Revised Multibeam Bathymetry, Sun-Illuminated Bathymetry, and Multibeam Backscatter Data Files

Hudson River Benthic Mapping Project

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for data products go to
http://www.nysgis.state.ny.us/gisdata/inventories/details.cfm?DSID=1136

## Introduction and Background

High-resolution multibeam bathymetric and backscatter data was collected from the Hudson River Estuary as part of Phases I, II and III of the Hudson River Benthic Mapping Project and a related mapping effort in upper New York Harbor, and data files were provided to NYS-DEC through Lamont-Doherty Earth Observatory, the prime contractor for the Hudson River Benthic Mapping Project (Bell et al., 2000; 2003; 2004a; 2004b). It became apparent during the study that water depths reported for some of the survey areas did not match the water depths reported for adjacent areas at their common boundary. This was thought due to errors in determining the elevations of local tide gauges deployed during the project because the depths determined during the multibeam bathymetric surveys were tied to the elevations of those tide gauges. The primary objective of the present project is to re-evaluate the water depths reported by the Hudson River Benthic Mapping Project, to make the changes necessary so that water depths are reported with respect to the North Atlantic Vertical Datum 1988 (NAVD88), and to provide revised files. Depth data from adjacent surveys were compared to determine the precision of the depth measurement and our water depths were compared to those measured by NOAA hydrographic surveys undertaken during the same time interval. Several other changes have also been made to the bathymetry and backscatter data files at this time, including editing and recalculating depths in some areas to remove anomalies, recalculating backscatter for Phase I surveys using the same approach used for Phases II and III surveys, and changing the area covered by the Phase I data files to match the Phase I areas as defined in Phase II and III.

## Results

Multibeam bathymetric and backscatter data were collected in 26 map areas of the Hudson River from 1998 to 2003 (Figure 1, Table 1). Water depths were determined using a Simrad EM 3000 or EM 3000D multibeam system. The depths were measured from the water surface, and a correction was applied in post-processing to correct depths to a fixed elevation such as NAVD88. We have re-evaluated the elevations of the water level records used during post-processing and recalculated the multibeam water depths.

*Water Level Offsets*

The tide wave in the Hudson River consists of a wave that propagates upriver at about 12 knots, which means that any point on the tide wave crosses through a survey area 5 nautical miles long in about 22 minutes. For most of the areas surveyed, at least two water-level gauges were deployed in each survey area in order to determine the characteristics of the tidal wave, and a correction was made to offset a water-level measurement to the location of the survey vessel at the time of depth measurement. In order to re-evaluate the multibeam water depths, the water level data used to reduce the bathymetry data were compared with the five recording tide gauges that are in operation along the Hudson River. These recording gauges include a NOAA gauge at The Battery and USGS gauges at Hastings-on-Hudson, West Point, Poughkeepsie and Albany. Data for the NOAA gauge is available online at http://tidesandcurrents.noaa.gov/ and data from the USGS gauges can be requested through http://waterdata.usgs.gov/ny/nwis/rt. The USGS water level data is reported relative to the datum NGVD29 while the NOAA water level data is reported relative to MLLW. The data at each station can be referenced to NAVD88 by correcting from NGVD29 or MLLW (0.847 m for Tidal Datum Epoch 1983-2001).

The results from this comparison are shown in Table 2. The offsets between the records from the online gauges and the water level used to correct the bathymetry files were determined visually because the project gauges were often short (perhaps just a few days), because of the temporal offset between USGS/NOAA gauges and project gauges, and because survey data was not collected throughout the tidal cycle. The offsets needed to align the two sets of records varied from 0 m to 1.28 m. The largest offsets of -0.53 m to 1.28 m occurred during Phase I when the vertical datum of the water-level recorders was poorly determined. Several of the offsets are in the range of -0.23 m to -0.3 m. These offsets suggest that the water levels were reported to NGVD29 rather than NAVD88. Offsets of -0.15 m and -0.04 m represent surveys where the processed water-level data reported by the USGS differed from the values available online at the time of the survey.

The water-level offsets in Table 2 were applied to the water level records used to reduce each survey area and thus to the depths in the different sections. An additional correction was made for Area A2, the first area surveyed during Phase I, when two water-level records were available for only part of the survey time. The water-level correction for this survey area was recalculated by determining how the tide wave measured at a single station propagated through the survey area. Following these corrections, the water depths for all survey areas are referenced to NAVD88.

