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REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE
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Department of Research and Development

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COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

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Columbia University

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Columbia University Lamont Doherty Earth Observatory

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Palisades, NY 10964

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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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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 twelve years, and three grants, NSF-OCE support has allowed us to develop software that is widely used in the international marine geology and geophysics community. We propose to add new MB-System functionality, particularly including visualization-based tools for editing bathymetry, analyzing sonar bias parameters ("patch test"), and real-time survey display. We will also continue ongoing user support, improve the documentation, and support new sonar data formats.

The MB-System project benefits NSF-supported marine geological and geophysical 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.

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.

MB-System also has a significant impact beyond the U.S. academic community. Download statistics and activity in an online discussion forum demonstrate that the software is used by researchers from at least 50 non-U.S. universities and 21 non-U.S. government agencies worldwide, in addition to 33 universities and 11 governmental agencies within the U.S. More than 20 commercial organizations also use MB-System; at least three of these use MB-System as their primary swath data processing package for marine survey work.

RESULTS FROM PRIOR NSF SUPPORT: D. W. CARESS AND D. N. CHAYES

Title: **Hardware and Software Upgrade for Shipboard Processing of Hydrosweep Multibeam Bathymetry Data on the R/V Maurice Ewing**
P.I.s: D. W. Caress (L-DEO) and D. N. Chayes (L-DEO)
Grant Number: OCE92-17724
Award Amount:
Duration: 2/15/1993 – 1/31/1995

This award supported enhancements to the operation of the Hydrosweep DS multibeam sonar on the R/V Ewing associated with the transfer of the operational responsibility from the Ocean Mapping Group of the University of Rhode Island (URI) to the Lamont-Doherty Earth Observatory (L-DEO).

The first component of the project involved the purchase and installation of hardware for shipboard data processing, including computers and plotters. The processing hardware was installed on the R/V Ewing in June 1993.

The second component of the project involved the development of software for the manipulation, processing, and display of multibeam sonar data. Although the immediate focus of the software development was processing of Hydrosweep DS data collected on the Ewing, 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. The outgrowth of this effort was the public domain software package called MB-System. Major MB-System releases during this grant included versions 3.0 (6/1993), 3.3 (11/1993), 3.4 (12/1993) and 4.0 (10/1994). Version 3.4 included support for several SeaBeam "classic" (the original 16 beam) data formats and several Hydrosweep DS formats; also included was a full processing capability for Hydrosweep DS data from the R/V Ewing and R/V Thompson. During 1994 the software was upgraded to handle sidescan as well as bathymetry data, and support was added for data formats associated with a number of sonars, including HMR-1, SeaBeam 2000, SeaBeam 2112, Simrad EM12, Simrad EM1000, ELAC Bottomchart, and Reson SeaBat 9001.

Interest in MB-System developed rapidly, and by the end of this grant the software was used in at least 25 oceanographic institutions worldwide. In particular, MB-System had become the primary data processing software for Hydrosweep DS multibeam data from the R/V Ewing and R/V Thompson and for SeaBeam 2112 multibeam installations on the R/V Knorr, the R/V Palmer, and several foreign research vessels.

Title: **Development and Support of the MB-System Software Package for Processing and Display of Multibeam Sonar Data**
P.I.s: D. W. Caress (L-DEO) and D. N. Chayes (L-DEO)
Grant Number: OCE95-05188
Award Amount:
Duration: 7/1/1995 – 6/30/2000

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

P.I.s: D. W. Caress (MBARI) and D. N. Chayes (L-DEO)

Grant Number: OCE00-83082 (MBARI)

Award Amount

Grant Number: OCE00-83120 (L-DEO)

Award Amount

Duration: 6/15/2001 – 6/14/2006

These awards supported continued development and support of the MB-System software package for five years each. Through this period we have fixed problems, added new data formats, added new functionality, built documentation, and distributed the open source code distribution. We have released many versions of MB-System, including:

