

Implementation of TCARI into NOS Hydrographic Survey Operations

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ABSTRACT

The Tidal Constituent and Residual Interpolation (TCARI) methodology was developed by Dr. Kurt Hess of the NOAA/NOS Coast Survey Development Laboratory to replace when appropriate, the practice of discrete tidal zoning and the inherent errors and uncertainties in that process. The use of TCARI is expected to produce more consistent and smoother application of tide reducers for multibeam sounding data in particular. TCARI uses LaPlace's Equation as the interpolation engine over a model grid constrained by boundary conditions and solved using finite difference methodology. Interpolation of the tide is performed over the model grid of the amplitudes and phases of individual tidal constituents determined from harmonic analyses of observations at historical tide stations. For project planning, TCARI steps include the generation of a model grid to cover the project area, the input of harmonic constants from observations at tide stations, the calculation of weighting functions for each grid cell, and the selection of tide stations to be in operation during the survey to provide data for interpolation of residual water levels. In the office, TCARI is implemented by running a series of programs and data base queries to get the appropriate harmonic constants. Several runs may be necessary to resolve the best set of tide stations and grid limits to use in the final interpolation. Onboard ship, the data processing will use TCARI with the predetermined grid, tidal constituents and weighting functions, together with the residual water level interpolation from the prescribed tide stations in operation during the survey, to create tide reducers for the locations of the individual ship tracks overlaid on the TCARI model grid. Examples of TCARI output from recent surveys are used to describe this process. The paper provides a step-by-step outline for use of TCARI in NOS hydrographic surveys.

INTRODUCTION

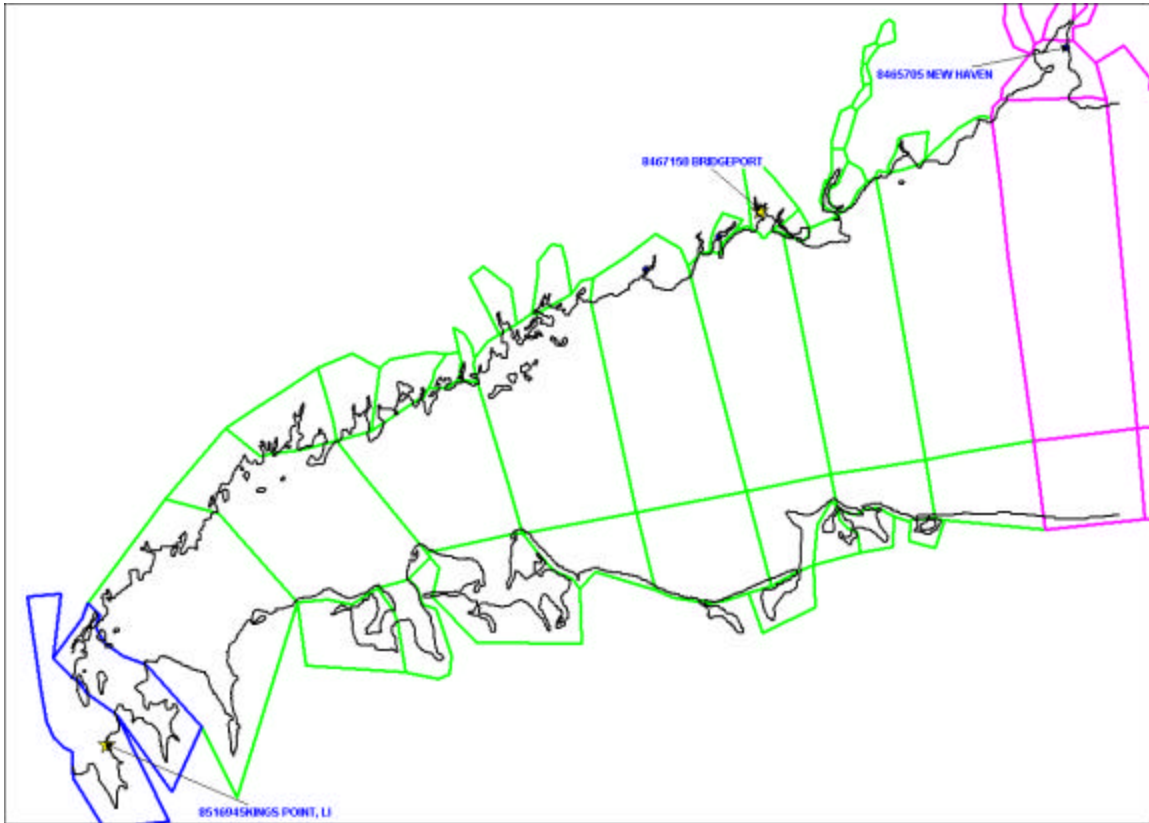
The inclusion of tide and water level requirements into National Ocean Service hydrographic surveys is a time critical function in phases of planning, field operations, and production of the smooth sheet. (Gibson and Gill, 1999). The Tidal Constituent and Residual Interpolation (TCARI) methodology was developed by Dr. Kurt Hess of the NOAA/NOS Coast Survey Development Laboratory to replace, when appropriate, the practice of discrete tidal zoning and the inherent errors and uncertainties in that process (Hess, 1999). The implementation of TCARI into operations is expected to produce more consistent and smoother application of tide reducers for multibeam sounding data in particular and is a potential tool for reduction of the time from ping-to-chart if the tool can be implemented on board ship as well. The NOS Center for Operational Oceanographic Products and Services (CO-OPS) is responsible for the tides support for all NOS hydrographic surveys and coordinates all activities with the Office of Coast Survey Hydrographic Surveys Division (HSD).

