Continuous Vertical Datum Separations for Canadian Waters

Creating Canada's First Hydrographic Vertical Separation Surfaces

By Shannon Nudds • Catherine Robin • Phillip MacAulay

Since 1883, the Canadian Hydrographic Service (CHS) has studied the oceans to ensure safe navigation of Canada's waterways. Bathymetric surveys, and the nautical charts and products they produce, play an important role in maritime transportation, ocean and freshwater mapping, identifying coastal hazards, and sovereignty—the four pillars of the CHS mandate.

Over the past 130 years, hydrography has evolved from single-point measurements with weighted lines to the use of multibeam echosounders. With recent advances in Global Navigational Satellite Systems (GNSS) it is now possible to perform hydrographic survey reductions through the ellipsoid, simplifying hydrographic operations and leading to more rapidly available and improved bathymetric products.

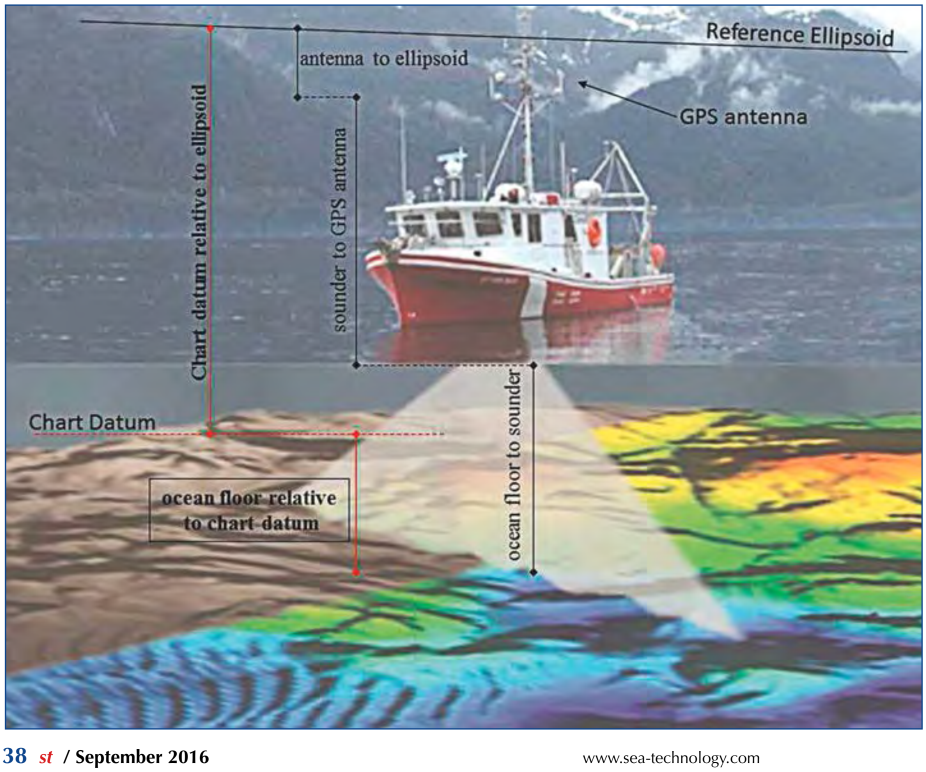
To accomplish this "through the ellipsoid" reduction process, the separation between chart datum (CD), the reference for all charted depths and the reference ellipsoid must be known. The Continuous Vertical Datum for Canadian Waters (CVDCW) project was conceived by CHS to develop hydrographic-quality ellipsoid to CD surfaces to support "through the ellipsoid" bathymetric reduction.

This article will present an overview of the CVDCW project and its products, Hydrographic Vertical Separation Surfaces (HyVSEPs).

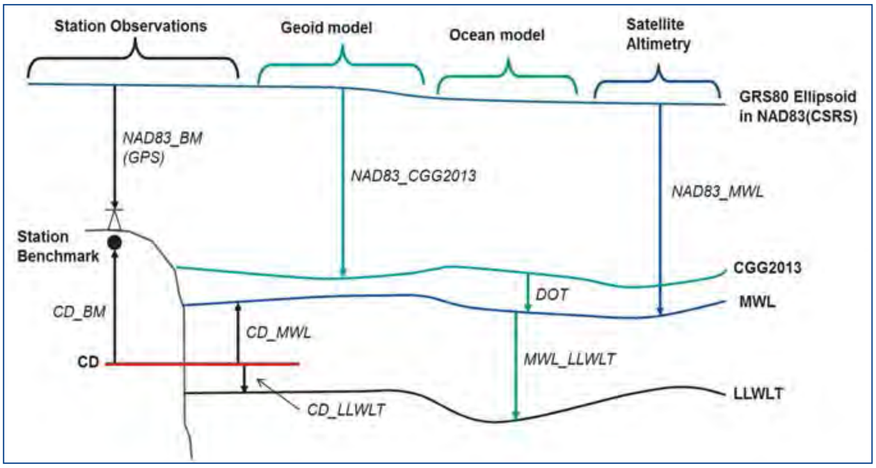
The CVDCW has developed HyVSEPs for a range of tidal target water levels. All are valuable resources for hydrography, coastal engineering, coastal planning, ecosystem management, or any effort requiring knowledge of vertical or horizontal water level target or datum positioning.

