Towards an Error Budget for Single- and Multi-Beam Data

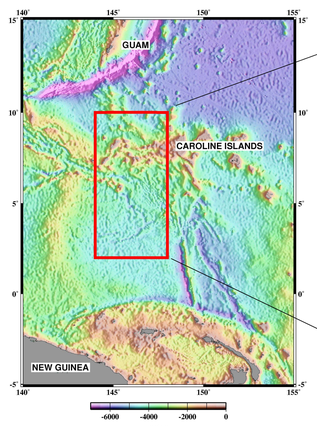
K. M. Marks and W. H. F. Smith
NOAA Laboratory for Satellite Altimetry, Silver Spring, Maryland, USA

Mapping the ocean basins requires a combination of single- and multi-beam depth measurements to obtain the most complete coverage. In order to give each data source proper weight, one should have a model for the expected uncertainty in each measurement. We are developing an error budget for single- and multi-beam data by comparing their values in areas where survey tracks overlap.

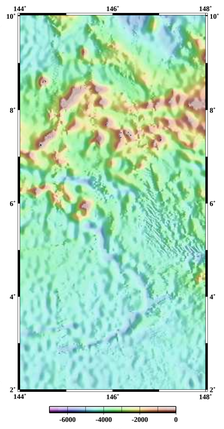
We present here preliminary results from some overlapping survey lines near the Caroline Islands of Micronesia, in the western Pacific Ocean. Ships proceeding between Guam and New Guinea frequently take the same course in this area, as there are only a few north-south passages between the atolls, as shown at right.

Before doing this analysis, we expected that single beam data would be much less accurate than multibeam data, and that single beam would measure the shallowest point within the ensonified cone. Both assumptions seem to be wrong. We find that multibeam measurements are repeatable to within about 0.25% of depth, though errors are systematic and apparently due to roll bias. Single beam data seem at least as accurate as multibeam.

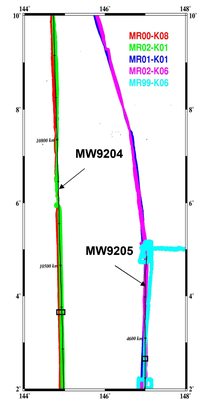
Study Area



Predicted Topography V9.1



Swath Paths

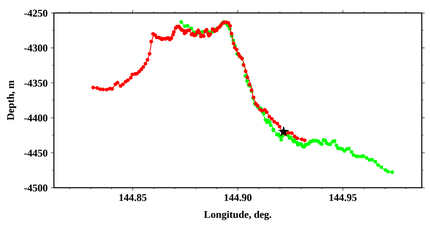


Overlapping surveys

- Multibeam (JAMSTEC)
  - MR00-K08 (2000)
  - MR02-K01 (2002)
  - MR01-K01 (2001)
  - MR02-K06 (2002)
  - MR99-K06 (1999)
  - R/V *Mirai*
  - Seabeam 2112.004
  - 150° swath width
- Single-Beam (NGDC)
  - MW9204 (1992)
  - MW9205 (1992)
  - R/V *Moana Wave*
  - 3.5 KHz
  - 30° beam width

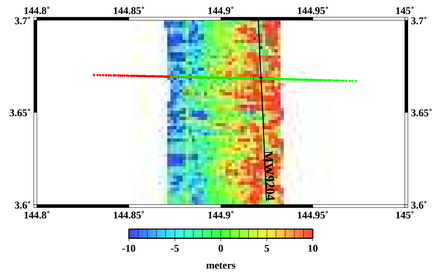
We thank JAMSTEC and NGDC for making these data freely available.

Overlapping Ping Profiles



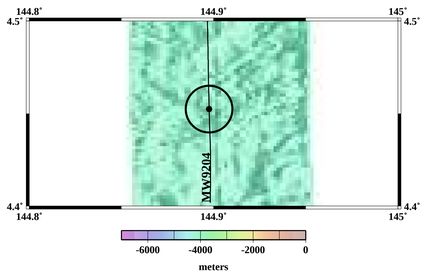
- Red dots are MR00-K08 ping points, red lines are from swath data gridded at 0.1□(roughly 200 m) spacing.
- Green dots are from MR02-K01 ping points, green lines are from swath data gridded at 0.1□spacing.
- Black star is single-beam sounding from MW9204
- 0.1□grids from swath bathymetry accurately honor ping data points here.
- The center portions of the overlapping profiles have similar depths.
- Differences in depths between MR00-K08 and MR02-K01 increase towards the outer beams of the profiles.

Depth Difference Grid



- Red and green dots locate the profiles shown to the left.
- The image shown is the difference between MR00-K08 and MR02-K01 bathymetry grids, each made at 0.1 arc-minute.
- There is a systematic difference, an east-west tilt, which might be due to a roll bias error in one or both swaths.
- The largest differences are around 10 m. If we assume each swath system is equally in error, the error is ~ 0.1% of depth (here, ~5 m).

