A free fully assessed 15 metre digital elevation model for New Zealand

Joshua Columbus, Pascal Sirguey and Robert Tenzer

A digital elevation model (DEM) is a fundamental data layer in any geographical information system (GIS). It has many uses and is required for a number of applications such as hydrological, environmental and climate modelling, geoid/quasi-geoid computations, or the ortho-rectification of satellite imagery. Several countrywide DEMs already exist in New Zealand. They have been produced by private companies, Crown Research Institutes, overseas institutions and enthusiast users.

Despite the multiplicity of DEMs, these products generally involve fees, restrictions of use, and sometimes a lack of documentation and quality assurance limiting their use. In addition, their spatial resolution, processing method, and assessment protocol are sometimes unsatisfactory or obscure. Difficulty of access and poor documentation results in many users still processing DEM layers for custom extents as they see fit, therefore adding to the inconsistency of data available.

This founded the need for a free publicly available countrywide DEM that would be transparent in its creation and assessment, as well as convenient for various applications and users. To achieve this, the resulting DEM not only required a sound, well documented processing method and thorough accuracy assessment, but it also needed to be presented in a format consistent with existing datasets of national importance in order to facilitate its usage.

This task was undertaken at the National School of Surveying, University of Otago. This article reports on the preparation and assessment of NZDEM SoS v1.0, a 15-m spatial resolution DEM for New Zealand. The quality of this product is then compared with two other nationwide DEMs.

Context

Source of data

The principal source of topographic data in New Zealand is the LINZ NZTopo database. This supplies a seamless coverage of the 1:50,000 scale topographic mapping of the country in industry standard digital format – the Environmental Systems Research Institute shapefile. The topographical heights data available in the LINZ database were obtained by a stereo photogrammetric approach using aerial photographs.

All of the data is projected on the New Zealand Transverse Mercator 2000 projection and is accurate to within certain tolerances. The database specifications state 90 per cent of all the well-defined points are within ± 22 metres planimetrically and ±5metres vertically. The contour lines, which are of 20 metres equidistance, are within ±10 metres in elevation. The errors in the position of the data result from errors inherent in the map production processes. This includes the cartographic principles of generalisation and displacement, and also errors in the digitising processes used to convert analogue data to a digital format.

Additional considerations

A clear understanding of how the final product would be presented in terms of spatial resolution and extent was required before the DEM could be created.

Spatial resolution

It was considered desirable to create a DEM with a spatial resolution as fine as possible, while ensuring its relevancy and practicality. A spatial resolution of 15 metres was chosen. It is believed that the 20 metre contours in the NZTopo database make such an interpolation relevant while ensuring that the final product would keep a reasonable size. In addition, this provides a desirable improvement compared to DEMs currently available for the country such as Geographx: 20m, Landcare: 25m, SRTM: 90m.

Spatial extent

The final product needed to be a user friendly database which could be related to easily and be consistent with existing datasets of national importance. In addition, the size requirements of a high resolution DEM of New Zealand was considered to be a potential obstacle in terms of future distribution. This justified the strategy to provide NZDEM_SoS_v1.0 as a set of individual but seamless tiles.

The LINZ Topo250 topographic map series was chosen as a practical reference. The Topo250 series contains 30 maps of 180 km by 120 km which seamlessly cover the entire country barring two maps which overlap some regions as shown in Figure 1.

Each map is easily distinguishable and can be uniquely identified by a map number and name. The only map to be excluded from the series in this project was Chatham Islands Map 31 as it was located outside the study area. Using the Topo250 series as the method of presentation for the final product was believed to have advantages.

- First, by being a LINZ topographic map series, it is already well documented and easy to relate to. This is a big assistance in helping to create an easy to use database which suits many users.
- Second, the extent of one map creates a raster file size of approximately 350 mb, allowing the data to be handled and transferred efficiently.
- Finally, the map extents are divisible by 15 making the interpolated raster grids correspond exactly with each map without distortion.

Users also have the option of selecting only certain areas of the country if desired and therefore are able to save on load times and storage space.