Discrete Zoning

Discrete tide zoning was developed as a way of estimating water levels relative to chart datum at any location in a survey area. Tidal zoning is the extrapolation of and/or interpolation of tidal characteristics from a known shore point to a desired survey area using time differences and range ratios. In this manner, the tide observed at operating tide stations during hydrographic surveys is extended out of the survey area using correction factors. In general, the greater the correction and the longer the distance from the operating station, the greater the error in the process. The tide zones used today are hand drawn using MapInfo (GIS). Oceanographers first hand draw co-tidal lines of time and range (i.e. – (Greenwich High water Interval(HWI), Greenwich low Water Interval (LWI), and Mean Range(MN) or Diurnal Range (GT) (NOS, 2000) using tide station information from historical and operating tide gauges, and also considering the bathymetry in the area. The HWI and LWI lines are drawn in 0.1 hr increments, and the range lines are drawn in 0.1 ft increments. Once the co-tidal lines are created, the oceanographer hand draws polygons in MapInfo from the co-tidal lines. The current standard is to construct zones such that no two adjoining zones can be greater than 0.2 ft and 0.3 hr. Once the polygons are drawn in MapInfo, unique time and range values are assigned to each zone based on the co-tidal lines.

The tide corrector within each zone is calculated by multiplying the amplitude of the water level above Mean Lower Low Water (MLLW) at a nearby gauge by the range factor assigned to that zone, and by applying the time difference for that zone. For preliminary zoning (submitted prior to the start of survey operations), range ratios and time differences are generated for the closest operating National Water Level Observation Network (NWLON) tide station. For final zoning (or smooth tides), the zoning scheme can be altered according to information from a short term, subordinate gauge installed specifically for the survey. Time correctors and range ratios are then generated for subordinate gauges as well as NWLON gauges.

Figure 1. Discrete Tide Zoning – Long Island Sound



TCARI - New Method for Generating Tide Correctors

TCARI was developed as an alternative method for generating tidal correctors for hydrographic surveys. TCARI decomposes, spatially interpolates, then re-composes both the tidal and non-tidal (residual) components of the water level signal, generating a smoother, more continuous tide correction. The grid sizes generated by the model are of much higher spatial resolution than the discrete tide zones can be constructed.

TCARI creates an estimate of the local astronomic tide by 1) spatially interpolating the tidal constituents amplitude and phases to a specific location and then reconstructing the astronomic tide by summing the constituents 2) spatially interpolating the residual, or non-tidal effects. Residuals are created by subtracting the predicted water level value from the observed water level value, and 3) spatially interpolating the datum offsets (Mean Sea Level (MSL) minus MLLW). The final tide corrector is created by summing these 3 variables (the astronomical tide, the residual, and the datum offset), at a specific grid cell corresponding to the specific location of sounding in a survey.

LONG ISLAND SOUND – A TCARI TEST PROJECT

Long Island Sound was selected to be the first CO-OPS run test of TCARI. This area was chosen because it had several long term NWLON tide gauges, as well as numerous historic stations. It is an enclosed sound and shows fairly non-complex tidal characteristics and fairly well understood progression of the tide.

