National Terrain Data Management on Discrete Global Grids in Canada

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Introduction

Terrain data can be acquired by various technologies with different data formats, spatial resolutions, datum, projections, and update cycles. In Canada, terrain datasets released by Natural Resources Canada (NRCan) mainly include the Canadian Digital Elevation Model (CDEM) and the High Resolution Digital Elevation Model (HRDEM). Because of their different coverage, datum, resolution, and accuracy, users who work with these two data collections may suffer from time-consuming pre-processing and inconsistent results due to different pre-processing methods. To achieve more effective utilization of multi-source terrain data, an integration solution is highly in need to merge and quality-control the terrain data on a standardized framework (Schumann and Bates, 2018).

Discrete Global Grid Systems (DGGS) is a new option for Earth reference standards. A DGGS is a system of hierarchical Discrete Global Grids (DGG) where the DGG at each resolution tessellates the entire Earth's surface by nearly equal-area cells without any overlaps and assigns a single identifier to each cell (OGC, 2017). DGGS can benefit the heterogeneous data integration, multi-scale analysis, consistent observation at a certain location, accurate analysis taking account of Earth's curvature, and efficient parallel computation given its discrete nature. For Canadian terrain data users, DGGS provide an opportunity to standardize the data acquisition process via data integration.

Previously, researchers have developed several DGGS implementations specifically for storing or rendering terrain data, such as the Quaternary Triangular Mesh, the Ellipsoidal Cube Map, and the Crusta (Bernardin et al., 2010; Dutton, 1984; Lambers and Kolb, 2012). However, terrain data management in DGGS is still in its infancy and has not been applied to support real-world decision-making. This study aims to 1) standardize Canadian terrain data at multiple resolutions in DGGS, 2) generate common geographical products and focal statistics products, and 3) apply the DGGS-based terrain data to flood mapping. This paper shows the modelling process, tests it on a 100 by 100 km area, and presents some preliminary results. The outcomes of this research will demonstrate the applicability of DGGS and the potential to support real-world decision-making.

Study Area and Data Sources

This paper demonstrates the terrain data modelling process on DGGS and tests the process over a 100 by 100 km area around Edmonton, Canada (Figure 1). The study area was urban or semi-urban area, where the elevation ranged from 581 to 908 m. The area contained both CDEM and HRDEM data, where the CDEM was available for the full area, while the HRDEM was only available for 20 by 20 km extent based on the source project. The ground control point dataset was obtained from the Alberta Survey Control network (Government of Alberta, 2020), 82 control points of which fell in the study area, and were used for quality evaluation (Figure 1). The conversion grids between vertical datums were offered by NRCan in the BYN format (NRCan, 2020). Two primary terrain data sources are introduced below.

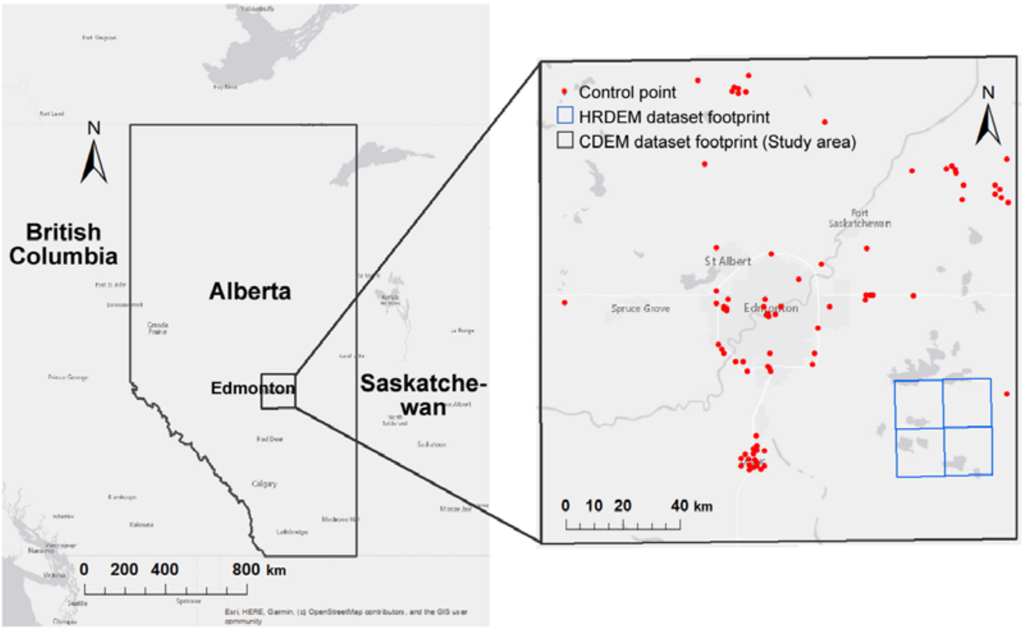

Figure 1: Study area and the distribution of control points, the HRDEM dataset, and the CDEM dataset.

