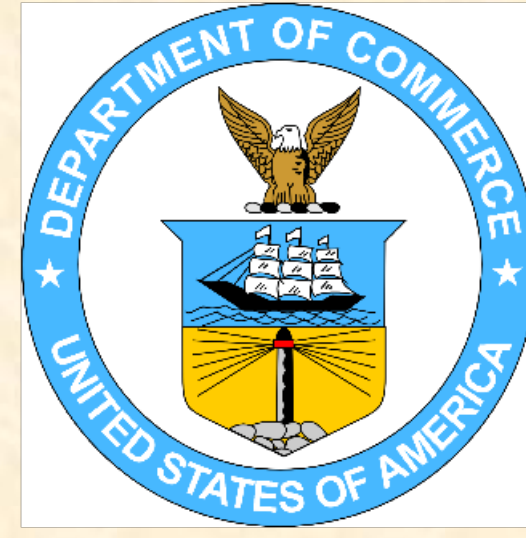


GEBCO Cookbook Contribution: Assessing Errors in Bathymetric Grids

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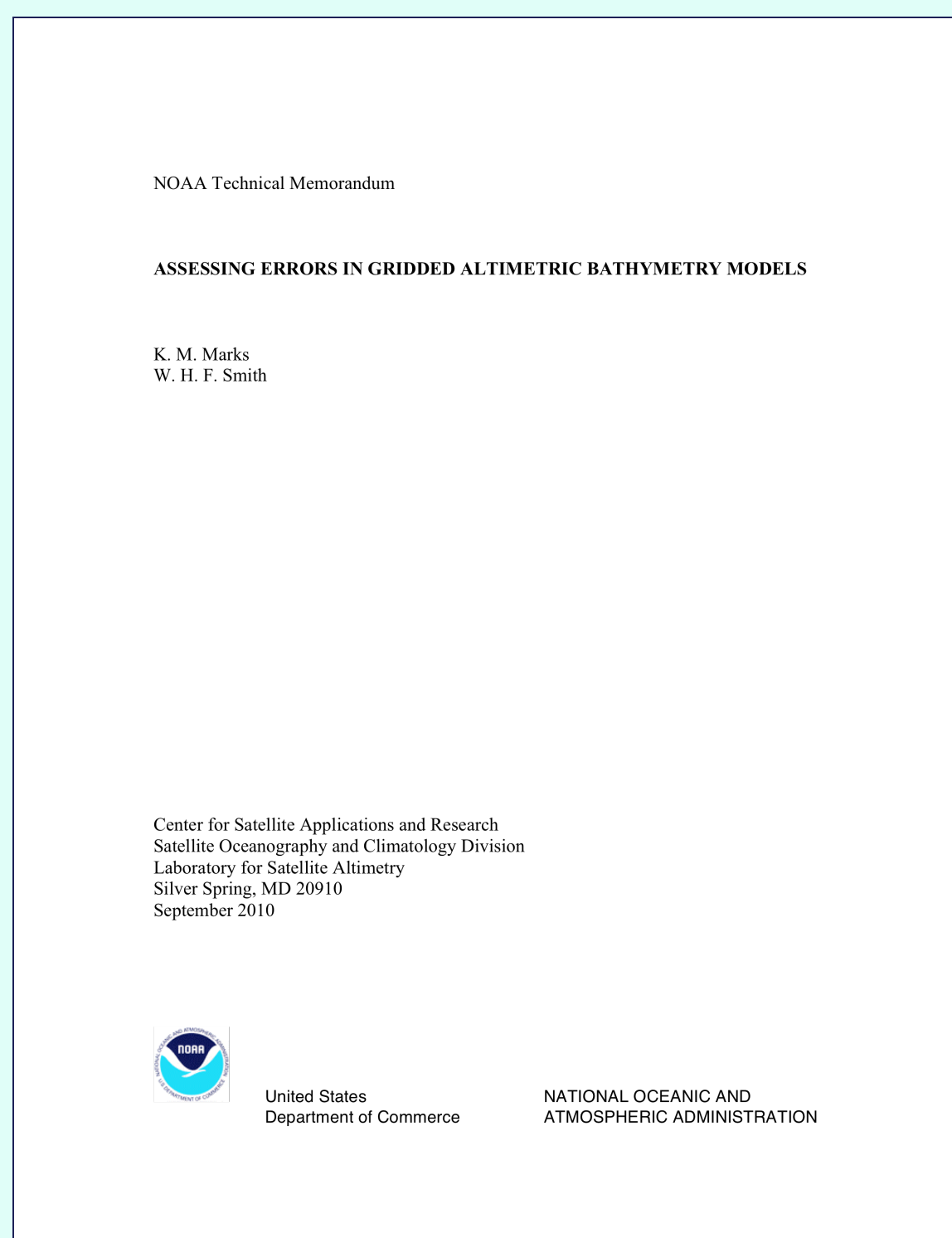
Abstract. At the GEBCO 25th meeting of the Technical Sub-Committee on Ocean Mapping (TSCOM) in September, 2009, a “Cookbook Working Group” was formed to write a “cookbook” to nurture and guide nascent regional mapping projects. One of the tasks was to test bathymetric grids resulting from numerical experiments using different interpolation schemes.

