



Multi-scale Digital Elevation Models for Canada

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Introduction

Topography plays a fundamental role in modulating land surface and atmospheric processes and therefore has a primary influence on the spatial distribution of water, light, heat and nutrients (Hutchinson 2007). It is an important determinant of plant and animal distribution, abundance and productivity (Mackey and Lindenmayer 2001). Over the last several years the Canadian Forest Service has been developing Digital Elevation Models (DEMs) of the Canadian landscape in partnership with the Canadian Centre for Topographic Information and the Australian National University. This note briefly describes Digital Elevation Models, their uses, some products now available and some issues for future consideration in the development of national Digital Elevation Models. We also provide some brief examples of their use for national applications.

Digital Elevation Models

Digital Elevation Models (DEM) are 3-dimensional representations of the topography of landscapes and can be used to generate information relevant to hydrological, geomorphological, biological and other environmental applications (Jenson and Domingue 1988; Moore et al. 1991; Wilson and Gallant 2000; Hutchinson and Gallant 1999, 2000; Hutchinson 2007). DEMs have now gained widespread use in computer-based tools such as Geographic Information Systems (high resolution DEMs are even useful for cut and fill calculations in golf course designs!).

Moore et al. (1991) identify and discuss a number of topographic attributes and their significance. They include elevation, slope, aspect, catchment areas and slopes, flow path lengths, upslope contributing area and others. Mackey et al. (2000) also discuss the role(s) of topography in a forest context. Wilson and Gallant (2000) provide an excellent synopsis of DEMs and digital terrain analyses for a wide

variety of applications). One role of topography often overlooked is its influence on climate. For example, elevation has been shown to strongly influence both temperature and precipitation patterns at a number of temporal scales (e.g., daily, weekly and monthly means) (Hutchinson 1991, 1995). Slope, aspect and topographic shading can also affect temperature, precipitation and radiation regimes particularly in rugged and/or mountainous terrain (e.g. Hutchinson 1998; McKenney et al. 1999).

Many organizations construct DEMs for their own purposes, usually for very local, specific applications. The Canada Centre for Topographic Information maintains and supplies national topographic data to users and resellers. The Canadian Forest Service has a mandate to investigate science and forest management questions related to the distribution, abundance and productivity of plants and animals. As noted these science issues are in fact often strongly tied to topography. Both organizations are part of Natural Resources Canada, a federal government Department strongly committed to the pursuit of sustainable resource development including development and use of primary data such as the digitized National Topographic Map series. Thus our partnership to improve and add value to primary topographic data via the construction of hydrologically reliable DEMs has served a number of purposes.

Using ANUDEM to build Canadian DEMs

While there are a number of techniques available to generate DEMs (see Moore et al. 1991; Hutchinson 2007), ANUDEM has become one of the more well known, reliable and computationally efficient tools for generating hydrologically sound DEMs from various data sources including contour lines, spot heights and stream lines. ANUDEM, which stands for “Australian National University Digital Elevation Model” is a Fortran program developed by Professor Michael Hutchinson of the Centre for Resource and Environmental Studies at the Australian National University. An early version of



ANUDEM has been implemented as the TOPOGRID command in the ARC/INFO Geographic Information System (Environmental Systems Research Institute, Redlands, CA). The mathematics behind the algorithms in ANUDEM can be found in Hutchinson (1988, 1989, 2000) and in the references provided at <http://cres.anu.edu.au/outputs/anudem.php>. The method is based on an efficient and accurate underlying interpolation procedure (Bishop and McBratney 2002) that simultaneously ensures a connected and downward flowing drainage structure by automatically removing spurious sinks (depressions) (Hutchinson 1989).