Method

Topographic interpolator

The topographic data available in the LINZ database contains features such as contour lines and height points and these needed to be interpolated to create the DEM raster grid. There are various methods of interpolation, each having their own advantages and disadvantages. Inverse distance weighed, Kriging and Spline interpolation are some such methods. ANUDEM is a specific topographic interpolator that aims to generate a hydrologically correct DEM by removing spurious sinks in the surface.

ANUDEM accommodates data points by means of a 2-D thin plate smoothing spline. The regularity of the spline is controlled by a user-defined roughness penalty that permits sharp changes occurring between slopes and valley floors to be accommodated while minimizing interpolation artefacts. ANUDEM was selected to be the method of interpolation for NZDEM_SoS_v1.0, along with a roughness penalty of 0.5 and 40 iterations, as this was proven to produce a DEM with competitive accuracy and limited artefacts compared to various other methods.

Process

Due to the sheer size and extent of the project the DEM could not be made in one stage. Being limited by the computer hardware available, the DEM was created in 150 tiles with each tile overlapping adjacent tiles by 6,000 metres. This overlap allowed mosaics of the tiles to be formed later in the creation process without negatively affecting the bounding areas of each tile. To create each tile, the 'Topo to Raster by File' tool in the 3-D Analyst extension of the ArcGis v9.3 software suite was used. This tool is in effect the ANUDEM v4.6 topographic interpolator for which a script was written in VBScript to fully automate the process.

Mosaics were created for every Topo250 map using only the created tiles required, thus saving on heavy computation times. Next, artefacts of the spline interpolator in flat areas such as lakes and sea, required correction. A mask containing all lakes of known elevation and the ocean was created. A conditional test using this mask was run over each mosaic to replace the interpolated values with the known elevation. The output raster was clipped at the same time to the extent of the respective Topo250 map. Finally, the tiles were exported to a GeoTIFF file format and named appropriately. The final product of this process was a database of smaller DEMs representing the Topo250 map series which could be seamlessly positioned together to create a high resolution countrywide DEM.

Accuracy assessment

Check points

The complete LINZ geodetic database was acquired (retrieved in January 2011) for the purpose of obtaining check points (CP) to assess the accuracy of NZDEM_SoS_v1.0 by statistical methods. The database, which contains over 100,000 geodetic survey marks of various accuracies and reliability, had to be filtered to ensure only a high standard of CPs were used in the assessment. A geodetic mark was considered eligible, if it matched the following criteria –

- It is located within the study area.
- It has a positive elevation in NZVD2009.
- It is of coordinate order 9 or lower, that is ±5 metres both planimetrically and vertically.
- It is more than 15 metres from any height point used in the interpolation process in order to avoid bias in the assessment.

All marks with heights in terms of the ellipsoid or one of the 13 major levelling datums from around the country were able to be converted to New Zealand Vertical Datum 2009 (NZVD2009) using the LINZ online conversion tool. All other marks in the database with heights on minor or unknown datums were ignored. To limit any direct bias between the creation and assessment of the DEM, marks within 15 metres of a height point used by the interpolation were also removed. A group of 42,090 geodetic marks were eligible to be selected as check points.

To create a strong statistical accuracy assessment of NZDEM_SoS_v1.0, a robust and acceptable sampling strategy of CPs was required. It was essential the CPs were randomly chosen but also that they maintained a distribution of heights that matches that of the terrain. This would allow the final selected CPs to be representative