TCARI is comprised of three programs: Program A creates a grid, Program B generates the weighting functions used for interpolation, and Program C generates the actual tide corrector. There is an additional program (Program M) that creates contours of the amplitudes and phases of the tidal constituents to be viewed by a GIS (specifically MapInfo).

Program A – Creating a Grid

TCARI creates a grid using the following input data:

- Latitude and longitude limits of the region.
- A digitized shoreline file
- A cell width (nmi)
- The latitude-longitude of a known water point
- List of tide stations that have tidal constituents, datums, and observed water levels for the time of the hydrographic survey.

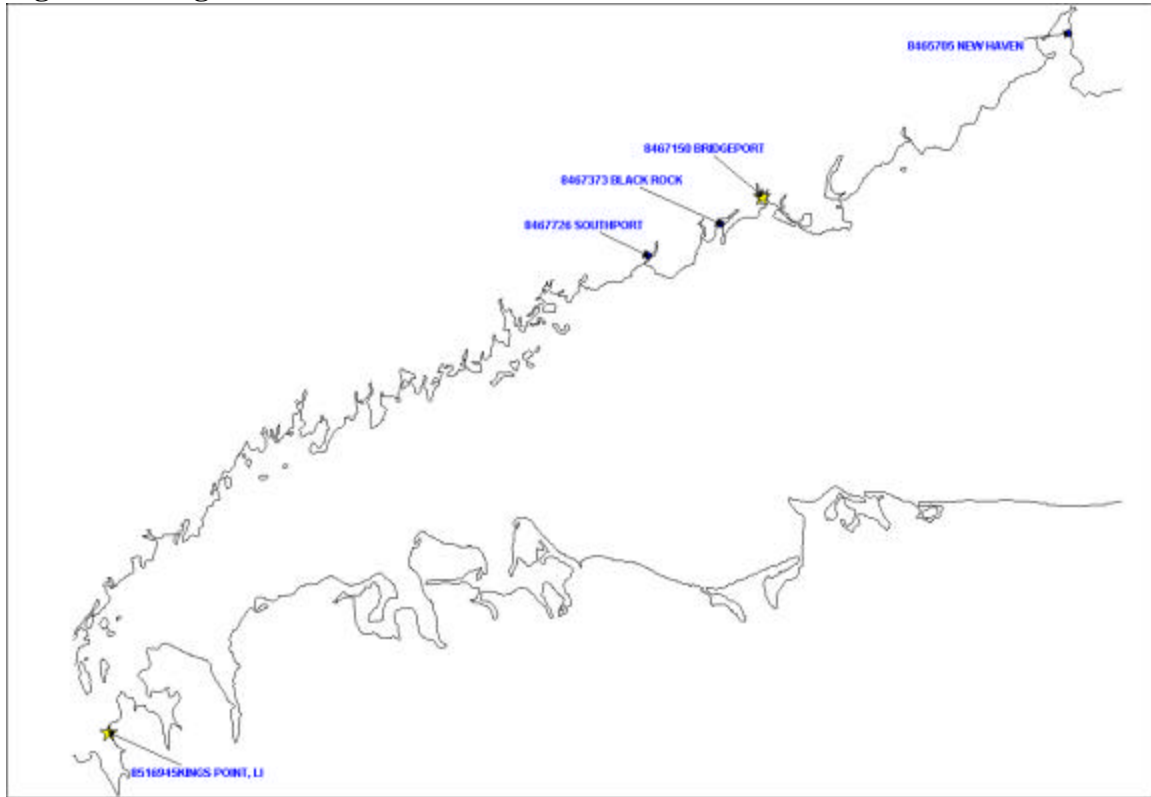
Tide gauge selection in a particular area is crucial to TCARI's accuracy. An SQL query searches the CO-OPS database (Data Processing and Acquisition System) for all historical and active tide stations within an area that meet the search criteria. In order for a tide gauge to be selected, it must have an accepted datum, and a set of either accepted or working tidal constituents. For stations that do not have tidal constituents in the database, a harmonic analysis had to be run on the historical data, and the constituents saved (Schureman, 1958) . These are considered a working set of constituents.

