List, and our records of source distribution downloads. We generally seek to estimate the list of organizations rather than of individuals that use MB-System.

We assume that signing up to receive ~400 emails per year regarding MB-System indicates a fair degree of interest, and therefore regard all list members as "users". However, there are clearly many users that do not sign up for all these emails. Some read the posts through the online interface, some choose to email us separately, and some apparently just don't need any help. During 2011, there were 412 posts to the Discussion List. As of January 25, 2012, the MB-System Discussion List had 235 members successfully receiving emails. On August 10, 2012, there were 245 registered members, and there had been 335 posts so far this year.

Inferring usage from the records of downloads is more problematic. The download list consists of the IP addresses associated with downloads and the files downloaded. During 2011, MB-System source distributions were downloaded 2535 times from 925 unique IP addresses. In many cases, the IP addresses are resolved to identifiable domain addresses (e.g. [somemachine.mbari.org](http://somemachine.mbari.org)) that allow us to know which organization is associated with the download, but the great majority of download IP's are either unresolved or resolve to commercial ISPs like comcast.net. Further, compiled MB-System distributions are available for Mac OS X through the Fink Project, for Red Hat Linux systems through the Scripps Institution of Oceanography's Shipboard Technical Support group, and as part of the Poseidon Linux distribution (an Ubuntu variant). We have no tracking of MB-System installations through these other distributions, but it is anecdotally clear that these are increasingly popular. Thus, a large part of the community that downloads the MB-System source distributions is undocumented. However, it must also be noted that downloading does not necessarily imply usage, and very likely some of the organizations that we identify as downloading MB-System may in fact not be installing and using it. For instance, it seems likely that a past download by someone at National Cash Register (NCR) was probably not related to any major NCR product development projects. Finally, we frequently receive emails from people using old MB-System installations; these users are certainly users, but they do not show up in recent download logs because they haven't downloaded anything lately.

Despite the above uncertainties, we have used a combination of Discussion List membership and identified source distribution downloads to construct a list of organizations that have recently expressed a significant level of interest in MB-System. For better or worse, this represents our best estimate of the current user base.

The following 197 organizations are inferred to have used MB-System during 2011 because at least one of the following is true:

- The software distribution was downloaded to an IP address resolved to the organization domain at least once between January 1, 2011 and February 14, 2012.
- A member of the organization was enrolled in the MB-System Discussion List on January 25, 2012 or August 10, 2012.
- A member of the organization emailed us regarding their use of MB-System after January 1, 2011.

### **U.S. Academic (41)**

American Museum of Natural History	University of Alaska
California State University Humboldt	University of California Davis
California State University Monterey Bay	University of California Irvine
Florida Atlantic University	University of California Riverside
Florida State University	University of California Santa Barbara
Lamont-Doherty Earth Observatory, Columbia University	University of California Santa Cruz
Massachusetts Institute of Technology	University of Hawaii
MBARI	University of Houston
Medical University of South Carolina	University of Maine
Miami University	University of Minnesota
North Carolina State University	University of Mississippi
Ohio State University	University of New Hampshire
Oregon State University	University of North Carolina
Scripps Institution of Oceanography, UCSD	University of Oklahoma
San Diego Supercomputer Center, UCSD	University of South Carolina
Santa Clara University	University of South Florida
Stanford University	University of Texas Austin
Texas A&M University	University of Washington
University Corp. for Atmospheric Research	University of Wisconsin
University of Alabama	University of Wyoming
	Woods Hole Oceanographic Institution

### **Non-U.S. Academic (68)**

Alfred Wegener Institut, Germany	Institute for Systems and Robotics Lisbon, Portugal
Anadolu University, Turkey	Institute of Marine Research, Norway
Australian National University, Australia	Institution du Physique du Globe de Paris, France
Ben-Gurion University of the Negev, Israel	Instituto Superior de Engenharia do Porto, Portugal
Burapha University, Thailand	Jacobs University, Germany
Chiba University, Japan	Kumamoto University, Japan
Delft University of Technology, Netherlands	Kunsan National University, Korea
Ecole Nationale Supérieure de Techniques Avancées Bretagne, France	Leibniz Institute for Baltic Sea Research Germany
Fluminense Federal University, Brazil	MARUM, University of Bremen, Germany
Friedrich-Schiller-Universität Jena, Germany	Memorial University, Canada
GEOMAR, Germany	Moscow State University, Russia
HafenCity Universität Hamburg, Germany	Northumbria University, United Kingdom
Hellenic Centre for Marine Research, Greece	Oxford University, United Kingdom
Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research, Germany	
Institut Pierre Simon Laplace, France	

Plymouth University, United Kingdom  
 Pontificia Universidad Catolica de Valparaiso,  
 Chile  
 Russian State Hydrometeorological University,  
 Russia  
 Sheffield University, United Kingdom  
 Sun Yat-Sen University, China  
 Tokyo Institute of Technology, Japan  
 Trinity College Dublin, Ireland  
 Universidad de Granada, Spain  
 Universidad Nacional Autonoma de Mexico,  
 Mexico  
 Universidade de Brasilia, Brazil  
 Universidade do Algarve, Portugal  
 Universita Degli Studi di Parma, Italy  
 Universitat de Girona, Spain  
 Universitat Hamburg, Germany  
 Universitat Kiel, Germany  
 Universitat Oldenburg, Germany  
 Universitat Politecnica de Catalunya Barcelona,  
 Spain  
 Universitat Wurzburg, Germany  
 Universitatea Alexandru Ioan Cuza, Romania

