Enhancing the SRTM Data for Australia

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1. Introduction

The SRTM dataset is a near-global DEM derived from interferometric radar data collected by NASA's Space Shuttle in February 2000. It is unique in providing reasonably good quality topographic data over most land masses but suffers from a number of artefacts including: voids in high relief areas and some other locations; striping artefacts; and offsets due to woody vegetation. It was produced at 1 second (about 30 m resolution) but degraded to 3 second resolution for public release except for the USA.

In Australia, the SRTM data provides better quality topographic information than other available sources over much of the continent. Its utility is hampered by the artefacts, particularly the offsets induced by vegetation. Many rivers in inland Australia are surrounded by remnant native vegetation while the surrounding land is cleared for agriculture; the rivers thus appear as raised features in the SRTM data preventing any useful hydrological analysis.

This paper describes methods developed to treat the artefacts in the SRTM data to produce a usable DLSM. Negotiations with Australia's Defence Imagery and Geospatial Organisation (DIGO) have resulted in access to the 1 second version of the SRTM data and permission to release processed versions of that data at 1 second resolution to government agencies within Australia. Reduced resolution 3 second versions will be publicly available.

The methods described could be applied to SRTM data in other areas that lack better quality DEM data, such as Africa, so long as vegetation mapping is also available to support the removal of vegetation offsets. The methods could also be adapted to treat similar offsets in other radar or photogrammetric products that do not directly map land surface heights in vegetated areas.

2. Removal of Striping Artefacts

The first step was to remove striping artefacts, which are clearly visible in some areas of low relief Australia. The stripes have a typical wavelength of about 800 m with an amplitude of about 0.2 – 4 m and are aligned diagonally in a pattern that suggests a close relationship to the orbital paths. A software tool was developed to display tiles of the raw SRTM data (¼ × ¼ degree) and a 2-D Fourier transform of the data and support identification and removal of frequency components corresponding to the stripes (Figure 1). The tool was used by a team of analysts to remove striping wherever stripes could be discerned across the continent.