Canadian Digital Elevation Model (CDEM)

As a legacy product, the CDEM collection is a part of the NRCan's altimetry system. The CDEM data are stored with the NAD83 CSRS datum and available at resolutions ranging from 0.75 to 12 arcsec along the latitudes. The CDEM data record elevation in integer meters with the Canadian Geodetic Vertical Datum of 1928 (CGVD28). The reported elevation bias ranges from 0 to 70 m across the country. The CDEM data within the study area were obtained as a CSV point dataset recording points' geographic locations at 0.75 arcsec resolution (Figure 1).

High Resolution Digital Elevation Model (HRDEM)

As a part of the CanElevation Series, the HRDEM largely improves the accuracy and spatial resolution of Canadian terrain data. The HRDEM consists of high-resolution DEMs derived from LiDAR and remote sensing imagery produced by separate projects. The HRDEM is only available over the project footprints. Within the study area, the HRDEM data were obtained at 1 m resolution with NAD83 CSRS UTM zone 12N projection in four 10 by 10 km tiles (Figure 1). The HRDEM stores elevation in decimal meters with the Canadian Geodetic Vertical Datum of 2013 (CGVD2013). The absolute vertical accuracy is 1-2 m depending on the source projects.

Methodology

The workflow of the geo-processing is presented in Figure 2, which includes pre-processing, DGGS modelling, and quality control. The analyses were carried out using open source libraries on the Advanced Research Computing cluster at the University of Calgary, Canada.

Pre-processing

The purpose of pre-processing is to standardize the horizontal and vertical datum of the CDEM and HRDEM. The elevations of the CDEM points were converted to the CGVD2013 by extracting delta elevations from the BYN conversion grids and calculating the values on CGVD2013 (NRCan, 2020). The HRDEM tiles were inversely projected to rasters in the NAD83 CSRS geographic space. Pre-processing also included converting the horizontal and vertical datum of the control points to the NAD83 CSRS and CGVD2013 datums.

DGGS modelling

DGGS configuration used in this study was the Icosahedral Snyder Equal Area Aperture 3 Hexagonal Grid (ISEA3H). At this point, the data were modelled at the resolution level 28 as the finest resolution, where the cell centroid spacing was about 1.5 m. Canadian boundary was centred on a single icosahedral face, with the grid orientation parameters: latitude of the pole (λ) = 37.6895°, longitude of the pole (φ) = -51.6218°, and azimuth (α) = -72.6482° (Zhou et al., 2020). DGGS cell centroids were generated by the library dggridR and used to extract elevation values from the CDEM or HRDEM sources (Barnes, 2016). As illustrated by the decision tree in Figure 2, the extraction process was done with a bilinear interpolation depending on the cell centroid’s location. The HRDEM was always used as the base data source for extraction wherever the HRDEM was available due to its better quality. Including the HRDEM and the neighboring CDEM when modelling was processed around the boundaries led to a smoother transition between the HRDEM and CDEM.

Quality control

Locations of the ground control points were converted to the corresponding ISEA3H DGGS cell centroids at the resolution level 28. Currently, 82 control points are available, and more control points will be available in the future from other sources especially within the HRDEM dataset extent. The Root Mean Square Error (RMSE) was calculated between the modelled values and the ground survey values to indicate the quality of modelling results.