Understanding tidal constituents is critical to understanding TCARI. Using standard NOS harmonic analysis procedures, the observed tides at a location can be broken down into a number of constituent tides, or harmonic constituents. Each constituent represents a periodic change or variation in the relative positions of the earth, moon, and sun (i.e. the spring/neap cycle), and has a unique amplitude and phase at each location. Tidal predictions for a location are generated by combining the harmonic constituent curves into a single composite curve.

Once the tide stations have been selected, the oceanographer must examine the data closely before proceeding. It was found, that some of the older, historic stations had problematic data and could not be used. In some instances, stations were located in very anomalous areas and small bays and rivers that did not reflect the larger area. Data quality must be looked at carefully to avoid inaccurate results in TCARI. For Long Island Sound, five tide stations were selected to be used for tidal constituents, and datums

(Figure 2). Of these five stations, only three were installed and operating at the time of the survey. All five stations were used for TCARI interpolation of tidal constituents, and datums, but only three stations were used to compute the residuals.

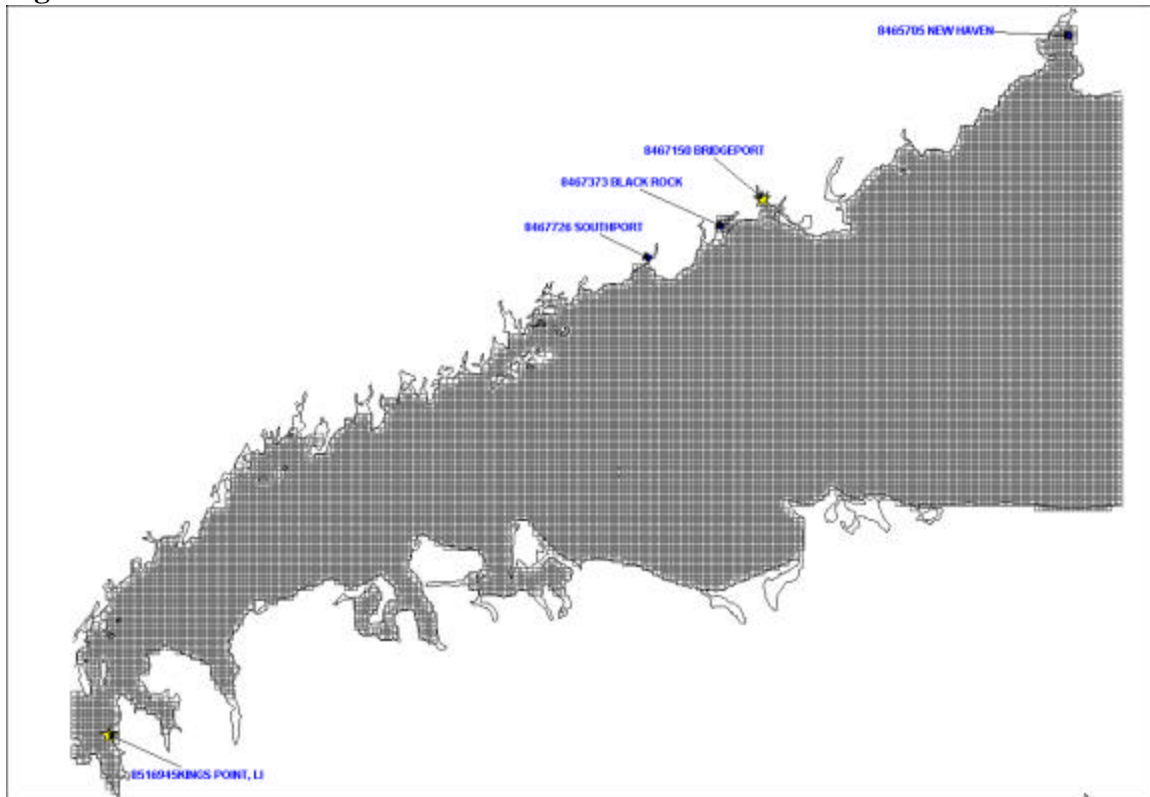
Figure 2: Long Island Sound Tide Station



Note that the distribution of tide gauges is not ideal, as Bridgeport, Southport, and Black Rock are clustered close together, and there is sparse data on the north side of Long Island. Several historical stations exist, but are located up inside coves and harbors and were not appropriate for use in interpolation to the middle of the Sound. . Several gauges on the southern end that were queried from the database had problematic data, and could not be used for this test.