Universite Brest (France)  
 Universite Laval, Canada  
 Universiteit Gent, Belgium  
 Universitet Stockholm, Sweden  
 Universitetet i Oslo, Norway  
 University of Auckland, New Zealand  
 University of British Columbia, Canada  
 University of Cambridge, United Kingdom  
 University of Durham, United Kingdom  
 University of Galway, Ireland  
 University of Iceland, Iceland  
 University of Manitoba, Canada  
 University of Otago, New Zealand  
 University of Patras, Greece  
 University of Stirling, United Kingdom  
 University of Southampton, United Kingdom  
 University of the Highlands and Islands, United  
 Kingdom  
 University of Tokai, Japan  
 University of Tokyo, Japan  
 University of Victoria, Canada  
 Yamaguchi University, Japan

### **U.S. Government Agency (11)**

Coastal Services Center, NOAA  
 Cooperative Institute for Research in  
 Environmental Sciences, NOAA  
 National Geophysical Data Center, NOAA  
 National Geospatial-Intelligence Agency  
 Oregon Department of Geology and Mineral  
 Industries

Pacific Marine Environmental Laboratory,  
 NOAA  
 United States Antarctic Program  
 United States Bureau of Reclamation  
 United States Coast Guard  
 United States Geological Survey  
 United States Navy

### **Non-U.S. Government Agency (40)**

Applied Geoscience and Technology Division,  
 SOPAC, Fiji  
 British Antarctic Survey, United Kingdom  
 Bundesamt fur Seeschiffahrt und Hydrographie  
 (BSH), Germany  
 Bundesanstalt für Geowissenschaften und  
 Rohstoffe (BGR), Germany  
 Centre Mediterrani d'Investigacions Marines i  
 Ambientals, Spain  
 Consejo Superior de Investigaciones Cientificas,  
 Spain  
 CSIRO Marine and Atmospheric Research,  
 Australia  
 Defence Research and Development, Canada  
 Department of Defense, Australia  
 Direccion Nacional de Recursos Acuaticos,  
 Uruguay  
 Directorate of Fisheries, Iceland  
 Fisheries and Oceans Canada, Canada

Fundacao Centro Tecnologico de Hidraulica,  
 Brazil  
 Geoscience Australia, Australia  
 GFZ German Research Centre for Geosciences,  
 Germany  
 GNS Science, New Zealand  
 Iceland Geosurvey, Iceland  
 IFREMER, France  
 Instituto de Investigaciones Electricas, Mexico  
 Instituto di Scienze Marine, Italy  
 Instituto Nacional de Investigacion u Desarrollo  
 Pesquero, Argentina  
 Institutul National de Cercetare-Dezvoltare  
 pentru Geologie si Geocologie Marina,  
 Romania  
 Istituto di Scienza e Tecnologia  
 dell'Informazione, Italy  
 Istituto Nazionale di Geofisica e Vulcanologia,  
 Italy  
 JAMSTEC, Japan

KORDI, Korea  
Korea Advanced Institute of Science and  
Technology, Korea  
Mamara Research Center, Turkey  
Marine Research Institute, Iceland  
Ministry of Energy and Mineral Resources,  
Indonesia  
National Defense and Canadian Forces, Canada  
National Institute of Advanced Industrial  
Science and Technology, Japan

National Institute of Oceanography, India  
NATO NURC, Italy  
Natural Resources Canada, Canada  
NIWA, New Zealand  
Petroleum Agency South Africa, South Africa  
Swedish Maritime Administration, Sweden  
Urząd Morski w Szczecinie, Poland  
United Kingdom Hydrographic Office, United  
Kingdom

### **Commercial (37)**

IOcean, (United States)  
Abyss Diving and ROV Services, (Norway)  
ALBUS, (Australia)  
Altas Electroniik, (Germany)  
Atlantide, (France)  
Baars-CIPRO, (Netherlands)  
C&C Technologies, (United States)  
Chevron, (Global)  
Consciousystems, (United States)  
Falkanger Snyder Martineau & Yates, (U.S.)  
Fielax, (Germany)  
General Dynamics, (United States)  
Geonautics, (Italy)  
Google, (United States)  
Hitachi, (Japan)  
Intec Sea, (Global)  
ISE, (Canada)  
Kawasaki Geological Engineering, (Japan)  
KESTI, (Korea)

Kinsale Angling, (Ireland)  
Korea Seabed Information, (Korea)  
MMT, (United Kingdom)  
Nomad Labs, (Germany)  
Ocean Floor Geophysics (Canada)  
Ocean Imaging Consultants, (United States)  
Oceanworks International, (U.S., Canada)  
Petrobras, (Brazil)  
Scanbio, (Norway)  
Stone Aerospace, (United States)  
Tekmap Consulting, (Canada)  
Teledyne, (United States)  
Thales, (Global)  
Tokyo Cartographic Company, (Japan)  
Viking Yachts, (United States)  
VITO, (Belgium)  
Wood Group, (Global)  
Z-pulley, (United States)