Marks and Smith developed a method of assessing errors in altimetric bathymetry models that was successfully employed in the manuscript “Evolution of errors in the altimetric bathymetry model used by Google Earth and GEBCO” (submitted to Marine Geophysical Researches, May, 2010). This method can also be used to assess errors in bathymetric grids produced by various interpolation schemes, thus providing a way to quantify how well the schemes are working.

We have prepared a NOAA Technical Memorandum that documents our error assessment method, and which can be incorporated into the GEBCO “cookbook” in fulfillment of the Cookbook Working Group task to test different interpolation schemes. In this poster we present salient portions of the memorandum.

NOAA Technical Memorandum

- Memorandum in preparation
- Contribution to the GEBCO “Cookbook Working Group” cookbook
- Documents in detail methods used in manuscript “Evolution of errors in the altimetric bathymetry model used by Google Earth and GEBCO,” submitted to Marine Geophysical Researches, May, 2010
- Detailed steps for gathering public data and software are provided
- Gridding and error assessment methods are documented in easy-to-follow steps
- Corresponding computer programs and GMT routine command lines are documented in Appendices
- Data and software tools used are freely available for on-line download



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Gather Data and Software

- Step-by-step instructions enable users to easily download JAMSTEC multibeam data, altimetric bathymetry models, and Generic Mapping Tools (GMT) software
- Users may provide their own data or download public data and proceed to section on data preparation
- JAMSTEC (Japan Agency for Marine Earth Science and Technology)
- SIO (Scripps Institution of Oceanography)
- GMT (Generic Mapping Tools)

We thank JAMSTEC (Japan Agency for Marine Earth Science and Technology) for making their multibeam data freely available (<http://www.jamstec.go.jp/cruisedata/>).

JAMSTEC Website



Figure 1. JAMSTEC Data Site for Research Cruises

2.1.1 Multibeam Data

Multibeam data may be downloaded from the JAMSTEC website as follows. The user first enters the “JAMSTEC Data Search Portal” tool, and then searches for bathymetry data within a selected study area. A list of cruises that traverse the selected area may be retrieved with “Quick Search,” and links to the individual bathymetry web pages (e.g., Figure 2) are provided.