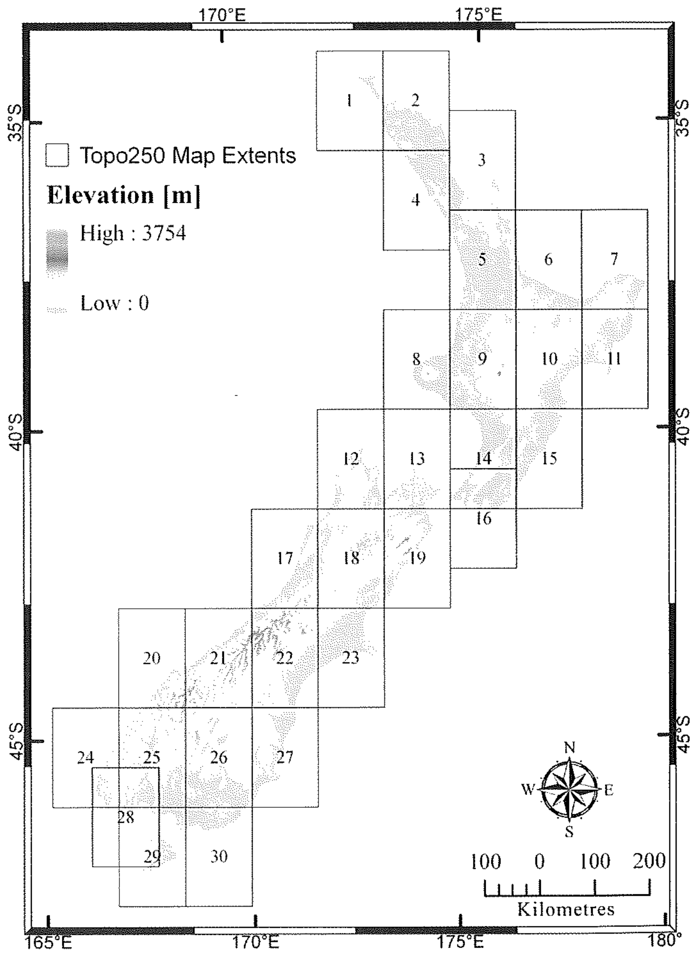

Figure 1. LINZ Topo250 topographic map series

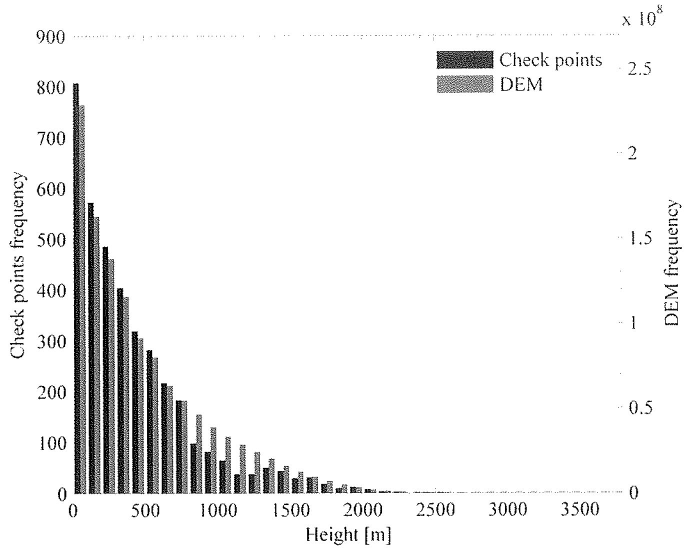

Figure 2. Frequency distribution of CPs heights relative to the DEM's heights.