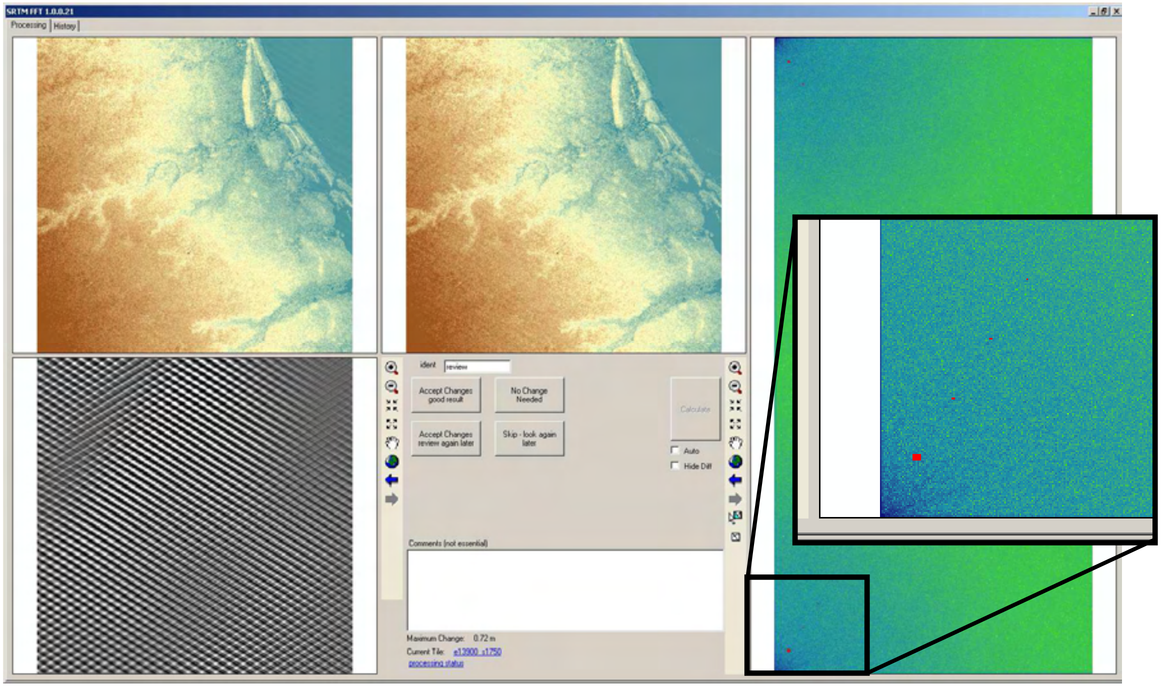

Figure 1. The SRTM striping removal tool. The DEM in top centre shows the stripes, the treated DEM is at top left. The removed stripes are at lower left and the right hand pane shows the magnitude of the Fourier transform with red boxes around frequency components to be removed (expanded in inset).

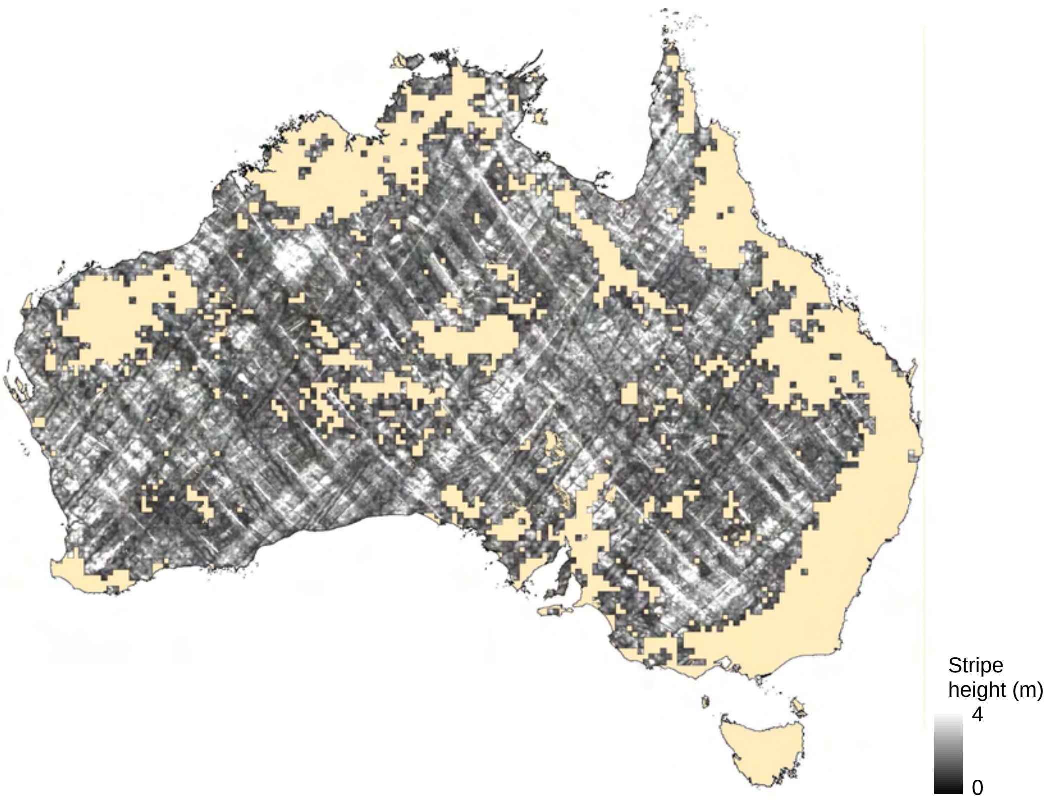

Figure 2. The magnitude of stripes removed across Australia. The tan areas were not treated because the striping was not visible in the higher relief terrain.