Program A uses the tide gauge locations, the shoreline, a known water point, and a cell size in nmi, to create a grid. The grid is composed of square cells, with each cell's width (or resolution) being the cell size in nmi. Cell resolution should be small enough so that complex shoreline features, such as entrances, and straits will have at least 2-3 cells across them. Smaller cell size, though can increase computation time considerably. In Figure 3, the cell size is .2 nmi. Starting from the known water point, TCARI flags each cell as either land, or water. No bathymetric data is needed to develop the grid.

Figure 3: TCARI Grid



Program B – Generating the Weighting Functions

The spatial interpolation at the core of TCARI is carried out by the use of a set of weighting functions that quantify (in percentages) the contribution from each tide gauge. The weighting functions themselves are generated numerically by solving LaPlace's equation on the grid (Hess, 1999). The variable to be interpolated is set up as a two-dimensional field for which the numerical solution of the LaPlace's equation is computed. One of the unique features of TCARI is that the spatial interpolation allows for overcoming the influence of land (peninsulas) within the grid. Boundary conditions for the interpolation model are the tides stations themselves, the ocean boundary, and the shore.

There are 3 sets of weighting functions, one for each of the variables (constituents, residuals, and datum). For the tidal constituents, and datum weighting functions, all five stations were used. For the residuals, only 3 stations were used, and therefore will have a different set of weighting functions based on those 3 tide gauges. Depending on the size and location of the survey area and the grid, there will be more stations with harmonic constituents and datums used to interpolate the tidal constituents than the number of stations required to interpolate the residual. Typically, the residual is a function of the effects of wind stress and barometric pressure on the tide and these effects tend to be highly correlated over large geographic area. Thus, these stations used for residual interpolation need to be in operation during a hydrographic survey using TCARI, but all

of the stations used to determine the tidal constituent weighting functions do not. This is determined during planning stages of the survey. Figure 4 is an example of the contoured weighting function for a tidal constituent amplitude or phase for a particular tide station. Similar contours can be generated for each tide station used and also for the residual weighting function as well as the MSL-MLLW datum function at each station.