*Additional processing of bathymetric data*

Additional corrections were made to the water depth data for several study areas. The most significant correction made to the bathymetric data set resulted from a unrecognized change in system alignment that affected the surveys for Areas B0, B1, B5, and B6. There does not appear to be an offset in the depth data for Areas B8 or B9 which were done immediately before those listed above, suggesting that the sonar alignment was altered during the transit from B8 to B6. New depth grids were created for Areas B4N and B2 following additional editing, and new grids were created for areas A1, A2, A3 and A4 due to the fact that the areas of these grids were redefined during Phase II, and the original Phase I grids did thus not cover the areas now defined for these grids. Additional editing of depth data was also done for Areas A1, A2, and A3, especially near stations. The depth data were recompiled for all survey areas to create the final depth data files, and sun-illuminated images were recalculated with illumination directions from the northeast and northwest.

*Depth comparisons between adjacent areas*

While the bathymetric data is reported in the various map areas (Figure 1), the actual surveys extended past the boundaries of the map areas and into adjacent areas. The precision of the depth data was evaluated by comparing depth data in 11 regions of overlap between surveys conducted in different years (Figure 2, Table 3). The comparisons were limited to data collected within two kilometers of the common survey boundary because data collected farther from the boundary may not be properly corrected for water level or sound velocity. Also, the navigation data used during the multibeam survey is accurate to about +/- 1 to 2 meters, so we can expect that the same feature surveyed at different times can be offset 2 to 4 meters. This navigation uncertainty can lead to a depth uncertainty in regions where there the river bed is sloped. For example, for a bottom slope of six degrees, a position error of 2 meters would result in a depth error of 0.2 meters. If the bottom slope increases to 20 degrees, a 2 meter position error would result in a depth error of 0.7 meters. To reduce depth errors that result from position errors, bottom slopes were calculated for both data sets in the area of overlap, and depth comparisons were only made where the bottom slope in each data set was less than 10°.

The mean depth differences in the overlap areas range from 0 m to 0.11 m with standard deviations in depth difference ranging from 0.15 m to 0.26 m. The maximum difference between grids ranges from 1.08 m to 3.97 m, with the average maximum difference 1.94 m. The low mean depth differences suggest that the depth data have now been corrected in a consistent manner throughout the Hudson River. Differences in depth between survey areas could result from errors in survey data or temporal variability in bottom characteristics. In addition to navigation errors, depth errors also result from errors in the vessel heave or in sound velocity profiles used to collect the data. We monitored the effects of variable loading during the project and determined that these changes were too small to correct for (less than 0.1 m), potential errors related to vessel heave and sound velocity are described more fully later. There may also be actual changes in water depth due to the migration of sand waves, manipulation of the bottom, or variable sedimentation. For example, the region of overlap between Area B0 and Area

H1 contains a sand wave field with waves over 1 m high as well as a mound of debris about 3 m high. The sand waves migrated horizontally and the mound of debris was removed between surveys for Area H1 in 2002 and Area B0 in 2003, resulting in large depth differences and a relatively high standard deviation in those areas (Figure 3). However, there are broad depth changes of +/- ~0.3 m (+/- two standard deviations) in the area of overlap that may be real or may be due to unrecognized errors in heave, loading or water level.

Two sources of potential vertical error need to be discussed in more detail: heave, and sound velocity. Vessel heave (or vertical position) is determined by a 1-2 minute average of the vertical position of the vessel. This average should removes 95% of vertical due to waves, but no information is available over longer time periods because motions over longer times average to zero. However, there can be changes in the vertical position of the vessel for reasons other that waves or tides. For example, the vessel can ride lower or higher in the water at some speeds or because of changes in vessel loading (e.g., fuel or number of persons aboard). We took the speed factor into account for our Hudson River surveys by attempting to survey at a fixed vessel speed. We also compared water depths measured at speed with those measured while the vessel was at rest, and determined that these depths agreed for our vessels. The largest routine changes in vessel speed and heave occurred at the ends of survey lines in some Phase I surveys. While these turns were generally outside of the map area boxes, they were in the areas used for depth comparisons.

