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An in-depth look at shallow water multibeam

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An in-depth look at shallow water multibeam
On being invited to this workshop

- Like everyone, I was proud of the Fab Four for having conducted this valuable course for ten years.
- I really wanted to participate, but this is a SHALLOW water workshop, and I am a DEEP water guy!
- So what to say, what to say?

Dave Monahan
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My Possible Titles

- An in-depth look at shallow water multibeam
- Deep thoughts on a shallow topic
- Far Field Rules, OK?
- Wading is for Wussies
  - (or in British English, Wading is for Wankers)
- Only 10 percent of the world ocean is less than 500 m deep
Technical Issues

1. Ensonification/ coverage
   a) Do you really need to mow the lawn
   b) Is there information in the existing single beam coverage that can be used to plan / orient the MBES survey?
   c) Is there information in the existing single beam bottom traces that could help select the most appropriate MB system for that area?

2. Portrayal of results
   a) How do you show adjacent/ overlapping areas that have been surveyed by MBES, by single beam, or by both?
   b) Can you do this on bathymetry maps and navigation charts the same way?
   c) How to express uncertainty for a map made from two types of data?
   d) How do you select a publication scale appropriate to both data types?

3. Prediction of the bottom.
   a) Can you extrapolate the convolution / texture of the seafloor captured by MBES into the areas not surveyed by MBES
Organizational/ Societal Issues

- Public expectations
- Role of standards
- Sending data to NGDC (or equivalent)
- UNCLOS
- Marine Protected Areas
Overall development process

- "A new medium is never an addition to an old one, nor does it leave the old one in peace. It never ceases to oppress the older media until it finds new shapes and positions for them.” McLuhan
- So what is the new role for single beam and sidescan?
- Instruments normally develop from external complication to “set and forget”. When will MBES require no or little operator intervention?
Types of hydrography

- **Navigational hydrography is concerned with**
  - Development of ports and harbours
  - Coastal erosion problems
  - Utilization of harbour and coastal conservation services
  - Especially, the safety of navigation in coastal waters

- **Off-shore hydrography is concerned with**
  - The provision of hydrographic data as an extension of the coastal zone normally encompassing the continental shelf,
  - The development of mineral deposits, including hydrocarbons
  - Provision of data for fisheries management

- **Oceanic hydrography is concerned with**
  - Acquisition of hydrographic data in the deep ocean areas for the depiction of sea-floor geomorphology

What do we know about the Future?

- Progress is a mix of incremental improvements and huge leaps
- Would taking MBES to the deep sea require a paradigm shift?
  - No, it will simply require incremental changes.
  - However, it may cause a paradigm shift in geology, depending on what is found (see Jim Gardner’s Continental Slope data)
- The future is the place for dreams
“Many earth scientists share the dream of having the entire surface of the earth, both subaerial and sub-aqueous, mapped seamlessly to a fine resolution.” Monahan, 2003

- “Seamlessly” is a very powerful word: many readers think that it refers to the vertical datum problem between seafloor and land maps.
- However, the horizontal fitting of adjoining data sets on the seafloor is not yet as seamless as it might be.
Deep Ocean Differs From Shallow Areas… or Does It?

**In the deep ocean:**
- Very few routine surveys
- Very small percentage of sea floor has been ensonified (estimates range from 1 to 10 percent)
- Data was originally measured from a variety of platforms, using different positioning and sounding systems, using (or not using) different sound velocities, units and plotting methods

**In shallow water:**
- Few MBES surveys
- Very small percentage of sea floor has been multibeamed
- Data was originally measured from a variety of platforms, using different sounding systems, using (or not using) different sound velocities
Layout and amount of data in the deep sea
Single Beam Tracks

Figure 9. Generalized “Navigation Instrument” GEODAS Trackline categories

Thanks to Martin Jakobsson
What is wrong with this picture?

- For a line to be seen by the human eye it has to be at least 0.5mm wide.
- At the scales used for these types of index maps, a line 0.5mm wide would represent a real world swath width to 50 - 100km.
A more understandable model of data density

Figure 2. Imagine how poorly known the topography of the United States would be if survey data were confined to the U.S. Interstate Highway System (top). The remote ocean basins are just that poorly surveyed. The bathymetric survey lines in the South Pacific are shown (bottom) at the same scale as the Interstate highway map. The gaps between surveys are much larger than the bottom features of interest so conventional interpolation schemes fail to reveal the important features. Image courtesy of David Dearing, NOAA.
MBESTracks held by NGDC March 2005, from NGDC website
MBES Tracks that NGDC know exist (but don’t hold the data) from NGDC website

Multibeam Bathymetric Data Inventoried at NGDC
(but not at NGDC)