3.2 (07/1993)	3.3 (11/1993)	3.4 (12/1993)	4.0 (10/1994)
4.1 (11/1994)	4.2 (2/1995)	4.3 (3/1996)	4.4 (8/1996)
4.5 (9/1997)	4.6 (4/1999)	4.6a (5/1999)	4.6.6 (9/1999)
4.6.10 (4/2000)	5.0 (12/2003)	5.0.1 (12/2003)	5.0.2(12/2003)
5.0.3 (2/2004)	5.0.4 (5/2004)	5.0.5 (2/2005)	5.0.6 (9/1999)
5.0.7 (4/2005)	5.0.8 (2/2006)		

The current suite of MB-System tools and their capabilities are listed in the MB-System web pages (http://www.ldeo.columbia.edu/res/pi/MB-System/) at http://www.ldeo.columbia.edu/res/pi/MB-System/html/mbsystem_man_list.html. The significant additions to MB-System during these grants are too numerous to list here. It is perhaps more pertinent to note that we have fully accomplished the development goals listed in the more recent proposal. In 2000, we proposed to:

- Development improved documentation.

  Each MB-System program and macro is fully documented with a separate manual page accessible through web pages or the man utility. The 144 page *MB-System Cookbook* was released in late 2004, and continues to be updated and improved.
- Restructure the i/o library that lies at the heart of MB-System in order to support new, increasingly complex data formats and to simplify code maintenance.

  The underlying code has been substantially rewritten, providing a more flexible set of internal functions and gracefully handling data formats that combine multiple sources of sonar data with navigation, attitude, and other information logged at different times.
- Make the source code ANSI and POSIX compliant to enhance portability.

  Done.
- Add new utilities to allow a more efficient approach to data processing in which a single processed file is maintained for each input file regardless of the number or order of the analysis, editing, and processing tools applied.

  Version 5.0 features a parallel processing scheme in which one program, *mbprocess*, applies processing parameters and information generated by analysis and editing tools to generate processed swath files. The program *mbprocess* can apply bathymetry edits from *mbedit* and *mbclean*, navigation edits from *mbnavedit*, sound velocity profile changes from *mbvelocitytool*,

and a variety of other corrections. Users can modify all processing parameters directly using *mbset*.

- Continue to support new swath sonar data formats as requested by the community.

  The number of supported formats has been increased from 46 to 61, including support for the Furuno HS10 multibeam, Atlas SURF format, Atlas HSDS2 multibeam, IFREMER Caraibes formats, a revised HMR1 format, the Edgetech Jstar sidescan/subbottom format, and the new Reson 7k multibeam format. Additionally, some formats (e.g. Simrad multibeam, Generic Sensor Format) have been augmented over time, requiring considerable effort to maintain support.

In addition to the planned development, we have also added functionality allowing MB-System to easily manage a database composed of many surveys from many sources. For example, at MBARI we use MB-System to manage a database with over 70,000 swath files. Only a single command is necessary to efficiently obtain a grid of a desired region incorporating all relevant data or to reprocess any swath files that have been edited or had processing parameters updated since the last processing. We have also developed a 3D visualization library, and used this to build a simple grid visualization and survey-planning tool called *mbgrdviz*. This new library is ready to serve as the foundation for a suite of visualization-based utilities in the next generation MB-System (see proposed work below). Several data formats now incorporate subbottom profiler data. MB-System now includes tools to extract subbottom data into the SEGY seismic data format, and to manipulate and display SEGY format data.

The popularity of MB-System has continued to grow during this project. Our download statistics (available at http://www.mbari.org/data/mbsystem/MBpropSup.html) and email over the past year indicate that the software is used by researchers and graduate students at most of the major oceanographic centers in the U.S., at many other universities, and by several groups within NOAA, the Navy, and the USGS. MB-System is also used at universities and government agencies in other countries, including Australia, Belgium, Canada, Chile, Germany, Greece, Fiji, France, Iceland, India, Indonesia, Ireland, Italy, Japan, Korea, Mexico, New Zealand, Norway, Russia, Spain, Taiwan, Turkey, and UK. Some additional indications of the software's broad acceptance include:

- The National Geophysical Data Center requests that multibeam bathymetry submitted to its archive be in one of the data formats supported by MB-System.
- Sixteen letters and emails have been received in support of the current proposal (available at http://www.mbari.org/data/mbsystem/MBpropSup.html).
- The MB-System Discussion forum (http://listserver.shore.mbari.org/read/?forum=mbsystem) has approximately 100 registered members, and has had more than 375 posts since January 2005.