Significant enhancements have been made in ANUDEM in recent years to cope with the large number of cliffs, lakes, rivers, streams and islands in Canadian landscapes. The representation of lakes, and islands within lakes, has been revised to treat each lake boundary as a contour with unknown elevation and then iteratively estimate the elevation of this contour from the grid points on the lake boundary. The elevations of each lake, and island, boundary are thus made consistent with the neighbouring DEM values and any heights on connecting stream lines (Hutchinson 2006). During Canadian DEM production several procedures were developed to rapidly process mapsheets. This was necessary because Canada is so large and has an extremely varied landscape. Examples of these procedures include automation of the first iteration of correcting stream directions and, batching tools to select data from adjacent sheets to reduce potential input error and repetitive long commands. In fact, almost every repetitive task that did not require human review was automated/simplified so that operators could spend the bulk of their time on inspections that required intervention.

The basic steps to generating DEMs using ANUDEM are summarized in **Figure 1**. Errors such as spurious heights and sinks may arise from incorrectly labeled stream and contour lines. Various

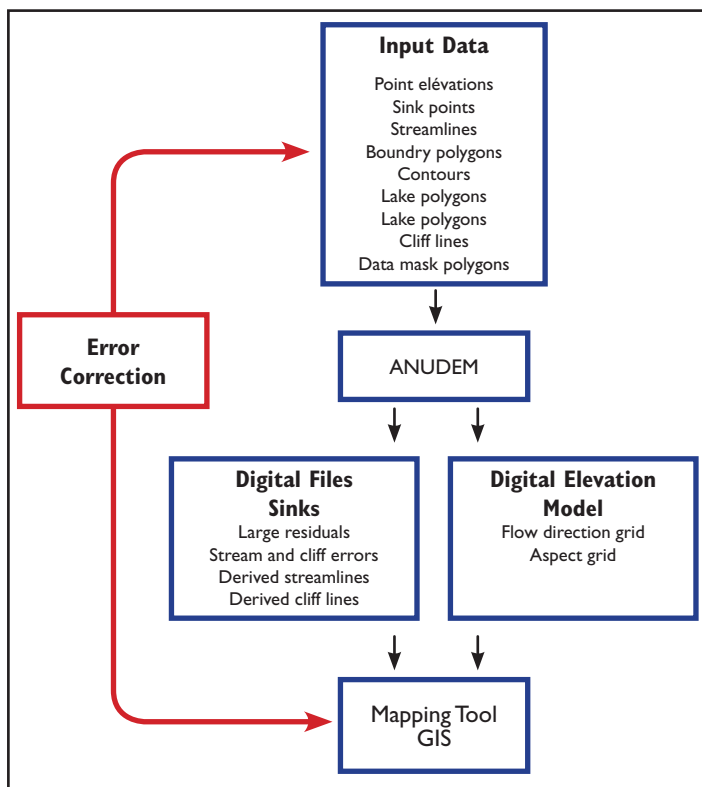


Figure 1: Flow chart of typical DEM creation procedures using ANUDEM (see <http://cres.anu.edu.au/outputs/anudem.php>)

inspection procedures have been developed to rapidly identify these types of problems. These Quality Assurance/Quality Control procedures have included contouring the model at half the input data interval and viewing both together with color coding. This allows for rapid visual review of models to ensure that they were within reasonable limits of source data. Other procedures include examining the statistical output of the model against the source data to automatically set flags for areas of concern; pan and scan visual tools were used to inspect greyscale images of the model against the source data to identify incorrect source data tagging.

Digital Elevation Models for Canada

Many of the models are available on interactive web sites. New models are added regularly so visit the climate home page for updates. The internet is used to visualize results, distribute data and create online mapping applications.

DEMs for Canada have been created using ANUDEM from two general sources of topographic data. The first set of DEMs has a coarser resolution of 3 arc seconds (roughly 100-150 meters horizontally) and is based on the National Topographic Series (NTS) 1:250,000 mapsheets. The second resolution has been developed from the NTS 1:50,000 datasets and a variety of other provincial topographic data sources. For example, in British Columbia the provincial DEM, based on a Triangulated Irregular Network approach (see Moore et al. 1991), was resampled to the $\frac{3}{4}$ arc second (~25 meters horizontal resolution) resolution. In Nova Scotia a dense network of spot heights and stream lines was processed through ANUDEM to generate the required regular grid and in Ontario 1:10,000 and 1:20,000 provincial topographic data have been processed through ANUDEM. The resulting DEM in this case is a $\frac{3}{4}$ arc second grid (~25 meters horizontal resolution). It is worth noting that there are some places for which there were no fine-scale topographic data available to generate the $\frac{3}{4}$ arc second product. Other approaches, such as remote sensing, may be required to generate fine-scale DEMs in these regions. Fine-scale DEMs may also be available from some provincial mapping agencies.