SIO Website

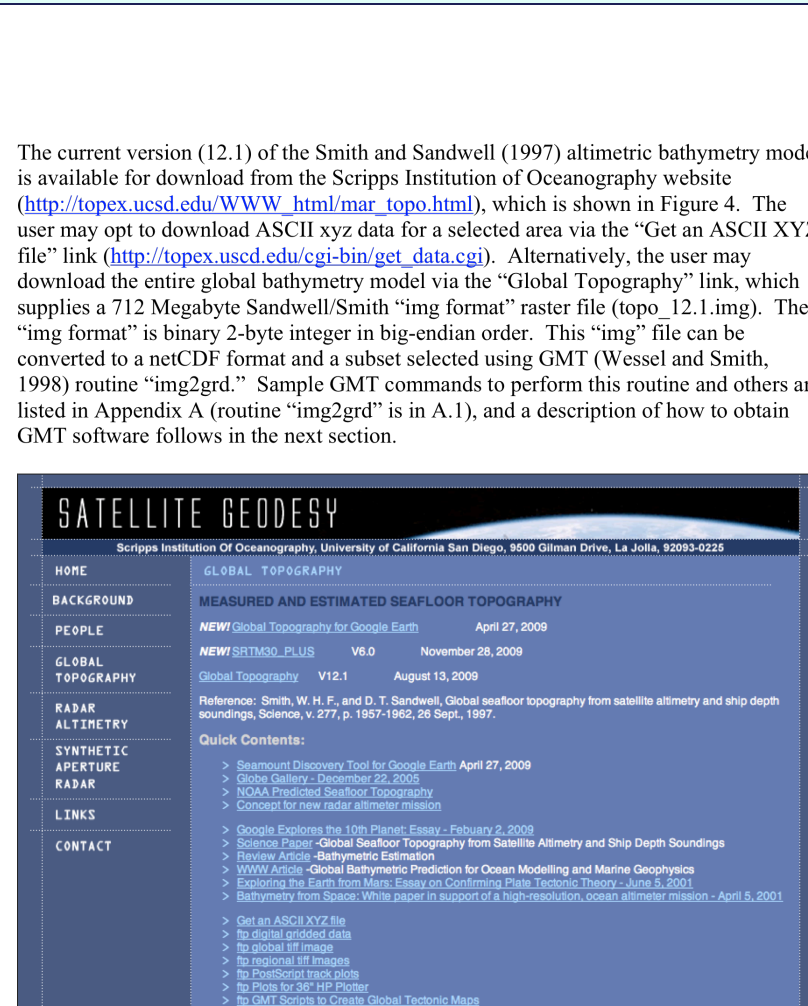


Figure 4. Scripps Institution of Oceanography web page for Global Topography (V12.1) is current version.

2.3 Generic Mapping Tools

GMT (Generic Mapping Tools) (Wessel and Smith, 1998) is a collection of open source mathematical and mapping routines for use on gridded data sets, data series, and arbitrarily located data. The GMT package is available for download from the University of Hawaii website (<http://seamless.usc.edu/gmt/>) (see Figure 5). We utilized GMT routines for all of our data analyses and mapping, and the specific routine commands listed in Appendix A.

GMT Website

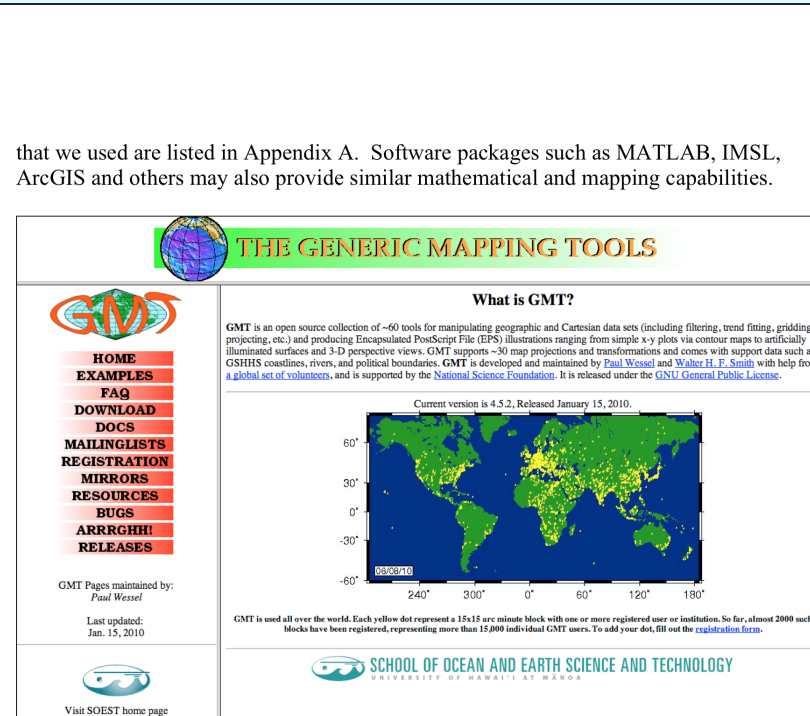


Figure 5. University of Hawaii website for GMT

3. Data Preparation

Data need to be prepared for subsequent analyses. Multibeam xyz ping files which contain millions of individual points need to be gridded onto both fine-scale grids (6 arc-second spacing) and grids that match the spacing of bathymetry models (1- or 2-minute spacing). It is also necessary to create a grid of distance from sounding controls that are included in the bathymetry models.