Eight peer-reviewed papers have derived in whole or in part from the MB-System project:

Caress, David.W., and Dale N. Chayes, Improved processing of Hydrosweep DS Multibeam Data on the R/V Maurice Ewing, *Marine Geophysical Researches*, **18**, 631-650, 1996.

Kastens, K., E. Bonatti, D. Caress, G. Carrara, O. Dauteuil, G. Frueh-Green, and M. Ligi, The Vema Transverse Ridge (Central Atlantic), *Mar. Geophys. Res.*, **20**, 533-556, 1998 (actually published 2000).

Manley,Patricia L. and David W. Caress, Mudwaves on the Gardar Sediment Drift, NE Atlantic, *Paleoceanography*, **9**, 973-988, 1994.

Schuur, C. L., M. F. Coffin, C. Frolich, P. Mann, C. G. Massell, G. D. Karner, D. Ramsay, and D. Caress, Sedimentary regimes at the Macquarie Ridge Complex: interaction of Southern Ocean circulation and tectonism, *Paleoceanography*, **13**, 646-670, 1998.

Kastens, K., E. Bonatti, D. Caress, G. Carrara, O. Dauteuil, G. Frueh-Green, and M. Ligi, The Vema Transverse Ridge (Central Atlantic), *Mar. Geophys. Res.*, **20**, 533-556, 1998 (actually published 2000).

Jordahl, K., D. Caress, M. McNutt, and A. Bonneville, Seafloor topography and morphology in the Superswell region, in R. Hekinian, P. Stoffers, and J. Cheminee Eds., *Oceanic Hot Spots*, Springer, pp. 9-28, 2004.

Paull, C.K., B. Schlining, W. Ussler III, J.B. Paduan, D. Caress, H.G. Greene, Distribution of chemosynthetic biological communities in Monterey Bay, California. *Geology* 33:2; 85-88, 2005.

Stakes, D.S., M.R. Perfit, M.A. Tivey, D.W. Caress, T.M. Ramirez, N. Maher, "The Cleft Revealed: Geologic, magnetic and morphologic evidence for construction of upper oceanic crust along the southern Juan de Fuca Ridge", Geochemistry, Geophysics, Geosystems, in press, 2005.

Fourteen meeting abstracts have resulted from the MB-System project:

Chayes,D. N., and D.W. Caress, Processing and display of multibeam echosounder data on the R/V Maurice Ewing, *EOS Trans. AGU*, **74**, 562, 1993.

Caress, D.W., G. Karner, J. Fang, M. Coffin, C. Frohlich, P. Mann, C. Massell, L.Schuur, C. Helsley, D. Johnson, D. Falvey, D. Ramsay, and J. Lebrun, Processing of HMR1 bathymetry and sidescan data from the Macquarie Ridge, *EOS Trans. AGU*, **75**, 669, 1994.

Caress, D.W., G. Karner, M. Coffin, D. Falvey, J. Fang, C. Frohlich, C. Helsley, D. Johnson, J. Lebrun, P. Mann, C. Massell, D. Ramsay, and L.Schuur, Processing of HMR1 bathymetry and sidescan data from the Macquarie Ridge, *EOS Trans. AGU*, **76**, F613, 1995.

Caress, D. W. and Chayes, D. N., New software for processing sidescan data from sidescan-capable multibeam sonars, *Proc. IEEE Oceans 95 Conf.*, 997-1000, 1995.

Caress, David W., Sharon E. Spitzak, and Dale N. Chayes, Software for multibeam sonars, *Sea Technology*, **37**, 54-57, 1996.

Tyce, R. C., S. M. Dzurenko, P. A. Cohen, D. W. Caress, A PC/Linux software toolkit for coastal swath mapping, *Proc. Ital. Hydro. Conf.*, 1997.

Caress, D.W., and D.N. Chayes, Optimal navigation adjustment for poorly navigation swath bathymetry surveys, *EOS Trans. AGU*, **81**, F1096, 2000.

Caress, D.W. and D. N. Chayes, Improved management of large swath mapping datasets in MB-System Version 5, EOS Trans. AGU, **82**, 2001.