Our primary interest here was simply to document the generation and some uses of the 1:250,000 DEM. Further information about the 1:50,000 DEMs can be found at http://www.cits.rncan.gc.ca/cit/servlet/CIT/site_id=1&page_id=1-005-002-002.html.

The 1:250,000 DEM has also been used to generate several aggregate DEM models (e.g. 3, 30, 60, 150, 300, 600 and 900 arc seconds. Figures 2 and 3 show images of two DEM resolutions over northwestern Ontario – 30 arc seconds or roughly a 1km resolution, and 300 arc second (~10km). The higher resolution model shows the landscape texture of the region. These and other even coarser resolution models have been useful to support the generation of various spatial climate models that are being used for other types of environmental modeling problems. For example, the 300 arc second models have been used to update Canada's plant hardiness zones (McKenney et al. 2001; McKenney et al. 2006). In some cases finer resolution models have been generated to support water catchment studies where there is a desire to assess stream flows against precipitation. Many climate models have been generated and are being distributed and used for a wide variety of environmental modeling (including climate change impact and adaptation studies) see <http://cfs.rncan.gc.ca/subsite/glfcc-climate/climate>.

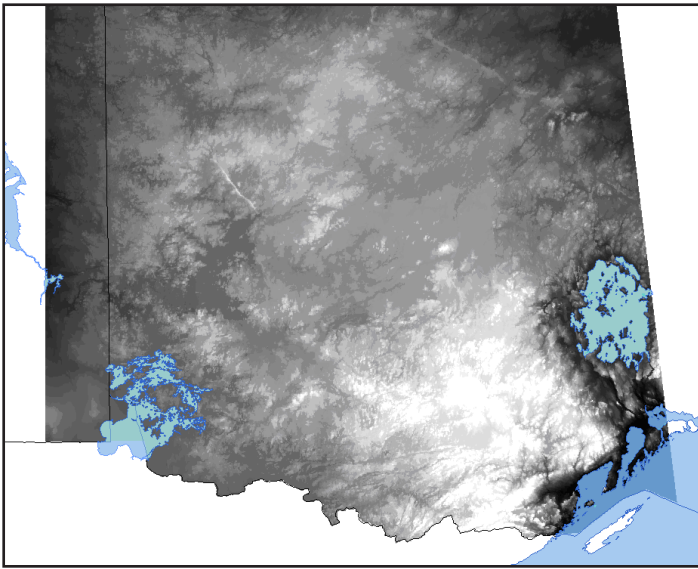


Figure 2: DEM at 30 arc second or roughly a 1km resolution.

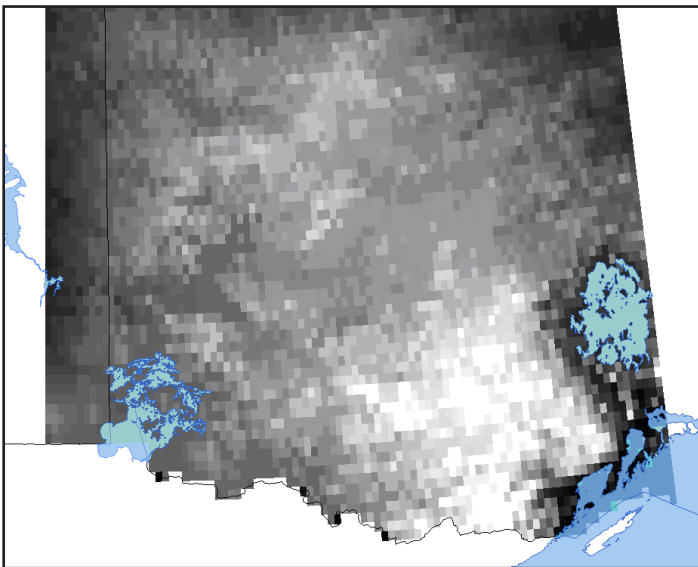


Figure 3: DEM at 300 arc second or roughly a 10km resolution.