Sound velocity profiles were generally collected at 2-3 hour intervals and the velocity profile was entered into our survey software. Sound velocity structure is needed to calculate the ray path that each echosounding beam takes in the water column, and thus the depth and location of the resulting depth measurement. If the sound velocity correction is incorrect, a flat sea floor can be made into an apparent trough or mound depending on whether the actual velocity is larger or smaller than the assumed water velocity. The sound velocity profile schedule worked well when there were minor changes in sound velocity with time and distance. However, if there was strong stratification then velocity profile could change quickly with tide and position in the estuary and we could not collect enough sound velocity profiles to fully characterize the changing sound velocity field. We attempted to correct for this error by applying a refraction correction in post-processing, and software is now available that would allow us to make better corrections based on the observed sound velocities. However, some depth error resulting from sound velocity errors are inevitable. The sound velocity profiles may have the greatest error in areas of overlap where many of the stations were collected.

*Depth comparisons with NOAA hydrographic surveys*

The accuracy of our multibeam depth surveys can be assessed by comparison of our results with recent NOAA bathymetric surveys in the area. Four bathymetric surveys have been identified that can be compared with our multibeam data: H10937, H10938, F00455 and H11353 (Table 4). Surveys H10937 and H10938 are adjacent and were collected at the same time, and will be analyzed as one survey. Bathymetric data from surveys H10937, H10938 and F00455 are available as point data while bathymetric data from survey H11353 is gridded at 2 m. Water depths in the NOAA surveys are reported to MLLW, and the offset from MLLW to NAVD88 at The Battery has been determined to be 0.847 m for the Tidal Datum Epoch 1983-2001. The mean difference between the Hudson River multibeam depth data and the NOAA depth data ranges from 0.04 m to 0.14 m with standard deviation ranging 0.11 m to 0.25 m, indicating that the Hudson River multibeam data represents the actual water depth at the time of survey. The water depth difference between the Hudson River and NOAA surveys ranges is similar to that for the overlap between adjacent Hudson River surveys with the exception of surveys H10937 and H10938 where larger differences are observed (to over 10 m). The data for surveys H10937 and H10938 are reported as point data rather than grid data, so the depth comparison includes data in areas of high slopes such as at the edges of channels and near obstacles. The areas with high depth differences occur primarily in areas with high relief.

*Backscatter images*

We have recalculated the multibeam backscatter results for the Phase I surveys using the same approach used as used for the later surveys, and in addition we have changed the area covered by the Phase I backscatter files to match the Phase I areas as defined in Phase II. In the later surveys we processed the multibeam backscatter data by removing the effects of transducer beam angle. This reduced the effect of across-track variations in backscatter and made the resulting backscatter images more uniform. We have now applied this same approach to the Phase I backscatter data which results in a more uniform backscatter image. However, we note that this processing step compares the signal strengths with a local average of the backscatter. As a result, the backscatter on the image can be different for different tracks in the same area. In processing these backscatter data we have also corrected the 1998 backscatter data in Area A2 and part of Area A3 to match the gain levels used in the rest of the survey areas.

*File Summary*

The bathymetric, sun-illuminated bathymetry and backscatter data were copied into the 26 non-overlapping map areas (Figure 1; Table 1), with each map area having a grid size of 1 m and containing only data from one survey. A total of eight files are created for each map area: gridded depth data in ArcView binary raster file format (.flt) with associated header file (.hdr), sun-illuminated bathymetry illuminated from the northwest (si) and northeast (sj) as uncompressed, 8-bit georeferenced tiff files (.tif) and associated world files (.tfw), and backscatter (bs) as an uncompressed, 8-bit georeferenced tiff files (.tif) with associated world files (.tfw). A binary raster file can be imported into GIS software such as ArcView 3.x (requires Spatial Analyst) or ArcView 8 or 9 (using Conversion Tools in the Arc Toolbox). Georeferenced tiff files can also be easily displayed in GIS software. All files are in UTM Zone 18N (WGS84 / NAD83). The vertical datum for the bathymetry is NAVD88.

The 1 m gridded bathymetry files (including overlapped areas) were converted to a 10 m gridded bathymetry file of the entire study area using the "aggregate" and "merge" functions in the Grid Transformation extension available for ArcView 3.x. This file was exported as in binary raster format as hudsonriver-10m-navd.flt (associated header file hudsonriver-10m-navd.hdr). Shape files of the 1, 5 and 10 m contours of the 10-m grid are also provided (hr-10m-1m_contour, hr-10m-5m_contour and hr-10m-10m_contour).