Chayes, D.N, A. Slagle, D.W. Caress, and R.A. Arko, First results from the (multibeam) Hydrosweep DS2 upgrade on the R/V Maurice Ewing, EOS Trans. AGU, **82**,, 2001.

Caress, D.W. and D.N. Chayes, Processing, Archiving, and Disseminating Large Swath Mapping Datasets Using MB-System, EOS Trans. AGU, **83**, 2002.

Caress, D.W. H.G. Greene, and C.K. Paull, Plunge pools in submarine canyons, EOS Trans. AGU, **83**, 2002.

Caress, D.W., W. J. Kirkwood, H. Thomas, M. Sibenac, R. McEwen, F. Shane, R. Henthorn, P. McGill, A. Hamilton, D. Thompson, K. Salamy, A subbottom profiler survey of the upper Monterey Canyon using the MBARI Mapping AUV, *Eos Trans. AGU*, 85 (47), Fall Meet. Suppl. Abstract OS43B-0563, 2004.

Kirkwood, W., D. Caress, H. Thomas, R. McEwen, F. Shane, R. Henthorn, P. McGill, "Results from MBARI's integrated mapping system", Proceedings MTS/IEEE Oceans 2005, Abstract 050217-03, 2005.

Caress, D. W., H. Thomas, R. McEwen, R. Henthorn, W. J. Kirkwood, D. Thompson, C. K. Paull, P. McGill, High-resolution multibeam, sidescan, and subbottom surveys in and around Monterey Canyon

using the MBARI Mapping AUV, *Eos Trans. AGU, 86*(52), Fall Meet. Suppl., Abstract OS33C-1490, 2005.

Three major versions of open-source software and a "cookbook" manual have been distributed by the MB-System project:

Caress, D.W., and D.N. Chayes, MB-System Version 3, Open source software distributed from the L-DEO ftp site, 1993.

Caress, D.W., and D.N. Chayes, MB-System Version 4, Open source software distributed from the MBARI and L-DEO web sites, 9 major releases, 1994-2003.

Caress, D.W., and D.N. Chayes, MB-System Version 5, Open source software distributed from the MBARI and L-DEO web sites, http://www.mbari.org/data/mbsystem/ , http://www.ldeo.columbia.edu/res/pi/MB-System/, 2003-2006.

Schmidt, V., D. Chayes, and D. Caress, *The MB-System Cookbook*, http://www.ldeo.columbia.edu/res/pi/MB-System/mbcookbook.pdf , 2004-2006.

INTRODUCTION

The MB-System [Chayes and Caress, 1993; Caress et al., 1996; Caress and Chayes, 1995, 1996, 2000, 2001, 2002, 2003-6; Schmidt et al., 2004-6] is an open source UNIX software package consisting of programs that manipulate, process, list, or display swath mapping sonar bathymetry and sidescan data. Over the past twelve years, NSF support has allowed us to develop MB-System from a poorly documented and limited set of homegrown programs into a package that is widely used in the US and international marine geology and geophysics (MG&G) community (see Results From Prior Support above, and the download statistics and support letters available at http://www.mbari.org/data/mbsystem/MBpropSup.html).

Although the development effort has progressed to the point where MB-System is a reliable and powerful set of tools for working with swath mapping data, long term software support, maintenance and development effort remains necessary for MB-System to continue to be relevant to the MG&G community. Users of the software frequently have questions or problems that we can resolve quickly, saving time and effort on their part. Users also frequently provide suggestions that we try to implement as time and support allows. Rapid advances in sonar technology are requiring (and will continue to require) support for data from new systems and updated file formats, while scientific advances will generate requirements for new or improved capabilities in the software. Continuing 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 maintain and further develop the MB-System software while providing general support to the MB-System user community, we propose a five-year project at modest funding levels. 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. This is a collaborative proposal submitted jointly (with separate budgets) by the Monterey Bay Aquarium Research Institute (MBARI) and the Lamont-Doherty Earth Observatory of Columbia University (L-DEO). MBARI is the lead institution.

DESCRIPTION OF THE MB-SYSTEM SOFTWARE PACKAGE

MB-System (http://www.mbari.org/data/mbsystem/) is an open source software package consisting of programs which manipulate, process, list, or display swath sonar bathymetry, amplitude, and sidescan data. The swath mapping sonar data may derive from multibeam sonars, interferometry sonars, or sidescan sonars. This software is distributed freely (and for free) in the form of source code for Unix platforms.