This processing took about 8 weeks for four analysts, and revealed that striping at varying levels occurred everywhere except where it was obscured by high topographic relief. Figure 2 shows the pattern and level of striping that was removed.

3. Filling Voids

Voids were filled using a modification of the delta surface fill method (Grohman *et al*., 2006). The Geodata 9 second DEM (Geoscience Australia, 2008) was used as the infill data. The delta surface fill method was modified to use natural neighbour interpolation (Sibson, 1981; implemented in ArcGIS 9.3) to create the delta surface, and the mean plane inside the larger voids was not used. The delta surface fill method was chosen because it offered better prospects of filling extensive voids in rugged terrain (such as those shown in Figure 3) than an interpolation-based algorithm.

The void filling process provides an effective fill in both flat and high relief terrain, although many voids in low relief terrain are surrounded by erratic heights that propagate into the void. Figure 3 shows an example of void filling.

The product of the destriping and void filling is a cleaned digital surface model (DSM) that still includes offsets due to vegetation and constructed features but is a valuable product for some applications such as calculating line of sight and illumination angles for correcting remotely sensed imagery.

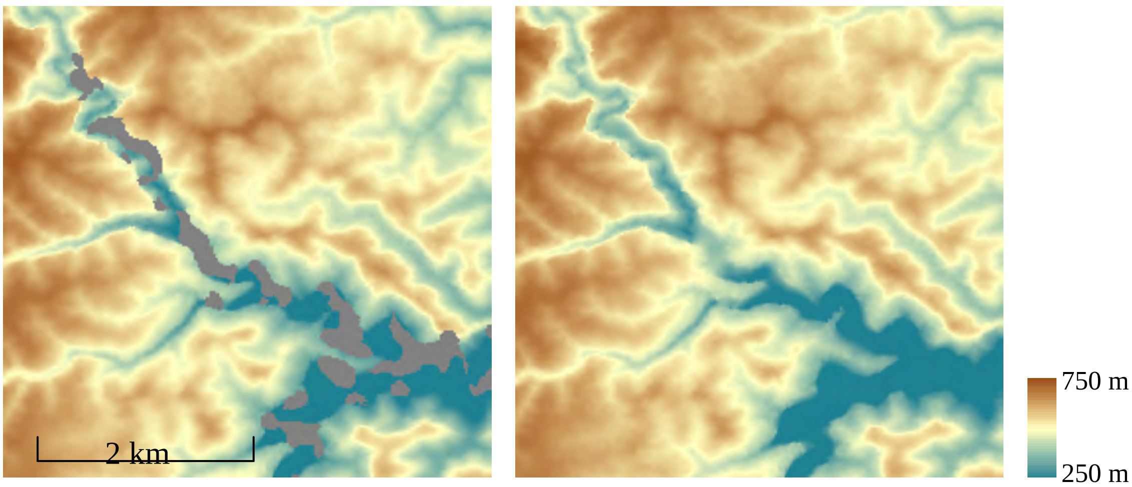

Figure 3. An example of void filling. The voids due to terrain shadowing are replaced with adjusted lower resolution data. Some areas at the base of the deep valleys are not accurately represented but the results are much better than would be achieved using interpolation across the voids.

4. Removing Vegetation Offsets

The removal of vegetation offsets is the most complex part of the cleaning process. The strategy taken here is to identify areas that are affected by vegetation offsets, estimate the height offsets around the edge of each patch and derive a vegetation offset surface that is then subtracted from the destriped SRTM data to produce a bare-earth elevation model.