### Supplement 3: Publications That Cite MB-System

We include here a list of peer-reviewed publications that cite MB-System. This list does not include papers authored or co-authored by either David Caress or Dale Chayes. These papers were identified using Google Scholar. These publications may have cited the software distribution itself, or one of the few publications that have been focused on the MB-System package, as shown in this list:

- Caress, D.W., and D.N. Chayes, MB-System Version 3, Open source software distributed from the L-DEO ftp site, 1993.
- Caress, D.W., and D.N. Chayes, MB-System Version 4, Open source software distributed from the MBARI and L-DEO web sites, 9 major releases, 1994-2000.
- Caress, D. W. and Chayes, D. N., New software for processing sidescan data from sidescan-capable multibeam sonars, *Proc. IEEE Oceans 95 Conf.*, 997-1000, 1995.
- Caress, David.W., and Dale N. Chayes, Improved processing of Hydrosweep DS Multibeam Data on the R/V Maurice Ewing, *Marine Geophysical Researches*, **18**, 631-650, 1996.
- Caress, D.W., and D.N. Chayes, MB-System Version 5, Open source software distributed from the MBARI and L-DEO web sites, 2000-2012.
- Schmidt, V., D. Chayes, and D. Caress, The MB-System Cookbook, distributed from MBARI and L-DEO web sites, 2006.

Here is our assuredly incomplete list of papers that have cited MB-System in one fashion or another:

1. Adam, C. (2012), Hotspot Concept: The French Polynesia Complexity, in *Updates to Volcanology - A Comprehensive Approach to Volcanological Problems*, edited by F. Stoppa, InTech. [online] Available from: <http://www.intechopen.com/articles/show/title/hotspot-concept-the-french-polynesia-complexity>
2. Adam, C., V. Vidal, and A. Bonneville (2005), MiFil: A method to characterize seafloor swells with application to the south central Pacific, *Geochem. Geophys. Geosyst.*, 6(1), Q01003.
3. Antobreh, A. A., and S. Krastel (2006), Morphology, seismic characteristics and development of Cap Timiris Canyon, offshore Mauritania: a newly discovered canyon preserved-off a major arid climatic region, *Marine and petroleum geology*, 23(1), 37-59.
4. Ardhuin, F., and T. H. C. Herbers (2002), Bragg scattering of random surface gravity waves by irregular seabed topography, *Journal of Fluid Mechanics*, 451, 1-34.
5. Baines, A. G., M. J. Cheadle, H. J. B. Dick, A. H. Scheirer, B. E. John, N. J. Kusznir, and T. Matsumoto (2006), The evolution of the Southwest Indian Ridge and the implications of major changes in ridge axis geometry since 26 Ma, *Geodynamic investigation of ultra-slow spreading oceanic lithosphere: Atlantis Bank and vicinity, southwest Indian Ridge*, 30.

6. Baines, A. G., M. J. Cheadle, H. J. B. Dick, A. H. Scheirer, B. E. John, N. J. Kuszniir, and T. Matsumoto (2007), Evolution of the Southwest Indian Ridge from 55°45'E to 62°E: Changes in plate-boundary geometry since 26 Ma, *Geochemistry Geophysics Geosystems*, 8(6), Q06022, doi:10.1029/2006GC001559. [online] Available from: <http://www.agu.org/pubs/crossref/2007/2006GC001559.shtml> (Accessed 15 February 2012)
7. Barthelemy, M., and R. Pockalny (2002), A Regional Analysis of Multibeam Backscatter Data from the Southwest Pacific, *UNIVERSITY OF RHODE ISLAND*, 1.
8. Beaman, R. J., P. E. O' Brien, A. L. Post, and L. De Santis (2011), A new high-resolution bathymetry model for the Terre Ad{é}lie and George V continental margin, East Antarctica, *Antarctic Science*, 23(01), 95-103.
9. Beaman, R. J., and P. T. Harris (2005), Bioregionalization of the George V Shelf, East Antarctica, *Continental shelf research*, 25(14), 1657-1691.
10. Becker, N. C. (2005), Painting by numbers: A GMT primer for merging swath-mapping sonar data of different types and resolutions, *Computers & geosciences*, 31(8), 1075-1077.
11. Berglar, K., C. Gaedicke, D. Franke, S. Ladage, F. Klingelhoefer, and Y. S. Djajadihardja (2010), Structural evolution and strike-slip tectonics off north-western Sumatra, *Tectonophysics*, 480(1-4), 119-132.
12. Bolmer, S. T., R. C. Beardsley, C. Pudsey, P. Morris, P. Wiebe, E. Hofmann, J. Anderson, and A. Maldonado (2004), *A High-resolution bathymetry map for the Marguerite Bay and adjacent west Antarctic Peninsula shelf for the Southern Ocean GLOBEC Program*, Woods Hole Oceanographic Institution, Woods Hole, MA. [online] Available from: <https://darchive.mblwhoilibrary.org/handle/1912/49> (Accessed 15 February 2012)
13. Calder, B. R., and L. A. Mayer (2001), Robust automatic multibeam bathymetric processing, in *Proc. US Hydrographic Conference, Norfolk, VA*.
14. Calder, B. R., and L. A. Mayer (2003), Automatic processing of high-rate, high-density multibeam echosounder data, *Geochemistry Geophysics Geosystems*, 4(6), 1048.
15. Canepa, G., O. Bergem, and N. G. Pace (2003), A new algorithm for automatic processing of bathymetric data, *Oceanic Engineering, IEEE Journal of*, 28(1), 62-77.
16. Carranza, A., A. Munoz Recio, M. Kitahara, F. Scarabino, L. Ortega, G. Lopez, P. Franco-Fraguas, C. De Mello, J. Acosta, A. Fontan, et al., Deep-water coral reefs from the Uruguayan outer shelf and slope (2012), *Marine Biodiversity*, 42 (3), 411-414, DOI: 10.1007/s12526-012-0115-6.
17. Chadwick, W. W., R. W. Embley, P. D. Johnson, S. G. Merle, S. Ristau, A. Bobbitt, and others (2005), The submarine flanks of Anatahan Volcano, commonwealth of the Northern Mariana Islands, *Journal of volcanology and geothermal research*, 146(1-3), 8-25.