Example Single-Beam Cone on MR02-K01 Multibeam data

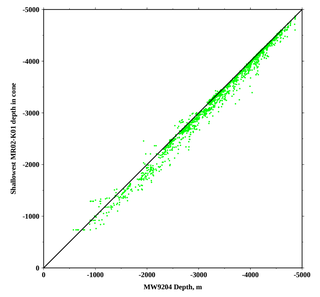


- A single-beam system samples a patch of seafloor within its ensonified cone (half-angle 15°). The size of the patch depends on the depths within the cone. In the example at left, the diameter of the patch is ~2.8 km.
- At each digitized single-beam sampling point along track MW9204, we found all the multibeam data within the ensonified cone, assuming the cone axis was vertical. From the multibeam data in each such single-beam patch area we calculated:

  Shallowest depth
  Deepest depth
  Mean depth
  Standard Deviation

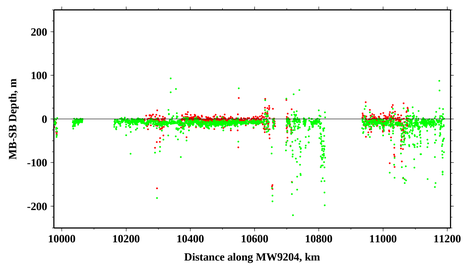
- We also calculated the slope of the least-squares plane best-fitting the multibeam depths in the cone, and also the residuals about the plane.

Shallowest Multibeam Depth vs Single-beam depth



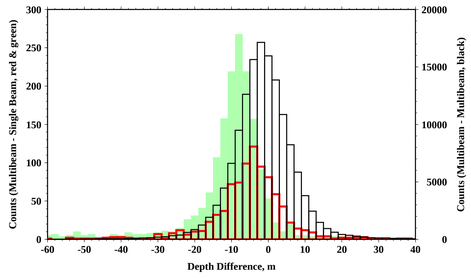
- We anticipated that the reported single-beam depth would be the shallowest depth in its ensonified cone.
- However, we find that single-beam depths are systematically deeper than the shallowest multibeam depth found in the cone.
- While this could be due to 1) incomplete multibeam coverage in cone or 2) location errors of sounding points, it is also possible that the single-beam system does a rather good job of averaging the depths within the patch it samples.

Histogram of Multibeam and Single-beam Depth Differences



- MR00-K08 multibeam depths are about the same as single-beam depths at corresponding locations.
- MR02-K01 multibeam depths (directly beneath MW9204 location) are systematically ~10 m deeper than the corresponding single-beam depth.
- Assuming navigation of all three is good, MW9204 samples the east side of the MR00-K08 swath and near the center of the MR02-K01 swath. Do these results suggest there is no roll bias in MR00-K08?

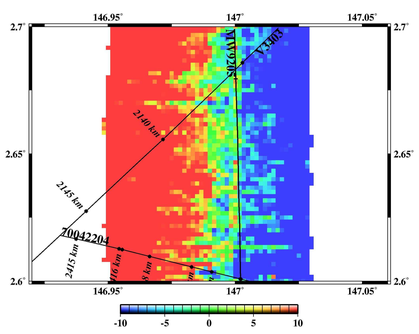
Multibeam minus Single-beam Depths along MW9204



Histograms of the differences show the same offsets, and a surprise in the spreads of the distributions.

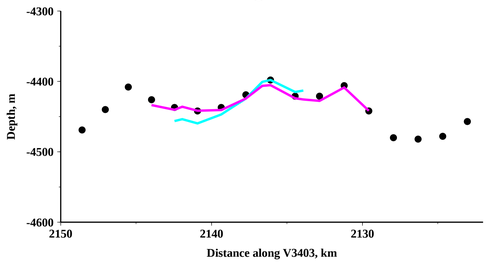
- There is a -10 m median offset of MR02-K01 multibeam minus MW9204 single beam depths (green area), despite the fact that MW9204 runs nearly down the middle of the MR02-K01 swath.
- The median offset of MR00-K08 multibeam minus MW9204 single beam is only -4 m (red lines), despite the fact that MW9204 runs along the eastern edge of the MR00-K08 swath.
- The histogram of differences between multibeam depths from MR02-K01 and MR00-K08 (black lines) appears wider than the red and green histograms of differences between multibeam and single-beam depths. This suggests single-beam measurements may be at least as accurate as multibeam measurements.

Depth Difference Grid

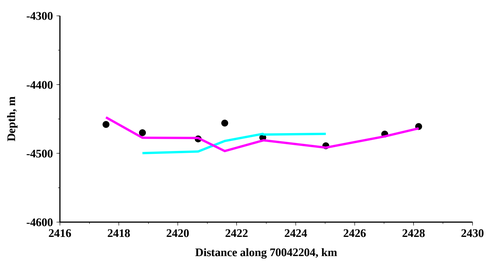


- Depth differences MR02-K06 minus MR99-K06 multibeam swath grids.
- These also show an east-west tilt of the differences, again possibly due to roll bias error.
- Single-beam tracks V3404 (1977) and 70042204 (1970) traverse this area.

Data along V3403



Data along 70042204



- MR02-K06 multibeam depths (purple lines) match single-beam depths (black dots). MR99-K06 multibeam depths (blue lines) are tilted with respect to the single beam depths. Note that both multibeam swaths are from the R/V *Mirai*'s Seabeam 2112 system operating in ~4450 m of water, yet the system seems to have operated in two different modes on these two cruises, as the swath widths are different.
- It appears multibeam swath MR99-K06 contains a roll bias error, which shows up as a tilt in the difference grid (left), and also as a tilt in the profiles above.

Note this implies we can use old single beam to find errors in new multibeam data!