3.1 Gridding Multibeam Data

A grid can be formed from the individual multibeam xyz points downloaded from the JAMSTEC website. Because there are so many data points it is advantageous to first take their block averages using GMT routine “blockmean,” calculating the median (or the 4- or 5-location of the median) for every non-empty grid cell on a 6 arc-second mesh. The next step is to use GMT routine “surface,” an algorithmic routine that uses a surface gridding algorithm to form a grid at a 6 arc-second spacing in latitudinal and longitudinal from the median depth. Routine “grdmath” is then used to create a mask that is applied to the grid using “grdmask” so that it holds values only in cells that contain one or more of the original xyz points. In Appendix A we list the GMT routines used to create the grid from KR05-01 xyz multibeam points that is shown in Figure 6.

Gridding Multibeam Data on 6” Grid

Data Preparation

- Example of how to grid multibeam data onto a 6 arc-second grid
- Gridding steps are documented in detail in Appendix
- Distance from control values at corresponding grid cell locations are needed for local error analyses
- Program to calculate distance from control is provided in Appendix
- With detailed documentation and programs provided in memorandum, users can easily perform error analyses on their own bathymetric grids

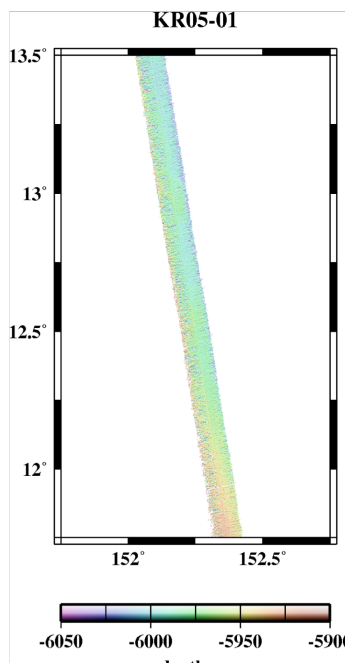


Figure 6. Color shaded-relief image of gridded KR05-01 multibeam points.

In Appendix A.5.1 we list the GMT routines used to produce Figure 6.

3.2 Create a Grid of Distance from Control

Included in the Smith and Sandwell (1997) altimetric bathymetry model (type 12.1 img) is information on which grid cells contained acoustic echo sounding data to constrain the solution. At grid points constrained by ship measurements, the depth value is the median of all soundings nearest the grid point, rounded to the nearest odd integer meter. At grid points estimated from satellite gravity, the depth value is rounded to the nearest even integer meter. W. H. F. Smith wrote a computer program (Appendix C) that, for each grid cell, searches the neighborhood for the nearest control point and calculates the distance to it, writing the output to a “distance img” file. Depending on the user’s computer system architecture (i.e., big or little endian), it may be necessary to swap adjacent bytes of the Smith and Sandwell “img” file prior to use and after running Smith’s computer program. GMT routine “img2grd” can then read on the byte-swapped “distance img” file to create a netCDF grid of distance from control in a selected area. The command lines used to produce the “distance img” file are listed in Appendix A.6, and the GMT routines used to make the left panel (V12.1) of Figure 7 are listed in Appendix A.7.

Gridding Documented in Appendix

Appendix A: Sample GMT routine command lines

- ```
A.1 img2grd xyz 12.1 img -R105.0/105.0/10.0/10.0 -Gkr05-01.img -A0 -B0.01 -M1 -T1 -Q -V
A.2 gridmath kr05-01.img -A0 -B0.01 -Gkr05-01.grd
A.3 gridmap kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
A.4 gridmath kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
A.5 gridmath kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
A.6 gridmath kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
A.7 gridmath kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
A.8 gridmath kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
A.9 gridmath kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
A.10 gridmath kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
```