Building Surfaces from the Datum Up

The vertical separation between the ellipsoid and the target datum is the sum of three components or layers: the geoid, which gives the separation between the reference ellipsoid and equipotential surface; the dynamic ocean



Surveying to the ellipsoid. Bathymetry is measured relative to the reference ellipsoid and can be easily reduced to a value relative to chart datum if the separation between chart datum and the ellipsoid is known.



Schematic of HyVSEP components and data sources.

typography (DOT), which gives the separation between the geoid and mean water level (MWL); and the separation between MWL and the target datum, developed from appropriate statistical analysis of observed and modeled water level data.

Where satellite altimetry is available and reliable, it can be used to provide direct measurement of the separation between the ellipsoid and MWL, the first two components combined.

The reference ellipsoid for Canadian HyVSEPs is the GRS80 ellipsoid in the NAD83(CSRS) reference frame. The geoid model, CGG2013, is provided by Natural Resources Canada. The DOT and target datum to MWL values are derived from regional dynamic ocean models and tidal models provided by Fisheries and Oceans Canada.

Observed water levels from tide gauges along coastline are used at various stages of the process for both general and local solution guidance and adjustment. The methods used to integrate all these data are incorporated into the HyVSEP development tools, and allow the user to examine the results of the integration procedure at each step through visualization and simple statistical analyses. The process also permits the user to evaluate ocean model results before selecting which will be incorporated into HyVSEPs, and to quality control observations at tide stations (i.e., tidal constituent sets and GPS campaign results). This has provided the impetus and the opportunity for the CHS to examine its tide station holdings in their entirety, which has led to a significant number of updates and improvements where necessary. Finally, it has helped plan the acquisition of new data, an ongoing process.

Methods used to populate, manipulate and adjust each HyVSEP component layer rely on three elements: the resolution and connectivity of an underlying grid, custom built for the CVDCW's HyVSEPs; a Laplacian interpolator; and a finite element (FE) smoother.

The Laplacian interpolator and the finite element smoother are straightforward mathematical functions whose behaviors mimic elements of the real physical processes.

Honoring Existing Chart Datum

When the HyVSEP for CD is used to reduce new bathymetric data, the new bathymetry should closely match existing bathymetric data sets that were collected with reference to the existing chart datum values on which the CHS has traditionally relied. The CHS's target datum for CD is Lower Low Water Large Tide (LLWLT). However, under CHS standard practice, once CD is established, it remains fixed while LLWLT slowly moves due to changes in relative sea level. Thus, over time, differences between CD and LLWLT develop. Standard procedure is that the CHS "adjusts" CD to match recent realizations of LLWLT. However, this process only takes place as necessary on a station by station basis. Since HyVSEPs are developed with respect to target water levels, in this case LLWLT, to achieve a HyVSEP referencing CD requires an additional step to locally warp the target surface to match the existing "in-use" chart datum at, and in the vicinity of, the tide gauges.