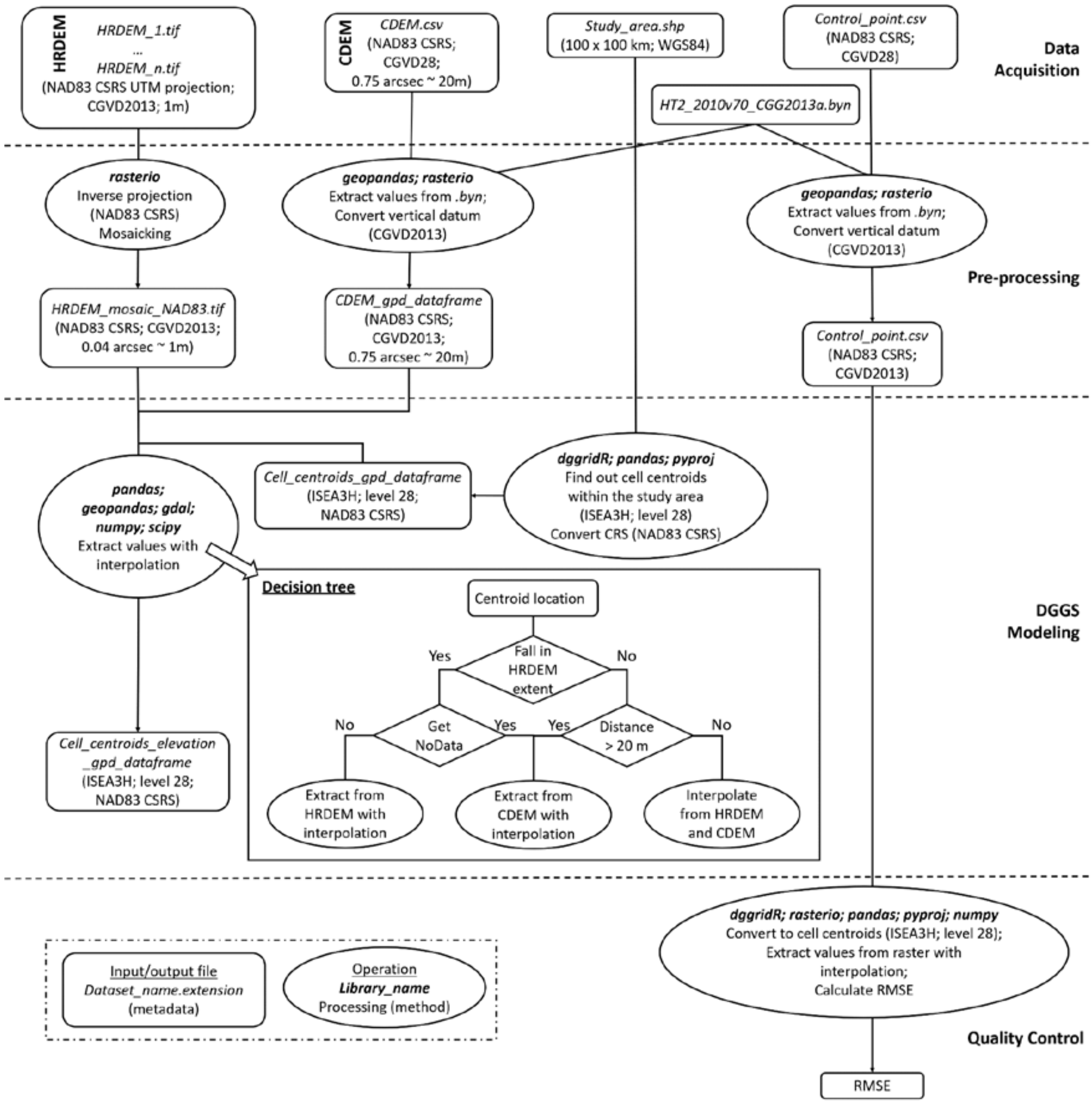

Figure 2: Workflow of the geo-processing in this paper.

Results and Discussion

The integrated terrain data within the study area were modelled on the ISEA3H DGGS at the resolution level 28. Modelled elevation values were compared to their observations for 82 control points, with the RMSE = 9.04 m. The RMSE comparing the raw CDEM and the ground survey values was 9.10 m.

This section only presents the preliminary results, and the rest of the work is in progress. Attempts can also be made on modelling on other DGGS configurations. After modelling the terrain data on a certain DGGS configuration, decisions need to be made on how to aggregate values at the finest resolution to generate values on the hierarchically coarser resolutions. One option is to sample the cell centroids with coarser intervals and extract values with interpolation. Another option is to statistically summarize the values of the child cells at the finer resolution and assign the average value to their parent cell.

Desired output products include multi-resolution elevation data, topographic products (i.e., slope, aspect, hill-shade, etc.), focal statistics products (i.e., max, min, range, etc.), and the spatially referenced metadata. Different focal statistics products are useful for different applications. For example, over the waterbody area, the minimum elevation helps determine stream channel areas while the maximum elevation is useful for ship navigation. The topographic products and focal statistics products are expected to be generated in the context of DGGS by using in-database analytics (Hojati and Robertson, 2020). Hence, new algorithms compliant with the DGGS cell geometry such as hexagon and triangle are needed to produce such elevation-based products. Spatially referenced metadata includes the original data sources, data accuracy, resolution, etc. The reported data accuracy can be indices according to the calculated RMSE. Lastly, terrain data modelled on DGGS are expected to be applied to flood mapping to explore the potentials of DGGS in supporting decision-making.

Conclusions

This paper used a 100 by 100 km study area as an example to show the process of integrating CDEM and HRDEM and modelling on DGGS at the native resolution. Quality control was done by calculating RMSE between the modelled elevation values and the ground survey elevations. Other explorations and the rest of the work are in progress.

Acknowledgements

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