**Cover Sheet for Proposal to the National Science Foundation**

**Program Announcement/Solicitation No./Closing Date:** PD 98-1620  08/15/12

**For Consideration by NSF Organization Unit(s):** OCE - Marine Geology and Geophysics

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**Employer Identification Number (EIN) or Taxpayer Identification Number (TIN):** 770150580  0623687

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**Name of Organization to Which Award Should Be Made:** Monterey Bay Aquarium Research Institute

**Address of Awardee Organization, Including 9 Digit ZIP Code:**

Monterey Bay Aquarium Research Institute

7700 Sandholdt Rd

Moss Landing, CA 95039

---

**Name of Primary Place of Perf:** Monterey Bay Aquarium Research Institute

**Address of Primary Place of Perf, Including 9 Digit ZIP Code:**

Monterey Bay Aquarium Research Institute

7700 Sandholdt Rd

Moss Landing, CA 95039

---

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

**Requested Amount:** $322,387

**Requested Starting Date:** 04/01/13

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**PI/PD Name:** David W Caress

**CO-PI/PD Name:**

---

**Check Appropriate Box(es) if this Proposal Includes Any of the Items Listed Below:**

- Beginning Investigator (GPG I.G.2)
- Disclosing Lobbying Activities (GPG I.G.1.e)
- Proprietary & Privileged Information (GPG II.D.1.d)
- Historic Places (GPG II.C.2.i)
- EAGER (GPG II.D.2)
- Rapid** (GPG II.D.1)
- Vertebrate Animals (GPG II.D.6) IACUC App. Date

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**High Resolution Graphics/Other Graphics Where Exact Color Representation Is Required for Proper Interpretation (GPG I.G.1):**

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**PI/PD Department:** Department of Research and Development

**PI/PD Postal Address:** 7700 Sandholdt Road

**PI/PD Fax Number:** 831-775-1620

**Moss Landing, CA 95039 United States**

---

**Names (Typed):**

- David W Caress

**High Degree:** PhD

**Year of Degree:** 1989

**Telephone Number:** 831-775-1775

**Electronic Mail Address:** caress@mbari.org
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.)

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 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 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, 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:

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(2) building (and any related equipment) is covered by adequate flood insurance.

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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
## COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

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| TITLE OF PROPOSED PROJECT | Collaborative Research: Development and Support of the MB-System Software Package for Processing and Display of Swath Mapping Sonar Data |

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CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

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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 Nondiscrimination

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AUTHORIZED ORGANIZATIONAL REPRESENTATIVE SIGNATURE DATE
Maribel Respo 02/13/12

TELEPHONE NUMBER ELECTRONIC MAIL ADDRESS FAX NUMBER
845-365-8829 mrespo@admin.ldeo.columbia.edu 845-365-8112

* 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.

<table>
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<tr>
<th>Section</th>
<th>Total No. of Pages</th>
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<td>Project Description (Including Results from Prior NSF Support) (not to exceed 15 pages) <em>(Exceed only if allowed by a specific program announcement/solicitation or if approved in advance by the appropriate NSF Assistant Director or designee)</em></td>
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*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.*
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- **Appendix** (List below.) __________ __________
  - **Appendix Items**:

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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](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/](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 (*mblist*).
- Copy swath data from one format to another (*mbcopy*).
- 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 (mbbackangle, 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 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 acrosstrack 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 acrosstrack 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 *mbgrdviz* 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 4. Example of using mbnavadjust to adjust navigation of repeated 1-m lateral resolution AUV surveys of Axial Seamount after an eruption emplaced new lava flows [Caress et al., 2012]. Because the multibeam resolution is better than the vehicle navigation, adjustment is required to avoid mismatch artifacts. (Top) Screen capture of program mbnavadjust. This tool allows users to interactively or automatically determine the relative navigation offsets required to make bathymetric features match where swaths overlap or cross. This image shows the bathymetry-matching interface, with a contour plot on the right and a cross correlation function on the left. Once crossings have been analyzed, mbnavadjust solves for an optimal navigation model that satisfies the relative offsets while minimizing perturbations to speed and acceleration. The solution is applied using the program mbprocess. (Middle) mbgrdviz view of part of two surveys showing the original and the adjusted navigation tracks. (Bottom) Maps showing (A) bathymetry before the eruption, (B) bathymetry after the eruption, and (C) bathymetry difference, which is effectively a map of new lava flow thickness.
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.

*MB-System Project Description – Page 12*
• **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**

3. **Collaborative Research: Development and Support of the MB-System Software Package for Processing and Display of Swath Mapping Sonar Data**
   b. LDEO: OCE00-83120 $250,616 6/15/2001 – 6/14/2006

*MB-System Project Description – Page 13*
4. Collaborative Research: Development and Support of the MB-System Software Package for Processing and Display of Swath Mapping Sonar Data

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. 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](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](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:


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


REFERENCES


Schmidt, V., D. Chayes, and D. Caress (2006), The MB-System Cookbook, distributed from MBARI and L-DEO web sites.


MB-System References – Page 1
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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


Five Other Significant Publications


**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** Lecturer, Multibeam Course, US/Canada Hydrographic Comm.
- **1993 -1996** Member, ODP Lithosphere Panel

**Consulting:**

- **2012** Ocean Floor Geophysics, MB-System training.
- **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:**


**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.
Visualization of Arctic Ocean Multibeam Bathymetric Data and the Constraints it Offers
to Tectonic Reconstruction Models, GSA, 2010 Meeting Paper 172-3.