## Distance from Control Maps

### V12.1

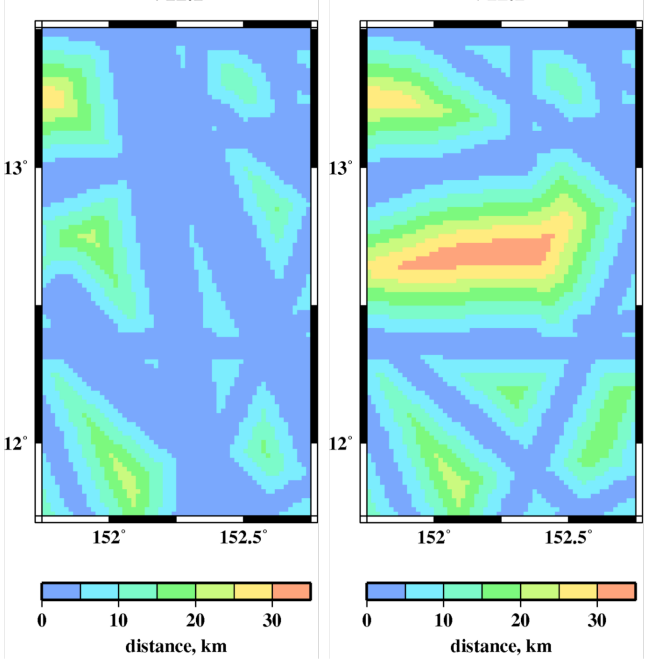


Figure 7. Maps of distance from control grids corresponding to bathymetry model versions 12.1 and 12.1\*. JAMSTEC data were withheld in V12.1\* for testing purposes.

### 4. Bathymetry Model Errors

Our method of assessing errors in bathymetric models is based on comparing the model depths to JAMSTEC multibeam “ground truth” data that were not available when the model was prepared, or were withheld for testing purposes. Even though multibeam data suffer from errors, they are small relative to bathymetric model errors (Marks et al., submitted 2010). This method can be employed on local, regional, and global scales, each revealing different aspects of the errors.

### 4.1 Local Errors

To illustrate our method used locally, we calculate the difference between xyz multibeam depth points from KR05-01 and a special version of bathymetry model 12.1 that was constructed without JAMSTEC data (see V12.1\*, Figure 8), in a small study area. The xyz data were first projected into the Mercator coordinates used in the

## Distance to Control Program in Appendix

### Smith, W. H. F. and D. T. Sandwell (1997): Global sea topography from satellite altimetry and ship depth soundings. Sci., 277, 1956-1962.

Wessel, P. and W. H. F. Smith (1998): New, improved version of Generic Mapping Tools released. EOS Trans. AGU, 79, 579, doi:10.1029/98EO00070.

### Appendix A: Sample GMT routine command lines

- ```
A.1 img2grd xyz 12.1 img -R105.0/105.0/10.0/10.0 -Gkr05-01.img -A0 -B0.01 -M1 -T1 -Q -V
A.2 gridmath kr05-01.img -A0 -B0.01 -Gkr05-01.grd
A.3 gridmap kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
A.4 gridmath kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
A.5 gridmath kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
A.6 gridmath kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
A.7 gridmath kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
A.8 gridmath kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
A.9 gridmath kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
A.10 gridmath kr05-01.grd -R105.0/105.0/10.0/10.0 -Gkr05-01.grd -A0 -B0.01 -M1 -T1 -Q -V
```

Assessing Gridding Errors

- Local errors are differences between multibeam data and gridded bathymetry with focus in survey gaps
- Regional errors are differences between gridded bathymetry and a control grid
- Global errors are differences between global JAMSTEC multibeam data and altimetric bathymetry model with JAMSTEC withheld
- Error assessment method can be applied to any type of bathymetry grids, and can be used to test grids produced by various interpolation schemes
- Technical memorandum documents steps to perform error assessments in detail
- Users can test gridding algorithms by assessing errors in resulting grids