## Conclusions

The 1-m gridded bathymetry files for the Hudson River Benthic Mapping Project have been revised and replotted based on corrected tidal data and a 10 m gridded depth file has also been created for the entire area. All of the files are now referenced to NAVD88, and there is good agreement between adjacent map areas and with recent NOAA bathymetric surveys. New sun-illuminated bathymetry and backscatter images have also been created. The sun-illuminated images are recalculated based on the revised bathymetry and the backscatter images are recalculated to be consistent across all the areas. The boundary of Phase I maps have also been revised to match the areas as defined during Phase II.

The mean difference of all overlapped bathymetry data in areas of bottom slope less than 10° within the Hudson River Benthic Mapping Project is 0.01 m, the total standard deviation is 0.20 m, and the mean difference between that data and recent NOAA surveys is also less than 0.01 m. Some of the differences that occur in areas of overlap are due to instrumental limitations (e.g., navigation accuracy, sound velocity variability or heave corrections); however, a number of actual changes have also been recognized. Man-made changes include removal of debris from the sea bed and anchor drag marks while natural changes include sand-wave migration and sediment deposition.

## References

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Table 1: Survey areas (north to south), survey year, and names of the bathymetry, sun-illuminated bathymetry and backscatter files.

| Area | Year | Bathymetry | Sun-illuminated from Northeast | Sun-illuminated from Northwest | Backscatter |
|---|---|---|---|---|---|
| B9N | 2003 | B9N-r1m.flt / .hdr | B9N-r1m-si.tif / .tfw | B9N-r1m-sj.tif / .tfw | B9N-r1m-bs.tif / .tfw |
| B9S | 2003 | B9S-r1m.flt / .hdr | B9S-r1m-si.tif / .tfw | B9S-r1m-sj.tif / .tfw | B9S-r1m-bs.tif / .tfw |
| B8N | 2003 | B8N-r1m.flt / .hdr | B8N-r1m-si.tif / .tfw | B8N-r1m-sj.tif / .tfw | B8N-r1m-bs.tif / .tfw |
| B8S | 2003 | B8S-r1m.flt / .hdr | B8S-r1m-si.tif / .tfw | B8S-r1m-sj.tif / .tfw | B8S-r1m-bs.tif / .tfw |
| A4N | 1999 | A4N-r1m.flt / .hdr | A4N-r1m-si.tif / .tfw | A4N-r1m-sj.tif / .tfw | A4N-r1m-bs.tif / .tfw |
| A4S | 1999 | A4S-r1m.flt / .hdr | A4S-r1m-si.tif / .tfw | A4S-r1m-sj.tif / .tfw | A4S-r1m-bs.tif / .tfw |
| B7N | 2001 | B7N-r1m.flt / .hdr | B7N-r1m-si.tif / .tfw | B7N-r1m-sj.tif / .tfw | B7N-r1m-bs.tif / .tfw |
| B7S | 2001 | B7S-r1m.flt / .hdr | B7S-r1m-si.tif / .tfw | B7S-r1m-sj.tif / .tfw | B7S-r1m-bs.tif / .tfw |
| A3N | 1999 | A3N-r1m.flt / .hdr | A3N-r1m-si.tif / .tfw | A3N-r1m-sj.tif / .tfw | A3N-r1m-bs.tif / .tfw |
| A3S | 1999 | A3S-r1m.flt / .hdr | A3S-r1m-si.tif / .tfw | A3S-r1m-sj.tif / .tfw | A3S-r1m-bs.tif / .tfw |
| B6N | 2003 | B6N-r1m.flt / .hdr | B6N-r1m-si.tif / .tfw | B6N-r1m-sj.tif / .tfw | B6N-r1m-bs.tif / .tfw |
| B6S | 2003 | B6S-r1m.flt / .hdr | B6S-r1m-si.tif / .tfw | B6S-r1m-sj.tif / .tfw | B6S-r1m-bs.tif / .tfw |
| B5N | 2003 | B5N-r1m.flt / .hdr | B5N-r1m-si.tif / .tfw | B5N-r1m-sj.tif / .tfw | B5N-r1m-bs.tif / .tfw |
| B5S | 2003 | B5S-r1m.flt / .hdr | B5S-r1m-si.tif / .tfw | B5S-r1m-sj.tif / .tfw | B5S-r1m-bs.tif / .tfw |
| A2N | 1998 | A2N-r1m.flt / .hdr | A2N-r1m-si.tif / .tfw | A2N-r1m-sj.tif / .tfw | A2N-r1m-bs.tif / .tfw |
| A2S | 1998 | A2S-r1m.flt / .hdr | A2S-r1m-si.tif / .tfw | A2S-r1m-sj.tif / .tfw | A2S-r1m-bs.tif / .tfw |
| B4N | 2001 | B4N-r1m.flt / .hdr | B4N-r1m-si.tif / .tfw | B4N-r1m-sj.tif / .tfw | B4N-r1m-bs.tif / .tfw |
| B4S | 2001 | B4S-r1m.flt / .hdr | B4S-r1m-si.tif / .tfw | B4S-r1m-sj.tif / .tfw | B4S-r1m-bs.tif / .tfw |
| B3 | 2001 | B3-r1m.flt / .hdr | B3-r1m-si.tif / .tfw | B3-r1m-sj.tif / .tfw | B3-r1m-bs.tif / .tfw |
| A1 | 1999 | A1-r1m.flt / .hdr | A1-r1m-si.tif / .tfw | A1-r1m-sj.tif / .tfw | A1-r1m-bs.tif / .tfw |
| B2 | 2001 | B2-r1m.flt / .hdr | B2-r1m-si.tif / .tfw | B2-r1m-sj.tif / .tfw | B2-r1m-bs.tif / .tfw |
| B1N | 2003 | B1N-r1m.flt / .hdr | B1N-r1m-si.tif / .tfw | B1N-r1m-sj.tif / .tfw | B1N-r1m-bs.tif / .tfw |
| B1S | 2003 | B1S-r1m.flt / .hdr | B1S-r1m-si.tif / .tfw | B1S-r1m-sj.tif / .tfw | B1S-r1m-bs.tif / .tfw |
| B0N | 2003 | B0N-r1m.flt / .hdr | B0N-r1m-si.tif / .tfw | B0N-r1m-sj.tif / .tfw | B0N-r1m-bs.tif / .tfw |
| B0S | 2003 | B0S-r1m.flt / .hdr | B0S-r1m-si.tif / .tfw | B0S-r1m-sj.tif / .tfw | B0S-r1m-bs.tif / .tfw |
| H1 | 2002 | H1-r1m.flt / .hdr | H1-r1m-si.tif / .tfw | H1-r1m-sj.tif / .tfw | H1-r1m-bs.tif / .tfw |