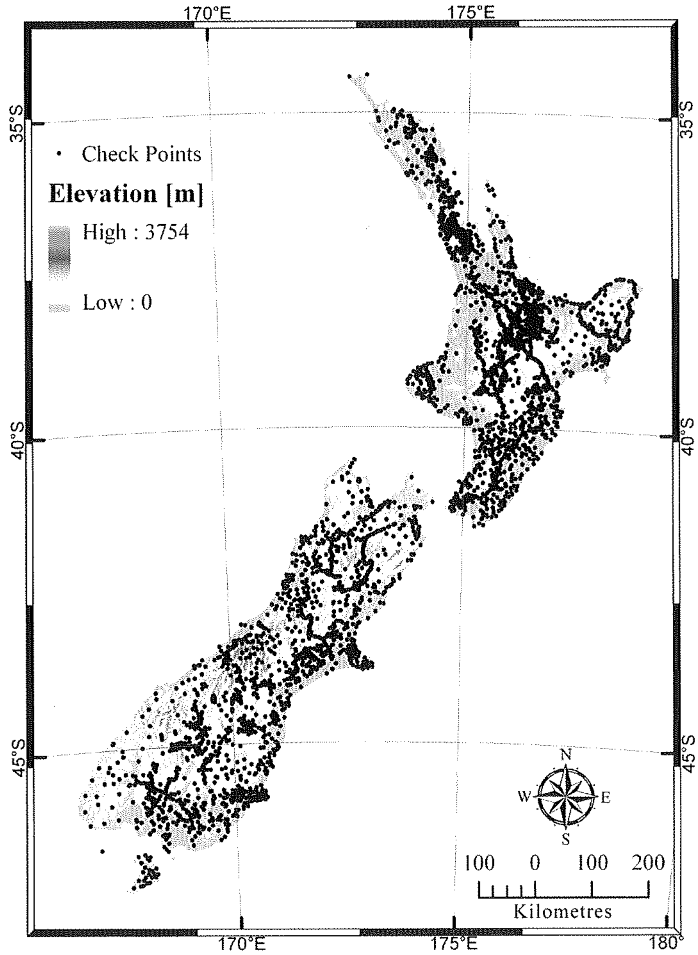

Figure 3. Spatial distribution of check points over the study area.

of the terrain being assessed. A minimum distance of 1500 metres between selected CPs was implemented to minimize the spatial correlation between survey marks too close to each other, while creating an even distribution over the country.

A MATLAB script was written to select the CPs. The script selected marks at random while constantly ensuring the minimum distance criteria was met. The script continued selecting points until either enough points were collected to represent the terrain, or until there were no more points left which passed the criteria.

The graph in Figure 2 shows the frequency distribution of the final CPs heights relative to the created DEM's heights. The spatial distribution of the final CPs is displayed on the map in Figure 3. After the script selection and some minor rational investigating, a final collection of 3,791 accurate and reliable CPs remained to be used in the accuracy assessment.

Standard statistical measures

The quality of a DEM is a relative concept that is assessed in accordance with its intended use. To describe the ability of a model to produce reliable observations Willmott et al (1985) recommended the use of several measures to allow reliable conclusions about the performance. Given a set of control points of known elevation, the modelling error $\varepsilon_i = P_i - O_i$ between the height P_i predicted by the DEM at the point i and the observed height O_i can be computed. The mean error (μ_ε), the mean absolute error (MAE), and the root mean square error (RMSE) often form the core of goodness-of-fit measures and model assessment. The performance of these standard statistical methods, that is, μ, σ, RMSE and MAE) for NZDEM_SoS_v1.0 are shown in the table on page 19.

Contour bias

In the context of assessing DEMs, Wise (2000) argued that standard statistical measures based on a limited sample of CPs such as the RMSE are too crude to assess fully the quality of DEMs, because they fail to indicate gross errors. In the search for additional metrics that would be suitable to measure the quality of DEMs, Carrara et al. (1997) pointed out that the interpolated heights should be uniformly distributed between the elevations of two bounding contours. In other words, when interpolating from 20 metres contour lines, 20 per cent of the point heights should lie within ±2 metres of a contour elevation.

Within this context, Carlisle (2002) showed that some interpolators create DEMs where point elevations tend to be close to those of contour lines used as the primary source for the interpolation. Such artefacts can result in a more or less severe flattening of the output surface as it crosses the contour. This is sometimes readily visible by the typical terracing effect in a hill shaded DEM. Carlisle (2002) proposed to quantify this effect by means of the contour bias criterion that represents the proportion of points that lie within 10 per cent of the height of a contour line. Any substantial increase in contour bias from the ideal 20 per cent could therefore be interpreted as a lesser quality interpolated surface. This contour bias was found to be 27 per cent for the NZDEM_SoS_v1.0 as shown in the table on page 19. This non ideal contour (i.e., >20 per cent) can be partially explained by the fact that relatively flat areas are more susceptible to contour bias.

