The Canadian Geodetic Vertical Datum of 2013
A modernized Reference for Heights

Height System Unification with GOCE
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WHAT is Canada’s Height Modernisation?

- It is the release of a new vertical datum for Canada in November 2013
  - The Canadian Geodetic Vertical Datum of 2013 (CGVD2013)

- It replaces the levelling-construct Canadian Geodetic Vertical Datum of 1928 (CGVD28)
  - Adopted in 1935 by an Order in Council

- Three important changes:
  - **New definition**: from mean sea level at specific tide gauges to an equipotential surface
  - **New realisation**: from adjusting levelling data to integrating gravity data
  - **New access**: from benchmarks to a geoid model

- CGVD2013 is compatible with Global Navigation Satellite Systems (GNSS) such as GPS

Orthometric height determination by two techniques: levelling and combination of GPS measurements and a geoid model.
WHY Height Modernisation in Canada?

- COST, ACCESS & TECHNOLOGY

Levelling is a precise technique that served Canada well over the last 100 years to realise and maintain a vertical datum, but for a country as wide as Canada ...

- It is prone to the accumulation of systematic errors over long distances;
- It does not provide a national coverage (BMs only along major roads and railways);
- It is a costly and time-consuming technique.
Modern technology in positioning

- GNSS positioning is now mature and has gained widespread adoption by users.
- It is a cost efficient technique in determining precise heights everywhere in Canada.
- Satellite gravity missions (GRACE & GOCE) offer unprecedented precision in the determination of the long and middle wavelength components of the geoid.
- A geoid model realizes an accurate and homogeneous vertical reference surface all across Canada (land, lakes, rivers and oceans).
Canadian Geodetic Vertical Datum of 1928 (CGVD28)?

<table>
<thead>
<tr>
<th>Name:</th>
<th>Canadian Geodetic Vertical Datum of 1928</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abbreviation:</td>
<td>CGVD28</td>
</tr>
<tr>
<td>Type of datum:</td>
<td>Tidal (Mean sea level)</td>
</tr>
<tr>
<td>Vertical datum:</td>
<td>Mean sea level at tide gauges in Yarmouth, Halifax, Pointe-au-Père, Vancouver and Prince-Rupert, and a height in Rouses Point, NY.</td>
</tr>
<tr>
<td>Realisation:</td>
<td>Levelling (benchmarks). Multiple local adjustments over the years since the general least-squares adjustment in 1928.</td>
</tr>
<tr>
<td>Type of height:</td>
<td>Normal-orthometric</td>
</tr>
</tbody>
</table>

\[ \Delta H = BS - FS \]
CGVD28: Levelling networks

Original constraints for Canada’s mainland

Examples of later constraints

~ 90,000 benchmarks
Levelling surveys over the years in Canada

Kilometres of levelling lines surveyed per year

- 1906-1928
- 1929-1939
- 1940-1965
- 1966-1971
- 1972-1981
- 1982-2012

Time (Year)

Distance (km)
## Canadian Geodetic Vertical Datum of 2013 (CGVD2013)

<table>
<thead>
<tr>
<th><strong>Name:</strong></th>
<th>Canadian Geodetic Vertical Datum of 2013</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abbreviation:</strong></td>
<td>CGVD2013</td>
</tr>
<tr>
<td><strong>Type of datum:</strong></td>
<td>Gravimetric (geoid)</td>
</tr>
<tr>
<td><strong>Vertical datum:</strong></td>
<td>$W_0 = 62,636,856.0 \text{ m}^2\text{s}^{-2}$</td>
</tr>
<tr>
<td><strong>Realisation:</strong></td>
<td>Geoid model CGG2013 (ITRF2008 and NAD83(CSRS))</td>
</tr>
<tr>
<td><strong>Type of height:</strong></td>
<td>Orthometric</td>
</tr>
</tbody>
</table>

$$H = h_{\text{GNSS}} - N_{\text{geoid}}$$

Diagram showing the relationship between orthometric height $H$, geoid height $N_{\text{geoid}}$, GPS height $h_{\text{GNSS}}$, and topography.
WHAT is the definition of CGVD2013?