18. Clague, D. A., J. C. Braga, D. Bassi, P. D. Fullagar, W. Renema, and J. M. Webster (2010), The maximum age of Hawaiian terrestrial lineages: geological constraints from Koko Seamount, *Journal of Biogeography*, 37(6), 1022-1033.
19. Cohen, P. A., S. E. Spitzak, and S. P. Miller (1996), A graphical user interface for multibeam map production and survey management, in *OCEANS'96. MTS/IEEE.'Prospects for the 21st Century'. Conference Proceedings*, vol. 2, pp. 980-983.
20. Coombs, M. L., D. A. Clague, G. F. Moore, and B. L. Cousens (2004), Growth and collapse of Waianae Volcano, Hawaii, as revealed by exploration of its submarine flanks, *Geochemistry, Geophysics, Geosystems*, 5(8).
21. Cormier, M. H. et al. (2006), North Anatolian Fault in the Gulf of Izmit (Turkey): Rapid vertical motion in response to minor bends of a nonvertical continental transform, *J. geophys. Res.*, 111(10.1029).
22. Cunningham, M. J., S. Hodgson, D. G. Masson, and L. M. Parson (2005), An evaluation of along-and down-slope sediment transport processes between Goban Spur and Brenot Spur on the Celtic Margin of the Bay of Biscay, *Sedimentary Geology*, 179(1-2), 99-116.
23. Cuschieri, J. M., L. LeBlanc, M. Singer, and P. P. Beaujean (1996), Development of a 3-D forward look electronically scanned sonar system, in *OCEANS'96. MTS/IEEE.'Prospects for the 21st Century'. Conference Proceedings*, vol. 2, pp. 778-783.
24. Daniell, J. J. (2008), Development of a bathymetric grid for the Gulf of Papua and adjacent areas: A note describing its development, *J. Geophys. Res.*, 113, F01S15.
25. Dewangan, P., T. Ramprasad, M. V. Ramana, A. Mazumdar, M. Desa, and F. K. Badesab (2010), Seabed morphology and gas venting features in the continental slope region of Krishna--Godavari basin, Bay of Bengal: Implications in gas-hydrate exploration, *Marine and Petroleum Geology*, 27(7), 1628-1641.
26. Dewangan, P., G. Sriram, T. Ramprasad, M.V. Ramana, P. Jaiswal, Fault system and thermal regime in the vicinity of site NGHP-01-10, Krishna--Godavari basin, Bay of Bengal, *Marine and Petroleum Geology*, **28**, 10, 1899-1914, doi:10.1016/j.marpetgeo.2011.03.009, 2011.
27. Drolia, R. K., and C. DeMets (2005), Deformation in the diffuse India-Capricorn-Somalia triple junction from a multibeam and magnetic survey of the northern Central Indian Ridge, 3 S--10 S, *Geochem. Geophys. Geosyst.*, 6(9), Q09009.
28. Eakins, B. W., and J. E. Robinson (2006), Submarine geology of Hana Ridge and Haleakala Volcano's northeast flank, Maui, *Journal of volcanology and geothermal research*, 151(1-3), 229-250.
29. Faichney, I. D. E., J. M. Webster, D. A. Clague, C. Kelley, B. Appelgate, and J. G. Moore (2009), The morphology and distribution of submerged reefs in the Maui-Nui Complex, Hawaii: New insights into their evolution since the Early Pleistocene, *Marine Geology*, 265(3-4), 130-145.
30. Geersen, J., D. Volker, J. H. Behrmann, C. Reichert, and S. Krastel (2011), Pleistocene giant slope failures offshore Arauco Peninsula, Southern Chile, *Journal of the Geological Society*, 168(6), 1237.