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. MB-System programs allow users to do things like:

- Find out what is in a swath data file (*mbinfo*).
- Extract arbitrarily constructed ASCII tables of navigation and per-beam information (*mblist*)
- Copy swath data from one format to another, when appropriate, and/or window data in time and space (*mbcopy*).
- Generate GMT-compatible Postscript plots of contoured bathymetry, color fill bathymetry, shaded relief bathymetry, and grayscale sidescan directly from the swath data (*mbcontour* and *mbswath*).
- Automatically identify and flag obvious artifacts in bathymetry data (*mbclean*).
- Interactively identify and flag artifacts in bathymetry data (*mbedit* – Figure 1).
- Interactively identify and fix errors in navigation (*mbnavedit* – Figure 1).
- Interactively model the effect of changes in a water sound velocity profile (SVP) on bathymetry calculations (*mbvelocitytool* – Figure 2).
- Recalculate swath bathymetry from travel time information using a user-specified SVP (*mbprocess*).
- Identify overlapping/crossing swaths in a survey, interactively determine navigation offsets required to make bathymetric features match, and solve for a navigation model satisfying the required navigation offsets (*mbnavadjust* – Figure 2).
- Correct amplitude and sidescan data (*mbbackangle*, *mbprocess*).
- Generate processed swath files (*mbprocess*).
- Grid bathymetry data using a variety of algorithms (*mbgrid*).
- Mosaic sidescan data using priority functions involving swath position and look angle to govern which imagery used in regions of swath overlap (*mbmosaic*).
- Export grids, mosaics, and images to GIS packages such as ArcView (*mbm_grd2asc, mbgrdtiff, mbm_grdtiff*).
- Visualize bathymetry with 2D and 3D views (*mbgrdviz* – Figure 3).
- Interactive survey planning (*mbgrdviz*– Figure 3).

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 (a bug in one program is not necessarily

in another). Several shell script macros make common operations easier (e.g. a first cut plot of the bathymetry and navigation in a swath file). 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 one simple visualization tool (*mbgrdviz*). The results from the interactive tools are integrated with the command line utilities.