Local Errors

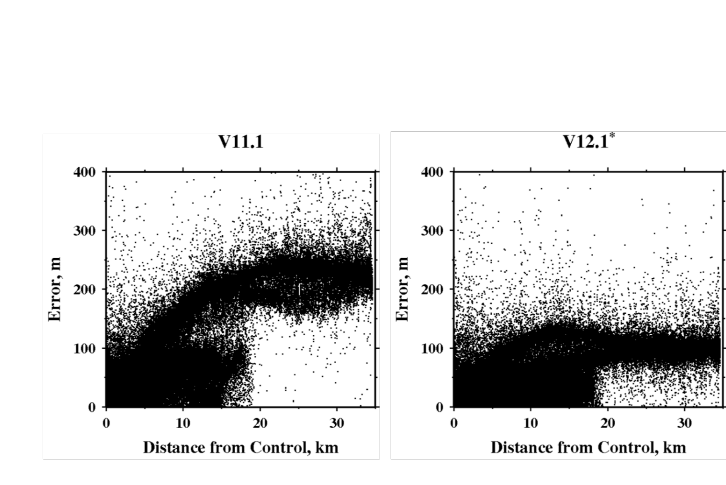


Figure 9. Errors are the absolute value of the differences between KR05-01 multibeam depths and bathymetry model versions 11.1 and 12.1, plotted against distance from the nearest sounding constraining the bathymetry model.

The distribution of depth differences may be plotted in a histogram (Figure 10). For both versions in this example, the depth differences are generally negative (bathymetry model is shallower than multibeam depths) and they are not normally distributed, and version 11.1 has larger depth differences. The GMT routines used to plot the errors in histogram form as shown in Figure 10 are listed in Appendix A.8.

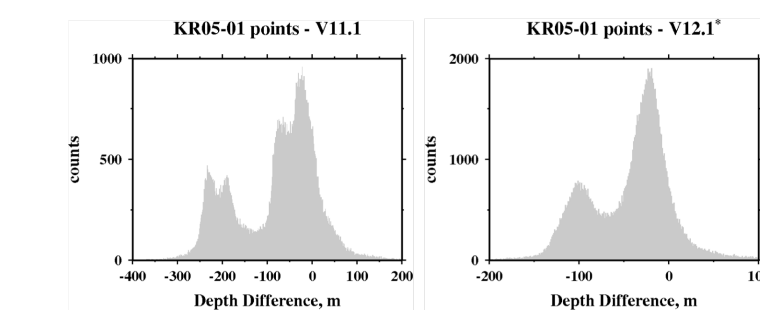


Figure 10. Histogram of the differences between KR05-01 multibeam depths and versions 11.1 and 12.1 depth.

4.2 Regional Errors

Long-wavelength errors can be evaluated on a regional scale, which we demonstrate by using our error assessment method on a large area in the Pacific Ocean. In the left panel of Figure 11, we show the depth difference between Smith and Sandwell bathymetry model version 11.1 and a comparison version 11.1 that had JAMSTEC multibeam data withheld. The depth differences are the “error,” and they are colored to enhance their