Table 2: Results of a comparison between water levels used to reduce the previously delivered bathymetric data and NOAA or USGS tide records near the survey areas. These offsets need to be applied to the earlier depth data files.

| Survey | Map Area | Years | Offset to NOAA / USGS Tide Record (NAVD88, m) |
|---|---|---|---|
| Phase III | B9 | 2003 | -0.23 |
| Phase III | B8 | 2003 | -0.23 |
| Phase I | A4 | 1999 | 1.26 |
| Phase II | B7 | 2001 | -0.04 |
| Phase I | A3 | 1998 / 1999 | 1.28 |
| Phase III | B6 | 2003 | -0.15 |
| Phase III | B5 | 2003 | -0.15 |
| Phase I | A2 | 1998 | -0.53 |
| Phase II | B4 | 2001 | 0.00 |
| Phase II | B3 | 2001 | 0.00 |
| Phase I | A1 | 1999 | -0.30 |
| Phase II | B2 | 2001 | 0.00 |
| Phase III | B1 | 2003 | -0.32 |
| Phase III | B0 | 2003 | -0.32 |
| Upper Harbor | H1 | 2002 | -0.34 |

Table 3: Results of an analysis of depth differences between adjacent survey areas surveyed in different years. Differences are calculated by subtracting the southern from the northern area.