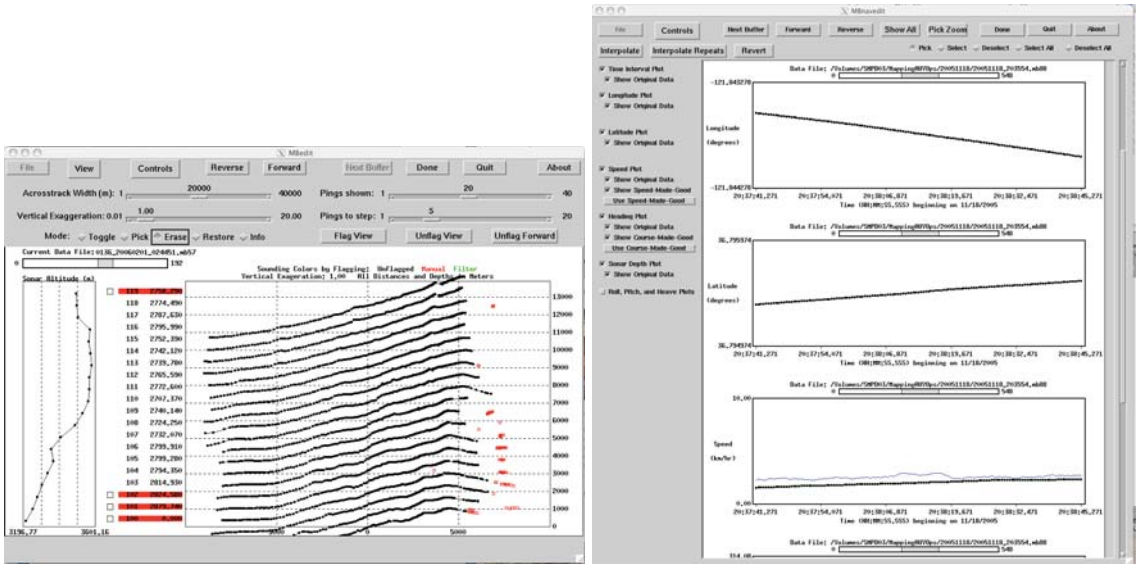

Figure 1. Screen dumps of two MB-System editing tools. (left) Program *mbedit*. This interactive MB-System tool is used to edit swath bathymetry data. The data here derives from the R/V Revelle's Simrad EM120, a 12 kHz multibeam sonar whose data are supported as MB-System formats 56 and 57. The acrosstrack profiles are shown stacked in a waterfall style plot. The black dots show unflagged soundings, and the red dots show soundings which have been flagged as bad data. Automated filters may be applied in *mbedit* or in the command line program *mbclean*. The optional plot on the left can show several types of information, but here shows sonar altitude. (right) Program mbnavedit, a tool used to correct navigation data. Several time-series style data plots are stacked for a selected time interval; this figure shows longitude, latitude, and 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).

The heart of the system is an input/output library called MBIO which allows programs to work transparently with any of the 61 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).

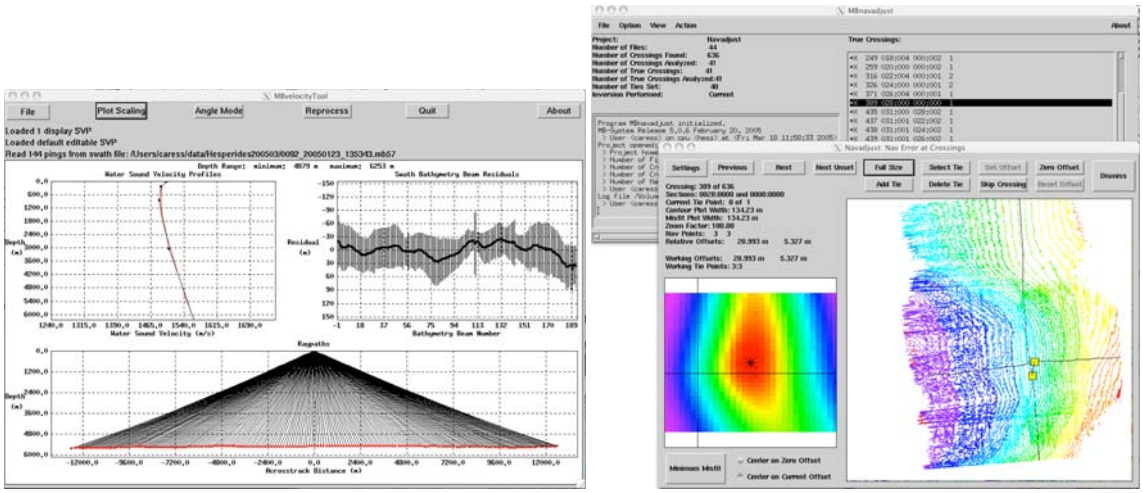

Figure 2. Screen dump of two MB-System analysis tools. (left) Program *mbvelocitytool*. This tool allows users to assess the effect of changing the water sound velocity profile (SVP) on bathymetry calculations using raytracing. The user can display several reference SVP's and interactively edit the active SVP. Once swath bathymetry with travel times are read in, average bathymetry residuals can be 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. This is a necessary but not sufficient condition for the SVP to be correct; in general additional constraints (e.g. surface water velocity from measurements at the hull, shallow water velocity from XBT's) are required for confidence in an SVP. Once the SVP is well determined, the bathymetry data can be recalculated using that SVP and the MB-System program *mbprocess*. (right) Program *mbnavadjust*. This tool identifies crossing swaths in a survey, and then allows users to interactively determine the relative navigation offsets required to make bathymetric features match at the crossing points. This image shows the bathymetry-matching interface, with a contour plot on the right (the contours can be shifted interactively), and a cross correlation function on the left. Once all the crossings have been identified, *mbnavadjust* solves for an optimal navigation model that satifies the relative offsets while minimizing perturbations to speed and acceleration. The solution is applied using the program *mbprocess*.

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), insuring 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 provides additional background and examples to supplement the manual pages.