Regional Errors

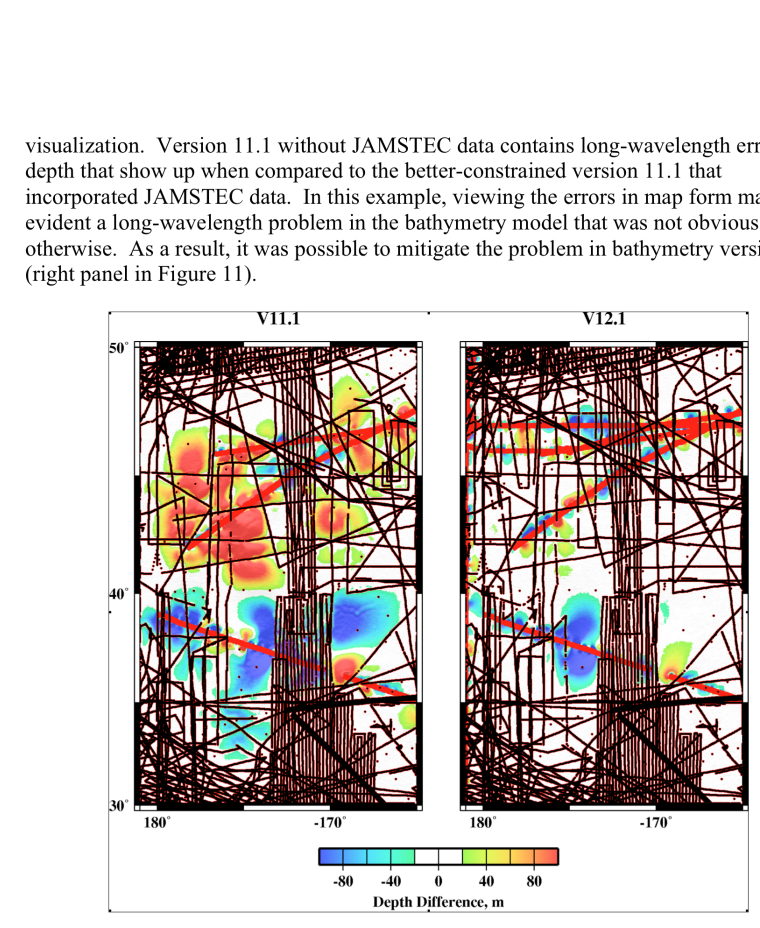


Figure 11. Depth differences (Error) are between version 11.1 with JAMSTEC data (red dots are controls), and version 11.1 with JAMSTEC withheld (black dots are controls) (left panel). Right panel is same as left except using version 12.1. The problem causing long-wavelength errors in version 11.1 has been mostly corrected in 12.1 (right panel in Figure 11).

The GMT routines used to produce the right panel in Figure 11 are listed in Appendix A.9.

4.3 Global Errors

Our error assessment method may also be applied globally to bathymetry models. In this case the median values of all JAMSTEC multibeam data falling within 1 minute Mercator grid cells are subtracted from corresponding bathymetry model grid cells, which contain the median value of all available soundings within the cell. The differences in depth are the “error,” and they are colored to enhance their

Global Errors

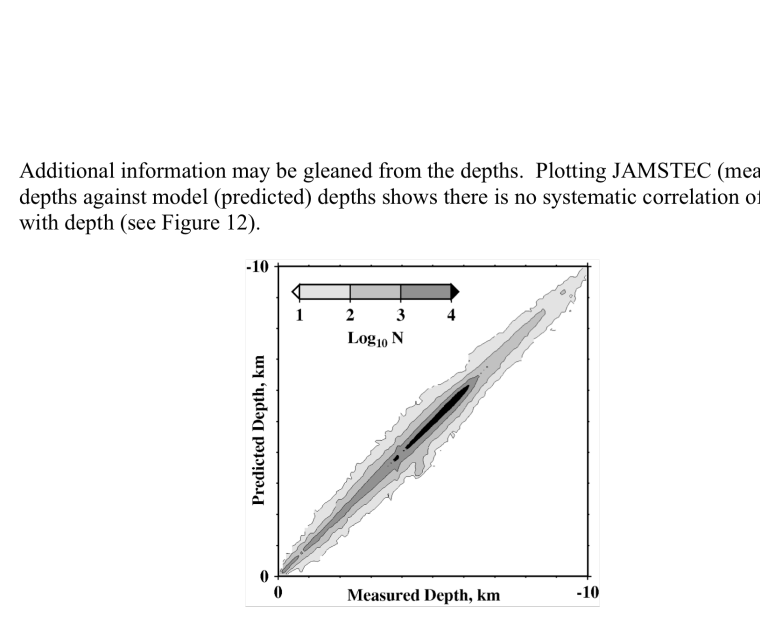


Figure 12. Version 12.1 JAMSTEC controlled (measured) depths plotted against predicted depths (V12.1, JAMSTEC withheld). The number of points (N) are contoured. GMT routines “img2grd,” “blockmean,” and “grdmath” are used to calculate median depth differences. Examples of these routines are in Appendix A.10, and those used to make Figure 12 are listed in Appendix A.11.

Bathymetry (and gravity) data series may also be compared in the frequency

(wavelength) domain. For this example we produce profiles along JAMSTEC track KR05-01 that traverse rough southeast north of the local study area discussed above. We used a computer program written by W. H. F. Smith to compute along-track distance (Appendix D), which was appended to each data record. Gravity measurements collected along the track were downloaded from the JAMSTEC website (see section 2.1.2), the along-track distance was appended, and GMT routine “plottrack” was used to sample the corresponding 6 arc-second KR05-01 multibeam grid (see section 3.1) at the points where the gravity measurements were made. The latitudes and longitudes of the gravity points were then projected into the Mercator coordinates used in the bathymetry model via GMT routine “mapproject” and “plottrack” was used to sample bathymetry model versions 11.1 and 12.1 as well. The resulting profiles are shown in Figure 13.