Figure 4: Tidal Constituents Weighting Functions for Kings Point, NY

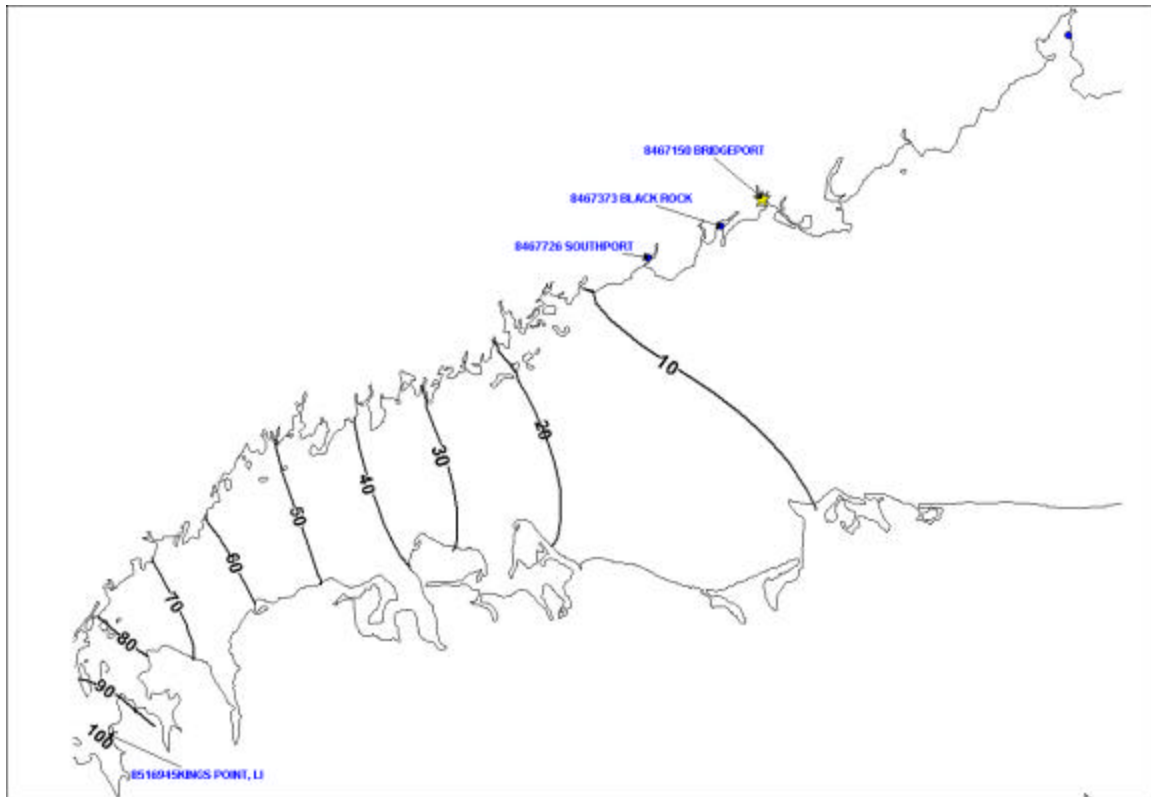


Figure 4 shows what percentage of the constituents' phase and amplitude is due to the value at Kings Point. The weighting function is 100% at the Kings Point tide gauge, and 0% at the other 4 tide station locations.

Program C – Generating the Tide Correctors

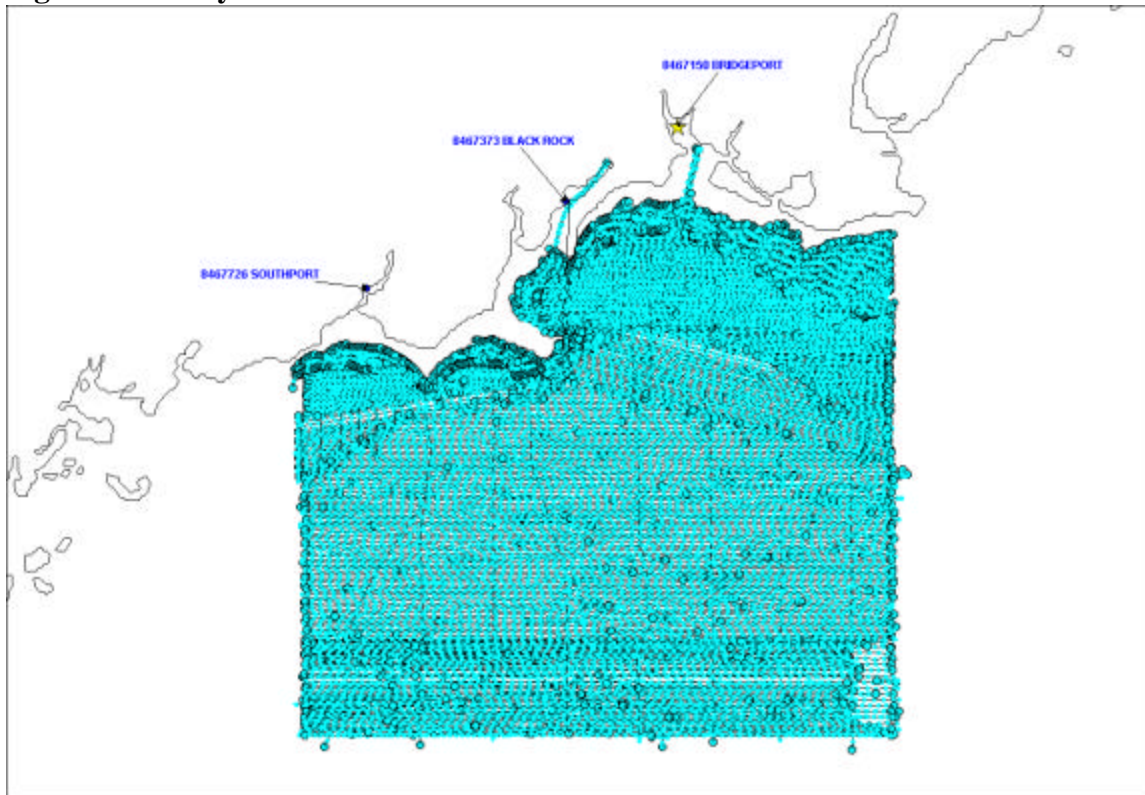
TCARI generates a tide corrector using the following input data:

- Ship Trackfile of ship time and position
- Previously computed weighting functions for all 3 variables (tidal constituents, residuals, and offsets)
- Tidal constituents (amplitudes and phases)
- Equilibrium argument and lunar node files

- Observed, verified, six-minute water levels for tide gauges that were operating during the time of the hydrographic survey (on MSL).