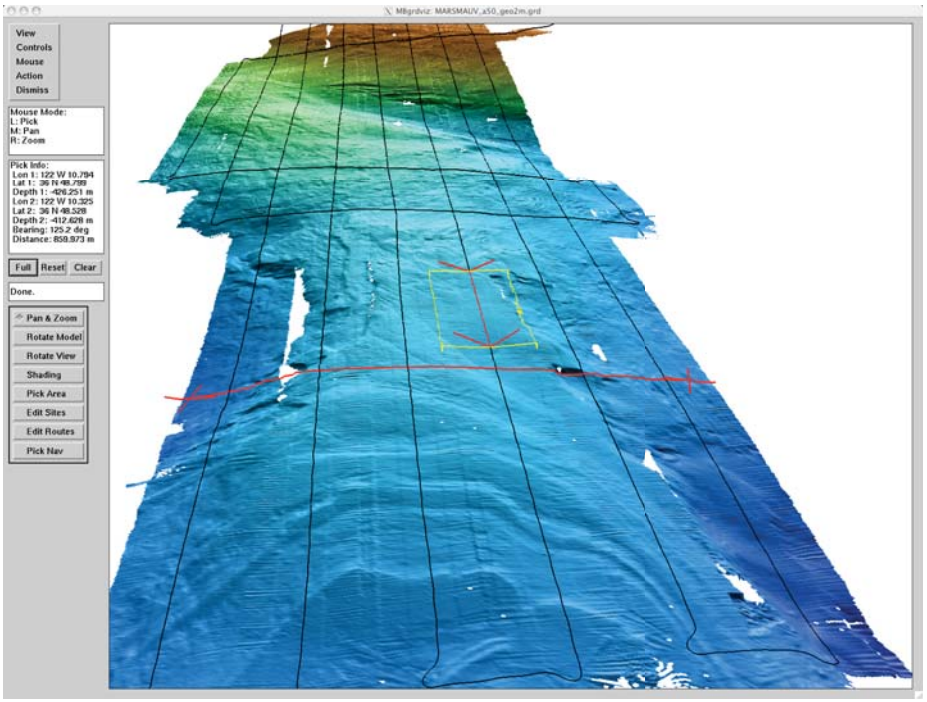

Figure 3. Screen dump of MB-System visualization tool mbgrdviz. This view shows a 3D view of 2 meter resolution bathymetry obtained from a Reson 7125 200 kHz multibeam sonar operated from an autonomous underwater vehicle (AUV). The 150 m spaced tracklines are shown draped on the bathymetry; a section of selected trackline shows the region covered by pings along that section. The red line shows an interactively selected line segment. This program also has automated and interactive survey planning capabilities. *MBgrdviz* is built on a visualization library called *mbview* that will be the foundation of future bathymetry editing, patch test, and real-time display tools.

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; Simrad Neptune: http://www.km.kongsberg.com; OIC GeoDAS: http://www.oicinc.com; QINSy http://www.qps.nl/; IVS Fledermaus: http://www.ivs3d.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 any and 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 processing and 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 insure 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. Three of the MB-System tools have been written entirely by users, and several other programs have benefited from substantial contributed improvements. For all these reasons, we think that the oceanographic research community will be best served by continuing the open source development of MB-System.

Because MB-System is freely available (and for free), installation and use is within the resources of nearly all potential users of multibeam data. This low barrier allows exploration of multibeam processing in a much broader range of situations including the teaching environment. It also provides a low cost approach that allows users to learn about multibeam and processing prior to considering the purchase of commercial software.

There is, of course, also the question of cost to NSF. Our download statistics (available at http://www.mbari.org/data/mbsystem/MBpropSup.html) show that at least 33 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 commercial software licenses for all NSF-supported researchers and students working with seafloor mapping data. Furthermore, the 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 general software maintenance and support, as well as development work.

The 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 (http://listserver.shore.mbari.org/read/?forum=mbsystem) greatly facilitates this effort by involving the user community in responding to queries. We will also continue to freely distribute the MB-System source code through the web and the LDEO ftp site.