Vegetation patches are identified using woody vegetation mapping based on satellite remote sensing, supplemented by detection of narrow linear features directly from the SRTM data. The edges of the patches are adjusted to match changes in height in the DEM. The vegetation height is estimated by fitting a surface to elevations in a circle of 5 cell radius; the surface is represented as:

$$z(x,y) = a_0 + a_1 x + a_2 y + a_3 xy + a_4 m \quad (1)$$

where $a_0 \ldots a_3$ are parameters of the land surface, a_4 is the vegetation height and m is the vegetation mask smoothed by a Gaussian filter to match the response of the SRTM data to sharp edges. The estimates of vegetation height are accepted where the fit of

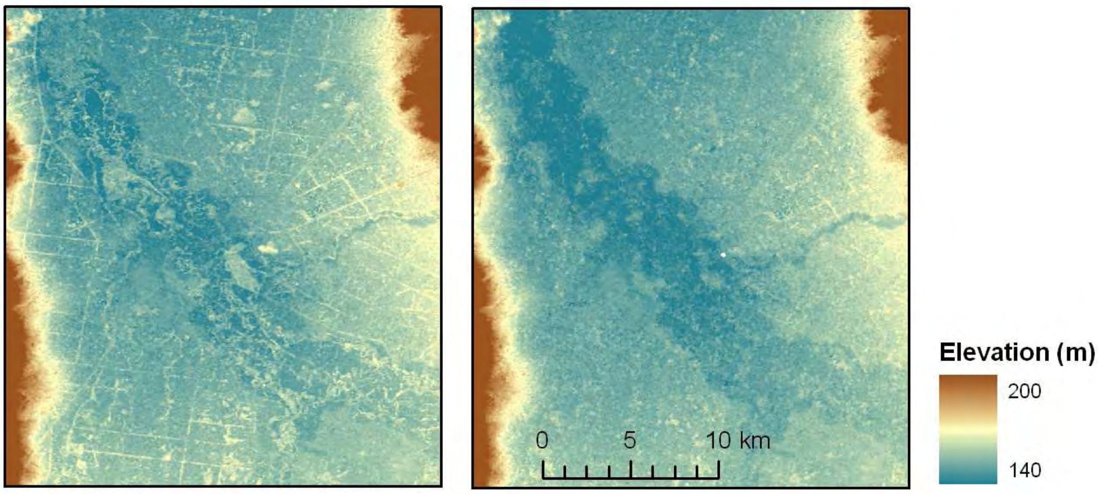

Figure 4. An example of vegetation removal. The elevated linear features are due to trees along roads, while the larger elevated features are patches of forest among cleared land. Most of the offsets are completely removed, revealing the inset floodplain of the river flowing through the centre of the image.

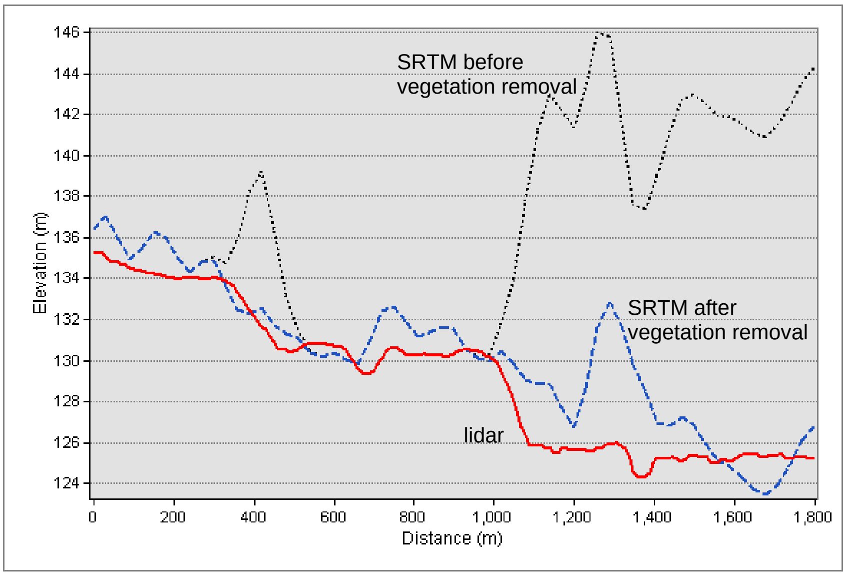

Figure 5. Profiles through SRTM data before and after vegetation removal, compared with lidar data. The profiles are on a transect from cleared farming land (left) through a narrow tree line (~400 m) into forested floodplain (right).