For this test project, we used the ships navigation file as the ships trackfile. The navigation file contains a latitude and longitude, date, day of year, and time for each navigation point. Program C reads each navigation point and computes a tide corrector for that exact location in the survey area.

Figure 5: Survey Trackfile



For a tide corrector at a specific location and time, TCARI computes the astronomic tide relative to MSL, the residual water level due to meteorological effects, and the offset (MSL-MLLW). The sum of these three quantities is the tide corrector, and when subtracted from a sounding will give a depth relative to MLLW.

To compute the astronomic tide at a specific location in a survey, TCARI uses the amplitudes and phases of the 37 tidal constituents for each tide gauge. Using the weighting function created for the tidal constituents, the amplitudes and phases are interpolated to produce amplitudes and phases at the location of the ship. The tide is computed by summing the interpolated constituents.

To compute the residual water level at a specific location in a survey, the observed water level is subtracted from the reconstructed astronomical tide at each tide gauge. Using the

set of weighting functions created for the residuals, they are interpolated to produce the residual water level at the precise location of the ship.

To compute the datum (MSL-MLLW) at a specific location in a survey, the datum offsets are computed at each tide gauge, and using the set of weighting functions for the offsets, are interpolated to generate a datum at the precise location of the ship.

TCARI output is an ASCII text file containing the latitude and longitude of each navigation point, and the corresponding astronomic tide, residual, datum, and tide corrector on MLLW for each point.

PRELIMINARY RESULTS

Processing and analysis is currently underway. Comparisons are being made between tide correctors generated through TCARI, and those generated through the traditional method of discrete zoning. It is expected that there would be close agreement in areas with non-complex tidal characteristics. For the Long Island Test Project, the actual survey area only crossed 2 discrete zones, and both zones apply a time difference, and range ratio to Bridgeport, CT. Preliminary results indicate very close agreement between the two methods. Hess (1999) reported that TCARI was able to reproduce the measured water levels with mean errors of less than 2.0 cm, RMS errors of less than 9.0 cm, and maximum individual data point errors of less than 45.0 cm for TCARI runs on Galveston and San Francisco Bays. Error sources are due to numerical interpolation errors, lack of historical and operating tide stations within the grid, and poor quality harmonic constituents.

IMPLEMENTING TCARI INTO HYDROGRAPHIC OPERATIONS

TCARI consists of 3 distinct programs, programs A, B, and C. Developing the grid, choosing appropriate tide stations, and developing the weighting functions can be seen as part of the planning stage of a hydrographic survey. Once the grid and weighting functions are generated for an area, there is no need to create them again, unless the coastline changes, or tide stations are added or removed from the survey area. For the project planning phase, TCARI would build a grid and the weighting functions for a large area, and potentially would not have to be changed for the duration of the project.

Program C can be considered a ship or processing branch operation, to be performed once the survey is completed and final tides are available. Onboard ship, the data processors require the observed 6 minute water levels, and a ship trackline file, as well as the grid, and weighting functions created by CO-OPS. Once the tide correctors are generated, data processors apply the correctors to the bathymetry to reduce the soundings to chart datum. The hardware and software platforms for operating TCARI on board ship need to be determined.

With this breakdown of responsibility, several issues need to be addressed. Once the grid and weighting functions are created, they do not have to be re-computed unless tide gauges are added or subtracted. In the case where a tide gauge goes down due to weather, or technical malfunctions, the grid and weighting functions would have to be recomputed to reflect the removal of the tide gauge. The communications path for the ship to continuously obtain the water levels from the tide stations used for residual water level interpolation needs to be implemented.

CONCLUSION

The preliminary research indicates that TCARI produces a smoother, more continuous tide correction than the traditional method of discrete zoning. TCARI eliminates the occurrence of “steps” when moving between discrete zones, and therefore might be more compatible with high density multibeam datasets, and the navigation surface concept. TCARI’s accuracy depends on the existence of tide data at several locations bracketing a survey area. The TCARI method does not alleviate the need for contemporary tide measurements. Because of this, TCARI may not be feasible in all areas, particularly those with limited historical and current water level measurements. , TCARI grids and weighting functions have been developed for Puget Sound, WA, Galveston Bay, TX, and San Francisco Bay, CA. Future areas may include Cook Inlet, AK, and Lake Charles, LA.

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