31. Geist, E. L., P. J. Lynett, and J. D. Chaytor (2009), Hydrodynamic modeling of tsunamis from the Currituck landslide, *Marine Geology*, 264(1-2), 41-52.
32. Gonidec, Y. L., G. Lamarche, and I. C. Wright (2003), Inhomogeneous substrate analysis using EM300 backscatter imagery, *Marine Geophysical Research*, 24(3), 311-327.
33. Graham, A. G. C., R. D. Larter, K. Gohl, C. D. Hillenbrand, J. A. Smith, and G. Kuhn (2009), Bedform signature of a West Antarctic palaeo-ice stream reveals a multi-temporal record of flow and substrate control, *Quaternary Science Reviews*, 28(25-26), 2774-2793.
34. Grevemeyer, I., G. Helffrich, B. Faria, G. Booth-Rea, M. Schnabel, and W. Weinrebe (2010), Seismic activity at Cadamosto seamount near Fogo Island, Cape Verdes—formation of a new ocean island?, *Geophysical Journal International*, 180(2), 552-558.
35. Grevemeyer, I., B. Schramm, C. W. Devey, D. S. Wilson, B. Jochum, J. Hauschild, K. Aric, H. W. Villinger, and W. Weigel (2002), A multibeam-sonar, magnetic and geochemical flowline survey at 14° 14'S on the southern East Pacific Rise: insights into the fourth dimension of ridge crest segmentation, *Earth and Planetary Science Letters*, 199(3-4), 359-372.
36. Helly, J. J., R. S. Kaufmann, M. Vernet, and G. R. Stephenson (2011), Spatial characterization of the meltwater field from icebergs in the Weddell Sea, *Proceedings of the National Academy of Sciences*, 108(14), 5492.
37. Hirano, N., A. A. P. Koppers, A. Takahashi, T. Fujiwara, and M. Nakanishi (2008), Seamounts, knolls and petit-spot monogenetic volcanoes on the subducting Pacific Plate, *Basin Research*, 20(4), 543-553.
38. Hornbach, M. J., L. L. Lavier, and C. D. Ruppel (2007), Triggering mechanism and tsunamogenic potential of the Cape Fear Slide complex, US Atlantic margin, *Geochem. Geophys. Geosyst*, 8(Q12008), Q12008.
39. Ike, T., G. F. Moore, S. Kuramoto, J. O. Park, Y. Kaneda, and A. Taira (2008), Tectonics and sedimentation around Kashinosaki Knoll: A subducting basement high in the eastern Nankai Trough, *Island Arc*, 17(3), 358-375.
40. Jakobsson, M., L. Polyak, M. Edwards, J. Kleman, and B. Coakley (2008), Glacial geomorphology of the central Arctic Ocean: the Chukchi Borderland and the Lomonosov Ridge, *Earth Surface Processes and Landforms*, 33(4), 526-545.
41. Kamesh Raju, K. A., A. K. Chaubey, D. Amarnath, and A. Mudholkar (2008), Morphotectonics of the Carlsberg Ridge between 62° 20' and 66° 20'E, northwest Indian Ocean, *Marine Geology*, 252(3-4), 120-128.
42. Kamesh Raju, K. A., K. Samudrala, R. K. Drolia, D. Amarnath, R. Ramachandran, and A. Mudholkar (2012), Segmentation and morphology of the Central Indian Ridge between 3°S and 11°S, Indian Ocean, *Tectonophysics*, 554-557, 114-126.
43. Kirkwood, W. J. (2007), Development of the DORADO mapping vehicle for multibeam, subbottom, and sidescan science missions, *Journal of Field Robotics*, 24(6), 487-495.

44. Kloser, R. J., J. D. Penrose, and A. J. Butler (2010), Multi-beam backscatter measurements used to infer seabed habitats, *Continental Shelf Research*, 30(16), 1772-1782.
45. Kloser, R. J., A. Williams, and A. Butler (2007), Exploratory surveys of seabed habitats in Australia's deep ocean using remote sensing--needs and realities, *Mapping the Seafloor for Habitat Characterization. Geological Association of Canada, Special Paper*, 47, 93-109.
46. Kopf, A., D. Klaeschen, W. Weinrebe, E. R. Flueh, and I. Grevemeyer (2001), Geophysical evidence for late stage magmatism at the central Ninetyeast Ridge, Eastern Indian Ocean, *Marine Geophysical Research*, 22(3), 225-234.
47. Kopp, H., C. Kopp, J. P. Morgan, E. R. Flueh, W. Weinrebe, and W. J. Morgan (2003), Fossil hot spot-ridge interaction in the Musicians Seamount Province: Geophysical investigations of hot spot volcanism at volcanic elongated ridges, *J. geophys. Res*, 108(0).
48. Kopp, H. et al. (2008), Lower slope morphology of the Sumatra trench system, *Basin Research*, 20(4), 519-529.
49. Kottke, B., T. Schwenk, M. Breitzke, M. Wiedicke, H. R. Kudrass, and V. Spiess (2003), Acoustic facies and depositional processes in the upper submarine canyon Swatch of No Ground (Bay of Bengal), *Deep Sea Research Part II: Topical Studies in Oceanography*, 50(5), 979-1001.
50. Kukowski, N., J. Greinert, and S. Henrys (2010), Morphometric and critical taper analysis of the Rock Garden region, Hikurangi Margin, New Zealand: Implications for slope stability and potential tsunami generation, *Marine Geology*, 272(1), 141-153.
51. Kukowski, N., A. Hampel, S. Hoth, and J. Bialas (2008), Morphotectonic and morphometric analysis of the Nazca plate and the adjacent offshore Peruvian continental slope--Implications for submarine landscape evolution, *Marine Geology*, 254(1-2), 107-120.
52. Kukowski, N., T. Schillhorn, E. R. Flueh, and K. Huhn (2000), Newly identified strike-slip plate boundary in the northeastern Arabian Sea, *Geology*, 28(4), 355.
53. Kukowski, N., T. Schillhorn, K. Huhn, U. von Rad, S. Husen, and E. R. Flueh (2001), Morphotectonics and mechanics of the central Makran accretionary wedge off Pakistan, *Marine Geology*, 173(1), 1-19.
54. Levitt, D. A., and D. T. Sandwell (1996), Modal depth anomalies from multibeam bathymetry: Is there a South Pacific superswell?, *Earth and planetary science letters*, 139(1-2), 1-16.
55. Livermore, R. et al. (2000), Autopsy on a dead spreading center: the Phoenix Ridge, Drake Passage, Antarctica, *Geology*, 28(7), 607.
56. Lom, H., V. Spieß, and V. Hopfauf (n.d.), 4 Mudwaves on the western flank of the Zapiola Drift, Argentine Basin-Evidence for variations in Late Quaternary bottom flow activity, *aus dem Fachbereich Geowissenschaften der Universität Bremen*, 56.
57. von Lom-Keil, H., V. Spiefl, and V. Hopfauf (2002), Fine-grained sediment waves on the western flank of the Zapiola Drift, Argentine Basin: evidence for variations in Late Quaternary bottom flow activity, *Marine geology*, 192(1-3), 239-258.