- CGVD2013: Conventional equipotential surface ($W_0 = 62,636,856.0 \text{ m}^2/\text{s}^2$) averaging the coastal mean sea level for North America measured at Canadian and American tide gauges.

- It also corresponds to the current convention adopted by the International Earth Rotation and Reference Systems Service (IERS) and International Astronomical Union (IAU).

- U.S. NGS and NRCan’s GSD signed an agreement (16 April 2012) to realize and maintain a common vertical datum for USA and Canada defined by $W_0 = 62,636,856.0 \text{ m}^2/\text{s}^2$.

- Canada’s recommended definition for a World Height System.
Canadian Gravimetric Geoid of 2013 (CGG2013)

Boundaries
North: 90°
South: 10°
West: -170°
East: -10°

Resolution
2’ x 2’

Satellite model
EIGEN-6C3stat (GFZ)
Fürste et al., IAG 2013
GOCE (until May 24, 2013)

Transition zone
Degrees: 120-180

Reference frames
ITRF2008 and NAD83(CSRS)
Canadian Gravimetric Geoid of 2013 (CGG2013)

Specifications
- Equipotential Surface: 62,636,856.0 m²s⁻²
- Stokes Kernel: Modified Degree-Banded
- Transition zone (degree): 120-180

Analysis
- Tested different satellite-only and combined global gravity models: R3, R4, R4/EIGEN, R4/EGM08, …
  - Overall, models are fairly similar for the same degree expansion
- Tested different cut-offs of the satellite gravity models
  - Too high cut-offs certainly worsen geoid models
- Combination of shipboard gravity data and satellite altimetry-derived gravity data

Challenges
- Determination of optimum cut-off of satellite contribution
- Bandwidth of transition zone (60 degrees)
- Limitation in validating geoid models with independent datasets (distribution and precision)
GOCE contribution from L150 to L180
GOCE contribution from L180 to L200
GPS-Levelling validation of satellite gravity models

- **Canada (CA 2449)**
- **Yukon (YK 173)**
- **Northern British Columbia (NBC 78)**
- **The Great Lakes (GL 681)**
- **Maritimes (MT 193)**
- **Newfoundland (NFLD 113)**

Graphs showing the StdDev of h-H-N (cm) for various locations and models.
The accuracy considers data errors (gravity and DEM), grid resolution, discrepancies between gravity solutions and cut-off of satellite contribution.

- 3 cm or better **accuracy** over 80% of Canada’s landmass

- Decimeter level in areas with greater topography/mass distribution variability

- Centimeter level **relative precision** over distances of 100 km or less

67% confidence (1 σ)
Future activities

➢ The release of CGVD2013(CGG2013) does not mean an end in geoid development
  ✔ Resume analysis of new satellite-only and combined global gravity models
  ✔ Integration of GRAV-D data to the high-resolution geoid model
NRCan has released a new vertical datum in November 2013
- Canadian Geodetic Vertical Datum of 2013 (CGVD2013)
- Realised by geoid model CGG2013, which includes GOCE data via EIGEN-6C3stat (provided by GFZ)
- Compatible with GNSS positioning technique
- Access to the vertical datum all across Canada

Challenges to come
- Promoting the new datum in Canada
- Improving on the realization of the geoid model
  - Integration of the GRAV-D data into the next model
  - Resume analysis of satellite gravity models

Now that US and Canada chose a $W_0$; Canada and U.S. are supporting the adoption of $W_0 = 62,636,856.0 \, \text{m}^2/\text{s}^2$ by the International Association of Geodesy (IAG) as the convention for a World Height System or as the reference surface to estimate offset between existing height systems.
QUESTIONS?

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- General information:
  - Web: http://wwwapp.geod.nrcan.gc.ca
  - Email: information@geod.nrcan.gc.ca
  - Phone: 1-613-995-4410
  - Fax: 1-613-995-3215
WHAT is the difference between the Canadian levelling datum and mean sea level?