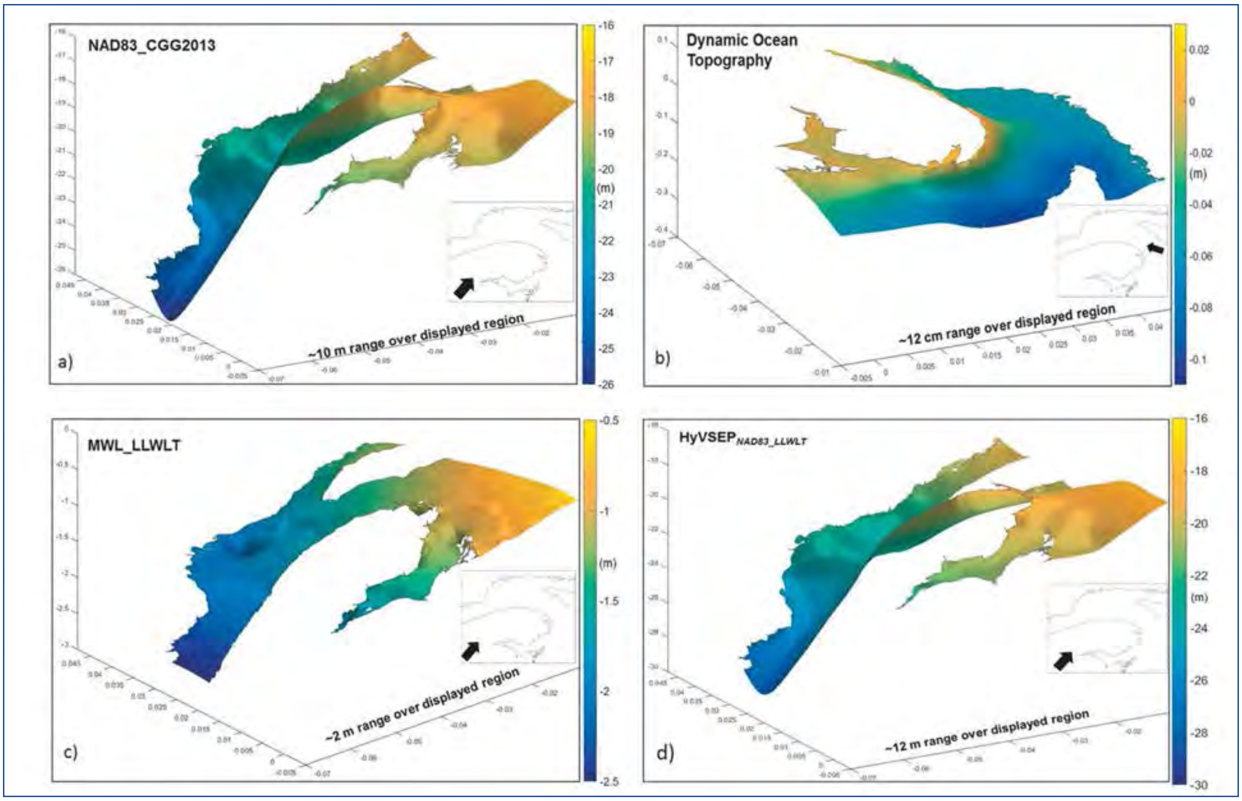
It was decided that the warping of the solution should only be applied inside a specified area along the shoreline called the "blend zone". This decision recognizes that distal to the tide gauges the ideal LLWLT target solution is potentially a better reference for CD as it incorporates spatial variations in LLWLT behavior that are not as effectively included in earlier tide gauge-based reduction solutions.

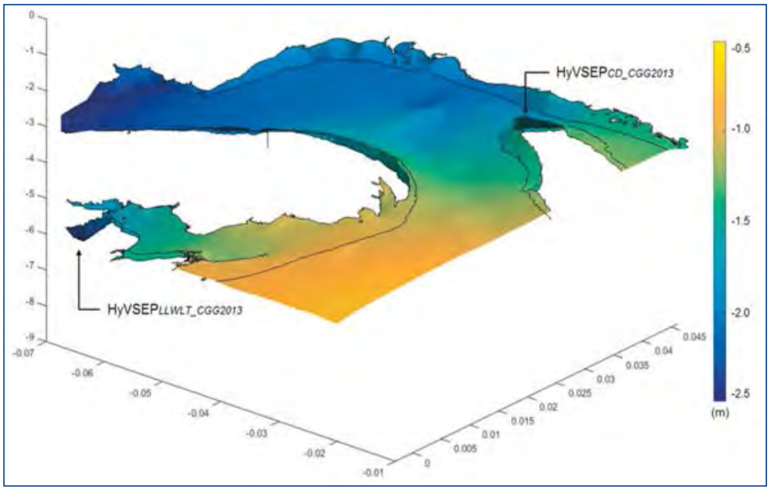
Outside the blend zone, the HyVSEP for CD remains identical to that of the HyVSEP for LLWLT.

Data Acquisition

Nationally, approximately 1,340 tide stations are established. Over the past 20 years, 505 benchmarks have been occupied with GPS to establish ellipsoid to datum separations.