As for further MB-System development, we intend to continue improving the package throughout the duration of this project. In the short term, we expect to focus on the following issues:

- **Visualization-based bathymetry editing.**
  We will implement a bathymetry editing tool that incorporates a 2D/3D map and trackline view (based on the existing *mbview* library) with the existing *mbedit* ping-based editing interface and with a 3D sounding edit interface (showing a cloud of soundings that may be viewed, and edited, from any perspective). Selecting a section of trackline in the map will bring up the selected pings in both interfaces; selecting a region of the map will bring up the soundings in that region in the 3D edit view.

- **Visualization-based based patch test tool**
  We will implement a patch test tool that incorporates a 2D/3D map and trackline view (the existing *mbview* library) with an interface allowing users to model roll bias, pitch bias, heading bias, and time lag. Data selected in the map view will be shown as a 3D cloud of soundings, and users will interactively change bias parameters while viewing the resulting consequences. This tool will be integrated with the *mbprocess* environment, so that bias parameters can be directly applied to the relevant data files or entire surveys.

- **Visualization-based real-time tracking display.**
  We will augment the existing *mbgrdviz* tool to accept real-time navigation and show the ship/vehicle location and tracklines in a 2D/3D view.

- **Visualization-based real-time bathymetry survey display.**
  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 existing *mbview* library.

- **Interactive processing GUI.**
  We will implement a graphical interface allowing users to access the most-used components of MB-System by point-and-click rather than the command line.

- **Continue to support new swath sonar data formats as requested by the community.**
  At present, we have requests to support Simrad EM710 data and the XTF format families. Support of even the simplest new format requires at least one solid week of effort, and some of the more complicated formats have required up to two months of serious effort.

- **Augment *mbcopy* to support copying data from many sonar formats into the GSF format.**
  The Generic Sensor Format (GSF) seems to be evolving as a format of choice for many users and is serving as a path to import multibeam data into other processing environments. We plan to satisfy this popular user request for a GSF translation capability.

- **Continue improvements to the MB-System Cookbook.**
  The original version of the cookbook was authored with DocBook. In the last few months we have completed the conversion to xml and are now using Oxygen (http://www.oxygenxml.com/) to build the cookbook. We will now focus our cookbook resources on adding new content.

- **Development of a "test suite" to allow automatic determination that an MB-System installation is successful.**
  As MB 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 and compare the results against a pre-defined set of results.

- **Improved project management.**
  We have recently installed an open source web-based request-tracking tool (RT) (http://www.bestpractical.com/?rt=3.4.5) developed and maintained by Best Practical Solutions. As we become familiar with this tool, it is improving our ability to keep track of bugs and feature requests. We anticipate adding an

automatic email interface that will reduce the labor required to enter requests so that we can focus on dealing with them.

- **Implement the CUBE algorithm as an MB-System tool.**
  CUBE is an algorithm developed by Brian Calder (Calder and Mayer, 2003) that automatically processes swath bathymetry soundings. The algorithm 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 which 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. However, MBARI and L-DEO are negotiating with UNH to allow compiled binaries of the CUBE library to be distributed. If an agreement is reached (certainly Calder and Mayer are enthusiastic about this approach), then we will develop an optional MB-System tool using the CUBE library for both automated bathymetry editing and as an alternative gridding algorithm.

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. Over the past three years, Val Schmidt of L-DEO (now also at University of New Hampshire) has led the authoring of the MB-System Cookbook and assisted in user support.

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. Although Val Schmidt's is now a full time graduate student in ocean engineering, we propose to continue his involvement in improving the cookbook and assisting with user support at a reduced level. LDEO will hire a new software/systems engineer part of whose time will be devoted to supporting MB-System. We also propose to add a small amount of support for Bob Arko of L-DEO to the MB-System team to assist with development support (e.g. testing installation of new releases on different platforms and maintaining the list server and request tracker) and user support. It is important that multiple people be available to answer questions and solve problems because all are committed to a variety of other projects and travel frequently.

At MBARI we request 1.5 months/year salary for Caress. MBARI will match the proposed NSF support for Caress' salary with another 1.5 months/year effort, yielding a total of 3.0 months/year MB-System effort.

At L-DEO we request 1.0 month/year of Chayes' salary, 2.0 months/year of a new hire (to be shared with other work) a few hours per week for Schmidt, and 0.5 months/year of Arko's salary.

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