58. Lundblad, E. R., D. J. Wright, J. Miller, E. M. Larkin, R. Rinehart, D. F. Naar, B. T. Donahue, S. M. Anderson, and T. Battista (2006), A benthic terrain classification scheme for American Samoa, *Marine Geodesy*, 29(2), 89-111.
59. Lundblad, E. R., D. J. Wright, D. F. Naar, B. T. Donahue, J. Miller, E. M. Larkin, and R. W. Rinehart (2004), Classifying deep water benthic habitats around Tutuila, American Samoa, in *Proceedings of the 24th Annual ESRI User Conference, San Diego, California, Paper*, vol. 1208.
60. Lundblad, E., D. J. Wright, J. Miller, E. M. Larkin, R. Rinehart, T. Battista, S. M. Anderson, D. F. Naar, and B. T. Donahue (2006), Classifying benthic terrains with multibeam bathymetry, bathymetric position and rugosity: Tutuila, American Samoa, *Marine Geodesy*, 29(2), 89-111.
61. Malahoff, A. (1998), An integrated shipboard ocean floor research system using a SeaBeam 210 ocean survey system installed on the R/V Ka'imikai-o-Kanaloa, *Marine Geodesy*, 21(2), 97-109.
62. Maldonado, A. et al. (2000), Tectonics of an extinct ridge-transform intersection, Drake Passage (Antarctica), *Marine Geophysical Research*, 21(1), 43-68.
63. McKnight, A. R. (2001), *Structure and evolution of an oceanic megamullion on the Mid-Atlantic ridge at 27 degrees N*, Massachusetts Institute of Technology and Woods Hole Oceanographic Institution, Woods Hole, MA. [online] Available from: <https://darchive.mblwhoilibrary.org/handle/1912/3039> (Accessed 15 February 2012)
64. Miller, S. P., J. Helly, A. Koppers, and P. Brueggeman (2001), SIOExplorer: digital library project, in *OCEANS, 2001. MTS/IEEE Conference and Exhibition*, vol. 4, pp. 2288-2296.
65. Nakanishi, M., Bending-related topographic structures of the subducting plate in the northwestern Pacific Ocean, in *Accretionary Prisms and Convergent Margin Tectonics in the Northwest Pacific Basins, Modern Approaches Solid Earth Sci.*, vol. 8, edited by Y. Ogawa, R. Anma, and Y. Dilek, pp. 1-38, Springer, Dordrecht, Netherlands, 2011.
66. Nakanishi, M., J. Hashimoto, 2011, A precise bathymetric map of the world's deepest seafloor, Challenger Deep in the Mariana Trench, *Marine Geophysical Research*, 32, 455-463, 2011.
67. De Mol, L., D. Van Rooij, H. Pirlet, J. Greinert, N. Frank, F. Quemmerais, and J. P. Henriot (2011), Cold-water coral habitats in the Penmarc'h and Guilvinec Canyons (Bay of Biscay): Deep-water versus shallow-water settings, *Marine Geology*, 282(1), 40-52.
68. Moore, G. F. et al. (2001), Data report: structural setting of the Leg 190 Muroto Transect, *Proceedings of the Ocean Drilling Program, Initial Reports, 190*, 1-14, doi:10.2973/odp.proc.ir.190.102.2001.
69. Nakanishi, M. (2010), Bending-related topographic structures of the subducting plate in the northwestern Pacific Ocean, *Accretionary Prisms and Convergent Margin Tectonics in the Northwest Pacific Basin*, 8, 1.
70. Nakanishi, M., and J. Hashimoto (2011), A precise bathymetric map of the world's deepest seafloor, Challenger Deep in the Mariana Trench, *Marine Geophysical Research*, 1-9.