Mercator projection
LAMONT (LDEO) U.HAWAII SOEST SCRIPPS INST.OC UNITED KINGDOM U.WASHINGTON
RUSSIA FRANCE GERMANY US NSF HYDR.DEPT.JAPAN

EXISTING DATA
NGDC Data Assimilation Rates
Sharman, 2003

**Bathymetry Assimilation**

\[ y = 517876x - 1E+09 \]
\[ R^2 = 0.9798 \]

\[ y = 1E+63e^{-0.0664x} \]
\[ R^2 = 0.5144 \]

Nautical Miles, Bathymetry

**NGDC Data Assimilation Rates**

- **Singlebeam**
- **Multibeam**
- **Cumulative**
- **Linear (Cumulative)**
- **Expon. (Singlebeam)**

**Sharman, 2003**
Adding New tracks to NGDC

- In the past research ships would normally operate an echo sounder as part of their regular program.
- Single beam echo sounders required little in the way of operator or servicing at sea.
- MBES is a different story since it has not yet evolved to the point of requiring no operator intervention. Data processing for MBES is similarly resource intensive.
- Nevertheless, independent tracks of multibeam can be sent to NGDC where it is archived reviewed for quality, and inventoried for ready access, retrieval, and redistribution.
- So how to explain the graph?
Not all the world is covered and it will be a long time before it is

- For the next ten years, at least, MBES data will be collected from surface ships.
- Carron et al. 2001 estimate that it would take over 600 ship years to map waters 25-500 m deep, and approximately 200-250 ship years for the deep ocean (500 m and greater).
- No systematic program to map deep ocean appears likely.
- MBES surveys will be conducted in response to Article 76 of UNCLOS and methane recovery - Continental Shelf
- Beyond that, area surveyed per year may decrease with shift from the “expeditionary” style of at-sea data collection to repetitive measurements to collect time series (McNutt 2002).

- Conclusion – will have to use MBES and other data together for some time
Where will deep MBES data be collected in the next ten years?

- On Continental Slopes.
  - UNCLOS Article 76 requirement to map the Foot of the Slope and the 2500 meter contour.
  - Presence of methane hydrates in the sediments of the slope
  - These data may or may not enter the public domain
- Tsunami effected area (and other emergencies)
  - We will see a debate over which is more important, the shallow water run-up zone, or the deep water path
- In areas of specialized interest
  - E.g. The Ridge Program
  - “Random” tracks that collect data will decrease
    - shift from the “expeditionary” style of at-sea data collection to repetitive measurements of the same point or small area to collect time series
Un fortunately, the net result will be...

Gary Larson, The Far Side
SCHEMATIC: EXISTING / HISTORICAL SEAFLOOR MAPPING

Schematic typical ocean floor region (depth contours in units of 100m), with schematic track patterns for different types of sea-floor mapping efforts: This shows the type of ocean-floor bathymetric and sidescan coverage typically present in data banks. NRL 7420 graphic (P. Vogt and L. Jewett)
Making maps from this data set

- Not the same as making navigation charts from tidy data sets
- Requires interpretation and consideration of other types of data
- Can be treated as numerical exercise (algorithm) only up to a point
Would you write software to contour data that:

- Is at best a Stratified Aligned Sample and at worst, randomly distributed (how to test for random?)
- Contains horizontal wavelengths that can be tens or hundreds of times shorter than the distance to the next track
- Is auto-correlated along its length but has no correlation with other data in the area
- Has little or no intentional redundancy
- Is of variable, and perhaps unknown, horizontal positioning accuracy
- Is of variable, and perhaps unknown, vertical measurement accuracy and where because of beam width effects the vertical measurements are not all measuring the same thing
- Where a selective smearing or elimination of incised features and a horizontal exaggeration of protruding features has occurred along track.
- Where the corrections that must be applied to the vertical measurements are of varying accuracy, currency and frequency
- Where some “profiles” are only sampled and the means of sampling is unknown.
- Can have more than one data point at the same location?
And would you simultaneously write software to contour a surface that:

- Possesses enormous variability and covers two thirds of the earth’s surface
- Can consist of wavelengths ranging from centimeters to thousands of kilometers
- Can consist of wavelengths that have no relationship to the sample spacing
- Can be smooth and rough, at a variety of scales.
- Can have abrupt changes at scarps, cliffs and fault lines
- Can have overhangs
- Can include stream networks (some anastomosing) and razorback ridges?

Or would you simply forget about the surface and just try to contour the data?
Patch test, we don’t do no stinkin’ patch test!