| Overlapped Areas | Number of Observations | Mean offset (m) | Standard Deviation (m) | Minimum Difference (m) | Maximum Difference (m) |
|---|---|---|---|---|---|
| | | | | | |
| B8S and A4N | 738,339 | 0.08 | 0.26 | -2.55 | 2.13 |
| A4S and B7N | 548,570 | 0.00 | 0.19 | -1.39 | 1.53 |
| B7S and A3N | 1,325,922 | -0.02 | 0.21 | -2.34 | 2.22 |
| A3S and B6N | 1,099,873 | -0.01 | 0.25 | -3.36 | 2.24 |
| B5A and A2N | 1,191,204 | -0.01 | 0.17 | -1.08 | 1.76 |
| A2S and B4N | 1,942,168 | 0.01 | 0.23 | -1.89 | 2.25 |
| B4S and B3 | 2,327,888 | 0.04 | 0.15 | -1.23 | 1.29 |
| B3 and A1 | 1,105,873 | -0.11 | 0.15 | -1.10 | 1.49 |
| A1 and B2 | 1,005,292 | 0.10 | 0.16 | -3.18 | 1.60 |
| B2 and B1N | 2,144,606 | -0.03 | 0.15 | -1.23 | 1.20 |
| B0S and H1 | 1,695,113 | 0.10 | 0.16 | -3.97 | 1.64 |

Table 4: Results of an analysis of depth differences between Hudson River surveys and NOAA surveys undertaken at about the same time. Differences are calculated by subtracting the Hudson River depths from the NOAA depths.

| Overlapped Areas | NOAA Survey Year | Number of Observations | Mean offset (m) | Standard Deviation (m) | Minimum Difference (m) | Maximum Difference (m) |
|---|---|---|---|---|---|---|
| NOAA H11353 and H1 | 2004 | 309,968 | -0.04 | 0.12 | -3.26 | 1.29 |
| NOAA F00455 and H1 | 1999 | 7,775 | 0.14 | 0.11 | -0.26 | 0.96 |
| H10937/H10938 and B0 | 1999 | 261,298 | 0.05 | 0.25 | -10.41 | 7.37 |

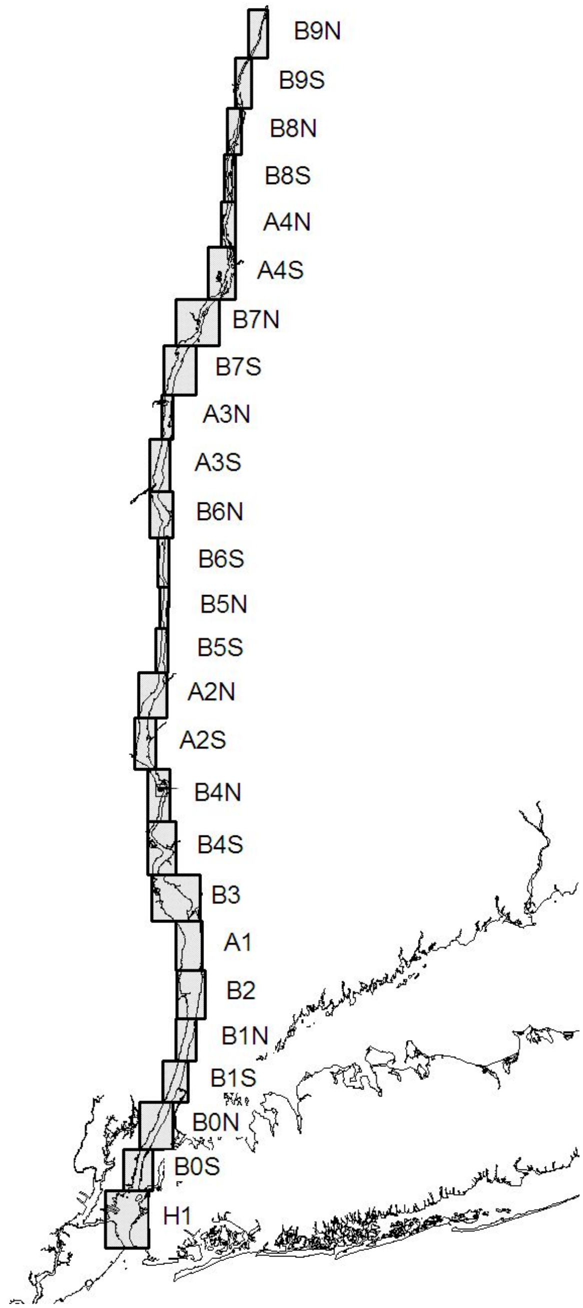


Figure 1. Location of Hudson River Benthic Mapping Project and Upper New York Harbor map areas. The A series of maps were collected during Phase I and the B series of maps were collected during Phases II and III.