71. Nitsche, F. O., S. Jacobs, R. D. Larter, and K. Gohl (2007), Bathymetry of the Amundsen Sea continental shelf: Implications for geology, oceanography, and glaciology, *Geochemistry Geophysics Geosystems*, 8, Q10009.
72. Okamura, Y., K. Satake, A. Takeuchi, T. Gamo, C. Kato, Y. Sasayama, F. Nakayama, K. Ikehara, and T. Kodera (2002), Tectonic, geochemical and biological studies in the eastern margin of the Japan Sea—preliminary results of Yokosuka/Shinkai 6500 YK01-06 Cruise—, *JAMSTEC J. Deep Sea Res*, 20, 77-114.
73. Okino, K., K. Matsuda, D. M. Christie, Y. Nogi, and K. Koizumi (2004), Development of oceanic detachment and asymmetric spreading at the Australian-Antarctic Discordance, *Geochem. Geophys. Geosyst*, 5(12), Q12012.
74. Okino, K., Y. Ohara, T. Fujiwara, S. M. Lee, K. Koizumi, Y. Nakamura, and S. Wu (2009), Tectonics of the southern tip of the Parece Vela Basin, Philippine Sea Plate, *Tectonophysics*, 466(3-4), 213-228.
75. Okino, K., and K. Fujioka (2003), The Central Basin Spreading Center in the Philippine Sea: Structure of an extinct spreading center and implications for marginal basin formation, *J. Geophys. Res*, 108, 2040.
76. Pratson, L. F., and M. H. Edwards (1996), Introduction to advances in seafloor mapping using sidescan sonar and multibeam bathymetry data, *Marine Geophysical Research*, 18(6), 601-605.
77. Preston, J. M., A. C. Christney, W. T. Collins, and S. Bloomer (2004), Automated acoustic classification of sidescan images, in *Oceans '04 MTS/IEEE Techno-Ocean '04 (IEEE Cat. No.04CH37600)*, vol. 4, pp. 2060-2065, IEEE. [online] Available from: <http://www.mendeley.com/research/automated-acoustic-seabed-classification-swath-images/> (Accessed 15 February 2012)
78. Ramana, M. V. et al. (2009), Multidisciplinary investigations exploring indicators of gas hydrate occurrence in the Krishna--Godavari Basin offshore, east coast of India, *Geo-Marine Letters*, 29(1), 25-38.
79. Ranero, C. R., R. Huene, W. Weinrebe, and C. Reichert (2006), Tectonic processes along the Chile convergent margin, *The Andes*, 91-121.
80. Rathburn, A. E. et al. (2009), Geological and biological heterogeneity of the Aleutian margin (1965–4822m), *Progress In Oceanography*, 80(1-2), 22-50, doi:10.1016/j.pocean.2008.12.002. [online] Available from: <http://dx.doi.org/10.1016/j.pocean.2008.12.002> (Accessed 31 October 2011)
81. Riedel, C. et al. (2006), First results from the North Iceland experiment, *Marine Geophysical Research*, 27(4), 267-281.
82. Robinson, J. E., and B. W. Eakins (2006), Calculated volumes of individual shield volcanoes at the young end of the Hawaiian Ridge, *Journal of volcanology and geothermal research*, 151(1-3), 309-317.
83. Scheirer, D. S., D. J. Fornari, S. E. Humphris, and S. Lerner (2000), High-resolution seafloor mapping using the DSL-120 sonar system: Quantitative assessment of sidescan and phase-bathymetry data from the Lucky Strike segment of the Mid-Atlantic Ridge, *Marine Geophysical Research*, 21(1), 121-142.
84. Schulz, H. D. et al. (n.d.), METEOR CRUISE, *Meteor-Berichte*, 6, 3.

85. Schwenk, T., V. Spieß, C. Hübscher, and M. Breitzke (2003), Frequent channel avulsions within the active channel-levee system of the middle Bengal Fan--an exceptional channel-levee development derived from Parasound and Hydrosweep data, *Deep Sea Research Part II: Topical Studies in Oceanography*, 50(5), 1023-1045.
86. Seamount, A. (n.d.), EEZ, 224 for Southwest Planning Region, 226 lessons learned from the representative marine protected area program, 263-265, *algorithms*, 149, 151.
87. Sethi, A. K., A. V. Sathe, and M. V. Ramana (2004), Potential natural gas hydrates resources in Indian Offshore areas, in *AAPG Hedberg conference on ``Gas Hydrates: energy resource potential and associated geologic hazards`` Vancouver, BC, Canada*.
88. Smith, J. A., C. D. Hillenbrand, R. D. Larter, A. G. C. Graham, and G. Kuhn (2009), The sediment infill of subglacial meltwater channels on the West Antarctic continental shelf, *Quaternary Research*, 71(2), 190-200.
89. Smith, J. R., A. Malahoff, and A. N. Shor (1999), Submarine geology of the Hilina slump and morpho-structural evolution of Kilauea volcano, Hawaii, *Journal of volcanology and geothermal research*, 94(1-4), 59-88.
90. Smith, J. R., K. Satake, J. K. Morgan, and P. W. Lipman (2002), Submarine landslides and volcanic features on Kohala and Mauna Kea volcanoes and the Hana Ridge, Hawaii, *Geophysical monograph*, 128, 11-28.
91. Smith, J. R., K. Satake, and K. Suyehiro (2002), Deepwater multibeam sonar surveys along the southeastern Hawaiian Ridge: Guide to the CD-ROM, *Geophysical monograph*, 128, 3-9.
92. Strozyk, F., M. Strasser, S. Krastel, M. Meyer, and K. Huhn (2010), Reconstruction of retreating mass wasting in response to progressive slope steepening of the northeastern Cretan margin, eastern Mediterranean, *Marine Geology*, 271(1-2), 44-54.
93. Takeuchi, C. S., J. G. Sclater, N. R. Grindlay, J. A. Madsen, and C. Rommevaux-Jestin (2010), Segment-scale and intrasegment lithospheric thickness and melt variations near the Andrew Bain megatransform fault and Marion hot spot: Southwest Indian Ridge, 25.5 E--35 E, *Geochemistry, Geophysics, Geosystems*, 11, 7012.
94. Tolimieri, N., M. E. Clarke, H. Singh, and C. Goldfinger (2008), Evaluating the SeaBED AUV for monitoring groundfish in untrawlable habitat, *Marine habitat mapping technology for Alaska. Alaska Sea Grant College Program, University of Alaska Fairbanks*, 129-141.
95. Tucholke, B. E., J. Lin, M. C. Kleinrock, M. A. Tivey, T. B. Reed, J. Goff, and G. E. Jaroslow (1997), Segmentation and crustal structure of the western Mid-Atlantic Ridge flank, 25 25 --27 10 N and 0--29 my, *Journal of geophysical research*, 102(B5), 10203-10210.
96. Verlaan, P. A. (1997), New seafloor mapping technology and article 76 of the 1982 United Nations Convention on the law of the sea, *Marine Policy*, 21(5), 425-434.