The sparsity of the shore stations is particularly evident in the Arctic. The sparse nature of Canada's existing tide gauge and ellipsoid to datum links necessitates support





(Top) 3D views of the component surfaces used to create the HyVSEP for LLWLT (a-c) and the surface itself (d). The map in the bottom right corners show the region in plan view; black arrows point in the direction of line of sight. (Bottom) 3D depiction of HyVSEP$_{LLWLT_CGG2013}$ overlaid by the warped HyVSEP$_{CD_CGG2013}$. Note that HyVSEP$_{LLWLT_CGG2013}$ is only warped inside the blend zone. The ellipsoid to geoid component is not included in these surfaces to better portray the spatial behavior of the warp.

for an ongoing program to collect new data sets. As new data are collected, they will be incorporated into updated versions of the HyVSEPs.

New, Improved Grids for HyVSEPs

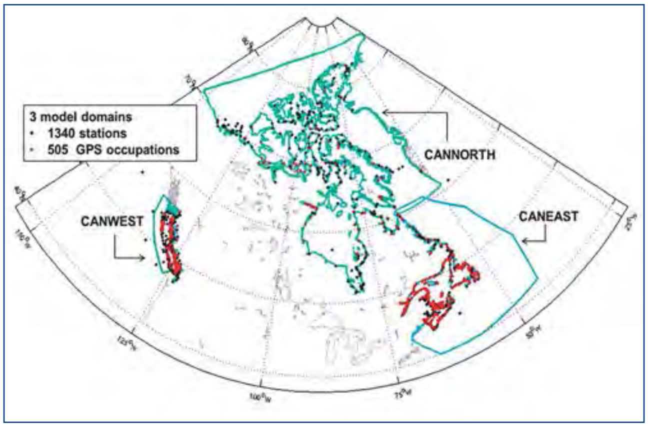
Initially, HyVSEPs grids were developed from existing ocean model grids. Although the ocean model grids had sufficient resolution to capture the basic spatial variability of the tidal dynamics and DOT, they were insufficient to meet important criteria for the HyVSEPs, specifically the detailed tidal range changes in complex coastal areas (e.g., inlets, bays and narrows) as observed at tide gauges.

Significant efforts were made to combat this liability, finally culminating in the decision to develop grids specific to meet the CVDCW project needs. Thus, the project has adopted new techniques and applications to generate large area unstructured grids with high coastal density that properly capture the level of coastal detail to support both present and future surface enhancement. The new high-resolution grids provide the structure on which the Laplacian interpolator and the finite element smoother function. The new grid structure has the necessary resolution to, in conjunction with appropriate water level and ellipsoidal references and the Laplacian interpolator and finite element smoother, provide a detailed solution along a long narrow channel.

Flexibility with Pseudo Stations and the Blend Zone

Pseudo stations are a method of adding additional control points to the existing shoreline where the sparse distributions of existing tide stations is deemed to be missing key behavior. They can be added as individual isolated points on the boundary or offshore. They are used to locally force the solution to adopt expected behavior with the objective to overcome obvious liabilities in the existing station data, or to extend the influence of existing stations. They are judiciously employed based on expert understanding of the expected dynamical behavior of the surface and to force the HyVSEPs to adapt to historical datum.

Pseudo stations are not used to adjust the solutions in areas where existing shore control is arguably too sparse to provide sufficient boundary information. In such areas it was judged best to rely entirely on modeled estimates. Thus, the final solutions relax to those of the target model away from station control points. The blend zone is a narrow band along the coast over which the target surface is



Map with working grid domains and station locations.

warped to fit the observed values at existing shore stations, more specifically, to fit CHS's existing realization of CD. A tool has been developed to permit easy editing of the blend zone so that its width can be adjusted to local conditions.

The use of pseudo stations and the ability to manipulate the blend zone width lend flexibility to how the final surface is generated, ultimately allowing the tidal officer's expertise on the local conditions to be incorporated with observations and models.