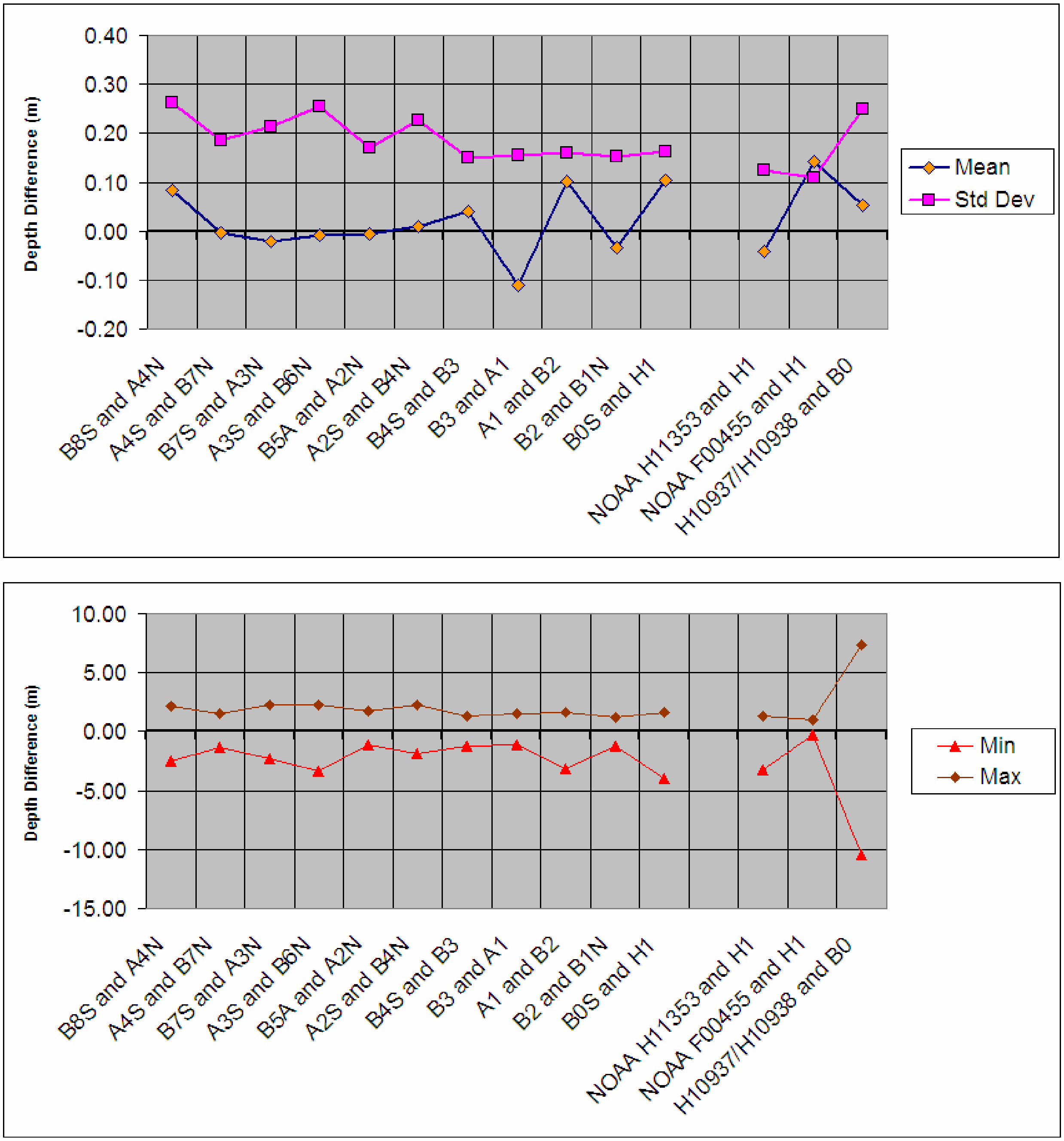


Figure 2. Plot of depth differences in areas of overlap between surveys undertaken in different years. The left-hand side compares surveys conducted for this project while the right-hand side compares our surveys with NOAA hydrographic surveys. Upper: Mean and Standard Deviation. Lower: Maximum and Minimum of depth differences.