97. Villinger, H., I. Grevemeyer, N. Kaul, J. Hauschild, and M. Pfender (2002), Hydrothermal heat flux through aged oceanic crust: where does the heat escape?, *Earth and Planetary Science Letters*, 202(1), 159-170.
98. Völker, D., T. Reichel, M. Wiedicke, and C. Heubeck (2008), Turbidites deposited on Southern Central Chilean seamounts: evidence for energetic turbidity currents, *Marine Geology*, 251(1), 15-31.
99. Völker, D., F. Scholz, G. Geersen (2011), Analysis of submarine landsliding in the rupture area of the 27 February 2010 Maule earthquake, Central Chile, *Marine Geology*, 288(1), 79-89.
100. Volker, D., J. Geerson, E. Contreras-Reyes, J. Sellanes, S. Pantoja, W. Rabbel, M. Thorwart, C. Reichert, M. Block, W. Weinrebe (2012), Morphology and geology of the continental shelf and upper slope of southern Central Chile (33°S-43°S), *Int. J. Earth Sci.*, DOI: 10.1007/s00531-012-0795-y
101. Von Huene, R., D. Klaeschen, M. Gutscher, and J. Fruehn (1998), Mass and fluid flux during accretion at the Alaskan margin, *Geological Society of America Bulletin*, 110(4), 468-482.
102. Wanless, V. D., M. O. Garcia, F. A. Trusdell, J. M. Rhodes, M. D. Norman, D. Weis, D. J. Fornari, M. D. Kurz, and H. Guillou (2006), Submarine radial vents on Mauna Loa volcano, Hawaii, *Geochem. Geophys. Geosyst*, 7(10.1029).
103. Watanabe, M., K. Okino, and T. Kodera (2010), Rifting to spreading in the southern Lau Basin: Variations within the transition zone, *Tectonophysics*, 494(3), 226-234.
104. Watts, A. B., C. Peirce, I. Grevemeyer, M. Paulatto, W. Stratford, D. Bassett, J. A. Hunter, L. M. Kalnins & C. E. J. de Ronde (2012), Rapid rates of growth and collapse of Monowai submarine volcano in the Kermadec Arc, *Nature Geoscience*, 5, 510-515, doi:10.1038/ngeo1473.
105. Webster, J. M. et al. (2006), Drowned coralline algal dominated deposits off Lanai, Hawaii; carbonate accretion and vertical tectonics over the last 30 ka, *Marine geology*, 225(1-4), 223-246.
106. Weinrebe, W., and J. Greinert (2002), Sounding Ocean Floor Morphology at Continental Margins to Understand Geodynamic History, in *HYDRO 2002*.
107. Wessel, P. (2010), Tools for analyzing intersecting tracks: The x2sys package, *Computers & Geosciences*, 36(3), 348-354.
108. Wright, D. J., S. H. Bloomer, C. J. MacLeod, B. Taylor, and A. M. Goodlife (2000), Bathymetry of the Tonga Trench and Forearc: a map series, *Marine Geophysical Research*, 21(5), 489-512.
109. Wright, D. J., B. T. Donahue, D. F. Naar, and others (2002), Seafloor mapping and GIS coordination at America's remotest national marine sanctuary (American Samoa), *Undersea with GIS*, 33-63.
110. Wright, D. J., B. T. Donahue, and D. F. Naar (2002), GIS Coordination at America's Remotest National Marine Sanctuary (American Samoa), in *Undersea with GIS*, edited by D. J. Wright, pp. 33-63, ESRI Press.
111. Yokose, H., and P. W. Lipman (2004), Emplacement mechanisms of the South Kona slide complex, Hawaii Island: sampling and observations by remotely operated vehicle Kaiko, *Bulletin of volcanology*, 66(7), 569-584.

112. Zühlsdorff, L., and V. Spiess (2004), Three-dimensional seismic characterization of a venting site reveals compelling indications of natural hydraulic fracturing, *Geology*, 32(2), 101.

---

Last updated: 13 August 2012