**Other significant publications:**


**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.
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**

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<td><em>UNIV. ALASKA</em></td>
<td>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)</td>
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<td>NSF</td>
<td>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.)</td>
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### 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 Colónos 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 and their aide-in-kind to CCOM. That’s the mechanism under which I see MB-System taking part in the project.

MB-System Proposal Supplement – Page 2
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
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 ’90s) 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)

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
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, Geocoustics Geosearch+, multibeam data logged using Hyseep or water column data of Seabeam 3000 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,

[Signature]

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Prof. Dr. Peter Herzig, Direktor | Ursula Frank-Scholz, Verwaltungsdirektorin (r.m.)
MinDr. Karl Eugen Mühlenbecher, Vorsitzender des Ausfallräums

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MB-System Proposal Supplement – Page 6
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,

[Signature]

Robert Covill
President

Tel (902) 860-1496   Fax (902) 860-1496   www.tekmap.ns.ca
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

Dana R. Yoerger
Senior Scientist
Letter of Intent 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

MB-System Proposal Supplement – Page 10
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) 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
- California State University Humboldt
- California State University Monterey Bay
- Florida Atlantic University
- Florida State University
- Lamont-Doherty Earth Observatory, Columbia University
- Massachusetts Institute of Technology
- MBARI
- Medical University of South Carolina
- Miami University
- North Carolina State University
- Ohio State University
- Oregon State University
- Scripps Institution of Oceanography, UCSD
- San Diego Supercomputer Center, UCSD
- Santa Clara University
- Stanford University
- Texas A&M University
- University Corp. for Atmospheric Research
- University of Alabama
- University of Alaska
- University of California Davis
- University of California Irvine
- University of California Riverside
- University of California Santa Barbara
- University of California Santa Cruz
- University of Hawaii
- University of Houston
- University of Maine
- University of Minnesota
- University of Mississippi
- University of New Hampshire
- University of North Carolina
- University of Oklahoma
- University of South Carolina
- University of South Florida
- University of Texas Austin
- University of Washington
- University of Wisconsin
- University of Wyoming
- Woods Hole Oceanographic Institution

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

- Alfred Wegener Institut, Germany
- Anadolu University, Turkey
- Australian National University, Australia
- Ben-Gurion University of the Negev, Israel
- Burapha University, Thailand
- Chiba University, Japan
- Delft University of Technology, Netherlands
- Ecole Nationale Superieure de Techniques Avancees Bretagne, France
- Fluminense Federal University, Brazil
- Friedrich-Schiller-Universitat Jena, Germany
- GEOMAR, Germany
- HafenCity Universitat Hamburg, Germany
- Hellenic Centre for Marine Research, Greece
- Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research, Germany
- Institut Pierre Simon Laplace, France
- Jacobs University, Germany
- Kumamoto University, Japan
- Kunsan National University, Korea
- Leibniz Institute for Baltic Sea Research Germany
- MARUM, University of Bremen, Germany
- Memorial University, Canada
- Moscow State University, Russia
- Northumbria University, United Kingdom
- Oxford University, United Kingdom
- Institute for Systems and Robotics Lisbon, Portugal
- Institute of Marine Research, Norway
- Institution du Physique du Globe de Paris, France
- Instituto Superior de Engenharia do Porto, Portugal
- Jacobs University, Germany
- Kumamoto University, Japan
- Kunsan National University, Korea
- Leibniz Institute for Baltic Sea Research Germany
- MARUM, University of Bremen, Germany
- Memorial University, Canada
- Moscow State University, Russia
- Northumbria University, United Kingdom
- Oxford University, United Kingdom
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
Universitza Degli Studi di Parma, Italy
Universitat de Girona, Spain
Universitat Hamburg, Germany
Universitat Kiel, Germany
Universitat Oldenburg, Germany
Universitat Politencica 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 Southhampton, 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 Seeschifffahrt 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 Acuaiticos, 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 y Desarrollo Pesquero, Argentina
Institutul National de Cercetare-Dezvoltare pentru Geologie si Geocologie Marina, Romania
Istituto di Scienza e Tecnologie dell'Informazione, Italy
Istituto Nazionale di Geofisica e Vulcanologia, Italy
JAMSTEC, Japan
<table>
<thead>
<tr>
<th>Organization</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>KORDI, Korea</td>
<td>Korea</td>
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<tr>
<td>Korea Advanced Institute of Science and Technology, Korea</td>
<td></td>
</tr>
<tr>
<td>Mamara Research Center, Turkey</td>
<td>Turkey</td>
</tr>
<tr>
<td>Marine Research Institute, Iceland</td>
<td>Iceland</td>
</tr>
<tr>
<td>Ministry of Energy and Mineral Resources, Indonesia</td>
<td>Indonesia</td>
</tr>
<tr>
<td>National Defense and Canadian Forces, Canada</td>
<td>Canada</td>
</tr>
<tr>
<td>National Institute of Advanced Industrial Science and Technology, Japan</td>
<td>Japan</td>
</tr>
</tbody>
</table>

**Commercial (37)**

1Ocean, (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 5, Open source software distributed from the MBARI and L-DEO web sites, 2000-2012.

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

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.


9. Beaman, R. J., and P. T. Harris (2005), Bioregionalization of the George V Shelf, East Antarctica, Continental shelf research, 25(14), 1657-1691.


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.


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.


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