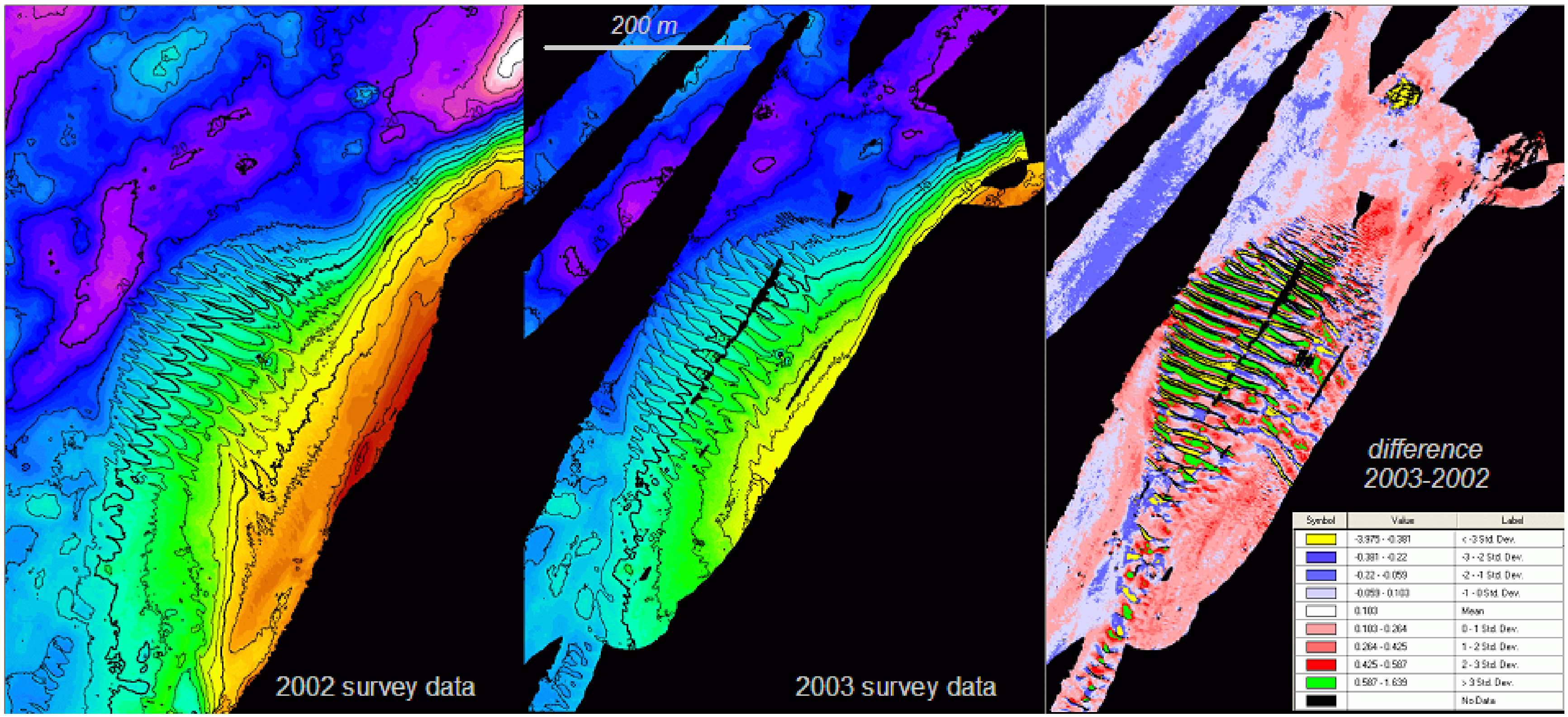


Figure 3.  Depth comparison for a portion of the overlap area between Area B0S and Area H1.  Left:  Area H1 bathymetry collected in 2002 (contour interval = 1 m).  Center:  Area H1 bathymetry collected in 2003 (contour interval = 1 m).  Right:  Depth difference between 2002 and 2003 colored by standard deviation.  Most of the area lies within one to two standard deviations of the mean.  Depth differences larger than two standard deviations (colored yellow and green) are related to migrating sand waves and to the fact that a mound of debris on the sea bed was removed between the two surveys.  Depth differences are only calculated for areas where sea-floor slopes are less than 10°.