Modeling tidal water levels for Canadian coastal and offshore waters: implications for coastal change and adaptation


1. Introduction: Hydrographic Vertical Separation Surfaces (HyVSEPs)

The Canadian Hydrographic Service with support from the Canadian Geodetic Survey has created a set of surfaces which connect tidal levels and datums (high and low water levels, chart datum, etc.) to a national geodetic reference frame over all Canadian tidal waters. These surfaces capture the spatial variability between stations and offshore by integrating ocean models, gauge data (water level analyses and/or GPS observations), sea level trends, satellite altimetry, and a geoid model. HyVSEPs will enable the use of GPS for hydrographers and navigators. It will also be useful for oceanographers, environmental and coastal scientists, surveyors and engineers. It will allow the integration of hydrographic and terrestrial data through a common reference frame, provide a baseline for storm surge modeling and climate change adaptation, and aid with practical issues such as sovereignty and the definition of the coastline. High and low tide HyVSEPs will delineate flooding thresholds and inter-tidal ecosystem zones and boundaries.

2. Data and Methods

Tidal HyVSEPs cover all of the Canadian Coast and offshore waters in 5-km and highly-detailed finite element grids (see figure). HyVSEPs are a sum of discrete layers, each of which fill a vertical portion of the separation between tidal levels and the GRS80 ellipsoid in the NAD83/CD1986 reference frame. Gauge data varies in quality, with stations operating between 3 weeks and 100+ years; we include as many as possible especially where gauge observations are sparse. An ongoing campaign of GPS surveys at tide station benchmarks has been in operation since the early 1990s. Gauge and GPS data are brought to a common epoch with local and global motion adjustments.

Calculations are primarily done with a Laplacian Interpolator, in effect modeling spatial variations in tidal regime as a steady-state linear transfer problem. Thus it is important that our grid boundaries reproduce real coastlines with great detail, to keep tidal restricted areas not properly isolated. Because our calculations are simple, our grids can be much more detailed than the ocean model grids upon which they are based. The figure to the right shows a close-up of the Pacific Coastline from Prince Rupert.

3. Chart Datum

Chart Datum (CD) is the vertical datum for nautical charts. In Canada, CD targets Lower Low Water Large Tide (LLWLT), the lowest predicted tide in a 19-year astronomical cycle (see figure). It nearly coincides with LLWLT hPaLW, especially where CD was set 100 years ago and where relative sea level rise is large. In this figure we show 4 tidal levels, but many more can be defined. We currently have HyVSEPs for CD, 6 high and low tidal levels, and Mean Water Level.

4. Modeling tidal water levels

Layer 1: The Geoid (Artic grid). The foundation of HyVSEPs is a good model, a gravitational equipotential (or level) surface which best represents Mean Sea Level (MSL); it maps where water would rest if it were all of the same density. We use the Canadian Geodetic Grid model, which integrates data from terrestrial gravity measurements (land, ship and airborne observations) as well as from the dedicated satellite gravity missions GRACE and GOCE. CDGEO2005 provides HyVSEPs with their link to the ellipsoid, and their spatial variability is to first order the result of good geoid calculations.

Layer 2: Dynamic Ocean Topography (DOT) (Artic grid). Observed MVL does not fall on an equipotential surface due to variations in density caused by temperature and salinity differences. The difference between CDGEO2005 and MVL is DOT, which can be observed or modeled. Our DOT layer includes a model DOT from a hydrodynamic ocean model, which we modulate using observations from tide gauges and satellite altimetry. We use Satellite Altimetry more than 8 km away from the shore, and remove the variance between tide stations by smoothing. Thus the DOT layer provides the mean sea level surfaces, and its observations where they are available. Adding the DOT layer to the geoid layer gives us a Sea Surface Height (SSH), the ellipsoidal height of observed MVL.

Layer 3: Tidal Regime (SL Lawtsey Estuary Grid). The third layer joins MBL to the target water level, LLWLT in the case presented here. The amplitude of SSH to LLWLT (see figure) is approximately half the tidal range. Since gauges capture tidal regime only at isolated and unoccluded distributed coastal points, we rely on hydrodynamic ocean models to infer this layer between stations and offshore where models are not optimized for predicting tidal extremes, as seen in the figure, so we modify them using trends in tide station observations. This procedure exploits the connectivity of the highly detailed grid, in effect modeling changes in tidal regime with much greater detail than traditional hydrodynamic models can achieve.

The final product is a sum of the layers, connecting the CDGEO ellipsoid with LLWLT, and LLWLT with LLWLT (see figure). Because CD targets that nearly matches LLWLT, HyVSEPs includes a final Layer 4 (not shown) which is used to vary HyVSEPs, so that it honours currently adopted CD close to shore and in the vicinity of tide stations.

A histogram of the difference between HyVSEPs and LLWLT at tide stations is shown below for the Atlantic region.

5. Coastlines 4 Canada

HyVSEPs interacted with coastal DEMs can be used to define a suite of shorelines representing high, low and mean tide coastlines. We have tested the intersection processes using a new Canadian Land Line (LL) which is the most accurate and detailed coastal DEM we have at this time (see figure). Since Canada contains 25% of the world’s coastline, and much of it is remote and uninhabited, we will only be able to do this on a small portion of the coast. However, HyVSEPs also link bathymetry (typically referred to CD) and topography through a common reference frame, it will be possible to create digital elevation models of coastal areas including the intertidal zone.

6. Conclusions

HyVSEPs are a new 3D paradigm in vertical referencing for the CHS. HyVSEPs will permit the use of CHS technologies in data collection and reduction, will improve the quality of bathymetric data on nautical charts, and will help connect bathymetry to the terrain. While other hydrographic organizations have created similar products, our methods are unique in order to accommodate the size and complexity of the Canadian coast. HyVSEPs themselves will improve over the next few years as new data is collected and models are further optimized. HyVSEPs will also be used as a tool to address climate change impacts and adaptation in coastal regions, in particular the HyVSEPs-based coastlines delineating high and low waters.

7. References


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