Comparison

A comparison of NZDEM_SoS_v1.0 with two existing countrywide DEMs was undertaken to gain a better understanding of its relation to existing datasets. A 20-m DEM created by Geographx Ltd and a 25-m DEM created by Landcare Research were used for the comparison. The same metrics used in the initial accuracy assessment were calculated for the additional two DEMs. This involved using the exact same set of check points and methods of calculations to allow the various metrics to be compared directly using a common reference. The final results of the comparison show NZDEM_SoS_v1.0 is an improvement on both existing datasets. All of the metrics used displayed this improvement except for the contour bias which remained in a similar category to the Landcare Research DEM. The computation of confidence intervals for each metric is yet

Results of the accuracy assessment for each DEM

Statistics	NZDEM_SoS_v1.0 (15-m)	Geographx DEM (20-m)	Landcare Research DEM (25-m)
μ_ε [μ]	-2.1	-2.3	-2.5
σ_ε [μ]	6.8	7.1	7.6
MAE [m]	5.1	5.5	5.6
RMSE [m]	7.1	7.5	8.0
Max Absolute Error [m]	53.2	54.2	55.9
Contour Bias [%]	27.4%	40.5%	27.3%

to be completed in order to demonstrate the significance of the improvements achieved by NZDEM_SoS_v1.0.

Summary

NZDEM_SoS_v1.0, a digital elevation model covering the whole of New Zealand at a spatial resolution of 15 metres, was created to accommodate the need for a transparent, free and publicly available DEM. The DEM was created to correspond exactly with the LINZ Topo250 topographic map series. The 30 various maps allow smaller regions to be obtained individually but also fit together seamlessly to create a full countrywide DEM.

These maps create a user friendly database which is efficient in the handling and transferring of data. An accuracy assessment was undertaken using a statistically robust set of check points which minimized any bias from influencing the final results. Standard statistical methods and the contour bias criterion were able to be used to assess the quality of the DEM and obtain a direct comparison with two existing DEMs of New Zealand. The results from this comparison exhibit a visible improvement of NZDEM_SoS_v1.0 in terms of quality that comes in addition with a finer spatial resolution.

Joshua Columbus is currently an honours student at the School of Surveying, University of Otago and conducted this research within a summer bursary programme.

Pascal Sirguey received a MSc degree in structure dynamics from the Ecole Centrale de Lyon, France, in 2001. After a brief career in the industry, he completed a PhD in remote sensing at the School of Surveying, University of Otago, in 2010 where he has been a lecturer since 2008. He teaches remote sensing, photogrammetry, and spatial analysis.

Robert Tenzer completed his PhD studies in 1999 (STU Bratislava) and in 2008 (CVUT Prague). He joined the School of Surveying as a lecturer in 2009. His research area is physical and satellite geodesy, geophysics, and geodynamics.

A full list of references is available on request – Editor

Industry scholarship gives Tamehana Wickliffe a career boost

A survey cadet from Downer NZ in Hamilton is one step closer to achieving his career goals, after receiving a $10,000 National Diploma Scholarship for Maori. Tamehana Wickliffe was awarded the scholarship by InfraTrain New Zealand through its Te Poutama Kaiahumahi programme. The programme is run in partnership with Te Puni Kokiri and aims to strengthen the skills and qualifications of Maori working in the civil infrastructure industries.

Tamehana Wickliffe with InfraTrain Chief Executive Philip Aldridge and Dr Pita Sharples.

The scholarship will enable Tamehana, who is of Ngati Hako, Pae Ahi, Ngati Tara Tokanui and Ngati Tamatera descent, to study for a National Diploma in Surveying.

InfraTrain has awarded a total of 18 National Diploma Scholarships since it started working with Te Puni Kokiri in 2008. The latest winners, including Tamehana and several civil engineering cadets, were presented with their scholarships in Auckland recently by the Minister of Maori Affairs, Hon Dr Pita Sharples.

Speaking at the presentation, Dr Sharples said, 'It really is wonderful to be back again to present more Scholarships and recognise the ongoing success of Te Poutama Kaiahumahi. The winners represent the aspirations we want to stimulate within the wider Maori workforce. That is of a skilled, talented and highly qualified workforce realising its potential.'

Dr Sharples continued, 'What is great about the Te Poutama Kaiahumahi programme is that the benefits flow two ways. On one hand, Maori staff improve their skills and gain qualifications which improves their job and promotion prospects. On the other hand, employers will gain higher productivity and efficiencies.'

InfraTrain Chief Executive Philip Aldridge added, 'InfraTrain congratulates Tamehana and all of the scholarship winners. The applications were of an extremely high standard, and we were impressed by their motivation and commitment to their chosen careers. We expect great things from them in the future.'