Several of the coarser DEMs are available for download at http://cfs.nrcan.gc.ca/index/topographic_models. The original 3 arc second DEMs associated with each 1:25,000 mapsheet are available through the Centre for Topographic Information: http://www.cits.nrcan.gc.ca/cit/servlet/CIT/site_id=1&page_id=1-005-002-002.html

A three-dimensional function is being developed for viewing these DEMs on an internet mapper. This function will provide enhanced visualizations of the DEMs and should help to provide greater context for examining surface features of specific locations in the Canadian landscape.

Sample Application – checking elevations recorded at weather station locations

Having a national topographic model has proven useful for generating elevation estimates at particular longitude and latitude locations. Processes have been developed to interrogate the DEMs

to append elevation estimates to point location files such as research plots, field survey locations and even the coordinates of weather station locations. The latter provides a useful mechanism to check and flag potential anomalous elevation values; that is, those station locations where there may be georeferencing problems. **Figure 4** provides an example of this for Canadian weather stations using the 3 arc second DEM. The reason to verify locations is that for generating spatial climate models inclusive of elevation influences, more accurate location records may be warranted. More than 93% of the DEM elevation values were within 100 meters of the recorded values (over 99% were within 500 meters). However, there are some outliers that are being further investigated. This capacity has been particularly useful for a recent application of developing daily weather models for Canada dating from 1961 (Hutchinson et al., in review).

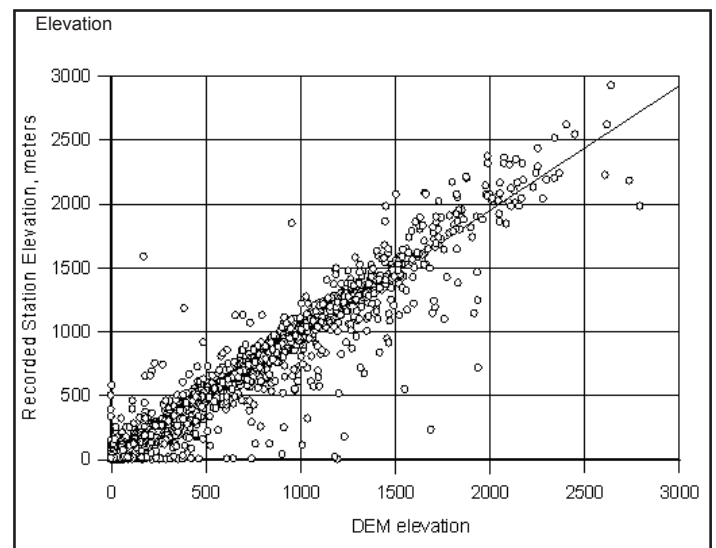


Figure 4: 3 arc second DEM elevation estimate compared to the recorded elevation at Canadian weather stations

Conclusions

In this computer-intensive and computer-based modeling age, DEMs have become a key data element for many environmental modeling problems. Over the last several years significant effort has been put into generating national Digital Elevation Model products for Canada. The DEMs come from different source data including 1:250,000 and 1:50,000 national topographic data and in some cases provincial data sources. While this effort represents a huge step forward in the availability of topographic data for Canada there remain some additional opportunities for improvements. These include updating the 1:250,000 product using the latest version of ANUDEM, which has significant improvements in capturing ridgelines and cliffs, and generating floating point DEMs for those clients whose applications require better representations of slopes.

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