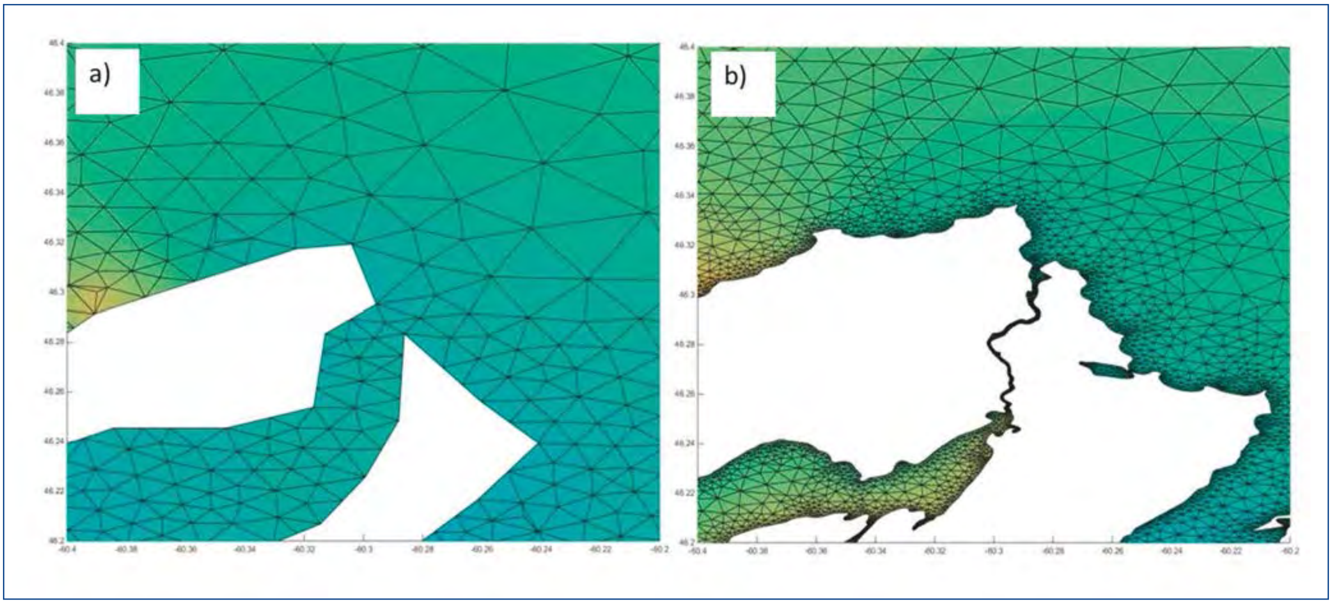
Enhanced CARIS Attitude Editor Visualization Tool

A challenge faced by any organization developing vertical separation models is validation of the surface products and the GNSS-based vertical control measures used in the associated hydrographic surveys. To facilitate validation of these processes the CHS contracted CARIS to enhance their existing Attitude Editor. The enhanced version of the Attitude Editor is available on HIPS version 9.0.17 and later. The tool now permits more effective comparisons between the recorded water level at tidal stations and calculated GPSTide elevations along hydrographic data collection survey lines (GPS tide is the water level elevation above datum as determined by the difference between the ellipsoid to datum separation of the HyVSEP and the ellipsoid to water line separation measured by the survey platform at the same location). The capacity to easily view and compare the observed water level with the GPSTide permits rapid identification of potential problems.

Operationalization of Procedures

The CVDCW project has developed tools to generate, manage and maintain HyVSEPs in an accessible calculation environment, Matlab (Mathworks, 2014). The tools and methodologies are designed to be user-friendly and transportable for use in other regions or by organizations that may not have the resources to develop a similar system of their own. However, the expert hydrographic knowledge provided by hydrographers and/or tidal officers is essential to the development of quality surfaces.

Once an established calculation methodology exists, to manage, maintain and update HyVSEPs requires the capacity to: assess and incorporate new model results as they become available (geoid, DOT and target to MWL separation); assess and incorporate new or updated observations (water levels and ellipsoid links), including full epoch updates if and when required; make adjustments to the grids to account for local coastline or coastal structure changes and improved coastline information; assess the quality of HyVSEPs through simple statistical analysis of each layer, and adjust if needed; adjust and modify the boundary conditions and the methods of their employment; and recalculate and archive the solutions.



A comparison of the a) old and b) new grid for the CANEAST HyV SEPs. Note that the old grid includes an onshore "buffer", which in the new grids is added at a later stage in the process, permitting a finer degree of variability in the calculations near the coast.

To address these requirements, CVDCW processes have been packaged in a set of structured modules. Each module contains the necessary materials, tools and instructions to complete a discrete portion of the HyVSEP production process. The existence of these tools and packages means that the process of updating and recalculating an existing surface is significantly automated.

Application to Other Regions

Operation of the modules is not tied to any specific area or underlying data structure and relies on a commonly available scientific and engineering computational environment. Thus, the process is transportable for use by other organizations based on the data sets available at their own location. A detailed description of the modules and the procedure for creating HyVSEPs will be published in an upcoming Canadian Technical Report of Hydrography and Ocean Science.

Acknowledgments

The authors would like to thank the following members of the CVDCW working group, without whom this work would not be accomplished: Andre Godin, Bodo De Lange Boom and Jason Bartlett.

References

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