Equation 1 produces sufficiently low fitting error and they satisfy some sanity checking and the acceptable estimates are then interpolated to form a continuous vegetation height surface. The vegetation height surface multiplied by the smoothed vegetation mask *m* is subtracted from the destriped SRTM data.

The vegetation-removed product is a digital land surface model (DLSM) that is a good source for many geomorphic and ecological applications but lacks drainage connectivity in low relief areas. A comprehensive manual quality assurance process was used to assess the quality of vegetation removal and identify any issues with the product.

Figure 4 shows an example of the removal of vegetation offsets. Figure 5 compares the SRTM data before and after vegetation removal with elevations from a lidar DEM; most (but not all) of the vegetation offsets have been removed and the resulting DLSM is a reasonably good match to the lidar data considering the inherent uncertainty in the SRTM data.

5. Drainage Enforcement and Smoothing

The vegetation-removed bare-earth DLSM lacks drainage connectivity in lower relief areas, due to both the noise in the SRTM data and to the effects of vegetation along drainage lines. In much of inland rural Australia the land is cleared for agriculture except for riparian woodlands and forests along waterways that obscure the channel itself. Mapped streamlines derived from aerial or satellite imagery are required to support enforcement of drainage lines in the terrain surface. This has been achieved using ANUDEM (Hutchinson 1989, 2000, 2006), modified to improve its performance with dense noisy data such as SRTM (Hutchinson *et al*, 2009). The ANUDEM processing also produces a modest degree of smoothing that reduces the noise in the surface.

The finest scale of mapped drainage lines covering all of Australia is 1:250,000, which is a much coarser scale than the SRTM data which has an effective scale of approximately 1:50,000. Finer scale drainage line data is expected to be acquired for much of Australia over the next few years and will be incorporated into the SRTM products (and subsequent better quality terrain data) as they become available.

6. Discussion

The cleaning of the digital surface model has not resolved all issues with that data. Broad-scale striping with a wavelength of about 30 km (compared to about 800 m for the fine striping removed) has been detected in one area of southern New South Wales. There are abrupt changes in height of up to 5 m in some areas, random height variations due to noise are as large as ± 10 m in some areas, and one area of grossly incorrect height has been detected in a canyon west of Sydney. With some effort, and with supporting data, the areas of incorrect height can be detected and corrected, and noise can be reduced by adaptive smoothing.

The method to remove vegetation offsets performs well where the vegetation patches are well mapped and where the distance between estimated heights is not too large. Within larger vegetation patches the estimates of vegetation height are dependent on interpolation from distant edges and become less reliable. Some additional information on vegetation height would help to constrain the heights in these areas.

As of May 2009, the destriping and void filling is complete, vegetation removal is complete and drainage enforcement for the Murray-Darling basin is expected to be complete by June 2009.

The production of a continental DLSM at 1 second resolution from SRTM data represents a major advance in digital terrain data from Australia. The current best continental coverage is at 9 second resolution interpolated from 1:250,000 and 1:100,000 topographic data. The 1 second data is expected to support many new applications including study of landforms in the arid and low relief areas of Australia.

The methods developed for this project are applicable to other parts of the world that lack high resolution digital terrain data, provided the supporting data – mapping of woody vegetation in particular – are available. Use of the methods to remove vegetation offsets in other digital surface models, such as those derived from ASTER data, is also under investigation.

Acknowledgements

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The 1 second resolution SRTM data for Australia was provided by Australia’s Defence Imagery and Geospatial Organisation (DIGO). The products of this work can be obtained from Geoscience Australia at 1 second resolution for Australian Government users and at 3 second resolution for other users.

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