- **CGVD28:**
  - Assume that oceans are at a same equipotential surface
  - Use entirely gravity values from a mathematical model
  - Omit systematic corrections on old levelling data
  - Neglect post-glacial rebound

- **NAVD 88 (not adopted in Canada):**
  - Significant east-west systematic error (~1 m) of unknown sources in Canada (in the US too)
WHAT is the difference between CGVD2013 and CGVD28?

**Preliminary values**

<table>
<thead>
<tr>
<th>Location</th>
<th>Difference (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>St John’s</td>
<td>-37 cm</td>
</tr>
<tr>
<td>Halifax</td>
<td>-64 cm</td>
</tr>
<tr>
<td>Charlottetown</td>
<td>-32 cm</td>
</tr>
<tr>
<td>Fredericton</td>
<td>-54 cm</td>
</tr>
<tr>
<td>Montréal</td>
<td>-36 cm</td>
</tr>
<tr>
<td>Toronto</td>
<td>-42 cm</td>
</tr>
<tr>
<td>Winnipeg</td>
<td>-37 cm</td>
</tr>
<tr>
<td>Regina</td>
<td>-38 cm</td>
</tr>
<tr>
<td>Edmonton</td>
<td>-04 cm</td>
</tr>
<tr>
<td>Banff</td>
<td>+55 cm</td>
</tr>
<tr>
<td>Vancouver</td>
<td>+15 cm</td>
</tr>
<tr>
<td>Whitehorse</td>
<td>+34 cm</td>
</tr>
<tr>
<td>Yellowknife</td>
<td>-26 cm</td>
</tr>
<tr>
<td>Tuktoyaktuk</td>
<td>-32 cm</td>
</tr>
</tbody>
</table>
WHAT is the difference between CGVD2013 and the mean sea level?

<table>
<thead>
<tr>
<th>Location</th>
<th>Gauge number</th>
<th>Coordinates</th>
<th>Observation period</th>
<th>SST\textsubscript{CGVD2013} (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lat.</td>
<td>Lon.</td>
<td>From</td>
</tr>
<tr>
<td>Halifax</td>
<td>490</td>
<td>44.67</td>
<td>-63.58</td>
<td>12/1992</td>
</tr>
<tr>
<td>Rimouski</td>
<td>2985</td>
<td>48.48</td>
<td>-68.51</td>
<td>12/1992</td>
</tr>
<tr>
<td>Vancouver</td>
<td>7795</td>
<td>49.34</td>
<td>-123.25</td>
<td>12/1992</td>
</tr>
<tr>
<td>Churchill</td>
<td>5010</td>
<td>58.77</td>
<td>-94.18</td>
<td>01/1993</td>
</tr>
<tr>
<td>Tuktoyaktuk</td>
<td>6485</td>
<td>69.44</td>
<td>-132.99</td>
<td>08/2003</td>
</tr>
</tbody>
</table>

Table 1: Mean Sea Surface Topography (SST\textsubscript{CGVD2013}) at five tidal gauges in Canada. These are preliminary values based on CGG2010 ($W_0 = 62,636,856.0 \text{ m}^2\text{s}^{-2}$).
HOW CGVD2013 impact heights in Canada?

- All reference points will have a new elevation.
- Natural Resources Canada (NRCan) will stop levelling surveys for the maintenance of the vertical datum.
- NRCan will NOT maintain benchmarks by either levelling or GNSS technique.
  - However, the levelling networks will be readjusted to conform with CGVD2013 using existing data.
  - NRCan will publish CGVD28 and CGVD2013 heights at benchmarks.
  - NRCan cannot confirm the actual height of benchmarks in either CGVD28 or CGVD2013 (cannot confirm stability of benchmarks).
- The Canadian Active Control Stations (CACS) and Stations of the Canadian Base Network (CBN) will form the federal infrastructure for positioning.
  - 250 stations
- Modern alternative techniques will provide height determination.
  - NRCan’s Precise Point Positioning (PPP)
  - Differential GNSS positioning
  - Public and Private Real-Time Kinematic (RTK) positioning
- Levelling will remain the most efficient technique for most short distance work.
Speed of ocean currents