- One of the tenets of the MBES religion has been to do a patch test early on in a survey to calibrate the system.
- Without one, the data can contain artifacts created by systematic errors.
- A patch test creates a data set that is free of systematic errors.
- It is a mistake to believe that this data set is free from error. All the patch test can do is help render the data internally consistent.
- When trying to combine two MBES data sets, it’s possible that their patch tests offset them from each other.
- In the real world of disparate data sets, different data sets will have either had different patch tests or had no patch test at all.
- Since you wouldn’t accept a single line of your own survey without a test, how can you accept a line from a different survey without one?
Using new MBES data in combination with legacy single beam data in areas of sparse sounding coverage.

- That’s what we will have to do in GEBCO for many years to come
- This is not unique to deep water: there are many areas of shallow water that will not be covered by complete MBES data for some time, yet they have to be charted for navigation purposes.
- Don’t forget side-scan
To use different types of data together, we:

1. Must understand how they are collected
2. Must have an estimate of each piece of data’s uncertainty
3. Must have a means of comparing them
4. May have to adjust one to match the other
5. May have to down-grade to lowest common denominator
6. Understand scale implications
7. Have a means of interpretation that works on different types of data

most MBES work is done in the interior of one survey, aimed at making it internally consistent, but two data sets are more complicated
How have data been combined in the past?

- Easy answer is that they haven’t.
- Draping one over the other is not combining them, it’s just producing a picture and perhaps an illusion of combination.
- Often usually just replace chart with MBES image without trying to match the two eg Shep Smith navigation surface “rules were established for superseding one survey with another”

http://www.ccom.unh.edu/joy_creation.htm#A
Comparing single beam and single beam

- Cross-over
- Comparing two similar if not identical things
Comparing MBES and MBES swaths at cross-overs

- As a precursor to comparing MBES and single beam
Area in Amundsen Gulf.
Approximately 200 m depth.
The EM300 is the data that is vertical. You can notice a seafloor feature passing through each data set.
Results as seen on the MBES
Try to compare a SBES and MBES

- Say there is an area that has a MBES swath and a single track crossing it
- Where they cross, what constitutes agreement?
- What would agreement look like?
- SBES is probably broad beam, so: a) rough parts on bottom are smoothed and b) reported bottom is along track but first return might be a wiggly line
Compare MBES with existing contour map 1
Compare MBES with existing contour map 2
Compare MBES with existing contour map 3
Combining with altimetry

At the opposite end of the scale, altimetry provides long wavelength information (Smith, ). While combining altimetry and single beam has been made operational (Smith and Sandwell. 1994), interpreting the three data types together awaits development.
Extracting characteristics from the MBES areas and predicting the seafloor in white areas to have similar characteristics

- Can you extrapolate the convolution / texture of the seafloor captured by MBES into the areas not surveyed by MBES, anchoring the predicted surface to the single beam profiles?
- Kriging? Not sure how this will work – French are using it to reduce the number of soundings in an MBES data set
- Fractals— been tried and died
- All sorts of curve fitting to the MBES surface – eg splines,
- ? wavelets
Projecting from MBES coverage to empty white space or almost empty
Project 2
Project 3
Project 4
Add one single beam line
It may add or change things
Leads to a new role for interpretation

- Within the area ensonified during a multibeam survey, there is no need to interpret the shape of the seafloor and express it in contours as there was during the single beam, widely spaced track days.

- There is so much data that it creates the contours itself.

- Between multibeam passes, there is still a need to interpret the seafloor from single beam tracks, and ways may be devised to use, in the areas between tracks, the extra information provided by the multibeam.

- These unsounded areas have always been interpreted but we may be entering a new era where interpretation is aided by extracting data from MBES data and projecting it across the white spaces.
Portrayal of results

- a) How do you show adjacent/overlapping areas that have been surveyed by MBES, by single beam, or by both?
- b) Can you do this on bathymetry maps and navigation charts the same way?
- c) How to express uncertainty for a map made from two types of data?
- d) How do you select a publication scale appropriate to both data types?
- Generalization – a word that has almost disappeared from cartography – but perhaps applies to trying to put together MBES and SBES – my old notes on generalization might be useful (smoothing, displacement, caricature, aggregation)
- 2D - 3D visualization – in areas of little data, is this counterproductive?
Single and Multibeam portrayed together

- East Pacific Rise from LDEO website
AWI

- Skunk Stripes Good!
- For more than half the surface of the earth, they would be a great improvement
Some ponderables

- A lot of workers in MBES brag / complain about having too much data / vast amounts of data. In the deep sea, we have too little.

- The people who have developed wonderful visualization techniques are loath to use visual methods of data interpretation and prefer mathematical approaches.

- Lots of graphs show that many, many more data points have been collected in recent years. This does not mean that there has been a proportionate increase in information and knowledge.

- In the past have spent a lot of energy on removing artifacts within an ensonified area. In future should look at artifacts outside ensonified area – i.e. the white stripes on the map.
Take home messages

- Its time for multibeam to grow up, which means being able to play with other kids. Cant just do a MBES survey and have it stand alone any more.